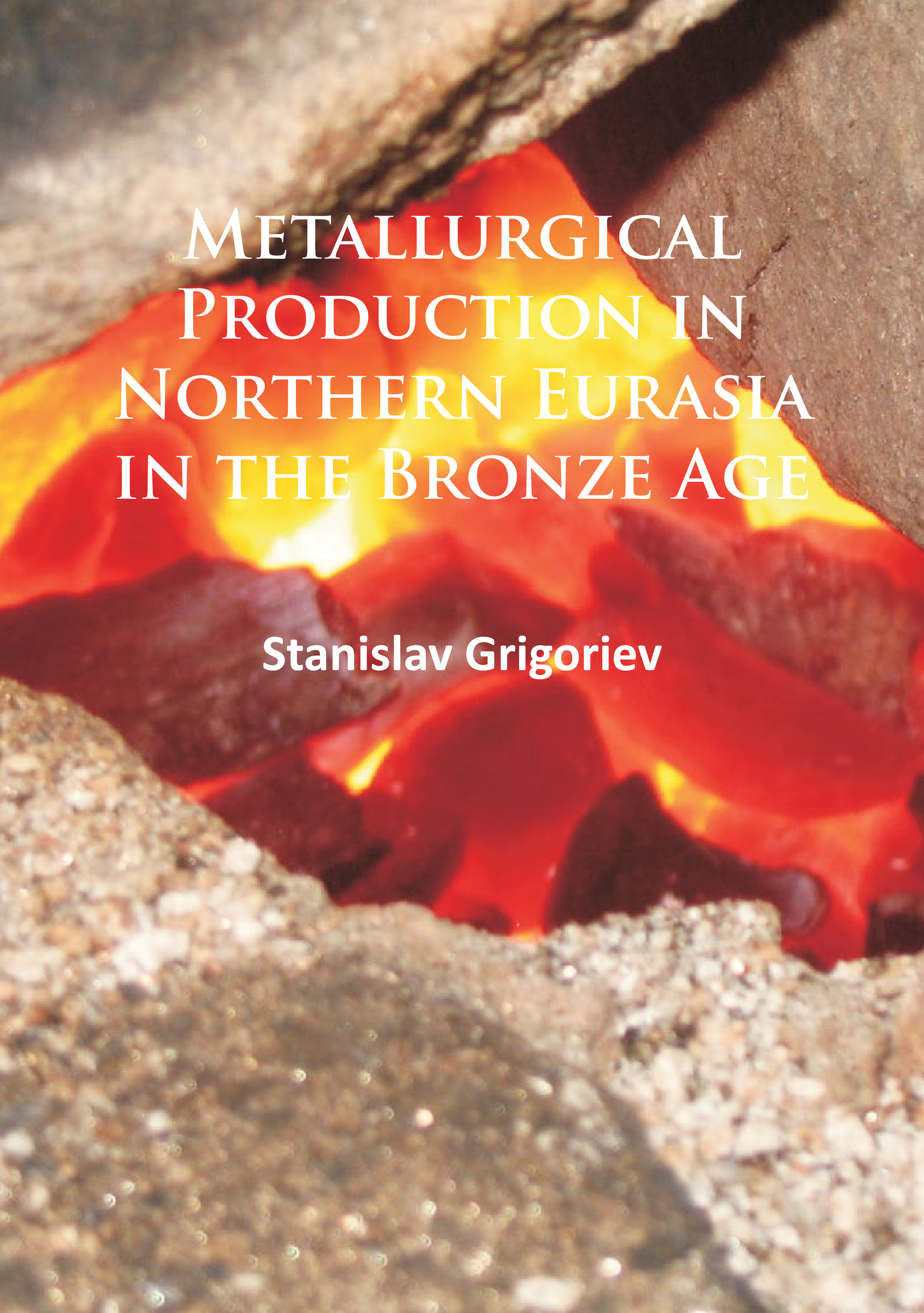

Metallurgical Production in Northern Eurasia in the Bronze Age

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Introduction

Copper is the first metal which had really played a large part in human history. It is considered that Latin *cuprus* from which chemical name of copper originated was connected with the island of Cyprus, with the meaning '*copper island'*. But actually it is not so. The Greek word κύπρος has uncertain etymology. For copper the Greeks had a word χαλκός; the term "Chalcolithic" goes back to this word. Latin language had another word: *aes*. The combination *aes cyprium* meant "Cyprian copper". Then *cyprium* was replaced by *cuprum*. All European words connected with it do not go back to a common Indo-European base. The Latin base is closer to them (Muhly 1973, p. 174, 175).

This work is devoted to history of metallurgical production in Northern Eurasia during the Bronze Age. It should be noted that archaeometallurgical studies include a huge range of works in various directions reflecting different fields of activity of ancient metallurgists. Very often all they are united by the term 'metallurgy'. A starting point of copper production is ore extraction. And this phase cannot be designated as 'metallurgy', it is 'mining'. To date this aspect of production activity in Northern Eurasia is studied extremely poorly. Significant studies have been performed by E.N.Chernykh on the Kargaly mines in Orenburg area (Chernykh 1997, 2002, 2004, Chernykh *et al*. 1999; Černych 2003). In the Transurals the mine of Vorovskaya Yama was investigated (Zaykov *et al*. 1995; 2000). It is supposed that it was exploited already in the Middle Bronze Age, however revealed materials belong to the Late Bronze Age. In Kazakhstan and the Altai a number of works was devoted to study of ancient mines (Zhauymbaev 1984; Margulan 1973, 2001; Chernikov 1949). S.I.Tatarinov studied mines in the Donetsk area (Tatarinov 1977, 1978, etc.). At the same time, many archaeological works contain information about ancient mines; however evidences about their use in antiquity are usually questionable. Unfortunately, these modest successes of Russian archeology in studies of ancient mining reduce possibility of studying metallurgy itself because it is often not clear what kind of ore was used, as well as volumes of production, main mining areas, etc.

Studies devoted to morphological analysis of metal artifacts are numerous. Very important research field is study of microstructure of copper artifacts and reconstruction of both forging and casting technologies on this base (Ryndina 1971; Degtyareva 2009). Another way of these reconstructions is experimental works (e.g. Savrasov 1998).

Very extensive and important studies of ancient Eurasian metallurgy were done by the Laboratory of natural sciences of the Institute of Archeology (Russian Academy of Sciences) headed by E.N.Chernykh. During long time this laboratory studies chemical compositions and typology of many copper-based artifacts of the Bronze Age of Northern Eurasia that allowed system ideas about metallurgy of this period within the huge area to be formulated (Chernykh 1970, 1977, 1992). The most outstanding result of these works is a theory of territory of 'metallurgical provinces', huge areas with similar chemical compositions of metal and types of artifacts. References to this thesis are common in many works on the Bronze Age, but they are not always correct. So, it is often possible to find a statement that "this culture was formed as a result of complicated processes accompanying disintegration of the Circumpontic Metallurgical Province" or something similar. Actually, this phrase is absolutely senseless as metallurgical provinces were not any really existing communities. It is only a cogitative construct for synthesis of characteristics of metallurgical production, though reflecting a certain ancient reality. And such statements reflect only misunderstanding of origins of this or that archaeological culture and attempt to come out of this situation. In works devoted to cultural genesis I tried to use in these instances another terminology, for example, "the south of the Circumpontic zone", etc. And numerous facts of distant migrations and very similar alloys and types of artifacts of remote territories belonging to different metallurgical provinces generated my doubts in absolute legitimacy of this theory which, however, weren't published. However, a system of metallurgical provinces is not only some production traditions or a set of similar traditions of various groups. As any complicated system, a province consists not only of elements, but also of system relationships, processes and channels/ space of their behavior. Respectively, any group with its technological skills, getting to another metallurgical province, is forced to be built in available system. But when I was working on this book and generalizing results of slag analyses from huge territories, I have found that this generalization and description is correct and possible only within the theory of 'metallurgical provinces'.

In this work I consider problems of proper metallurgy, i.e. extracting metal from ore. A number of accompanying operations is closely connected with it, such as charcoal-burning, ore dressing, furnace constructing, and preparation of crucibles. In some instances I should touch upon these operations; however the main topic of the work is smelting process. Closing stage of the metallurgical production is metalworking including various casting and forging operations, and also auxiliary operations: making of crucibles, casting molds, stone tools for metal forging. These problems are, as a rule, out of frameworks of this research.

Problems of copper ore smelting in Northern Eurasia are poorly studied. Certainly, archaeologists, who excavated sites with metallurgical complexes, touched upon problems of copper production (see e.g. Kadyrbaev 1983; Kadyrbaev, Kurmankulov 1992; Tatarinov 1977, 1978; Chernikov 1949). However these works are very rare; and credibility of reconstructions is often doubtful as it demands serious analytical studies of production remains, above all, slags. Similar works took place, but they were very local, based on single analyses and had no further development (Satpaeva 1966; Terekhova 1980; Kuznetsova *et al*. 1988; Zharkova, Sunchugashev 1975). A very interesting research of metallurgical production on the Kargaly mines was executed by Salvador Rovira, and subsequently in this book we will repeatedly use results of this research (Rovira 1999; 2004). In the European archeology number of works devoted to analyses of ancient metallurgical production is extremely large and the first summarizing publications appeared many years ago (e.g. Coghlan 1951; Forbes 1958 and many others). It is possible to say that in archeology a new field was formed: archaeometallurgy. These studies always used the most modern analytical methods; however usually number of analyzed materials was very insignificant. Usually these studies are limited by careful analysis of one or several sites. Taking into account a large number of these studies, being based on them it is possible to make idea of nature of ancient metallurgy, but it is difficult to do this in a uniform system.

As materials of Northern Eurasia were not analyzed, within this work it was necessary to conduct studies of slags from the huge territory. The research task initially was to reconstruct various technological schemes in this area, history of their formation and distribution, and to determine, whenever possible, ore sources. However slag is a rather complicated system demanding application of various methods, often complex and expensive. Therefore, taking into account the huge volume of materials and high cost of scientific analyses, it was necessary to develop an optimum research scheme allowing, both to reconstruct an overall picture, and to solve individual problems.

The project of slag studies of the Bronze Age was started in 1986 and with some breaks proceeds hitherto. The first years the main emphasis was placed to slag analysis of Sintashta culture in the Southern Transurals, but simultaneously collection of materials from the huge territory from the Don River to the Altai and south of Central Asia was carried out. Perhaps, today it is the largest collection of analyzed ancient slags in the world. However, even this collection is not enough representative for this enormous territory. The most studied by various analyses is metallurgy of Sintashta culture, and, with certain reservations, it is possible to confide in conclusions drawn on the basis of these analyses. Other materials have not been analyzed by the whole complex of the methods. Such a study would be impossible not only to any single scientist, but also to a large scientific organization. Therefore the main task was to bring to light the most general regularities that will give a chance to future researchers of individual areas to consider their materials in wider context and to decide which problems should be solved. But the conclusions made in this book about metallurgy of the Late Bronze Age have to be subjected either to inevitable updating or to full refusal as they are based on unrepresentative probes selection and a limited set of analytical methods. However, the research scheme developed on the materials of Sintashta culture can be quite applied in other territories by research groups including both archeologists and scientists.

As a rule, archeologists are poorly familiar with methods of natural sciences, therefore they either ignored analytical studies or (as it often takes place with radio-carbon analysis) choose those data which are most acceptable. On the other hand, often archeologists confide in conclusions of scientists with an excessive confidence. Especially it is unjustified in those instances if analyses are done by people who do not work in archaeometry. Sometimes we see another situation: archaeologists wait from scientists an unambiguous result or consider his conclusions as that. However any analytical research is a process approaching gradually to the result. This work is also only a stage in this process, which is more satisfactory for materials of Sintashta culture and less satisfactory for all others.

Chemical processes of copper ore smelting

To do the subsequent text and research procedures clear, it is necessary to touch upon briefly physical and chemical processes which take place in the course of ore smelting. Many archeologists believe that smelting process is limited by temperature impact. However in reality it is much more complicated. The ore fusion is not able to bring to separation of metal from rock. The main role in metallurgical processes is played by chemical reactions. Temperatures create rather a condition of their successful behavior. In this book we will discuss various technologies of ore smelting caused by difference in ore base. Therefore it is necessary to discuss briefly types of copper ores and, respectively, those chemical processes which take place at their smelting.

Copper ores can be divided into two main groups: sulphidic and oxidized. The sulphidic ores can be subdivided into primary sulfides (unoxidized sulfides: chalcopyrite or copper sulfide – $CuFeS_2$), and the secondary sulfides (bornite – $CuFeS_4$, covellite – CuS, chalcocite – Cu_2S). Oxidized ores can be divided into oxides (cuprite – Cu_2O, tenorite – CuO, chrysocolla – $CuSiO_3H_2O$) and carbonates (malachite – $Cu_2(CO_3)(OH)_2$, azurite – $Cu_3(CO_3)(OH)_2$). It is also necessary to mention native copper (Cu), but it was a significant source only at the earliest stages of metallurgical development. There are many other copper minerals, but those mentioned above are the main source for ancient metallurgy.

Formation of primary ores is connected with magmatic processes, respectively, in many ore deposits these ores are situated in the deepest zones. Above, in the so-called “zone of cementation”, lie the richest ores, mainly secondary sulfides. At last, in the top parts of the deposits the oxidized ores are situated. Therefore ancient miners initially exploited the oxidized ores, and then, in process of deepening the mines, they reached the secondary sulfides, and subsequently the primary sulfides. Said above is, of course, a classical scheme because primary ores can be found on the surface, and in the zone of cementation both oxidized minerals and primary sulfides are situated. Nevertheless, in general this tendency is true. Respectively, smelting of ores with so various chemical compositions cannot be done using a single technological scheme.

Chemical reactions of these types of ores reduction are different. Here it is necessary to mention one more important point, namely, role of charcoal in this process. It is well known that charcoal is a source of thermal energy in metallurgical production. However its role as a chemical component reducing copper is also very important. But charcoal chemically is not so active to reduce copper. The main reagents are gases which form as a result of charcoal combustion: carbon monoxide (CO) and carbon dioxide (CO_2). The carbon monoxide is the reducing agent in metallurgical reactions. But carbon monoxide is stable only at high temperatures, above 710 °C, therefore it is the minimum of temperature from which metallurgical reactions begin (Charles 1980, p. 156).

Reactions between gases and solid carbon depend on oxygen content and are described by the following formulas:

$C + O_2 \rightarrow CO_2$ – full combustion of charcoal; reaction takes place at surplus of oxygen. Respectively, in case of this reaction metal reduction does not occur.

$2C + O_2 \rightarrow 2CO$ – reaction of formation of carbon monoxide.

$2CO + O_2 \rightarrow 2CO_2$ – reaction of formation of carbon dioxide from carbon monoxide in case of oxygen surplus.

$CO_2 + C \rightarrow 2CO$ – at higher temperatures and in case the gas phase passes through a charcoal layer, a back reaction of formation of carbon monoxide from carbon dioxide takes place. The content of carbon monoxide grows in the furnace at temperatures from 600 ºC to 1000 ºC. Starting from 700 ºC it is quite fast process which leads to copper reduction (Zimmerman, Gunter 1982, p. 319; Charles 1992, p. 12).

Respectively, for formation of quantity of carbon monoxide sufficient for metal reduction both temperatures and time are necessary. Besides, oxygen blowing has to be carried out through a charcoal layer, otherwise carbon monoxide is not formed too, and smelting will not be successful. Because of this simple reason (and not because of impossibility to reach high temperatures at all) it is impossible to reduce copper in an open fire. In the open fire it is impossible to create conditions for the carbon monoxide formation.

Thus, the achievement of positive balance CO/CO_2 was one of the most important problems in ancient metallurgy.

This problem was closely connected with types of smelted ores.

In case of rather developed metallurgy based on slag reactions, an example of this process can be following.

Classical type of slag has fayalite composition. It will be repeatedly discussed on pages of this book. Its formation can be described by two formulas:

$Fe_2O_3 + CO \rightarrow 2FeO + CO_2$ – reaction of hematite with carbon monoxide and formation of wüstite and carbon dioxide.

$2FeO + SiO_2 \rightarrow 2FeO{\cdot}SiO_2$ – reaction of wüstite with quartz and fayalite-type slag formation.

Thus, to form a fluid fayalite slag, in addition to necessary components, it is required to form wüstite, which is impossible in case of oxidizing conditions in the furnace and absence of necessary quantity of carbon monoxide.

Smelting of oxidized ores is carried out according to a rather simple scheme (Tafel 1951, S. 242-245, 249).

At a temperature of 550-600 °C in reducing atmosphere some of these ores (chrysocolla, $CuSiO_3{\cdot}2H_2O$) can easily reduce, losing water:

$CuSiO_3 + CO = Cu + SiO_2 + CO_2$

But in this case metallurgists inevitably had a problem with such refractory component as quartz that it was possible to solve, either forming fayalite slag by additions of iron oxides, or increasing the temperature. The latter, however, could lead to the back result as intensification of blowing caused an intensive oxidation of copper.

Malachite ($CuCO_3 \cdot Cu(OH)_2$) and azurite ($2CuCO_3 \cdot Cu(OH)_2$) already at a temperature of 220 °C lose carbon and water, forming tenorite (CuO). At usual long heating it starts disintegrate with formation of cuprite already at a temperature of 800 °C according to reaction

$4CuO \rightarrow 2Cu_2O + O_2$

At contacts with charcoal or carbon monoxide tenorite is quite easily reduced above the temperature of 550 °C:

$2CuO + C \rightarrow 2Cu + CO_2$

$CuO + CO \rightarrow Cu + CO_2$

However, after reaction with copper, tenorite can form cuprite again:

$CuO + Cu \rightarrow Cu_2O$

In case of high temperatures and sufficient volume of carbon monoxide a standard reaction starts according to the scheme:

$2CuO + CO \rightarrow Cu_2O + CO_2$

$Cu_2O + CO \rightarrow 2Cu + CO_2$

But cuprite is a rather refractory mineral; therefore the second reaction requires a high temperature. Here we meet a standard problem of early stages of metallurgy. Increasing blowing and temperature increases also oxygen volume in the furnace. Respectively, the CO/CO_2 balance comes down. As it follows from the formulas above, surplus of oxygen will hampers the copper reduction. Therefore, despite a common opinion that smelting of oxidized ores is much simpler, chemically it is not so, that often causes considerable losses of copper in form of cuprite.

It is paradoxically, but smelting of sulfide ores is often simpler.

In the case of chalcopyrite smelting ($CuFeS_2$) a reaction takes place (Zimmerman, Gunter 1982, p. 352):

$2FeS + 3O_2 \rightarrow 2FeO + 2SO_2$ – reaction of iron sulfide with oxygen and formation of wüstite and sulfur dioxide.

$2FeO + SiO_2 \rightarrow 2FeO{\cdot}SiO_2$ – reaction of wüstite with silicate components with formation of fayalite slag. Wüstite that did not participated in formation of fayalite slag, disintegrates into magnetite (Fe_3O_4) and metal iron (Fe).

As we see, a reducing agent in this case is not the carbon monoxide, but sulfur containing in ore and reacting with oxygen. It is accompanied by exothermic reaction of sulfur burning that promotes temperature increase. Another advantage of primary ores smelting is that the ores contain all components necessary for slag formation; and after this process the copper content raises because the iron oxides go into slag.

The next stage is reactions of copper sulfides. Similar reactions take place also in direct smelting of chalcocite:

$2Cu_2S + 3O_2 \rightarrow 2Cu_2O + 2SO_2$ – reaction of copper sulfides with oxygen and formation of cuprite and sulfur dioxide.

$2Cu_2O + Cu_2S \rightarrow 6Cu + SO_2$ – reaction of cuprite with copper sulfide and formation of copper and sulfur dioxide.

In this case sulfur acts as a reducing agent too. In addition to this there can be reactions which are described for smelting of oxidized ore.

Another copper sulfide, covellite (CuS), already at a temperature of 358 °C forms chalcocite (Tafel 1951, S. 237):

$2CuS \rightarrow Cu_2S + S$

This is the reason why it rarely participates in metallurgical processes; and its detection in slag may be explained by any other reasons: rapidity of the process, repeated additions of ore.

Thus, sulfides react at first with oxygen, and then with oxides, restoring copper directly. Therefore chemically this process is simpler as in this case there is no need in long maintenance of positive balance CO/CO_2.

There is one more important peculiarity of ores: they contain inclusions of gangue. As we saw from the formulas of fayalite slag formation, for this formation two components are necessary: iron oxides and silicates.

Usually the types of ore and gangue depend on genesis of copper-ore fields. Volcanogenic massive sulfide ore deposits are formed as a result of magmatic processes. As the main copper mineral there is chalcopyrite, ores of these deposits are rich in iron component. Iron oxides even form in the upper part of these deposits so-called “iron caps” or gossans. Deposits in sulfide quartz veins are formed as a result of hydrothermal processes when hot solutions rise along the cracks forming copper mineralization in quartz veins. Respectively, silicate component is well presented in these fields. Porphyry copper deposits had similar genesis. However in this case hydrothermal solutions can rise in basic rocks, rich in iron or magnesian components. For ancient metallurgy copper deposits in sandstones were also important. These sedimentary rocks can have copper mineralization from destroyed deposits. More often the sandstones have silicate composition, and oxidized minerals are more typical for them, secondary sulfides are rarer. However in different areas deposits of this type can differ that is explained by the breaking down of different rocks and different primary deposits.

There are many other types of copper deposits, however given above are the main types used by ancient metallurgists.

Silicate rock is very refractory. Contrary to it, basic rocks melt at various temperatures depending on oxide type. Melting temperature of iron oxides is lower in oxides with lesser oxygen content. So among Fe_2O_3 (hematite) – Fe_3O_4 (magnetite) – FeO (wüstite), hematite will be most refractory, and wüstite will be least refractory. Thus, for successful smelting of minerals from these rocks it is necessary to achieve the reducing conditions in the furnace.

However, it is ideally to form slag. So, fayalite slag, consisting of iron oxides and silicates, has melting point much lower, than the components from which it was formed. Therefore metallurgists were trying to form slag by special selection of ore, addition of iron oxides to ores from silicate ores or silicates to those from iron-rich rocks.

However some ores, for example, chalcopyrite, contain iron, irrespective of nature of ore-bearing rock. Besides, other components, for example molten sulfides or compounds of calcium, participate in slag reactions also. All this, taking into account many possible combinations, turns metallurgical process into the most complicated system which cannot be identical in different territories and during various epochs.

The situation becomes more complicated also by that, along with technological parameters of smelting caused by character of ore and ore-bearing rock, there were parameters caused by cultural traditions. The situation is simpler when any technological tradition develops in the same area, i.e. it was the local tradition. However in case of a migration of bearers of this tradition and transition to new types of raw materials we have a new situation with either possible borrowing of a local technological tradition ore attempts to adapt and transform their own.

All this causes variety of slags. So, the slags received at smelting according to the same technological scheme, can look very contrast because of sharp distinctions in ore base. Respectively, study of slag from either any individual area or a site is not able to reflect nature of metallurgical production of the period. On the other hand, the multiple character of the process forces to use quite wide range of analytical methods, without what it is impossible to do its relatively correct reconstruction.

Methodology

The methodology of this research was developed in the first years of this project (Grigoriev 1993), however subsequently it has being constantly changed due to attraction of new scientific methods and statistical procedures. As it was already said above, slag is rather complicated system, and its study demands use of a number of various methods. Use of a spectral analysis, traditional for archaeometallurgical studies in Russia, gives, in this case, very limited information. However, on the other hand, careful studies of small series of material can also lead the research to a dead-lock, as slag, unlike metal, is inhomogeneous. Moreover, in different zones of ancient metallurgical furnaces different thermal conditions and different balance of CO/CO_2 influencing the smelting atmosphere could be formed. As a result, very careful modern analysis can depend on a human factor: a sample chosen for studying (Rehren *et al*. 2007, p. 215). It was necessary to avoid this problem.

Therefore even the study of slag from a single settlement requires rather representative number of probes. Empirical experience allows me to believe that a minimum desirable number of probes from a single settlement are about 20. Any accurate figures are impossible here, as it depends on degree of uniformity of the analyzed series itself. But also within one, even rather small area, it is impossible to be limited by materials from one or two settlements, because metallurgists of different settlements could use different ore sources that could inevitably influence on microstructure and chemical composition of slag. Besides, a series of large-scale projects, carried out by E.N. Chernykh, showed that even such an imperfect method as emission spectral analysis applied widely and supplement by a series of statistical procedures, allows to receive rather adequate pictures of ancient metallurgical production.

Taking into account all said above, an optimum research way is to divide the research into two stages. At the first stage the cheapest analytical methods, allowing to study the most number of slag probes and to receive maximum information are applied. This allows different mineralogical and chemical groups of slag to be distinguished and to do their statistical comparisons. After this it is possible to study selected samples inside the groups more carefully by more expensive and perfect methods to solve individual problems.

The basic method of the research is analysis of polished slag sections under microscope in reflected light that allows the main phases rather surely to be diagnosed. This analysis was done at magnification 50-200×, although in exceptional cases larger magnification with use of oil immersion were also applied. The main questions which can be solved by means of this method are: identification of initial raw materials and possible ore base, identification of smelting temperatures and smelting atmosphere, relative rate of smelt cooling. As it will be shown below in more detail, within discussion of individual problems, answers even these questions cannot be quite unambiguous.

Now it is known about 150 slag minerals (Perepelitsin 1987, p. 215). In particular increase of number of these minerals is caused recently by the use of electron microscopy. The process of all phases' identification in slag is rather expensive and labor-consuming. It is certainly needed in case of analysis any concrete, rather local material. However, in case of the analysis of large slag collections it is almost impossible to do it. Therefore this research was limited by the main slag minerals.

The copper ore used in antiquity belongs to three types: oxidized ores, secondary sulfides, and primary sulfides. The main ores of the first group are malachite, azurite, cuprite and chrysocolla. All of them are rather well diagnosed by means of a microscope; however they, in particular malachite, can be easily formed in slag also for a period while the slag was deposited in the settlement layer. Especially frequently it occurs not in vitreous slag masses, but in gas pores. Therefore we quite frequently see malachite inclusions round in shape. Most often it indicates its secondary character. It is possible to judge about this more confidently already using X-ray microanalysis made by means of a scanning electronic microscope (SEM). As a rule, the secondary inclusions are freer from impurity, than the ore used for smelting. However this characteristic cannot be always decisive as there are rather pure oxidized ores. Impurity of copper chlorides in these inclusions is more indicative as they could not remain in conditions of high temperatures applied in metallurgy. Compounds of copper with chlorine ($CuCl$, $CuCl_2$) are formed at usual temperatures. But already at a higher temperature (250-340 °C) they disintegrate, and, as a result of oxidation, turn into tenorite (CuO). At a temperature of 500 °C copper chloride ($CuCl$) vaporizes (Tafel 1951, S. 234, 235, 245, 246). Therefore the presence of chlorides is an important sign of secondary character for malachite. Unfortunately, not for all probes can be studied by SEM. Therefore the main indication is the shape of a mineral.

A similar problem is also connected with determination of character of cuprite (Cu_2O). In some cases cuprite in slag could be formed later. However, in some instances it is a result of either of copper oxidation in the course of smelting, or as a result of smelting of oxidized copper minerals, for example, malachite. In this case, the simplest way of identification is the estimation of amount of inclusions of cuprite prills comparatively to copper prills. In principle, small copper prills must be oxidized in settlements layers much easier, than large. The density of copper is 8.96 g/cm^3, and that of cuprite is about 6 g/cm^3. Respectively, copper prills sink in liquid slag easier, than cuprite prills of the same size. If the cuprite prills are on the average larger than those of copper, it is possible to assume that they were formed during metallurgical reactions, and they were not a result of secondary oxidation in a settlement layer.

Secondary copper minerals (covellite and chalcocite) are quite easily diagnosed as they are anisotropic and have typical color. However, even if these minerals were the main component in charge mixture, in slag their presence can be very limited as they melt already at a quite low temperature. Besides, as a result of high temperatures and oxygen blowing, a part of sulfur leaves them, and they regenerate into isotropic copper sulfides which are very typical in this slag. As it follows from their name, they have no effect of anisotropy. Their color characteristics are quite close to cuprite, however they differ from it by absence of internal reflexes. Usually their broad presence indicates smelting of secondary sulfides. However they can be found also in slags formed at smelting of primary sulfides.

The main these sulfides are bornite and chalcopyrite. And the latter was more often used in ancient smelts. Unfortunately, its inclusions in slag can be found not so often, and they have quite small size. This results from the fact that after heating chalcopyrite disintegrates into copper and iron sulfides quickly enough. Having a low melting point copper sulfides melts, and the iron sulfides are oxidized and turn into wüstite, forming in this case very characteristic dendritic and latticed structures. The presence of these structures, accompanied by small chalcopyrite inclusions and molten isotropic sulfide, is diagnosing signs for identification of smelting of primary ores.

But in real slags the situation can be a little complicated by that various ore types could be used in smelting. Therefore the main conclusions have to become on the basis of analyses of rather large slag and ore series.

Identification of type of ore-bearing rock is also connected with some specific difficulties. In principle, it is possible to distinguish rather reliably slags formed at smelting of ores from silicate rocks, from those formed at smelting of ores from basic and ultrabasic rocks. The main sign here is the ratio of acid and basic oxides in slag and rock inclusions, especially rock associations with ore minerals. However, we have to take into account possible use of iron fluxes that increases the presence of the basic oxides in slag, but this was practiced in antiquity extremely rare. For the ultrabasic rocks an important diagnosing sign is the presence of chromspinelid grains. Sometimes it is possible to see sandstone inclusions in slag. They are visible in the form of small, extended in rows grains surrounded with ore inclusions. However, if the material is larger, such structures are not visible even in the ore from sandstones.

The use of fluxes is connected with the problem of initial ore too. At first sight, for identification of fluxes it is enough to compare compositions of ore and slag; however there are a number of objective difficulties. For example, around the metallurgical complexes of Sintashta culture we repeatedly discovered many small burned bones, and sometimes small pieces of calcite. All this allowed think about the use of these components as fluxes to add CaO in the furnace charge, promoting creation of more liquid slag. On the other hand, in slag a higher CaO content was often determined by chemical analyses in contrast to its absence in ore. This, at first sight, unambiguously indicates the use of fluxes. However, calcium contains also in ashes, and could get into slag from there. It is not possible in this instance to calculate how intensive the use of fluxes was. Similar problems rise also in case of use of iron fluxes which could be a part of gangue.

Determination of achieved temperatures is also a difficult challenge. In principle, their determination was based on studying of microstructures and of identification of molten and unmolten components whose melting point is well-known. However, in many instances it was quite difficult to distinguish the molten and unmolten inclusion. Besides, it gives not the achieved temperatures, but lower temperatures. A real temperature could be higher than it is fixed by the molten inclusions. On the other hand, sometimes the slag components melt not so much being influenced by the temperature, but by physical and thermodynamic processes in liquid slag. During the work with large slag collections it is better to use melting points of several minerals which are given in Tab. 0-1. (Zimmerman, Gunter 1982, tab. 173- 175).

Sometimes archaeometallurgists use thermal diagrams based on chemical analyses. But the diagrams using bulk (wet) chemical analysis indicate both a real temperature range and also an overestated one because the bulk chemical analysis takes into account also refractory unmelted components. So, Gale and coauthors' experimental studies demonstrated that a temperature determined by phase diagrams is always much higher than a point of this slag melting. In addition to this, the standard diagram SiO_2 – FeO – CaO is not so good, as the diagram anorthite – FeO – SiO_2 (Gale *et al*. 2000, p. 89, 92). The experiments made by A. Hauptmann with slags received at smelting of the so-called self-fluxing ores demonstrated that they melt at a temperature of 1130-1150 °C. However the phase diagram demonstrated higher temperature: about 1200-1250 °C (Hauptmann 1987, p. 130). On the other hand, a possible melting point of slag is not evidence at all that during the smelting higher temperatures were not achieved. Therefore such determinations give unreliable data and have to be verified by the whole complex of other analyses and calculations.

Use of the X-ray microanalysis of individual molten and crystallized components is more justified. But also in this case we receive melting point and temperature of solidification of any component, and the achieved temperature could be higher. Thus, this method has approximate character, but it allows us to get some ideas about the temperature. There are some instances when one of olivine inclusions showed very high temperature of melting while all other seem to be molten at lower temperatures. A possible explanation of this situation is thermodynamic processes.

Sometimes archaeometallurgists smelt slag and, by such a way, determine a probable temperature by means of measuring techniques (e.g. Mei, Li 2003, p. 114, tab. 9.4). But this method determines also only the melting point, instead of the temperature achieved.

The X-ray diffraction analysis can be used as an additional method for temperature determination too. The method identifies crystal phases in any material on the basis of study of characteristics of its crystal lattice. Crystals of various minerals differ from each other by atomic and molecular structures. In this work this method was especially useful for identification of high-temperature silica modifications (Grigoriev 2000). However, in practice this gives limited number of temperature points, namely formation of α-tridymite and α-cristobalite.

The behavior of quartz when heating is described by Fenner's classical diagram (Deer *et al*. 1966, 1966a, p. 221). There is no need to list all its phase transitions. It is enough to emphasize that the presence of quartz indicates a temperature below 867 °C, α-tridymite – an interval 867-1470 °C, α-cristobalite – over 1470 °C. The melting point of quartz is in a temperature interval of 1670-1700 °C. After cooling the molten quartz forms quartz glasses. However dissolution of quartz in slag and formation of olivine and glass starts also at lower temperatures.

In actual metallurgical slags the coexistence of two quartz modifications is possible. Let's imagine that we see in a probe both modifications: tridymite and cristobalite. It means that the temperature was above 1470 °C, but lasted at such level not too long.

Determination of smelting atmosphere is the most simple and, at the same time, the most subjective. It is a very important parameter; metal reduction depends on it. But this parameter is connected with a set of factors. The quantity of components containing oxygen is the most important. The main of these components are both air blown in the furnace and oxidized ore. Thus, metallurgists smelting the oxidized ores constantly dealt with a dilemma: at more intensive blowing temperature increases, but it resulted in oxygen surplus in the furnace that hampers the copper reduction. In many respects the success depended also on quality of charcoal. But it is not the last analytical problem, because the atmosphere in the furnace can have a local character. Experimental works showed that in different areas of the furnace the oxidizing and reducing conditions were observed. The reducing conditions usually appear at distance more than 15cm from the air blowing tuyeres (Telecote, Merkel 1992, p. 10). This results from the fact that carbon monoxide has no time to be formed closer to the tuyere. Respectively, in small furnaces it is easier to achieve high temperatures, but it is more difficult to create the reducing conditions. Probably, the size of reducing and oxidizing zones depended also on air pressure and speed of its movement in the furnace, and even on sizes of charcoal and other components of the furnace charge.

For these reasons, the smelting atmosphere determined on the basis of any analysis of slag relates only to an area where the ore was smelted. Besides, it is necessary to take into consideration that the atmosphere during the smelting was not constant. All this makes the conclusions about the atmosphere rather relative.

The presence of many cuprite inclusions in slag is the most important marker of the oxidizing atmosphere in the furnace. Other markers are: copper and iron oxide delafossite forming characteristic needle crystals. Contrary to this the markers of the reducing conditions are such minerals as wüstite, fayalite, and also in some instances inclusions of metal iron.

At slower cooling the dendrites, skeletal and idiomorphic crystals growing sometimes to large prismatic shapes are formed[1]. The last, however, cannot occur in case of lack of necessary components. Therefore the study of crystal shapes, being very informative, nevertheless is not fully informative, and it has to be supplemented with chemical analyses.

In this case the study of chemical composition of crystals by means of SEM is very useful. So, investigations of olivine in slag of Sintashta culture revealed that smaller crystals had started growing earlier, and they have more magnesian composition, than larger crystals. Besides, many olivines have the zonal structure visible even under light microscope. Research of different areas of the crystals demonstrated that they had been formed at different stages of smelting. More dark internal areas are more magnesian. Respectively, at different stages of smelt cooling different mineral phases are formed. Moreover, at various speeds of cooling even substance with the same chemical composition can crystallize in different phases. In case of the rapid crystallization the primary phase is spinel (Perepelitsyn 1987, p. 84).

Relative speed of smelt cooling was determined by the rate of crystallization of individual minerals, for example, olivine. In conditions of slow cooling rather large crystals can be formed. At fast cooling crystallization either does not take place at all, or crystals form small needle or dendritic structures (Textures and structures 1958, p. 67). However, sometimes lack of large fayalite crystals is not a sign of the high-speed cooling, because it was provoked by the absence of necessary components for their formation in the furnace charge. In this case the shapes of crystals were taken into consideration too. Needle crystals are formed usually at the rather high-speed cooling.

The speed of cooling is closely connected with the slag viscosity. Usually a significant amount of copper prills in slag is a good indicator of the high viscosity. However, sometimes the slag viscosity can be calculated on the base of chemical composition.

There are different ways of viscosity calculation. Its decrease is influenced by oxides of calcium, magnesium, iron, manganese, titan, sulfides. Silicon dioxide and aluminum oxide increase viscosity. Certainly, the slag viscosity is essentially influenced not only by the chemical composition, but also by the temperature. The higher temperatures make the viscosity lower. In addition to this, the character of viscosity changes at different temperatures is not identical in slags of different chemical compound. Besides, there are unmolten components in slag. Their larger number leads to viscosity increase. For example, at calculations of viscosity for a composition basing on bulk chemical analysis it is impossible to take into account if the oxides had been molten or not. It is not always possible to say about type of iron oxides. But the melting points of wüstite, magnetite and hematite are very different. The last two oxides are present usually in slag in solid form, increasing slag viscosity. It is quite distinctly noticeable at optical studying of slags. In areas of concentration of the magnetite crystals we often see more copper prills that points to higher viscosity there.

Slag is heterogeneous, and its chemical composition can differ in different areas of an ancient metallurgical furnace. The molten copper will promote the viscosity decrease. Besides, slag viscosity is very different at different stages of smelting.

[1] Dendrites are uniform two- or three-dimensional crystals with multi-branching tree-like form. Sometimes they consist of joint skeletal individuals. Skeletal crystals are imperfect hollow single-crystal individuals externally reminding contours of a crystal of the correct form. Unlike dendrites they have more perfect form (Perepelitsin 1987, p. 84).

For all above-mentioned reasons any calculations of viscosity have very approximate character. As a rule, they are not quite correct even in a strict frame, for example, made for a certain temperature. Nevertheless, they can be useful to general estimations and comparisons of slag of different territories and cultures.

A group of German scientists suggested a formula for viscosity calculation of slag at a temperature of 1400 °C (Bachmann *et al*. 1987):

$$\eta\ 1400\ °C = 4.9/\ K_z - 0.45,$$

$$K_z = (CaO + MgO + FeO + MnO + K_2O + TiO_2 + Na_2O + K_2O + SO_3)\ /\ (SiO_2 + Al_2O_3)$$

In principle, groups of oxides here are close to those applied at calculations of basicity of slag (see below). However magnesium oxide (MgO) is an exception, being the basic oxide it influences on increase of slag viscosity. It forces to use a bit different formula of calculations.

It should be noted that the slag viscosity depends very strongly on initial ore. For example, the table of viscosity for ore (Tab. 0-2.) looks as follows:

Slag formed from chalcopyrite which is rich in iron and sulfur should have a very low viscosity at a high temperature if to follow a formula strictly. Even slag from the oxidized ores extracted from the ultrabasic rocks should have slightly higher viscosity.

Viscosity of chemical composition of ore from Kargaly mines is the highest, due to a lot of silicate components.

Thus, when using the sulfide ores it is simpler to receive the fluid slag. The oxidized ores of the ultrabasic fields are less difficult for smelting, and the oxidized ores from deposits in quartz are very difficult.

However, the situation for the problem ore can be improved by the use of fluxes. Otherwise high losses of metal in slag are inevitable. It was almost impossible in this case to receive a copper ingot, and metallurgists had to crush slag for extraction of individual copper prills. Another possibility is the use of very pure pieces of malachite. Basing on archaeological evidence it is very difficult to estimate a primary ratio of ore and rock in the furnace charge. And the slag reflects, mainly, chemical composition of the rock.

Similar table for slag (Tab. 0-3.) is already another:

The viscosity of Sintashta culture slag (settlements of Sintashta and Arkaim) falls in the range of 1.46-6.2 Pa·s, on the average – 3.25 Pa·s. The collection of Abashevo and Early Timber-Grave slags from the Western Urals (Tyubyak, Beregovskoye, Birsk I) is not very representative. However the variability of the viscosity fluctuations is greater: between 2.18 and 9.91 Pa·s, on the average – 5.88 Pa·s.

Slags from the Late Bronze Age settlements in Central Kazakhstan (Atasu, Myrzhik, Ak-Mustafa, Sargari) show even greater viscosity variation: from 0.47 to 22.6 Pa·s with mean value of 4.93 Pa·s. However, it is necessary to take into consideration that at such insignificant sampling this last figure is a result of the accounting of single slags with the highest rate of these values.

In the Kyzyl-Kum slag (Besh-Bulak, Ayakagitma) the viscosity lies within the range of 2.08-13.93 Pa·s, on the average – 5.92 Pa·s.

Berezovaya Luka settlement – fluctuation within 8.23-31.09 Pa·s with the mean value of 19.33 Pa·s.

Slag of the Early Iron Age from area of Irtyash Lake in the Transurals shows the low viscosity between 1.28 and 1.33 Pa·s, the mean value – 1.3 Pa·s.

On the Bronze Age settlements in the Transurals and Northern Kazakhstan (Verkhnyaya Alabuga, Vishnyovka, Novonikolskoye, Petrovka II) the viscosity fluctuates between 0.31 and 7.12 Pa·s with the mean value of 2.67 Pa·s.

The Late Bronze slag in Orenburg area (Ivanovskoe, Rodnikovoe, Gorny, Kuzminkovskoe, Pokrovskoe) demonstrates the viscosity from 1.83 to 47 Pa·s, on the average – 13.3 Pa·s.

Thus, slags of the Early Iron Age from area of the Irtyash Lake show the minimum mean values of the viscosity (1.3 Pa·s); them follow slags of the Late Bronze Age settlements in the Transurals and Northern Kazakhstan and those of Sintashta culture in the Transurals (2.67 and 3.25 Pa·s respectively); then slags of the Late Bronze Age of Central Kazakhstan, Abashevo and Early Timber-Grave slags from the Western Urals and slags from the Kyzyl-Kum (4.93; 5.88; 5.92 Pa·s). The highest viscosity is demonstrated by slags from Orenburg (13.3 Pa·s) and Berezovaya Luka (19.33 Pa·s).

This result is quite explainable. The low viscosity of the Early Iron Age slag is explained by that it was iron smelting slag rich in iron component. Besides, it is the latest slag in the analyzed series, with more perfect technology.

The low viscosity of Sintashta slag is explained by smelting ore, mainly, from the ultrabasic rocks, with the high content of components influencing viscosity decrease. The high viscosity in slag from Berezovaya Luka and Orenburg is explained by the use of ores from silicate rocks. Thus higher viscosity in the slag from Berezovaya Luka against the slag from Orenburg surprises.

The viscosity depends on two factors: a temperature and chemical composition. As well as rocks, slags can be divided into some groups with a different ratio of acid and basic oxides (Perepelitsin 1987, p. 211-214). The basic oxides are: CaO, R_2O, MgO, FeO, MnO, the acid oxides: SiO_2, P_2O_5, TiO_2, B_2O_3. There is also a group of the amphoteric oxides (Al_2O_3, Cr_2O_3, Fe_2O_3) which in the basic slags behave as acid oxides, and in the acid slags they behave as the basic. Respectively, coefficients of acidity (A) and basicity (B) can be calculated:

$$A = (SiO_2 + P_2O_5 + TiO_2 + B_2O_3) / (CaO + MgO + FeO + MnO)$$

$$B = (CaO + MgO + FeO + MnO) / (SiO_2 + P_2O_5 + TiO_2 + B_2O_3)$$

If $A > 1$ ($B < 1$) the slag has the acid compound and vice versa.

However it is more correct to use more detailed classification (according to V.V. Lapin), corresponding to the geological one (Tab. 0-4.).

But also here it is necessary to kept in mind that any calculations based on chemical composition have relative character as they do not take into consideration quantity of unmelted components increasing the viscosity regardless of their chemical composition.

The main difficulties in mineralogical study of slags arose from that they are rather complicated system. The same microstructure can be influenced by various factors. So, the weak crystallization can reflect as the high speed of slag cooling (and, respectively, some technological parameters), and also by the lack of components needed for crystallization, and, therefore, it reflects the ore base. The main regularities here are the following

(Perepelitsin 1987, p. 82, 214). The ultra-acid slags do not crystallize at all. The acid slags show usually slag glass. Crystal phases are presented only by minerals with high crystallization ability (spinel, magnetite, orthosilicates, etc.). In case of a slow cooling the dendritic, skeletal, and even idiomorphic crystals (of relatively perfect crystal form) can be formed. The microstructure of slags of average composition depends on the speed of cooling. At the fast cooling the glass with skeletal spinel crystals, sulfides, and orthosilicates is formed. At the slow cooling in molds the slag can obtain a holocrystalline structure. The basic and ultrabasic slag even at the fast cooling crystallizes completely, forming fine-grained structure. At the slow cooling the formation of macrocrystalline structures is possible.

Emission spectral analysis

The second method applied in this research widely, was the spectral analysis of slag and ore. Chemical studying of metal, ore and slags from Volga-Ural region and Kazakhstan have a long history. A large work on the analysis of metal artifacts of the first region was carried out by E.N. Chernykh (Chernykh 1970), and metal artifacts of Kazakhstan was analyzed by S. A. Agapov (Agapov 1990). The spectral analysis of Abashevo and Balanbash (Abashevo culture in the Urals) metal artifacts resulted in their division into two main chemical and metallurgical groups (MP and TK) whose origins was explained smelting of ores from copper deposits in sandstones (MP) and the Ural mine of Tash-Kazgan (TK). The second group differs by the increased concentration of arsenic and is considered as a natural bronze. There is also a distinct regularity of predominance of TK copper in the Balanbash series and MP copper in the Abashevo sites (Chernykh 1970, p. 27, 28). In particular, it was supposed that the analyzed ore from the settlements of Balanbash and Urnyak was extracted from the Tash-Kazgan mine (Chernykh 1970, p. 42). Our studies of Sintashta slags demonstrated that the TK group may not be considered as the natural arsenic copper, it was artificial bronze, and the alloying was made at the stage of ore smelting (Grigoriev 2000a). It is also remarkable that diagrams of trace-elements concentration in the Abashevo and Balanbash TK metal have, as a whole, the identical configuration, but the arsenic content is much higher in the Balanbash series (Chernykh 1970, fig. 22). It is possible to explain this by the different degree of alloying only.

The main diagnosing elements used to relate the metal to some chemico-metallurgical group are As, Sb, Sn, Pb, Ni, Ag, Bi (Chernykh 1970, p. 17-31). It is necessary to kept in mind that there are positive correlations between concentrations of tin and lead with bismuth as they are geochemically connected elements which are present often in the same minerals. It is very indicative that in the diagrams of trace-element concentrations these elements behave in the same way in different chemico-metallurgical groups, showing all together both high or low contents, and often repeating the configuration of diagrams. Therefore these elements can reflect not only geochemistry of deposits, but also the alloying copper with tin (Chernykh 1970, p. 12, 21, fig. 8, 16, 20-24). Differences in diagrams of lead in the Abashevo, Balanbash and Early Timber-Grave series of the MP group (Chernykh 1970, fig. 23) are caused, apparently, by this. Deviations from this rule can be explained not only by the geochemistry of individual deposits, but also by differences in distribution of these trace-elements between slag and metal at different smelting temperatures.

The combination of increased concentrations of arsenic and antimony characterizes the chemico-metallurgical group VK (Volga-Kama). The total content of these elements fluctuates usually within 0.5-2.5%. Statistical calculation showed that the presence of these elements at alloys is not casual and it is possible to speak, apparently, about an antimony-arsenic alloying (Chernykh 1970, p. 16, 17, 21). At the same time, it is necessary to kept in mind the following circumstance. Antimony often replaces sulfur in sulfide minerals of arsenic and other elements. On the other hand arsenic, along with other elements (Ag, Au, Pt, Pb, Co, Ni, Mn, Sn, Zn, Se), can be present as in the form of impurity to copper sulfide minerals, replacing sulfur, as also in the form of arsenopyrite in copper sulfide deposits (Deer *et al*. 1966, p. 182). Therefore the combination of such elements as As and Sb can reflect both exploitation of copper sulfide deposits, and the use of arsenopyrite as an alloying component. Taking into account that the increased concentrations of other elements are peculiar to VK copper, the first variant could be, apparently, rather often. It is very indicative fact that antimony-arsenic impurities in metal appeared in the period when slag studies demonstrates the beginning of use of sulfide ores.

In this regard the 1st chemico-metallurgical group suggested for Kazakhstan bronzes is also very indicative, because its chemical characteristics are close to the VK group of Eastern Europe (Agapov 1990, p. 11). Altai copper deposits could be a source of this group. However, for Seima-Turbino sites of Asian zone connected with these deposits, these bronzes were not typical (Chernykh, Kuzminykh 1989, p. 166-170). Therefore, a final decision about their belonging to artificial alloys or to products of smelting of ores from the copper sulfide deposits enriched with arsenic and antimony, is problematic. It is not excluded that both of these reasons were a source of these bronzes.

The arsenic content is not also indicative for associating to a type of ore deposits. As we already showed in the former works (Grigoriev 1994, 2000a), TK copper group of the Middle Bronze Age in the Volga-Ural region and the Southern Transurals was not connected with the Tash-Kazgan mine, being a result of deliberate alloys of copper ores with arsenic minerals, although the use of some copper deposits with high arsenic content is not excluded. However the latter was not typical because in this period mainly oxidized ores with low arsenic content were the main source for copper smelting. Our studies also revealed a positive correlation between arsenic and nickel that allows assuming in some cases even the use of arsenic-nickel minerals for this alloying. Similar distinct connection of nickel and arsenic is seen also in metal (see Chernykh 1970, fig. 3, 4). Therefore, the growth of both these elements concentration in metal, as well as in the case with the VK copper, had different reasons: the alloys copper with arsenic and the use of copper ores with high arsenic content. In the case of TK copper the first reason is the best explanation. After the beginning of copper sulfide ores exploitation a part of the arsenic copper originated from them could increase.

Thus, the only trace-element silver is less dependent on such reason as the alloying. From this it is possible to draw a single conclusion. In most cases the chemico-metallurgical groups reflect either an alloying of metal or a type of ore (oxidized or sulfide). These groups do not reflect any concrete deposits or even a large mining area.

Possibly, MP copper is exception as being relatively pure it is characterized by the increased concentration of silver (Chernykh 1970, p. 17). Now it is supposed that in view of scarcity of forest in the area of Kargaly mines and huge scales of production, only limited local smelting was practiced there. The majority of ores was taken out to other, sometimes very remote, areas. To the north, in Bashkiria, traces of smelting of the ore from Kargaly have been found (Chernykh 1997, by p. 67, 68). Nevertheless, the statements that metal of this area is chemically comparable to the Kargaly ores (Chernykh 1997, p. 67, 68) it is not quite justified as silver is a very typical impurity for Bashkirian copper sandstones (Narkelyun *et al*. 1983, p. 12). On the basis of trace-elements comparison in copper it is, in principle, impossible to link this metal and ore from sandstones to any concrete area. This problem is outside opportunities of both emission spectral analysis and mineralogical analyses because the geochemistry of copper deposits in sandstones in the Western Urals is very uniform (Chernykh 1970, p. 37, 48). It is also necessary to take into consideration a possibility that some products smelted from oxidized ore with the increased silver concentration from deposits of other types can get to MP group. Nevertheless, taking into account this reservation, we can assume that this group is mainly connected with copper containing sandstones of the Western Urals. Unfortunately, recently the situation with MP group was aggravated, and a thesis has been formulated that all this group of metal was smelted even not from ores in sandstones, but from ores from the Kargaly mines. Moreover, even copper with obvious impurities is considered as copper from Kargaly alloyed with other metals (Chernykh 2007, p. 66). It is necessary to tell only one thing. Today we have no analytical method to do such conclusions.

One more group of copper EU in the Volga-Ural area is characterized, mainly, by the low concentration of silver. Its origin from Elenovka and Ush-Katta mines in the Mugodzhary zone is suggested (Chernykh 1970, p. 17, 22, 40). However it is not excluded that this group can reflect wider range of oxidized zones of different deposits in Orenburg area, the Mugodzhary and the Transurals.

As a whole, now many researchers are skeptical about former results of spectral analyses of metal. In the European literature it is now difficult to find references to the former works based on these analyses of copper artifacts. Many Russian archaeologists share this skepticism. Nevertheless, I would like to emphasize that the groups of metal based on this analysis have objective character, although their interpretation demands a considerable reconsideration.

All this provokes a necessity to discuss possibilities of application of the emission spectral analysis for studies of ore and slag. First of all, this analytical method is insufficiently reliable. In Russia the most reliable methodically spectral analyses were carried out by the Laboratory of natural sciences of the Institute of Archeology. However the repeated studies of Balkan copper artifacts by means of modern methods have found mistakes in some important trace-elements identified in Moscow. As a result, only some new chemical groups of copper have coincided with those suggested by E. Chernykh (Pernicka *et al*. 1997, p. 88-89, 102-106, 118). Nevertheless, the comparison of results of neutron activation analysis (NAA) and atomic absorption spectroscopy (AAS) with the old spectral analyses of the SAM project for Iberia are quite comparable (Müller, Pernicka 2009, p. 303).

I addition to the analytical problems, there are problems of the analyzed material. It is well known that trace-elements are distributed in ore very irregularly that does possible comparison of ore probes only statistically; the method is inapplicable at comparison of separate probes. We have the same situation also at the analysis of rough copper whose chemical compound is additionally influenced by fluxes. For example, a study of trace-elements in different parts of one copper object gives doubtful results as they differ; probes from deposits do not reflect character of its trace-elements in different areas; other minerals and fluxes could be added; re-melting makes its impact too (Palmieri *et al*. 1993, p. 577).

Very indicative experiments were carried out by U. Zwicker. After ore smelting the extracted copper was analyzed. As a result of this analysis it became clear that trace-elements are distributed unevenly in the metal. To receive a homogeneous metal the re-melting was required (Zwicker 1980, p.15). However, relatively correct result can be received only in case the metal was not mixed with another metal either initially or subsequently at the re-melting of scrap. But in the Middle and Late Bronze Age the part of the re-melted metal sharply increased that complicates substantially the correct determination of chemico-metallurgical groups (Chernykh 1970, p. 11, 12). Unfortunately, we do not know how many metal objects of any archaeological culture had been re-melted, but the degree of this utilization was apparently great. But the problems are not limited by this. Even smelting of ore from one deposit, with the use of the same fluxes and without next possible re-melting, can give as a result an absolutely various picture of trace-elements in metal. Very often such elements in copper as Ni, As, Sb and Ag are used as diagnosing for identification of a source of initial raw materials. However, studies of British scientists showed that they are insignificant for this problem solution, because their contents substantially depends on nature of technology (mainly, on a temperature) of metal production (Pollard *et al*. 1990, p. 135).

All above-mentioned problems limit the use of the emission spectral analysis only to determination of types of alloy. However, as it will be shown further, chemico-metallurgical groups based on this analysis have, nevertheless, quite objective character. Comparison of data on trace-elements based on spectral analysis of ancient materials from France with data based on the mass spectrometry method showed that correlation of trace-elements in ore and slag is quite good, although there are some problems (Berthoud *et al*. 1980, p. 87, 93). It is quite expected result because chemical compound of slag is based, mainly, on smelted gangue.

In this research the spectral analyses have been applied to the slag. Slag is quite seldom analyzed by this method as it is considered as heterogeneous material, therefore results of its analysis show considerable dispersion. To avoid it I selected for the analysis large probes, about 5-10g, pulverized them and only then analyzed. The analysis was carried out on the ISP-30 device, No. 740521 in the Chelyabinsk geological expedition. The received results were processed by means of the Brookhaven Date Handling Programs.

Here it is necessary to specify the legitimacy of application of this analysis. The problem of trace-elements transition from ore into slag and metal is quite important for the solution of a number of problems in ancient metallurgy. In particular it concerns a problem of correlation of slags and ores found on any concrete settlement, and also a possibility to link a slag probe with a concrete mine. At this stage this problem is almost unsolvable. Nevertheless, we need some ways to judge about the possibility of links of slag with this or that ore, based on its chemical composition. Similar studies were undertaken by E.N. Chernykh (Chernykh 1970, p. 11). He analyzed ore, slag and metal by means of the spectral analysis for the purpose of determination of regularities of trace-elements behavior in metal, slag and ore at metallurgical redistribution. The main attention was paid to their behavior in metal and ore, which is quite explainable owing to the tasks of his research. But now we will not discuss the problem of trace-elements transition into metal, because the object of this study is slag. E.N. Chernykh related to the group with decreasing coefficient of trace-elements transition into slag Ag, Sb, Au, As, and Bi, to the neutral group – Ni, Pb, Sn, Zn, and Co, and to the group with raising coefficient Mn, Ti, V, and Mo. Quite high coefficients of this transition (10-100) were suggested. My experience in Middle Bronze Age slags studies (Grigoriev 2000a), and also the latest works with slag of the Late Bronze Age showed that there are no so high coefficients of chemical distinctions between ore and slag. For the purpose to determine these coefficients the statistical work with results of spectral analysis of ore and slag from Northern Eurasia was done. I have selected only those analyses where ore and slag from one settlement were analyzed. It should be noted that on each individual settlement ore and slag if they are presented by single objects, could be not linked with each other. However, the comparison of the whole sampling has demonstrated the most general regularities. In total slag and ore from 14 sites were used: 155 analyses of slag and 106 analyses of ore (Tab. 0-5.). From the table it is well visible that overwhelming majority of sites (and, respectively, analyses), where both slag and ore were analyzed, belong to Sintashta culture (Arkaim, Ustye, Sintashta, Yagodniy Dol). It imposes some limitations on the drawn conclusions as Sintashta metallurgists used, mainly, oxidized ores and secondary sulfides. Secondly, the alloying with arsenic at the smelting stage was practiced, and an alloying mineral contained also high nickel concentrations. Therefore, the results relating to arsenic are doubtful, and those relating to nickel demand some correction towards reduction.

The data of the spectral analysis relating to individual trace-elements were summarized and divided by number of analyses. As a result, mean values of the content of each trace-element in slag and ore have been received. Comparison of these values allowed the coefficients of transition of trace-elements from ore to slag to be calculated. However, some trace-elements (Cd, Bi, W, Sn, Sb) show, as a rule, zero values, therefore the coefficients for them are statistically absolutely invalid and, probably, wrong. These elements and arsenic, introduced in these slags as an alloy, are marked out in the table (Tab. 0-6.).

Thus, the trace-elements with decreasing coefficient of this transition are: Ag, Sr, Pb, Ba, Ni, Zn, Co, Yb, and Y. Their content in slag descends. The coefficient of this decrease for different trace-elements fluctuates from 0.235 to 0.605. The maximum coefficient of 0.001 is revealed for silver. Relatively neutral are V, Be, Mo, Sc, and Mn. Ge, Ti, Zr, Ga, and Cr increase their values. The coefficient of the increase fluctuates between 1.31 and 2.374. Thus, we do not see considerable deviations in the content of the main trace-elements that makes comparable the chemical analyses of slag with ore analyses. However, it is needed be kept in mind that these data are correct for the oxidized ores smelting, and in case of slag relatively free of copper that was typical to Sintashta slag. The situation with slag from sulfide ores should be another, because they, on the one hand, are more polluted by impurities, on the other hand, they were smelted at higher temperature. Therefore, the behavior of trace-elements is less predictable in these conditions. But many researchers are convinced that the behavior of trace-elements depends on ore type (Brovender, Choubin 2008, p. 2).

Possibly, these coefficients are inapplicable also to smelting of oxidized ores in oxidizing conditions that resulted usually in the high copper content in slag. For example, experiments with ore, slag and ingots from archaeological sites showed that (unlike my results and those of Chernykh) nickel and cobalt remain, mainly, not in slag and their concentration in metal ingots decreases. But it was in ingots rich in cuprite, i.e., in the oxidizing conditions. In ingots with sulfide inclusions the content of these trace-elements is higher (Zwicker *et al*. 1980, p. 140). Therefore for all these slag types it is necessary to do separate calculations. In addition to this, it is necessary to remember about conditional character of these coefficients which reflect the most general tendencies. In a real situation the coefficient of this transition depended also on a ratio of copper and gangue in ore, and this ratio on different sites could be various.

For slags (27 samples) and ores (21 samples) of the Late Bronze Age settlement of Ilyaska a bit different coefficients are received (Tab. 0-7.). However the used sampling is too small. Therefore more precise calculations of these coefficients for the Late Bronze Age slag is needed. Nevertheless, the differences are not so considerable. They are notable only for arsenic that is explained by its use as alloy in many probes discussed above.

These coefficients for slags from oxidized ores (lower temperatures and oxidizing conditions) can be not so considerable as these slags contain a lot of inclusions of copper and cuprite. Therefore their chemical compositions differ not too much from initial ore that was heterogeneous itself and can show considerable variations in different areas of any ore field. Nevertheless, the results of any analyses have quite objective character, although they cannot be considered as absolute evidence. Thus, the use of the spectral analysis of slag is quite possible. It gives quite objective groups, however their interpretation as relating to any concrete mine is absolutely wrongful.

At the same time, so insignificant coefficients show that the slag analyses, in principle, can be compared to the ore analyses. Although slag is less homogenous in comparison with metal, it has one indisputable advantage. The huge mass of metal was repeatedly re-melted and often mixed with other metals. Slag was smelted from ore only once. However slag has some specific problems, namely, the transition of trace-elements from the furnace dressing or components of charge that will be discussed at the description of experimental works. Therefore, this analysis is not also absolutely reliable for slag.

Problem of ore sources identification

As it was already shown above, the method of the spectral analysis even in the slag or ore analysis (not to mention metal artifacts) gives no possibility to connect them not only with a concrete ore deposit, but even with a group of deposits in any area. In full measure it is applied to the RFA and others, more modern, types of analysis. The mineralogical analysis used widely in this work is a good way to determine a type of ore bearing rock only. However, the rock of the same type can be present in different deposits from distant areas.

In modern archaeometallurgy to the solution of this task the isotope method is widely applied. It is based on the fact that in metallurgical processes the ratio of three lead isotopes in slag, ore and metal remains invariable. It, as though, favorably distinguishes it from other chemical methods, and gives a chance for direct comparison of metal and ore. However this method has some problems too. Often individual probes in diagrams are situated along a straight line, having only different places on this line (see, for example, Gale, Stos-Gale 2002, fig. 2-4). It (purely graphically) makes impossible to distinguish probes from a large number of deposits (Fig. 0-8.).

These thoughts should not be considered as an appeal to refuse the use of this method, but its results are not a solution of the problem too. There are many works showing that this method perfectly copes with the tasks if probes of different deposits are situated in diagrams along parallel lines (see e.g. Gale *et al*. 2003). But in case of many deposits (and at large sampling of metal it is so), many of these lines coincide. Therefore, when two complexes of metal, slag and ore differ, we can ***reliably state this difference***. But if lines merge, it does not always mean that we may draw a conclusion about a single source.

There are also other problems. Studies in different regions, for example, in Armenia, Serbia and Bulgaria showed that within particular deposits the isotope composition can vary, and the composition of trace-elements is constant. In copper artifacts the set of trace-elements depends also on traditions of casting and forging (Ryndina, Ravich 2012, p. 12, 13). Studies of ores in Southwest Britain also showed that the ratio of isotopes in any individual ore deposit can strongly differ in different zones, and this method is not applicable in this area (Craddock, Craddock 1996, p. 61).

Probably, it is the only thing to do in this situation to use several analytical methods and correlate its results. Study of chemical compositions of chromites by means of the scanning electronic microscope can be one of them. However this method is not universal and is applicable only to materials of Sintashta culture. Possibilities to use this method for Sintashta metallurgy are very great owing to three circumstances:

1. Unlike the Late Bronze Age metallurgy, the Sintashta metallurgy was based on ores from the ultrabasic rocks; therefore the ore and slag almost always contain chromite inclusions that is typical also of the ultrabasic deposits.

2. The chromites are very refractory and their chemical composition does not change after ore smelting because they, practically, do not interact with other slag components as our numerous analyses of the Sintashta slags have demonstrated. It differ them from all other components and from the chemical composition of ore and slag as a whole.

3. Within a particular ore deposit the chemical composition of chromites is quite close and can be considered as an important diagnostic sign.

The phase diagram $Fe_2O_3 – Al_2O_3 – Cr_2O_3$ constructed on the basis of these analyses gives a possibility to compare chemical compositions of chromites in slag and ore fields.

One more method that can help in the solution of the discussed questions is identification of specific minerals, typical of any deposit, and chemical analysis of slag. Unfortunately, after metallurgical reactions these minerals cannot keep in slag, and the chemical composition is strongly transformed. Petrochemical calculations of slag chemical compositions can help.

The studies of chemical compositions of slag are, as a whole, a way to determine chemical compositions of ore-bearing rock and its mineralogy. This determination can be made by means of standard petrochemical calculations. In this research the Minpet program was used. However it is necessary to make some reservations here. These calculations would be correct in the case when only ore was used in smelting. But if the fluxes were added we inevitably receive a doubtful result. However, our study of large slag series of the Middle and Late Bronze Age of Northern Eurasia has not found the wide use of fluxes. It is possible to say quite definitely that Sintashta metallurgists of the Middle Bronze Age almost did not know the fluxes. Nevertheless, they added fragments of bones that introduced calcium and potassium in the furnace charge, promoting creation of more liquid slag. Phosphorus containing in the bones promoted temperature increase at exothermal reaction of its burning.

This circumstance forces to doubt in identification of Ca-containing pyroxenes, such as wollastonite[2]. This is also a reason to doubt in identification of apatite, nepheline and leucite – the minerals containing Ca and K. Reconstruction of some other components of the furnace charge, for example olivines and pyroxenes, owing to the resemblance of their chemical composition, cannot be recognized as the satisfactory too. Therefore this method is not strict and can be used only as an addition to the main methods. It is necessary to fix one more circumstance. In the following text the identification of this or that mineral in slag by means of these calculations is mentioned. But the minerals which are really present at slag, and the normative mineral compound reconstructed on the basis of recalculation of the chemical analysis are slightly different things. The latter is only idealized mineralogy.

There is one more reservation. The mineral composition depends not only on a chemical composition, but also on the speed of slag cooling. Therefore often it does not correspond to the idealized composition, based on the petrochemical calculations. Nevertheless, the method allows with confidence a type of the ore-bearing ore to be identified.

Base of the research

In the research mainly Bronze Age ores and slags of the area from the Don River to the Altai and Central Asia were included. In total 2331 slag and ore samples have been investigated (this number includes also some samples of our experimental smelts). On the whole, 2628 analyses have been done: 1184 emission spectral analyses, 738 by optical microscopy, 467 SEM analyses, 74 bulk chemical analyses, 88 RFA analyses of metal objects and 135 visual ore identifications[3].

Unfortunately, these figures only seem to be considerable. Actually for such huge temporal and spatial length they are insignificant. It is connected not only with large work content of all research procedures, but, often, also with lack of materials. So, data on Eneolithic metallurgy of the region are limited to only several samples, and data on metallurgy of the Early and Middle Bronze Age are simply absent. Only the final stage of the Middle Bronze Age is well presented by Abashevo and Sintashta settlements.

The Late Bronze Age is reflected in the research very irregularly too. The most slags are found on sites of Timber-Grave (Srubnaya culture). Slags from the Transurals and Kazakhstan are presented incomparably worse. But even on this background data on production during the Final Bronze Age, taking into account a huge number of bronze artifacts of this period, look depressing, and in many areas date on the Early Iron Age are absent at all. All this is partly explained by concrete research situations, but partly it reflects any other realities, for example, partial transfer of production to mines or increase of exchange operations and territorial specialization.

Archaeological cultures in Northern Eurasia

Before starting the description of cultures whose materials are analyzed in this work, and also historico-cultural processes connected with the development of metallurgical production in Northern Eurasia, it is necessary to touch upon the periodization accepted here. The studied materials belong to the Eneolithic, Early, Middle and Late Bronze Age, and the Early Iron Age. Belonging of any culture to the Eneolithic is not a special problems, although, as it will be shown below, often it can be quite controversial. However numerous problems arise with the belonging of other materials to this or that period. So, we consider Sintashta culture within the Middle Bronze Age (Grigoriev 1994, 1999, p. 34). But often scholars relate it to a transition period between the Middle and Late Bronze Age and even to the beginning of the Late Bronze Age. There are also many problems in correlation of materials from different areas. Because we will touch upon the

[2] Information about individual minerals is taken from Deer *et al*. (1965, 1966, 1966a).
[3] The author is thankful to many colleagues who helped collect slag for this research.

materials of the huge area, a question of vital importance is that in different areas the different schemes of periodization are used. In Eastern Europe a more or less harmonious system going back to V.A. Gorodtsov is developed. He suggested the following division: Early Bronze Age (Pit-grave culture), Middle Bronze Age (Catacomb culture) and Late Bronze Age (Timber-grave culture). Subsequently in both European and Asian zones of Eurasia many archaeologists started to distinguish a period of the Final Bronze Age, but many others consider it within the Late Bronze Age as its final phase. But in some areas the late Pit-grave complexes existed during the Middle Bronze Age. Besides, the Gorodtsov's periodization was not based on strict historico-metallurgical criteria, and differs from the periodization accepted in Central and Western Europe where the materials corresponding to the Eneolithic, are considered now within the Copper Age. The Early Bronze Age, if to be based on its name, should commence only since the appearance of arsenical alloys. Those in the Pit-grave complexes are known seldom, being, apparently, the Caucasian imports. In the Orenburg area, where ore smelting was practiced by the Pit-grave people, these alloys are not known. Therefore if to be based strictly on etymology of the terms, the Abashevo and Sintashta complexes should be considered as The Early Bronze Age.

However, it is a universal problem. So, in the Pre-Pottery Neolithic of Mesopotamia single metal objects are already known (Ryndina, Yakhontova 1989, p. 306, 308). Their number grows in the Neolithic. But, certainly, native copper was used for their production. The division of the Copper Age and Eneolithic is very problematic. Moreover, in the Urals and Western Siberia the Eneolithic complexes contain usually no metal finds. We simply know that metal was known in the region during this period. However, basing on flint and other finds it is very difficult to distinguish Eneolithic and Neolithic materials. Only experts familiar with the typology of ceramics of the region are able to do it. In Kazakhstan and Siberia the used schemes of periodization are not linked to those in Eastern Europe, against comparability of materials. The terms "Early Bronze", "Middle Bronze", "Developed Bronze", "Late Bronze", and "Final Bronze" are used, and this division is rather arbitrary in each territory. A situation in contact areas, especially in the forest zone, is even more complicated when near the Late Bronze Age cultures there are Neolithic cultures. And the designation of an epoch for the region turns into a question of preference.

Citation of similar paradoxes can be continued indefinitely, however there is no special need in it as from everything told it is clearly that available schemes of periodization have no enough rigid universal criteria; besides, development of these criteria is hardly possible, they will always have conditional character. It should be understood, and not to absolutize any of criteria. It seems more reasonable to adhere to the generally accepted terminology. Therefore, in spite of the fact that it is more correct to refer the Pit-grave culture to the Copper Age, all Russian archaeologists prefer the term "Early Bronze Age" (EBA). Similarly, it is more correct to refer the Abashevo and Sintashta complexes to the Middle Bronze Age (MBA). It corresponds also to historico-metallurgical criteria as during this period tin alloys were almost not known, and the arsenical alloys were widespread. Besides, chronologically these complexes correspond to the late Catacomb culture that allows them to be considered within the second phase of the Middle Bronze Age (MBA II). But chronologically they correspond also in Siberia to Elunino and Krotovo sites of the Late Bronze Age (LBA). Considering their connection with Seima-Turbino sites of the Late Bronze Age, Sintashta and Abashevo cultures of the MBA can be synchronized with the LBA cultures of the Asian zone. This is explained by that the stereotypes of the Late Bronze Age spread from the east to the west together with the movement of Seima-Turbino tribes (Chernykh, Kuzminykh 1989). Similar division of the material will be kept also in this book.

My former experience in the field of ancient metallurgy allows me to claim that any features of the technology and ore base, used in antiquity, were closely connected with global cultural and historical processes occurring on our continent. The essence of these processes was stated earlier (Grigoriev 1999, 2000a, 2002), however, it is necessary to give them the most general description here.

Although the earliest metal objects in Northern Eurasia are dated to the Eneolithic, there is not enough evidence of smelting for this period. There are no reliable data also on the ore smelting during the Early Bronze Age although copper deposits in sandstones of the Southern Urals were exploited at this time (Chernykh 2002). However the lack of settlements in this zone hinders studying of this problem. Most likely, the late Pit-grave complexes in this region continued to exist also during the MBA II. But the data on metallurgical production of this time are not present too.

Essential changes in Northern Eurasia started in the MBA II. In the 18th century BC (in the radiocarbon chronology, it is the late 3rd millennium BC) there was a migration of tribes from the Syro-Anatolian region to the Southern Transurals. It led to formation of Sintashta culture in the Transurals, and then to the appearance of Potapovo sites in the Volga region. Synchronously, in Eastern Europe several Abashevo cultures is formed. Possibly, with some lag from the described process, in the 17th century BC (the early 2nd millennium BC in radiocarbon chronology) the essential cultural transformations happened also in the east of the described region. The penetration of tribes bearing the Seima-Turbino traditions in metalworking to the Altai leads to emergence of Elunino culture here, and subsequently, with spread of this process westward, to formation of several cultures in the southern areas of Western Siberia: Krotovo, Tashkovo. Other cultural complexes (Vishnyovka, Odino-Krokhalevka) were connected with this process. The spread of the Seima-Turbino complex to the Western Urals led to the appearance of the Seima-Turbino burials and sites of Chirkovo culture in the Volga-Kama area. This migratory process influenced on Sintashta and Abashevo cultures. The disintegration of Sintashta system and migration of people to Eastern Europe began. As a result, in forest-steppe and the steppe areas of Eastern Europe Timber-grave culture is formed on the base of Sintashta Abashevo, Poltavka and late Catacomb populations. Similar process took place in the Southern Transurals: the formation of Alakul culture. At the heart of this process the Sintashta complexes lay. The spread of Alakul culture to the east resulted in assimilation of the related Petrovka tradition that had been formed in Northern Kazakhstan earlier on the base of the same Sintashta culture. As a result, in the 16th (17th) century BC a very large Timber-grave-Alakul cultural block arose. Thus, Sintashta culture was the main cultural component participated in these processes.

Some Alakul and Timber-grave populations penetrated the south of Central Asia. The Timber-grave penetration is limited to East Caspian area, and Alakul people penetrated in the east, up to Kyrgyzstan. However, it is impossible to say that this penetration was mass and reached Iran and Afghanistan although such belief can be met in Russian archeology.

In the 16th (17th) century BC new processes began. They were connected with the appearance of the Fyodorovo tribes in the Altai. From the Altai these tribes started spread by a wide stream to the west. The area of their movement included the steppe, forest-steppe and the southern part of the forests. In the steppe and forest-steppe these tribes actively interacted with the Alakul tribes that lead to formation of a series of syncretic types. In the forest zone these tribes interacted with bearers of former cultural traditions, including Seima-Turbino. As a result, the formation of Cherkaskul, and then Mezhovka culture of the Urals began. This process was continued also in Eastern Europe, with Fyodorovo and Cherkaskul-Mezhovka penetrations caused the formation of Suskan-Lebyazhinka and Prikazanskaya cultures.

In the 14th -13th centuries BC in the steppe and forest-steppe of Northern Eurasia cultures of the final bronze formed, characterized by vessels with an applied cordon below the neck. In the European part it is the Ivanovskoe (Srubno-Khvalinsk in another terminology), and in Asian part the Sargari. The formation of these cultures was based on Timber-grave and Alakul cultures, however, in the previous period penetrations into the steppe populations from the northern forest-steppe and the forest zone (Fyodorovo, Mezhovka, Suskan-Lebyazhinka) took place.

At last, in the early 1st millennium BC in the steppe archaeological sites almost disappeared. An exception is the Belozerka culture of the North Pontic area that was a continuation of its Sabatinovka predecessor. The latter originated being influenced from the Northeast Balkans and therefore these cultures were not connected with the cultures of Northern Eurasia described above. On the Lower Volga the rather sparse Nur sites are known, and the unexpectedly great number of the Dongal sites in Central Kazakhstan proceeded the Sargari tradition. The former cultural tradition remained also in the Western Urals where new cultures formed, as a whole, on a local basis, but it interrupted in the Transurals. However we, practically, have no slag materials of this time.

It is necessary to stipulate once again that the sampling is very limited for so vast area and so long period. It reflects even not quite adequately a real picture of development of metallurgical production in Northern Eurasia. In some areas excavators did not collected slag materials because their informative opportunities were not understood. In other areas archaeological works simply were not carried out. Therefore the available collection is capable to reflect only the most general tendencies of production development in this territory.

And, these tendencies are very important at reconstruction of historico-cultural processes, in particular, the migrations. It is possible to discuss doubtful opportunities of borrowings of types of ceramics and architectural styles over long distance, or even more doubtful possibility of borrowings of funeral rites, ideology and mythological system. But any discussions of borrowings of metallurgical technologies are in most cases absolutely senseless. First, these technologies cannot be passed without training. As we saw, metallurgical production is a very complicated process. This is also true for the change of alloys which were, as we will see, closely connected with type of ore. For example, the transition to new types of ore caused the transition to tin alloys, and the need of search and smelt the tin ore, cassiterite, thin-walled casting into closed molds, the lost wax casting, new techniques of forging operations and so on. So, the metallurgical technologies are a very difficult, interconnected system. Direct contact with experienced metallurgists is necessary for its borrowing. Close neighbors could borrow these technologies, but over barren areas, without ore deposits, it was impossible. If it occurred, it is a reliable indicator of migrations.

Any cultural processes depend on two major factors – culture of a former population and either influences or migrations from outside. The processes of cultural interactions of different forms provided formation of similar stereotypes within rather large areas. However, the former traditions disappear completely seldom. As a rule, they show themselves to some extent in the culture of derivatives. The technology of metallurgical production is not an exclusion. Moreover, if any other productions and features of material culture are dependent, above all, on traditions of composing components, the metallurgical production depends also on the ore base. Therefore the local components can be expressed as in borrowings of local technological traditions (and it is a standard cultural process depending on a concrete situation of cross-cultural interactions), as also in transition to local ores that is a forced transition.

This circumstance causes new difficulties in the system of description of Northern Eurasian metallurgical technologies. On the one hand, there are chronological regularities caused by technological changes in huge territories. However, they show themselves not always and not everywhere that is caused already by local specifics. Therefore, at first sight, it seems to be more logical to consider production of the whole region by phases. But, unlike ceramics, slag has no accurate cultural or chronological indications; often only comparative and statistical procedures allow slags of different periods in multilayer settlements to be distinguished. It forces to consider at the same time slags of different periods of any particular area. And from this point of view, the territorial approach has to dominate when slags from different areas are described successively that leads already to the loss of chronological approach. In the end, it is necessary to search for any compromises.

In particular, the starting point for consideration of the Bronze Age slags is Sintashta and Petrovka cultures of the Transurals that causes also discussion of some materials from Kazakhstan. Further, the materials of the Late Bronze Age of the European zone are considered. However, partially the Western Ural materials are considered also in the context of Sintashta culture. Chemical analyses of slags from the settlement of Tyubyak are considered as in the context of Sintashta as in the context of Timber-grave culture, which is caused by the necessity to do a comparative analysis.

Some of the discussed problems will be covered in different chapters in more detail. But, it would be desirable to emphasize that a task of this book is a development of any research standard and the most general model of development of copper production in this territory. This will do possible in the future to organize more detailed studying of individual areas and cultures. There is one more problem demanding a special discussion. It is the chronology used here. For the most part of the interval included in this work, it is possible to use as the traditional dating linked to the Middle Eastern chronology, as the radiocarbon dating. The last system of dating unconditionally dominates recently, but it is created not for all regions. On the other hand, there are serious problems with the radiocarbon dates, about which usually ones keep silence. Attempts to compare these two systems give while few hopes that it is possible, because for different periods the difference between them makes from 200 to 900 years (Michael 2004, p. 18). It is also obviously that the radiocarbon method works today only at a statistical level that does not allow it to be surely used in case of small series of dates (Müller 1998, S. 66). And for many cultures of Northern Eurasia these series are insignificant yet. I do not know how to regard with this problem, and how correct the calibration of radiocarbon analyses is. But it is just necessary to give the calibrated data. That means that irrespective of these dates correctness, they are used here for identification of relative time of discussed processes and their sequence. In addition to this, sometimes, I give dates in system of traditional chronology.

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Tab. 0-1. Melting points of some slag minerals.

Cu	Cu_2S	Cu_2O	CuO	FeO	Fe_3O_4	Fe_2O_3
1084°C	1127°C	1232°C	1336°C	1360°C	1530°C	1570°C

Tab. 0-2. Relative viscosity calculated for ores of different chemical compositions.

№	Site	Material	Kz	η 1400 (Pa·s)
2158	Experimental smelting № 9	Chalcopyrite	25.21	-0.26
2195	Experimental smelting № 12	Chalcopyrite	21.81	-0.23
2126	Experimental smelting № 5	Oxidized ore of the Dergamysh deposit in ultra-basic rocks	1.25	3.46
2161	Experimental smelting № 10	Oxidized ore of the Ishkinino deposit in ultra-basic rocks	0.99	4.5
2106	Experimental smelting № 4	Oxidized ore of the Nikolskoe deposit in quartz rock	0.58	7.95
2103	Kargaly	Oxidized ore of the deposit in copper sandstone	0.03	149.73

Tab. 0-3. Viscosity calculated for slags of different chemical compositions.

№	Site	Kz	η 1400 (Pa·s)
66	Verkhnyaya Alabuga	35.83	-0.31
2173	Experimental smelting № 11	25.39	-0.26
2193	Experimental smelting № 11	17.28	-0.17
2186	Experimental smelting № 11	16.61	-0.15
2116	Experimental smelting № 3	13.39	-0.08
1781	Arkaim	1.83	0.00
2145	Experimental smelting № 6	9.29	0.08
2121	Experimental smelting № 2	6.37	0.32
21	Atasu	5.35	0.47
26	Myrzhik	4.8	0.57
2123	Experimental smelting № 4	4.77	0.58
2212	Uzhovoy Island	2.83	1.28
2207	Guseva Gora	2.76	1.33

№	Site	Kz	η 1400 (Pa·s)
19	Atasu	2.6	1.44
1792	Arkaim	2.57	1.46
27	Myrzhik	2.45	1.55
54	Vishnyovka	2.4	1.59
Gor-E09/3	Gorny	2.15	1.83
483	Ayakagitma 234	1.93	2.08
1923	Tyubyak	1.86	2.18
1789	Arkaim	1.86	2.19
46	Novonikolskoye	1.79	2.29
1799	Sintashta	1.53	2.76
2144	Experimental smelting № 6	1.51	2.8
590	Besh-Bulak 1	1.45	2.94
588	Besh-Bulak 1	1.44	2.96
18	Atasu	1.44	2.96
1937	Beregovskoye	1.42	3.00
1946	Sintashta	1.23	3.52
1285	Kuzminkovskoye	1.16	3.78
1798	Sintashta	1.14	3.85
2129	Experimental smelting № 5	1.07	4.15
1303-1	Ivanovskoye	1.03	4.31
1925	Tyubyak	0.98	4.56
44	Sargari	0.92	4.89
1333-1	Rodnikovskoye	0.9	4.97
1318-1	Pokrovskoe	0.89	5.09
1787	Arkaim	0.77	5.94
1304-1	Ivanovskoye	0.75	6.09
Gor-E29/7	Gorny	0.74	6.21
1344	Rodnikovskoye	0.72	6.33
2169	Experimental smelting № 10	0.69	6.66
13	Petrovka II	0.65	7.12
Gor-E10/1	Gorny	0.64	7.17

№	Site	Kz	η 1400 (Pa·s)
Gor-E26/7	Gorny	0.64	7.21
Gor-E01/5	Gorny	0.63	7.3
580	Besh-Bulak 1	0.6	7.68
Gor-E11/3	Gorny	0.58	8
Gor-E12/1	Gorny	0.57	8,13
Gor-E27/5	Gorny	0.57	8,21
2063	Berezovaya Luka	0.56	8,23
Gor-E28/6	Gorny	0.49	9,48
1941	Beregovskoye	0.48	9,75
1942	Birsk I	0.47	9,91
Gor-E06/1	Gorny	0.44	10.58
Gor-E23/5	Gorny	0.39	11.97
Gor-E18/5	Gorny	0.39	12.09
Gor-E25/6	Gorny	0.37	12.8
Gor-E08/1	Gorny	0.36	13.13
2037	Berezovaya Luka	0.34	13.83
Gor-E20/3	Gorny	0.34	13.86
567	Besh-Bulak 4	0.34	13.93
1355	Rodnikovskoye	0.34	14.04
Gor-E30/4	Gorny	0.29	16,26
1356-2	Rodnikovskoye	0.29	16,4
Gor-1-5	Gorny	0.26	18,42
2146	Experimental smelting № 7	0.23	20.98
2047	Experimental smelting № 7	0.22	22.24
53	Ak-Moustapha	0.21	22.6
Gor-E22/5	Gorny	0.21	23.04
2044	Berezovaya Luka	0.2	24.15
Gor-E13/5	Gorny	0.19	25,06
Gor-E19/8	Gorny	0.17	28,41
2048-1	Berezovaya Luka	0.16	31.09
Gor-E21/5	Gorny	0.12	41.9

№	Site	Kz	η 1400 (Pa·s)
Gor-E24/5	Gorny	0.1	47
2030	Experimental smelting № 5	0.05	108,4
2029	Experimental smelting № 5	0.04	113.3
2074	Experimental smelting № 11	0.02	323

Tab. 0-4. Coefficients of basicity and acidity used for the classification of slag.

Group of slag	Coefficient of acidity	Coefficient of basicity
Ultra-basic	0-0.5	> 2.5
Basic	0.5-1	2.5-1.5
Average	1-1.5	1.5-1
Acid	1.5-3	1-0.5
Ultra-acid	> 3	< 0.5

Tab. 0-5. Quantity of analyses of ore and slag used for calculations of regularities of the trace-elements transition.

Site	Slag	Ore
Arkaim	55	12
Burli	1	1
Ilyaska	27	12
Itkul	1	1
Myrzhik	1	1
Novobaryatino	3	1
Petrovka	2	1
Rodniki	3	1
Sergeevka	2	3
Sintashta	16	38
Tash-Kazgan	2	4
Ustye	41	30
Yagodniy Dol	1	1
Total	155	106

Tab. 0-6. Coefficients of trace-elements transition from ore to slag. Statistically doubtful trace-elements are marked out with red.

Group		
decreasing	**neutral**	**increasing**
Ag 0.001	V 0.91	**As** 1.31
Cd 0.1	Be 0.93	Ge 1.335
Bi 0.125	Mo 1.186	Ti 1.571
Sr 0.235	Sc 1.217	Zr 2.1
Pb 0.238	Mn 1.22	Ga 2.25
Ba 0.353		Cr 2.374
Ni 0.375		**Sn** 12
Zn 0.392		**Sb** 13
Co 0.489		
W 0.5		
Yb 0.594		
Y 0.605		

Tab. 0-7. Coefficients of trace-elements transition from ore (settlement of Ilyaska).

Group		
decreasing	**neutral**	**increasing**
Ag 0.08	Cr 1.083	Mn 1.595
Pb 0.091		V 2.1
Sr 0.105		Sc 2.17
Ni 0.157		Zr 2.41
Ba 0.187		Ti 2.779
Co 0.253		Be 3.482
Zn 0.267		Mo 7.799
Ge 0.296		
As 0.4		

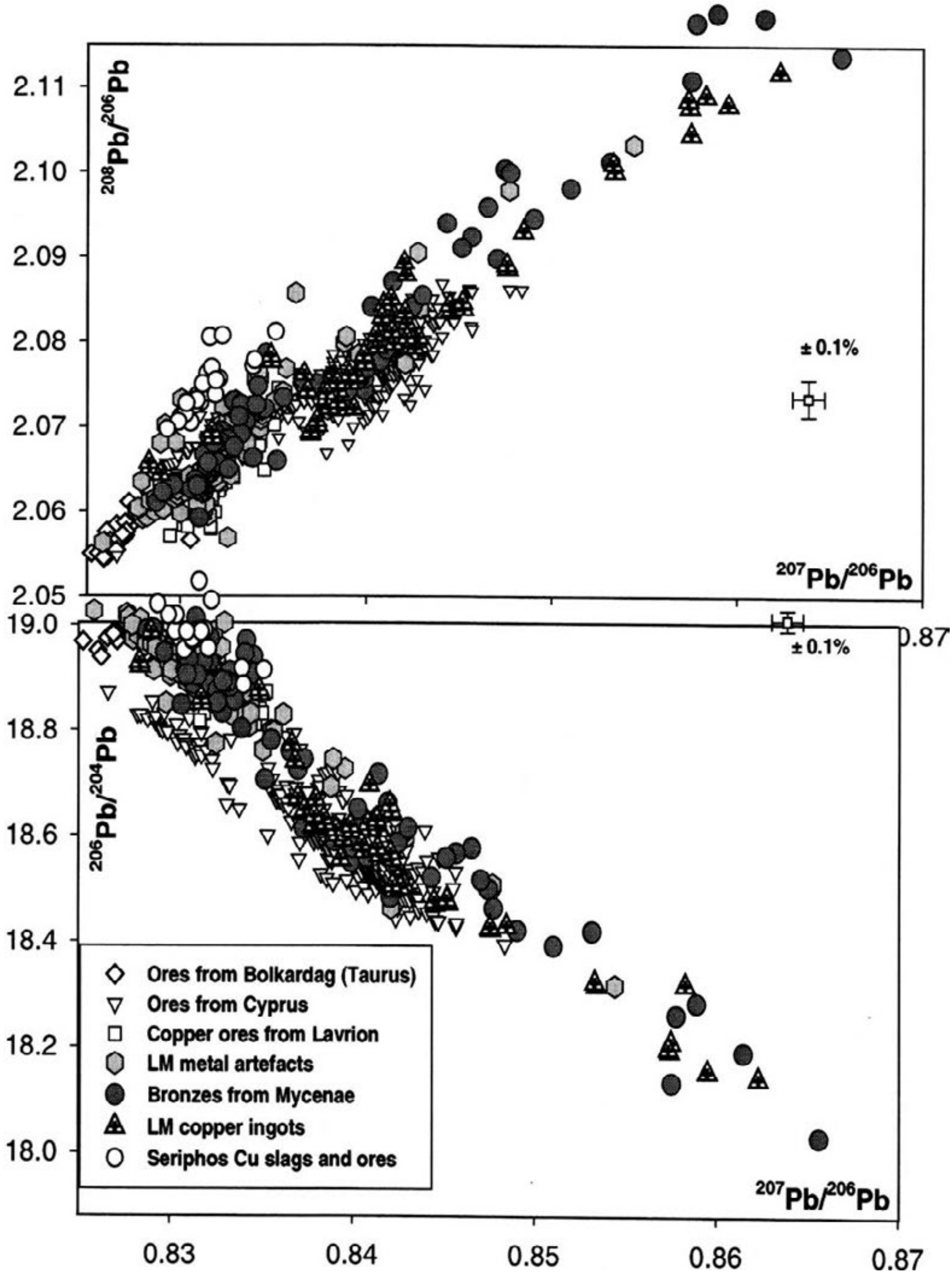


FIG. 0-8. DIAGRAM OF CORRELATION OF LEAD ISOTOPES (AFTER GALE AND STOS-GALE, 2002).

Chapter 1.
Experiments with Ancient Copper Smelting Technologies

Experimental works play an important role in reconstructing ancient technologies. Numerous experiments have been conducted by many scholars in studies of ancient ceramic production, metallurgy and metalworking, manufacturing and use of stone tools, weaving, housing construction and so on.

Within our works, mainly, ore smelting experiments were made. It was carried out also preparation of charcoal, but it had auxiliary character, for providing the metallurgical experiments with fuel. The well done experimental works on preparation of charcoal were carried out and described by another group of authors (Agapov *et al.* 1989, p. 101-103).

In archaeometallurgy, smelting experiments have been widely carried out and, although almost all of them had an incidental character, many have been successful (e.g. Rostan *et al.* 2006; Ueda 2006; Pollard *et al.* 2009). Unfortunately, their results have not yet been summarised. A unique and limited attempt of this sort known to me is that done by R.F. Tylecote and J. F.Merkel (Tylecote, Merkel 1992).

However, before describing our experimental approach, it is necessary to touch upon their place in historico-archaeological studies. Sometimes a successful experiment will directly correlate with ancient reality and their identity can be affirmed. Actually, only analyses of ancient materials can help us to understand ancient technologies. Experimental works show the possibility of using this or that method, and only that. Besides, it is frequently possible to obtain the same result in different ways and an optimal approach discovered by an experimenter may not necessarily be the one used in antiquity. At an experiment it is important not to try to make bronze better than colleagues from the Bronze Age, but to seek out many different options (Fasnacht 2009, p. 396). And the use of experimental reconstructions without this important thesis is absolutely false. Thus, despite much effort being expended on their preparation and execution, experimental reconstructions offer a limited research tool.

The study of ancient technologies should be based on analysis of the remains of ancient production activity by means of modern analytical methods and experimental approaches are therefore auxiliary to these. The optimal approach involves the analysis of experimental results by means of the same analytical methods. In addition to increasing the reliability of the experiment, a further advantage is gained, namely, the potential to compare analyses of experimental and ancient materials. In particular, analytical studies allow us to reach more authentic conclusions. Actually, this approach is not new. Initially it was a base for the use-wear analysis of ancient lithic tools; it is actively used by researchers of ceramics, metal working, and so on.

Copper ore smelting presents a rather difficult situation which poses a number of problems and necessitates using many methods. Slag systems are particularly problematic. Besides, all analytical methods demand examination and correction. For example, it is well known that trace elements are redistributed between slag and metal during metallurgical processing, with an increase in some elements and a decrease in others. However, the distribution of different trace elements will depend also on temperature. Changes in metal also occur during the process of refinement and most metal was subjected to numerous re-melts influencing the trace elements. In this situation a very typical was mixing metals from different sources and with different alloys. Finally, trace elements may be distributed non-uniformly during casting. These problems can be most effectively solved only by means of a specific experimental programme.

We have touched upon only one insignificant aspect, however there are many others.

In this regard, we gathered information about previous smelting experiments and carried out a series of new. All these works have a very preliminary character. Their results are in detail published in this book with the purpose to help the next experimenters to avoid our mistakes.

Initial studies were carried out in collaboration with I. Rusanov at the settlement of Arkaim (1989) and the Kargaly mines (1991) (Grigoriev, Rusanov 1995). Subsequently, a series of small lead-smelting experiments was carried out with A. Nikitin in 2004 (Grigoriev, Nikitin 2004, p. 141-143; 2005, p. 35-39). However, the major experimental series with use of both sulfide and oxidized ores was conducted on Vera Island in Lake Turgoyak in 2005-6. In this series the samples of ore, slag, ashes, charcoal and furnace loam were selected and analyzed. All experimental stages were described and timed. In total, it was possible to carry out 34 experimental smelting operations involving the construction of furnaces, the manufacture of crucibles, charcoal burning, etc.

The experiments are not described in detail here, as many observations are repeated from one experimental situation to another, although basic conclusions are reported. It is important to note that we were unable to achieve consistent results in terms of metal extraction but much important information was obtained and at the conclusion of this series of experiments, it was possible also to discover reasons for failure, although it is not certain that, after correcting the errors, other unexpected factors won't appear. But importance of these experiments is that many features of ancient production became obvious. For example, the reasons of transfer of production sites in the Late Bronze Age out of dwellings or need of use, so-called, melting cups.

Charcoal

Preparation of charcoal is a labour-intensive operation demanding considerable experience, despite its seeming simplicity. In principle, it can be done in piles, covering them with soil and turf, but this way is justified for large volumes of production. We used pits and placed a mixture of dry and crude wood; using only dry wood is not an option, as this will not smoulder but burns down quickly, whereas unseasoned wood simply goes out, so a combination of the two was used. Log diameter was 10-15 centimetres and we had to split larger logs. Dry branches and birch bark were placed between the logs and the pit was then covered by turf and soil. Around the perimeter, small apertures which could easily be blocked by turf were used as a means of lighting the branches and birch bark. The apertures also created a draft and this allowed the fire to burn at about the correct intensity. When the smoke had cleared, the apertures were sealed and the contents left to smoulder. For skilled miners, this operation would probably have taken no more than 1.5 hours; however, we took longer. Preparation of the wood took a considerable time, as the work was carried out exclusively using axes. The contents of the sealed pit should be left for several days while the wood slowly burns down to form charcoal. Our most successful experiments yielded about 50 per cent charcoal, with a considerable proportion of the wood simply charring; in antiquity, the success rate was, of course, higher, although it would never have been possible to convert all of the wood to charcoal.

For the experiments, we used birch and pine. Their properties differ markedly, with birch having the greater density. When crushed, birch charcoal forms larger pieces, which burn well, saving a long time in the furnace, whereas pine charcoal breaks up into a smaller fraction and tends to burn more intensely but only in certain parts of the furnace, close to an air source. Their behaviour inside a metallurgical furnace therefore differs. The larger pieces of birch charcoal allow air to circulate freely (Fig. 1-I.1), whilst the much smaller pine charcoal fragments form a dense mass that burns fiercely, creating showers of sparks, but only where this is exposed to air; in other parts of the furnace, such as against the opposite wall, it burns weakly. Also, small fragments of charcoal are easily blown away and the air stream then moves directly onto the ore, cooling or oxidising it, which does not happen with larger pieces. Pine is therefore not a good choice for use in a furnace, as it is unable to sustain the necessary temperatures and chemical process, although pine is more efficient when used for forging. There is no evidence to indicate that a similar distinction between these two sources of fuel existed in antiquity, although it is possible to draw certain conclusions regarding fuel preference from the density of trees (birch, oak). Probably, it was understood always, for classical antiquity this understanding is recorded. Pliny wrote that the best charcoal for ore smelting made of oak. Contrary to this, smiths preferred not such dense charcoal from a fir; it ignites and crushed better (Forbes 1958, p. 20, 21).

In my opinion, the optimal size of charcoal pieces is 10-12 centimetres. In this case, air is able to circulate freely and there is a significant surface area to react with the air.

When birch charcoal is crushed, a quantity of dust is formed, which provides an additional sealing layer over the contents of the furnace, generating higher temperatures. And as this smaller fraction gradually filters down between the larger pieces of charcoal, it forms a highly flammable mass maintaining elevated temperatures and inducing the intensive formation of carbon monoxide.

We used from 2.5 to 4.5 kilograms of charcoal depending on furnace size (25-50 centimetres in diameter). A single charge of charcoal burned for 1-1.5 hours, which was obviously insufficient for smelting and it was thus necessary to add charcoal periodically. A small furnace operating for 4 hours 50 minutes from the start of the process would consume 4.5 kilograms of charcoal.

Manufacturing of technological ceramics

During the preparatory phase, we needed to manufacture some ceramic components, including crucibles and tuyeres. It should be noted this was a subsidiary part of the experimental work and will be dealt with in brief. Comparisons should not be made with experiments focusing purely on ceramic production.

Ceramics used in metallurgical production require heat-resistant properties, which can be achieved by adding quartz sand. Crucibles and tuyeres were therefore made from clay with a substantial proportion of sand added taken from the lake. The analysis of this sand showed that it contains up to 70 per cent of quartz that allowed using it for preparation of fire-resistant masses (Tab. 1-1.). Clay for production was lying several days in water and mixed up to remove large dry fraction and to achieve homogeneous paste.

We used two types of crucible: a jar-shaped vessel for testing a hypothesis regarding ore smelting in crucibles, which was formed using a cone-shaped wooden model covered with damp cloth that enabled us to remove the crucible when dry; the second type was a shallow oval dish about 20 centimetres long (Fig. 1-I.2).

The tuyeres were moulded on sticks that allowed a longitudinal aperture to form. It was, probably, a universal way: we came to it independently, but the African metallurgists, as well as in our experiment, moulded the tuyeres on a stick (Schmidt 1997, p. 63).

The ceramic items were dried for two days and then fired for a further three hours. During the course of the primary drying, it was necessary to constantly firm the products by hand, as, after the evaporation of water from the wet crucibles and tuyeres, small cracks were formed. One of the tuyeres during the drying gave a small crack because the clay was not firmed in time. An attempt to seal this crack was made, but when firing the tuyere cracked in this place.

The firing of both tuyeres and crucibles was carried out on an open fire (Fig. 1-I.3). The tuyeres were firing together with the sticks. As a result of the firing the sticks burned out. It did not prevent the firing.

The tuyeres proved stable and generally no slag formed on the ends, despite the high temperatures (Fig. 1-I.4). Exceptions occurred only in cases where a tuyere came into contact with an object in a furnace, such as a piece of charcoal or smelted ore. The crucibles also withstood extremely high temperatures. We noted that a vessel subjected to the maximum temperature became practically white and slightly transparent from the heat, but did not melt. However, if the ore started to smelt in the crucible, slag appeared around the rim but not on the base. This was caused not only by the high temperatures involved but by slag interacting with the clay of the crucible.

Furnace design and manufacture

We used furnaces of different types. Experiments with furnaces of the Sintashta type connected to wells have been carried out, with wells at the Bronze Age settlements of Arkaim and Mochishe being used for this purpose. The diameter of the wells was about 120 centimetres and the depth 230 centimetres and they were covered by a cupola of clay or sandy loam. A small framework of rods was constructed over the well on which clay was gradually applied, which, after drying, proved stable. A channel connecting the well to the furnace was made as follows. On the settlement of Arkaim such channel had vertical traces of the thick carbonized rods on its walls. We put the rods in the form of arches, set against the walls. They were a basis for clay covering which after drying was burned. As a result, rods burned out, but the covering kept the form.

Building a furnace was labour-intensive. The first was constructed from dried clay blocks about 20 centimetres in length on clay mortar. These were moulded relatively quickly and dried for about two days. During work on Vera Island, we used granite pieces for the furnace (Fig. 1-I.5,6).

Once a location for the furnace had been selected, the turf was removed and a layer of sand deposited to a thickness of around three centimetres. This was then covered with a mixture of clay and sand. Granite or clay blocks were used to construct the walls of the furnace and these were laid on a sand and clay mortar, with both internal and external walls plastered over with the same material. As other smelting experiments had demonstrated, without this lining, the furnace would be unable to withstand the high temperatures involved and if the surfacing material was damaged in any part of the structure, the underlying granite wall would quickly disintegrate. Also, in those areas where the lining had cracked, in particular, around joints in the clay or stone blocks, the pressure inside the furnace would break through the wall, resulting in significant heat loss. The lining thus provided vital insulation and, where this was of poor quality, walls would become warm or even the hot.

Constructing and insulating a furnace takes several days, depending on the weather. We found that applying a thick layer of plaster resulted in a network of large cracks appearing in the surface during drying, with plaster peeling off easily; the best technique therefore involved applying thin layers, allowing each to dry, and ensuring that any cracks and internal pores were sealed, as these would result in weak areas that would crack when exposed to heat. In damp weather, this process took a considerable period of time to complete (Fig. 1-II.1). At the end of drying the lining could be fired, although this did not appear to be essential.

One of the furnaces used in the experiments proved very stable, having been constructed of clay layers, which was a time-consuming process but meant that there were no problems with the plaster during smelting.

As further experiments demonstrated, the lining withstood very high temperatures; however, it could not endure contact with smelted slag. When liquid slag became welded to the covering material, it was impossible to remove it. Attempting to prise it off with a crowbar or chip it away using a stone hammer frequently dislodged substantial pieces of covering at the same time. Therefore, before further smelting could take place, the insulating material had to be renewed, which again took a considerable time. Thus, paradoxically, any successful smelting operation resulted in the need to repair the furnace. But in case of the furnace made of clay layers without wall lining the object of this destruction were the walls.

At analysis of remains of the furnaces after smelting experiments we noted that walls of the furnace are burnt to red color on the considerable depth, while the bottom had usually dark or ashen shade. Therefore at archaeological excavation of furnaces it is not necessary to expect detection of red color on the bottom at all (Fig. 1-II.2,3).

The problem of furnace repairs did not arise provided the ore was placed in a crucible. Slag damage generally only affected the upper part of the crucible and crucibles could often be used repeatedly. This led us to the conclusion that the reason for the use of so-called 'melting bowls' had been to protect the furnace from the harmful effect of slag (Fig. 1-II.4).

There are, however, ways to accelerate drying the covering discovered by other experimenters. To remove crystal water it is necessary to add burned ceramic material in the covering, to dry and burn with charcoal and wood at a temperature of 1100 ºC within six hours (Woelk *et al.* 1998, p. 266). But this is a rather labour-intensive process and smelting in either a crucible or a melting bowl solves the problem more easily.

We have been using two types of furnace. The first (the Sintashta type with a well) had a diameter of 50 to 70 centimetres. But it was easier to achieve higher temperatures in a furnace with a smaller diameter and in some experiments this was reduced to 40 centimetres. The furnace was cupola-shaped, connected to a well by the air-blowing channel. Bellows were placed opposite the well; thus, a tuyere was placed above the level of the furnace base. After pre-heating the furnace, certain unexpected operational characteristics emerged. Due to a temperature difference between the furnace and the well, air circulated rapidly around the interior, uniformly warming the furnace. At the same time, air entering through the pressure tuyere gathered at the centre of the furnace and, where this met a counter air stream, maximum temperature observed (Fig. 1-2.). This airflow pattern, on the one hand, enabled the furnace to be heated using only a single set of bellows, with high temperatures being attained at the centre of the structure, while, on the other hand, oxygen, filtering through a charcoal layer, reacted with it to form carbon monoxide, the basic reducer of ore. This possibly explains the reducing conditions evident from analysis of Sintashta slag.

The second type was a cupola-shaped furnace lacking a flue and well and with an internal diameter at its base of some 50 to 55 centimetres. Wall thickness was about 10 centimetres and the furnace height 35 centimetres. During the course of the experiments, it became clear that there was insufficient air to run the furnace at a constant level and so we reduced its internal diameter to 25 centimetres and installed a second set of bellows. Bellows were set either directly opposite each other or at an angle of 120° to facilitate the mixing of air in the centre of the furnace and to attain maximum temperatures. A single set of bellows was clearly insufficient for a furnace of more than 30 centimetres in size.

Thus it must be kept in mind that we used two-chambered bellows for constant stream of air with rather high efficiency. The essence of this design is that air when lifting the top of bellows gets to the bottom chamber, and then via a valve in a partition between the chambers goes in the upper chamber; from where under pressure of the upper cover arrives through a tuyere into the furnace, providing constant blasting. Regulation of blasting is carried out by intensity of pumping, and its pressure and speed – by the weight of the cover (it is easy to regulate it by stones). It is very handy for work and an effective device; however it is doubtful that it existed in the Bronze Age (Fig. 1-II.5). Known Egyptian frescos with bellows show simpler devices in form of couples of small-sized single-chambered bellows. The workers pressed them by feet squeezing out air, and then raised a foot, at the same time raising the top part of the below by a rope attached to the hand, therefore the below was filled again. The use of couple of bellows provided rather uniform blasting. Other pictures show people blowing in pipes (Zwicker et al. 1992, p. 103, 104). It is rather difficult way. To smelt even in a crucible (i.e. in small volume) using the pipes the operating of 4-6 people is necessary (Fasnacht 2009, p. 396). At last, in the Hittite period in Anatolia pot bellows were used (Müller-Karpe A. 2000, S. 117, 118). For Sintashta culture we do not know archaeological evidences of two-chambered bellows, although it is not excluded that at the beginning of the Late Bronze Age they appear. At this time two-chambered furnaces appeared. Perhaps one of the chambers served as a depression for the bottom camera of bellows. On a flat surface these bellows are not so productive as if both chambers are filled with air the angle between the top cover and the surface is too great that does not create necessary pressure. In the course of our experiments on the Turgoyak we intentionally built the furnace on a slightly inclined place that provided space for the bottom chamber of the bellows. Nevertheless, the reason of the second depression in archaeological furnaces could be another.

The length of each chamber of bellows used in experiments was 90cm, the height in back part – 50cm, the width fluctuated from 20 to 60 cm. A lever for increasing the force of the bellows was angled on a portable support consisting of two connected poles. Although the structure was fairly unstable, during experiments with sulfide ore, when a considerable quantity of sulphurous gases escaped, it enabled the operator to change position, depending on wind direction. Accordingly, archaeological traces of similar bellows cannot remain.

However, in spite of efforts to optimise the flow of air into the furnace, igniting the charcoal remained a problem and pre-heating was necessary. According to other experimenters, this was a lengthy procedure taking from 1.5 to 3-5 hours (Bamberger 1992, p. 157; Caneva, Giardino 1994, p. 454). Our initial attempts took 2-3 hours; however, in subsequent experiments, we used firewood, which required less time, no more than half an hour or so (Fig. 1-II.6), assisted by the use of bellows. Charcoal was then placed onto the lighted wood and this ignited much more easily. Full pre-heating was a lengthier process. This procedure, except in terms of economy of time, saves charcoal.

During the experiments, a paradox, typical of ancient metallurgy, came to light. This technological contradiction occurs when the large volume of air needed to maintain of high temperature inside the furnace creates an oxidising atmosphere and the ore is turned into cuprite rather than metal. This reaction did not occur with a less intense air supply.

The atmosphere in different parts of the furnace can differ. For example, after smelting, the wall of the furnace around the tuyere exhibits an intense red colour while further away it is black. Thus, an oxidising atmosphere formed around a tuyere whilst elsewhere it was replaced by a reducing atmosphere. Thus, in primitive metallurgical furnaces, the reducing atmosphere formed some 15-18 centimetres from a blowing tuyere. This can be explained by oxygen from a tuyere reacting with charcoal to form, at first, carbon dioxide. This gas reacts with a charcoal layer to form the reducing gas carbon monoxide. In the upper section of the furnace, the environment was also oxidising as air enters the furnace through its mouth (Fig. 1-III.1).

It is thus possible to draw the following conclusion: in small-diameter furnaces, the oxidising atmosphere forms uniformly; in the case of blowing through a charcoal layer, the reducing zone can be at the distance of 12-15 centimetres. Therefore, it is desirable to place the oxidised ore at this distance. Sulfide ores can be placed closer to the tuyere. Similar evidence was obtained earlier by other experimenters (Tylecote, Merkel 1992, p. 10). In addition to this, in their opinion, the zone of maximal temperature was 10-15 centimetres from a tuyere.

Smelting process

Ore preparation

For the experiments, we used oxidised ore (malachite), secondary (covellite) and primary (chalcopyrite) sulfide ores. Before charging the furnace, the ore was crushed, the size varying in different experiments, from powdered fractions to pieces of 3-5 centimetres (Fig. 1-III.2,3). The powdered fraction was difficult to obtain by crushing and was used only infrequently. Besides, it seemed to us that, at high temperatures, the ore should smelt regardless of size. However, this proved to be a mistake, as it was discovered that large pieces of ore do not smelt efficiently. The quantity of ore differed too. As a rule, it was very insignificant that has been connected with its constant deficiency. As a result, even if somewhere in the furnace the ore was already smelted, it could be isolated by charcoal from other ore pieces which did not participate in slag reactions. Therefore it should use enough ore, not less than 0.5-1 kilogram, and it should be placed in the furnace compactly. Ore should be crushed to a powdered state. Incidentally, in ancient slag, unsmelted ore fragments are usually only about one millimetre in size. Discovered at some sites (for example, Atasu in Kazakhstan), ore prepared for smelting (pieces up to 3-5 centimetres in a ceramic vessel) could be actually prepared for crushing. In Iran on the settlement of Shakhr-i-Sokhta ore was crushed and was 5 mm in size (Hauptmann *et al.* 2003, p. 202), which is closer to the result discussed here. But it must be kept in mind that there mixed sulfide and oxidized ores were used, and smelting of sulfides is easier. The oxidized ores required better crushing to provide reaction with gases of larger surface.

The process of ore-crushing is very laborious. We rarely relied on stone tools, as used in antiquity, more often resorting to metal hammers and even occasionally lump hammers. There are no special problems in crushing the oxidised ore. Separating the powdered ore from rock inclusions in the shattered material, which (if quartz) crushes poorly, is a painstaking procedure. But it is difficult to reduce it to a powdery consistency using hammers; therefore, ancient miners also used tampers and stone plates for this purpose.

Crushing very hard chalcopyrite is more difficult. Attempts using an iron hammer and large pieces of granite were unsuccessful. Therefore, we were forced to use large ore fragments in our initial experiments. In the pre-heated furnace, 6.5 kilograms of chalcopyrite was placed on a layer of burning charcoal. The ore was covered by charcoal to the top of the furnace. Soon after this, there was a pungent smell of sulphuric gas, as occurred every time chalcopyrite was placed in the furnace, and puffs of yellowish-grey smoke carried the smell up to 15 metres. This made it impossible to work close to the furnace and the process was thus confined to locations other than living (and even manufacturing) rooms. We were helped in this respect by the ability to adjust the position of the bellows lever. The pungent smell remained for 1-1.5 hours but then began to subside. This suggested that the sulphur had completely burned out, as the temperature, judging by colour of flame, was around 1400 ºC. However, when the ore was removed, it appeared, generally, not to have smelted. When crushed, it was clear that the ore consisted of fragments of chalcopyrite, but on the joints of large grains the chalcopyrite was replaced by copper sulfide. The analysis of this material under microscope showed the same. The matrix of probes was chalcopyrite between whose grains the copper sulfide is fixed (Fig. 1-III.4). This weakened the chalcopyrite and facilitated its crushing. Thus, even a lengthy period in the metallurgical furnace did not result in the complete removal of sulphur from the ore.

It has not been ruled out that the disappearance of traces of metallurgical production in dwellings is indicative of a transition to sulfide ores. Exceptions are possible in cases where smelting indoors was a cultural tradition based on the smelting of oxidised ores, when a combination of oxidised and sulfide ores was used and particularly when flues were used and there was a good draft and efficient sealing of the furnace.

The preliminary roasting of sulfide ore is usually explained in terms of the requirements of the smelting process (Zwicker 1980, S. 195). But the easier crushing of burned ore could be suggested; that, in antiquity, roasting was required, not for sulphur removal, but for the simplification of this operation. Therefore, in one of the experiments an attempt to burn chalcopyrite in the furnace by means of firewood was undertaken. However, this proved difficult due to the small volume of the furnace. The first load of firewood burned down rapidly and a residue of unburned wood prevented more being added. After the addition of the first pieces of ore, the heat became less intense, despite continuous operation of the bellows. Additional firewood was loaded into the furnace from above instead of attempting to place it beneath the ore. The process lasted two hours, but the processing of chalcopyrite did not occur. As in the previous experiment, cracked ore pieces of red-violet colour (Fig. 1-III.5) were extracted from the furnace and were easily crushed. But this method of roasting proved extremely inconvenient and unproductive.

Therefore, in a subsequent experiment large pieces of chalcopyrite were placed in an open fire for eight hours. Within the first hour, the caustic smell of sulphur was evident. When extracted, the ore could be easily crushed, even by hand. This method was more convenient than roasting in the furnace and allowed the processing of a considerable amount of ore with less labour. However, there were no appreciable changes in the chemical properties of the ore; it is therefore unlikely that roasting was carried out with this aim.

Ore smelting

We were thus unable to smelt chalcopyrite successfully, as the pieces of ore we were using were too large. Our experiments demonstrated the impossibility of directly smelting chalcopyrite, as others have shown (Pigott 1999, p. 115). However, judging by the results of other experiments (Rostan *et al.* 2006), it is possible with bornite. Also, it has been established that in a crucible using air blown through pipes it was possible to obtain copper from sulfide ore, a chemical compound close to chalcopyrite. Its roasting was carried out at 800 °C and smelting at 1100 °C (Zwicker *et al.* 1992, p. 104).

The principal series of experiments involved oxidised ores. We used malachite; however, it is important to note that we did not have the significant amount of good, pure malachite that was available to ancient metallurgists. Experiments by other authors have shown that, when smelting pure malachite, slag was not formed and almost 90 per cent copper may be extracted from ore (Zwicker *et al.* 1992, p. 104). Reduction of copper from malachite in the furnace can be carried out at temperatures of 900-1000 °C. The particles of copper were collected and re-melted in a crucible with dry leaves at a temperature of 1100-1200 °C, which produced rough copper (Tylecote, Merkel 1992, p. 5).

Smelting experiments with oxidized ore containing a significant amount of sandstone rock were carried out on the Kargaly mines (Rovira 1999, p. 106-109; Rovira, App 2004). In the experiments small surface or pit furnaces, with a diameter to 40см were used; and malachite and azurite pieces were crushed to the size of 2-3mm. Smelting of the oxidized ore was conducted directly in the furnaces therefore the atmosphere there was oxidized. As a result, the received structure and composition of slag did not differ from archaeological slag that point to the reconstruction correctness. Nevertheless, in the majority of experiments the oxides were received. Copper was not reduced. In experiment №5 it was charged 3 kg ores and 6 kg charcoal. It was received 11 g copper from 207 g contained in ore. Thus, the coefficient of extraction was 53.1%. Rovira assumes that more skilled ancient metallurgists could extract to 200 g copper (Rovira 1999, p. 106-109). The low coefficient of copper extraction was also in experiments made in Spain (Rovira, Guttierez 2005, p. 241).

In a series of experiments in the Voronezh region and on the Donetsk mines experimenters managed to receive limited amount of copper when smelting secondary sulfides, but they had a lot of problems too smelting the oxidized ore (Savrasov 2009).

The malachite that we used contained too much rock. The oxidised ore was placed either directly into the furnace or in a crucible or melting bowl. In the first experiments, it was presumed that the ore in the crucible would start to react with the charcoal at a sufficiently high temperature and that the walls of the crucible would protect it from superfluous oxygen. Therefore, the ore and charcoal were placed in the crucible and blowing was carried out inside the crucible wall. However, no reaction occurred, despite high temperatures. The explanation is simple: the charcoal itself does not react with oxygen contained in the ore. At first, the oxygen from blowing should react with charcoal forming carbon monoxide. Therefore, the blowing scheme was changed and this was carried out from above into a crucible through a charcoal layer. But in this case, the contents of the crucible did not also react with the gases formed in the furnace. Reaction is carried out only with oxygen blown into the crucible and carbon dioxide, as carbon monoxide has insufficient time to form. This leads to superfluous oxygen in the crucible with oxidised ores. As a result, malachite was transformed into cuprite. The latter is a refractory material and it is impossible to reduce it without the smelt because of the absence of a reducing atmosphere in the crucible. Therefore, in all such cases, we extracted only a porous mass of cuprite and small particles of copper. The smelting of the oxidised ore using a similar method is difficult. Some quantity of copper under certain conditions can be extracted in this way, of course. But it could not be a basis of mass production.

In the case of less intensive blowing, the temperature decreases. After this the stiffened crust of slag forms over charge. It protects ore from high temperatures. We found only reduced particles of copper in the crucible after such smeltings. In a polished section of this product it is well visible (Fig. 1-III.6) that they are presented not in a form of molten prills, but in the form of particles or needles, and amorphous slightly fused grains. Probably, melting of copper did not happen, despite high temperatures.

Smelting in bowls does not differ in terms of chemical conditions from smelting in a furnace. Strictly speaking, it is not possible to name it ‘crucible smelting’. As stated, the only advantage in comparison with smelting directly in a furnace is that, after a successful smelting operation, the clay covering of the furnace bottom does not fail and it is more convenient to remove the contents and to search for extracted metal. During these experiments, it was possible without any particular problems, even with a single set of bellows, to reach temperatures 1200-1300 °C. Occasionally, during the closing stages of smelting operations, we reached temperatures of up to 1400 °C. Using sulfide ore, such high temperatures were attained more quickly and more easily, due to the exothermal reaction of burning sulphur. Assessing temperature was carried out visually, by reference to the colour of the charcoal and flame. So, a bright red flame is a sign of temperature 850-950 °C, yellowish-red – 1050-1150 °C, white – more than 1450 °C (Rehder 1999, p. 308). However, in certain cases, the colour of the flame can also reflect the nature of the chemical processes in the furnace. Thus, when burning sulphur, yellowish tongues of flame are accompanied by dense clouds of yellowish-white smoke. The smelting of oxidised ores produces a greenish flame.[1] This would allow ancient metallurgists to control the processes of chemical transformation in the furnace.

A sharp difference between the smelting of oxidized ores and sulfide ones is that this process is carried out almost without smoke and flame (Fig. 1-IV.1). They are present only at the pre-heating stage. Accordingly, smells are not detectable close to the furnace. Only occasionally is there a faint smell of sinter. Therefore it is possible to conduct smelts of this type in any dwelling.

Creating a reducing atmosphere in the furnace was the basic problem in smelting. In our experiments with malachite, it was generally possible to obtain cuprite. The quantity of extracted copper, as a rule, was insignificant. The situation was facilitated in the case of a mixed charge of malachite and a secondary sulfide, covellite. In this case, there was reduction of ores of both types, due to the reaction of sulphur with oxygen. Thus, the reaction was carried out only in rather small area of maximum temperature, where there blowing was most intense but where there was also a surplus of oxygen.

A similar result showing simpler smelting of this mix in comparison with smelting of oxidized ore was received by U. Zwicker (1987, S. 195). Another series of experiments has shown, it is possible to smelt a mix of sulfides and oxides even without charcoal, with dry firewood (Pigott 1999, p. 115). Earlier experiments in this field have ended with failure that has been explained by the absence of fluxes (Tylecote 1980, p. 5).

Reducing the diameter of the furnace to 25 centimetres, we had no problem achieving high temperatures. This resulted in the smelting of ore and rock, but the ore had been oxidising and we could obtain only cuprite.

[1] A green flame appears not only during the smelting of malachite, but also when heating copper (Charles 1992, p. 23).

As a result of the experiments, it was concluded that furnaces of minimum 50 centimetres in diameter were necessary for smelting oxidised ore. However, this is true only if malachite with rock is used. Smelting pure malachite is another process.

A furnace with a basal diameter of 50-55 centimetres is too large for smelting using a single set of bellows; the temperature towards the rear wall is not high enough and the charcoal burns weakly in these areas. In such cases, a second bellows placed opposite or blowing from a well, as in Sintashta metallurgy, is necessary. At about 25 centimetres diameter, the situation improves dramatically. Similar small sizes were also regarded as optimal by other experimenters; yet, even in these cases, six pressure-blowing tuyeres were used with intensive blowing at up to 250 litres of air per minute (Bamberger 1992, p. 152; Bamberger, Wincierz 1990, p. 123). High temperatures (1400-1600 °C) have repeatedly been reached also by other experimenters (Caneva, Giardino 1994, p. 454; Woelk *et al.* 1998, p. 270-4). Moreover, even using firewood in the furnace it was easy to reach temperatures of 1200 °C (Fasnacht 1999, p. 291). The fact that a kilogram of firewood generates more heat than a quantity of charcoal is easily explained (Rehder 1999, p. 308); coal is used in metallurgy not to achieve a high temperature but to create a reducing atmosphere.

It is impossible to smelt small volumes of ore in a furnace: ore particles are isolated from each other and do not form fluid slag in which ore can be molten. The situation becomes simpler in a crucible or melting bowl. Possibly, less viscous slag and the use of fluxes was necessary for normal extraction of copper from slag. But the greatest deficiency in our experiments was that the pieces of ore were too large; these should have been pulverised.

The duration of a single smelting operation was usually 2-4 hours, although it was possible to reach a high temperature quickly. We have found no possibility how to determine the time when to stop smelting. Usually we did it when felt a smell of sinter. So did also metallurgists in Africa. Metallurgists of Lubu tribes defined that process was complete by colour of smoke (Bisson 2000, p. 98).

It took 10-14 hours for the furnace to cool sufficiently to allow handling, although full cooling is necessary only when extracting or sorting the contents; if the ore is contained in a crucible or melting bowl, it can be removed more quickly using gloves, but even in these cases, 6-8 hours' cooling time is needed. Repeated smelting (provided the clay covering remains intact) is facilitated, if the furnace is not allowed to cool completely. Our experience has shown that repeated use of firewood for pre-heating is not required when reusing a hot furnace as the charcoal ignites relatively easily.

Lead smelting

Our interest to the problem how ancient metallurgist could smelt lead had been inspirited by finds of this metal on settlements of the Sintashta and Abashevo cultures of the Middle Bronze Age in the Southern Urals. This evidence has been supplemented recently by investigations of slag from the settlements of Sintashta and Arkaim. But the latest studies revealed presence of smelted lead ores. This investigation allowed a conclusion to be drawn that the aim of this smelts was to extract silver from this ore. In addition, the reducing atmosphere and high temperatures provoked an idea that a principal source of these smelts was galena, a lead sulfide (Grigoriev 2003; Grigoriev, Nikitin 2005). Taking into account a certain scepticism concerning ancient possibilities to smelt sulfides within the framework of a single-step process, that takes place in archaeology and sometimes in archaeometallurgy, we decided to do an experiment with smelting galena. Our experience in experimental archaeometallurgy demonstrated rather converse: the easiness to extract metal from the sulfide ores and a lot of problems connected with oxidation when smelting oxidised ores. This problem is actual not only to the copper ores, which were discussing in this sense, but to the lead ores as well. In particular, there is an opinion that ancient metallurgist were smelting oxidised ores such as cerussite and jarosite (Hess *et al.* 1998, p. 64). Others believe that secondary sulfides were used (Pernicka *et al.* 1998, p. 123, 128).

For our experiments (for some more details see Grigoriev, Nikitin 2005) we have used galena. The experiments were conducting in a dome-shaped furnaces attached to a well. The type of the furnace is described above.

Before the beginning of the first operation the furnace had been dried up and run-up. After the most part of the fuel had been burned up, a piece of galena was placed on the bottom of the furnace (40 g), and the ore had not been crushed. The ore was placed in an area where maximal temperature was observed as a sphere of white coloured gases. This area was situated in the place where the air streams from the well and the bellows were crossing. Then the furnace was filled with charcoal (350 g). In 15 minutes we stopped the draught and closed the furnace to achieve its getting cold uniform and slowly. The duration of the whole process was 35 minutes. As a result a very small ingot of lead was extracted (4 g). Some part (15%) of the ore was crusted by slag and therefore was out of the temperature maximum.

The second operation used 100g galena placed in a crucible. The crucible was placed on the bottom of the furnace, and the air stream was directed on its bottom part. The charcoal surrounded the crucible, and there were some large pieces of charcoal (5×8cm) placed in the crucible. The charge was covered by a layer of the powder-like charcoal (200-300g).

In 30 minutes the operation with bellows was stopped. The draught from the well provided full burning of remains of the charcoal.

On the lower part of the furnace cover and on the mouth inside the furnace we found yellowish-grey thin layer of condensed sulphur. When the draught was increased the sulphur burned out again.

Small ingots of lead (1.5×2cm, 15-20g) were found on the furnace bottom because the crucible went to pieces. Minimum slag of furnace lining and small number of ore (1-3%) was caused by stabile atmosphere, optimal fuel and location of the crucible.

Analysis of products of smelting

Difference of experimental series on the Vera Island in 2005 was that ore, slag, charcoal, and ashes were analyzed. Besides, analyses were made. The analyses of charcoal and ashes were needed to find possibilities of archaeological identification of production sites, and also to know how the chemical composition of ashes and charcoal can affect character of slag.

Charcoal and ashes analyses

For the chemical analysis were selected different probes of charcoal: charcoal that has not been used in experiments (sample 2201) and charcoal after the smelting experiment № 6 with chalcopyrite (sample 2202) (Tab. 1-3.). This charcoal had violet shade on the surface, as chalcopyrite after roasting. These samples showed quite comparable content of SiO_2, Al_2O_3, FeO, CaO, K_2O and SO_3. The only distinctions are in the content of CuO. In the charcoal from the furnace, its content grows.

Ashes probes from open fire (sample 2200) and from the furnace (experiment 11, sample 2199) were analyzed too. In the probe from the open fire the content of SiO_2 and Al_2O_3 was higher, but it is not indicative as these components make a basis of granites, the main rock on the island. FeO content in ashes from the furnace several times more than its content in ashes from the open fire that is quite expected result. It is interesting the much higher content of K_2O and especially CaO in ashes from the open fire. It can have a single explanation:

these components when smelting pass into slag more actively. Their increase in slag was recorded by the corresponding analyses that correspond to experimental data of others (Merkel, Rothenberg 1995, p. 163). Besides, there is higher content of Al_2O_3 in ashes from the furnace that goes to ashes more actively at thermal destruction of the furnace covering. This has lowered the K_2O and CaO content. It is also remarkable that sulfur containing in charcoal completely disappears from ashes as burns out. Thus, in the certain degree, the raised FeO and Cu content in ashes, and also lower CaO and K_2O content can be an additional indicator that ashes are remains of metallurgical production.

Disadvantage of this analysis is its high cost, not allowing large analytical series (for example, from different ashpits) on settlements to be done. Use at an initial stage of the spectral analysis (or RFA) is, apparently, the best solution. As we see from the table below (Tab. 1-4.) the majority of trace-elements in ashes and charcoal taken from the furnace, does not differ essentially from charcoal and ashes from the open fire. However, the copper content increases significantly, and can be used as a reliable diagnostic sign. Silver shows the same. However, as it has no explanation yet, and the number of analyses is insignificant, it is impossible to be based on the content of silver.

The chemical analysis can be used for additional argument and confirmation of the conclusions drawn on the basis of the spectral analysis. However the spectral analysis is a rather reliable diagnostic method for this purpose. These evidences quite correspond to analytical studies of ashes from ancient copper-smelting complexes which showed the increased concentration of copper (Shalev *et al.* 2006, p. 991).

It has been done 18 mineralogical analyses of slag and ore from the furnace, and also fragments of crucibles and furnace covering. As it was already discussed above, analyses of chalcopyrite showed that in case the smelting process was not successful, and ore roasting took place only, it does not influenced significantly the chalcopyrite transformation. However the transformations into other sulfides formed along its grains do chalcopyrite more fragile, allowing ore easy to be crushed (Fig. 1-III..4).

One of serious problems in archaeometallurgy is identification of smelting in crucible. It is quite problematic to reconstruct such smelting from slag microstructure; although in literature it is possible to meet an opinion that it is quite possible to identify the crucible smelting basing on slag (clay and ashes participate in formation of crucible slag, first of all, but there can be copper and iron, delafossite, and also silicates, calcium, aluminium oxide, copper and iron oxides) (Tylecote 1980a, p. 203). However all these components are present in the furnace covering.

Our experiments showed that the ceramics used in the experiment partly melts and turn into slag in case of its contact with slag smelted from ore. Accordingly, this slag is result of mix of the molten ceramics and ore. Therefore optical investigations of similar slag shows not only copper prills, but also very small ore inclusions, olivine, and magnetite. The slag on the edge of crucible investigated under microscope (sample 2148) was presented by porous glass matrix with single small copper prills and nuclei of olivine crystallization, but all this can be formed also at metal melting. However a fine chromite grain and individual fine serpentine grains were revealed, which was present in the gangue used in this smelting. Therefore, the slag on the edge of crucible originated from ore. Probably, it is the most reliable evidence of crucible smelting of ore. A similar result was received earlier by other researchers at experimental crucible smelting and at investigation of an ancient crucible (Zwicker *et al.* 1992, p. 104, 106). However, coming back to a problem of identification of smelting of ores from the ultrabasic rocks, it should be noted that single chromite grains can be contained also in furnace covering and crucible clay. For example, it was analyzed ceramic slag taken from the edge of crucible used for smelting the ore from the Kargaly mines where chromite inclusions are not typical; and a chromite inclusion was found in the slag (sample 2155). In slag smelted from ore in the same experiments the chromite was absent. Therefore only steady presence of ore minerals, for example, chromite has to be the indicator of crucible smelting of ore. The analyzed crucible slag is easy and porous. In glass matrix some needles of olivine crystallization, small quartz grains are visible (Fig. 1-IV.2). Copper minerals and copper are not detected. Thus, any analysis has an element of chance. In the last case ore inclusions did not participate in the crucible slag formation.

Similar microstructures can be also formed by fused furnace lining that reacting with metallurgical slag. Probe 2165 analyzed under microscope was presented by such slagged furnace lining. Because it is ceramic slag, the crystallization in it is very poorly, and the most part of the polished section is presented by glass with rare inclusions of magnetite particles, and small prisms of olivine. Partly the olivine is presented by needle-shaped crystals. Magnetite is in form of large octahedrons disintegrating from large amorphous grains. Particles of magnetite are partly fused that is quite natural at so high temperatures. Small copper prills (Fig. 1-IV.3) are met. However more often copper is presented by reduced particles (Fig. 1-IV.4). Small cuprite grains are occasionally met. In a large disintegrating magnetite grain the copper inclusions (Fig. 1-IV.5) are revealed. Presence of magnetite associated with copper minerals specifies that not only the furnace covering, but also smelted rock took part in the formation of slag. There is one chromite grain that reflects, apparently, smelting of ore from the ultrabasic rock. As a whole, the slag contains practically no ore, and only single copper prills. It is quite explainable for the slagged furnace covering. However in case of small sampling from any site just similar probes can fall into collection. Therefore, slags not always reflect a situation with metallurgical production of any settlement; in any case, it is not possible to do basing on a single probe. It is necessary to pay attention that against high reached temperatures (1400 ºC) unmelted particles of copper and cuprite remained. Respectively, it occurs not always as a part of furnace charge can be in zone of lower temperature.

The analysis of the slag smelted from oxidized ores in the ultrabasic rocks that is typical raw materials of Sintashta culture, revealed microstructures different from those known in the Sintashta slags. Different areas of the slag are non-uniform, unlike quite monotonous Sintashta slag. In some places the crystallization did not occur. Here the rock usually smoothly changes by glass. All this indicates much higher slag viscosity. In other places accumulations of reduced copper particles among particles of iron oxide (Fig. 1-IV.6) are revealed. Thus, these probes contain a lot of magnetite. In some places several minerals crystallized: needles of delafossite, cuprite dendrites, magnetite octahedra with delafossite at the edges of grains (Fig. 1-V.1). Sometimes delafossite needles are slightly bent. Between them the dendrites of cuprite grow. In some places of the slag rare small prisms of olivine crystallization, skeletons and dendrites of magnetite, particles and prills of copper (Fig. 1-V.2) were formed. Some large copper prills are also present. Copper content in slag is limited to 1-2%. Large copper prills are sometimes surrounded by magnetite border. Especially many copper prills are found in magnetite accumulations: rare round prills, particles are more often. But there are also accumulations of large copper prills. Serpentine inclusions are very typical. Individual chromite grains are revealed. The chromite surrounded with a magnetite border is present too. In three other samples (2144-2146) the crystallization almost did not take place as slag solidified very quickly. But small magnetite particles and one chromite grain are present. The latter, thus, can act as a rather reliable indicator of smelting of the ores from ultrabasic rocks. Slag from smelting №10 was most similar to that of Sintashta metallurgy. Sample 2169 is presented by usual metallurgical slag. There are areas without crystallization with only rare small prisms of olivine in glass matrix (Fig. 1-V.3). In comparison with most of Sintashta slag the olivine is crystallized worse pointing to higher speed of slag solidification. Accordingly, either the cooling of the larger Sintashta furnaces had been happening slower or slag is more viscous, than that of Sintashta. Small magnetite particles, occasionally small skeletons and dendrites of magnetite are found, as well as rare (1-3%) copper prills. There are prills of light-yellow metal. Some, larger ones, are surrounded by copper frame. There is also melting rock, and even copper in melting serpentine. Chromite is presented well, as well as in Sintashta slag. Thus, only one difference from the Sintashta slag is observed: faster solidification and slightly greater amount of copper.

Thus, in most cases of smelting of the ores from ultrabasic rock in spite of the fact that it was used the ore, typical of the Sintashta metallurgy, the slag does not show microstructures typical of the Sintashta slag. Crystallization of olivine is a common feature. However the presence of delafossite and magnetite indicates more oxidizing conditions, than the conditions of the Sintashta smeltings. Therefore, Sintashta metallurgists either more actively used secondary sulfides, than it is possible to conclude from slag microstructures, or they could create more reducing atmosphere due to the effective work of the system "furnace – well". But also in the case of reducing atmosphere as in sample 2169, the speed of slag cooling was higher.

Limited chemical analyses of components of smelting were carried out too. In principle, to investigate the behavior of trace-elements it is more correct to use statistical series. However as in experiments different ores and smelting technologies were used, it is more correct to describe the behavior of trace-elements not for all analyses, but for individual smeltings. Little changes (half-order) were ignored as in such small sampling they could be caused by inhomogeneity of material.

It must be kept in mind that adduced evidences cannot be fully applied for analysis of ancient slags because our experiments have not been successfully completed with full copper extraction. Besides, some conclusions which are even quite reliable, for example, about transition of trace-elements from furnace covering, are applicable only in some situations as the chemical composition of the coverings in different areas is different. The received result shows only such a possibility (Tab. 1-5.).

Chalcopyrite, slag and the furnace covering from experiment №2 yielded the following results. In comparison with initial ore in slag some trace-elements did not change: Co, Zn, Pb, Cd, Ga, Y, and Yb, but the content of Ni, Cr, Mn, and Ba considerably grew, and to a lesser extent Ti, Be. The As content considerably and the Ag content a few decreased.

In the roasted ore the content of Ni, Co, Cr, Zn, Ag, Cd, and Ba did not change, the content of Pb, Ga, Y, and Yb, but especially Mn grew, and the content of As decreased.

The bulk chemical composition of slag in comparison with that of ore almost did not change (Tab. 1-1.; Tab. 1-6.). The content of CaO remained the same, but the content of K_2O raised by 4.5 times. Ashes where the content of this component is rather great can be its source (Tab. 1-3., samples 2199, 2200). However there were, practically, no SiO_2 and Al_2O_3 in ore. In slag 9.66% SiO_2 and 2.11% Al_2O_3 were found. As fluxes were not used, the only possible source of these components is the covering of the furnace. The initial clay used in experimental works contained 66.75% SiO_2 and 13.33% Al_2O_3 (sample 2105). Accordingly, the covering could make impact also on the trace-elements composition. In this sense the analysis of the covering from this experiment is interesting (Tab. 1-5., sample 2117). Such elements, as V and Sc did not go into slag; they were present in clay and a covering, but absent in slag and ore. The presence of Mn, Ba, Be (a composition identical in both the furnace covering and slag), Cr, and Ti in clay could influence increase of their content in slag.

Existence of 0.03% copper in the furnace walls is not, probably, connected with its transition from ore and cannot be a sign of metallurgical processes as 0.02% copper are present in initial clay. Respectively, such concentrations not always reflect existence of copper metallurgy. Absence in the furnace lining of such elements as Ag and As could influence their fall in slag.

Thus, judging from experiment 2 (at low temperatures), some changes in trace-elements composition in slag can be caused by trace-elements of the furnace covering. Changes in compound of slagged lining in comparison with initial clay are noted too.

Comparable results have been received at unsuccessful smelting of chalcopyrite in experiment 3. Apart from some increase in a silicate component the chemical composition of slag did not change. The changes in the trace-elements composition have been processed taking into account the results of experiment 2. As a whole, in slag the content of such trace-elements as Ba, Ni, Mn, and Ti raises, the content of Co, Cr, Zn, Pb, Ag, Cd, W, Sn, V, Sc, Be, Ga, Y, and Yb does not change, and only the content of As decreases. As we discussed above, the increasing content of all elements except for Ni is explained by their transition to slag from covering. The decrease in concentration of arsenic in all the cases is symptomatic.

In experiment 4 (mixed oxidized ore and chalcopyrite) the bulk chemical analysis did not reveal particular changes. In slag the silicate component in comparison with the oxidized ore increased and in comparison with chalcopyrite decreased. However, optical microscopy of this probe demonstrated that chalcopyrite took part in formation of slag, which is confirmed also by the spectral analysis of slag. In comparison to chalcopyrite the composition of trace-elements did not change. The content of Ba grew only. Changes are noticeable only in comparison to malachite (growth of Ni, Co, Mn, Cd, reduction of Cr, V, Ti, Zn, As, Sr, W, Sn, Be, Zr), but it is explained only by that the chalcopyrite was slagged and the probe was taken from it. Thus, even at so low temperatures the primary sulfide ore starts easier to participate in slag reactions, than oxidized ores.

In experiment 5 the oxidized ore from ultrabasic rocks was used. Chemical analyses of slag, ore and furnace walls revealed the following picture. In slag in comparison with ore the chemical composition did not change. The content of SiO_2 and Al_2O_3 raised. Possibly, this increase was connected with penetration of these components into slag from the furnace walls. Some increase of the content of CaO and K_2O was probably caused by their transition from ashes.

As metal remained in slag, the composition of trace-elements in slag in comparison with initial ore did not change. Clay of the furnace walls had no impact on it. Actually, the furnace covering melted seldom, only near the tuyeres. In this case it did not participate in formation of trace-elements composition of slag.

In experiment 6 the chalcopyrite was used. The bulk chemical analysis revealed the following picture: in slag in comparison with ore the content of SiO_2 and Al_2O_3 grew considerably that was connected with their transition from the furnace covering. Absolutely insignificant growth (0.3-1%) of CaO and K_2O is explained by their transition into slag probably from ashes.

Some change of trace-elements composition is observed too: increase in the content of Mn, Ti and Ba, and reduction in the content of Zn and As. The content of some other elements (Ni, Co, Cr, V, Sc, Pb, Ag, Cd, Mo, W, Sn, Be, Ga, Y, and Yb) did not change. Comparison of this result to result of the analysis of furnace walls led to a conclusion that exactly the furnace walls had impact on change of trace-elements in slag.

It is remarkable that the content of Cr in furnace clay is higher than in ore and slag, although the ore had been extracted from a deposit in serpentines for which inclusions of chromite are typical. Therefore, in some instances these inclusions can get to slag from clay, not always being, thus, a diagnostic sign of ore from the ultrabasic rocks.

Comparisons of chemical compositions of furnace covering of different color from different walls of the furnace with chemical compositions of initial clay were carried out too (Tab. 1-5.). There was no essential difference.

In experiment 7 the chalcopyrite mixed with sand was smelted in a crucible. The chemical analysis (2146) showed that composition of slag is acid. It explains the absence of crystallization in slag. In comparison with ore the content of SiO_2 and Al_2O_3 grew sharply. In ore they are, practically, not present. The crucible edge was not molten. On the other hand, in slag there is not enough copper and Fe_2O_3; it is not excluded that in the slag formation a large role was played by granite sand in which SiO_2 and Al_2O_3 are well presented. Growth of CaO and K_2O was connected probably with ashes.

The spectral analysis showed (sample 2147) that in slag in comparison with ore the content of some trace-elements increased: Cr, Ti, Ba, Sr, Be, Ga; and the content of others decreased: Co, Cu, Zn, Pb, Ag, As, and Cd. It is difficult to say what made greater impact on behavior of trace-elements. Temperatures were rather high. For the majority of elements the shift was caused by the chemical composition of clay. But the crucible was not molten. It was slagged, but it was the slag from ore. Therefore, partly the change of trace-elements composition was caused by participation of granite sand in slag, and partly by metallurgical processes.

In experiment 8 the oxidized ore from the Kargaly mines was smelted in a crucible. Ceramic slag of the crucible edge and ore slag are analyzed. The comparison of chemical analyses of initial clay, crucible bottom and ceramic slag showed that they are, almost, identical. Therefore, most likely, the ceramic slag was formed from the molten crucible edge. In comparison with the crucible, in slag the content of copper slightly increased, therefore, the ore also took part in formation of this slag. Respectively, small olivine needles are caused not by the high speed of slag cooling, but by the lack of iron oxides. They can be also formed in ceramic slag.

Most trace-elements did not change. In ceramic slag in comparison with furnace covering and clay the content of Ag grew and the content of W (probably, thanks to slag smelted from ore) decreased. In slag from the ore surface the content of Pb, Ag and Ba grew, and the content of Sr decreased.

In experiment 9 the chalcopyrite was roasted in the furnace. Spectral analysis of the roasted ore did not reveal noticeable changes in trace-elements.

In 10th experiment the ore from ultrabasic rock of the Ishkinino mine was smelted. Slag and initial ore were subjected to chemical analyses. Clay and furnace covering analyses were taken into consideration. In slag, in comparison with ore, the content of copper decreased and the content of SiO_2, Al_2O_3, CaO and K_2O slightly grew. The first two components went into slag from the covering, the two others – from ashes. But the transition of components from ashes can be only insignificant, no more than 1-2% as this analysis shows.

The spectral analysis of slag, a tuyere, fragments of the furnace bottom and wall showed minor changes in the content of trace-elements. In slag in comparison with ore and in covering in comparison with clay the composition of trace-elements almost did not change. In slag the growth of some component is visible: Cr and Be, and in the greater extend Zn, Ba and Sr which, probably, came from lining. In the furnace covering the content of Ag and slightly that of Cr grew, and in the wall lining around a tuyere the growth of Cu and Mo content is noteworthy.

In the 11th experiment we smelted the oxidized ore and chalcopyrite of the Ishkino deposit. Slightly slagged chalcopyrite has been analyzed only. Its chemical analysis did not reveal changes. A situation with composition of trace-elements is the same. In the roasted ore, slag and ceramic mass the noticeable changes of trace-elements composition did not occur. Only the content of silver grew slightly everywhere.

After the roasting of chalcopyrite in open fire (experiment 12) any changes of its bulk chemical composition and trace-elements composition did not occur too.

Thus, in the analysis of chemical compositions of slag it is necessary to consider that some components (SiO_2, Al_2O_3, CaO and K_2O) can went into slag from the furnace walls and ashes. Basing on these experiments it is more difficult to judge about the behavior of trace-elements as these experiments were not successful in terms the copper and slag were not divided. However it is obvious that spectral analyses of slag in addition to the problems connected with its inhomogeneity, have one more problem: slag consists of ore and gangue, and sometimes from the furnace covering, and to some extent ashes and fluxes can influence composition of its trace-elements.

From other experimental works we know that at the temperature below 950 ºC the content of arsenic in copper in comparison with ore does not noticeably change. At higher temperatures the content of arsenic starts growing sharply. At the temperature of 1300 ºC almost all arsenic goes into metal. Therefore neither existence nor lack of such elements as Ni, As, Sb, Ag is indicator of an area from where metal was delivered as it depended on technology (Pollard *et al.* 1990, p. 130-132, 135).

Other experiments showed that when smelting the oxidized ore the content of arsenic and nickel increases. When smelting sulfide ores the content of all impurities decreases. Even the all arsenic leaves metal. It is a reason of purity of the Late Bronze Age metal. At greater impurity of sulfide ores, the metal purification was caused by higher temperatures. Refinement in a crucible influenced probably too (Tylecote 1980, p. 7). However in some instances we deal with mixed ore of various types that complicates the study of trace-elements.

Thus, many factors, including type of ore and temperature will influence variously on the behavior of trace-elements in metal and slag.

In this work alloys with arsenic will be discussed very often. Therefore it is necessary to mention a series of experiments on this subject (Marechal 1965; Ryndina *et al.* 2008). Smelting of copper ore together with arsenical minerals steadily results in arsenical bronze of the compound known for the Bronze Age.

Studies of the metal received in experimental smelting of ore from the settlement of Norshuntepe in Anatolia showed that trace-elements in it are distributed irregularly. A re-melting was required to achieve a homogeneous alloy (Zwicker 1980, p. 15). However it is also true in case of melting of native copper (Wayman, Duke 1995). But slag is even less homogeneous material, besides, a material received as a result of a single smelting.

In practice all this means that unlike metal, we cannot confide with full confidence in the slag groups distinguished on the base of analysis of trace-elements composition, although this analysis reflects some general tendencies quite objectively.

Coefficients of basicity of probes were calculated on the base of chemical analyses (Tab. 1-7.).

Ore and slag of the experimental works were divided into groups according to coefficient of basicity. It is quite obvious that all chalcopyrite samples used in the experiments relate to the ultrabasic group, because they contain very insignificant quantity of gangue. Accordingly, all slags received at smelting of chalcopyrite, belong to the ultrabasic group too, although their coefficient of basicity is notably lower because fluxes and furnace covering participated in formation of this slag. Only one sample (2144) belongs to slags of the average composition. Higher content of acid components here was connected with inclusions of ore-bearing rock.

Oxidized ores from the Nikolskoye mine had the ultra-acid composition. This mine contains ore bearing quartz veins; therefore this ore composition is quite explainable. Oxidized ores of deposits of Dergamysh and Ishkinino have acid composition. The slag received at smelting of this ore, shows the acid composition too. A weak crystallization in the slag is also explained by it. These deposits belong to the ultrabasic type, and they can contain also the ores of the ultrabasic group. The ancient slags received at smelting of such ores, have the ultrabasic composition too. Apparently, sorting of this ore had to precede its smelting. Slag of experiment

7 in which chalcopyrite was used, has ultra-acid composition. Possibly, the slag was formed mainly by sand used as flux. At last, the slag of experiment 8 showed ultra-acid composition too that is explained by that this is ceramic slag, formed from furnace walls.

Thus, this indicator may be used to explain reasons of slag viscosity.

Sometimes in this work ethnographic parallels on archaic smelting operations in Africa and India are used. But they cannot be always used directly, even in areas where it is possible to trace back the local development of the tradition. The furnaces of recent time near the African Great Lakes were constructed quickly for a single smelting. But it does not mean that the same situation was in antiquity. In ancient furnaces of this area traces of repairs are recorded (Schmidt 1997, p. 176). Therefore this information may be considered, but it cannot be used as a reliable proof of existence of this or that operation in the ancient time. It concerns not only studies in ancient metallurgy, but in general a possibility to apply ethnographic parallels in archeology is questionable.

Summing up the results of experimental works, I won't begin to come back to the partial conclusions drawn in them. They cannot have independent value for reconstruction of ancient production. We will repeatedly come back to them in process of the description of concrete archaeological materials. It is necessary only to touch upon those results which follow from mineralogical and chemical analyses of experimental materials as they be needed for understanding of correctness of analyses of archaeological materials.

As it was already repeatedly emphasized, any single analyses of slags can give a distorted picture, because of the inhomogeneity of their structure and possible formation in different zones of the furnace. The impossibility to identified ore deposits basing on the spectral analysis, which was discussed in introduction, is aggravated with that the furnace walls (in case of its melting) and ashes can influence on chemical compositions of slag. It does not lead to a total distortion of the picture, but in many cases such failures are inevitable.

But it would be desirable to touch upon one important and fundamental conclusion which can be made from our experiments and from many experiments of other researchers. As we saw, the most part of experiments cannot be regarded as successful. Nobody achieved rather full separation of metal and slag; especially it concerns the smelting of oxidized ore. But these experiments were organized by archaeometallurgists who know chemism of these processes, scientific literature, and experience of other experimenters. But the empirical experience of ancient metallurgists which was passed on from one generation to another was incommensurably better. And the transfer of this experience was impossible without a direct training process. Therefore the transfer of metallurgical technologies was possible only in case of this training process, i.e. in case of a **direct contact** of bearers of a metallurgical tradition with its new adherents. If this tradition was spread over large distance, we are simply obliged to raise a question about migratory processes.

FIG. 1-I. EXPERIMENTAL WORKS: 1 – LARGE PIECES OF BIRCH CHARCOAL ALLOW AIR TO CIRCULATE FREELY IN THE FURNACE. 2 – SMELTING BOWL FILLED WITH OXIDIZED ORE. 3 – THE FIRING OF TUYERES AND CRUCIBLES IN THE OPEN FIRE. 4 – TUYERE AFTER ITS USE. IT IS WELL VISIBLE THAT THE TUYERE IS ON SLAGGED. 5 – CONSTRUCTING OF THE FURNACE. GRANITE BLOCKS ARE PUT WITH THE USE OF CLAY MORTAR. 6 – THE SAME FURNACE AFTER COMPLETION OF ITS BUILDING.

1 – Heaving of the clay lining on the bottom in the process of drying. Therefore in the process of drying it was necessary to seal the surface.

2 – Dismantling of the furnace. The walls are fired to red color on considerable depth.

3 – Dismantling of the furnace. Before the tuyere a column of slag is visible. The bases of walls are painted in red color. Layer of lining on the bottom is of ashen color. Under it in the center a red fired spot is present, and on the perimeter and under the bases of walls the burnt places are of black color as there was no oxygen penetration.

4 – Smelting bowl after operation. Only top part of its walls has actively contacted with molten slag, but the bowl can be used again.

5 – Blowing with the bellows.

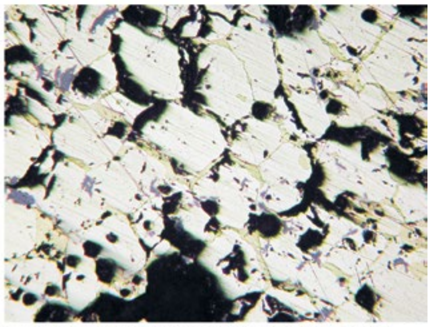
6 – Placing of firewood for the pre-heating.

Fig. 1-II. Experimental works: 1 – Heaving of the clay lining on the bottom in the process of drying. Therefore in the process of drying it was necessary to seal the surface. 2 – Dismantling of the furnace. The walls are fired to red color on considerable depth. 3 – Dismantling of the furnace. Before the tuyere a column of slag is visible. The bases of walls are painted in red color. Layer of lining on the bottom is of ashen color. Under it in the center a red fired spot is present, and on the perimeter and under the bases of walls the burnt places are of black color as there was no oxygen penetration. 4 – Smelting bowl after operation. Only top part of its walls has actively contacted with molten slag, but the bowl can be used again. 5 – Blowing with the bellows. 6 – Placing of firewood for the pre-heating.

1 – Furnace and smelting bowl after operation. The stick shows the direction of blowing from the tuyere. The red color around the tuyere demonstrates the area of the oxidizing conditions. The black walls show the area of the generation of carbon dioxide. The upper part of walls is red due to coming of air from above.

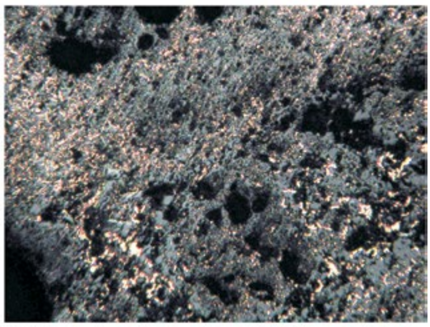
2 – Pieces of chalcopyrite (3-4cm) prepared for smelting.

3 – Crushed oxidized ore.



4 – Polished section of the roasted chalcopyrite. There is copper sulfide among the chalcopyrite grains, which explains easy crushing of these pieces.

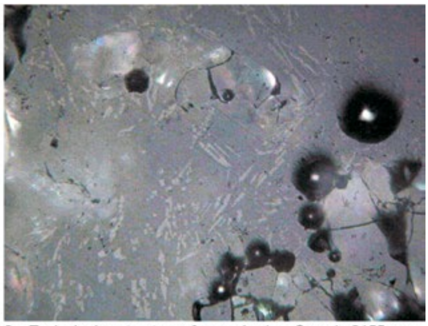
5 – Large pieces of chalcopyrite after their roasting.



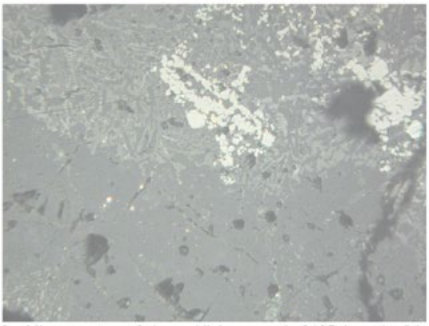
6 – Microstructure of gangue (sample 2156) of experimental smelting 8. Length of the photo is 1.55mm. Reduced particles of copper in the gangue.

Fig. 1-III. Experimental works: 1 – Furnace and smelting bowl after operation. The stick shows the direction of blowing from the tuyere. The red color around the tuyere demonstrates the area of the oxidizing conditions. The black walls show the area of the generation of carbon dioxide. The upper part of walls is red due to coming of air from above. 2 – Pieces of chalcopyrite (3-4cm) prepared for smelting. 3 – Crushed oxidized ore. 4 – Polished section of the roasted chalcopyrite. There is copper sulfide among the chalcopyrite grains, which explains easy crushing of these pieces. 5 – Large pieces of chalcopyrite after their roasting. 6 – Microstructure of gangue (sample 2156) of experimental smelting 8. Length of the photo is 1.55mm. Reduced particles of copper in the gangue.

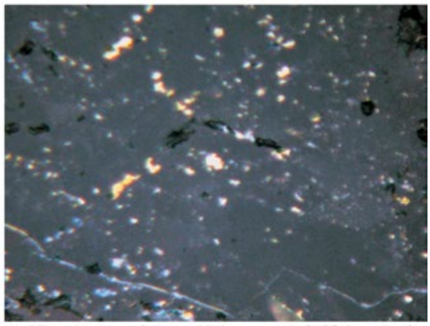
1 – Smelting of oxidized ores is carried out almost without smoke and flame. Color of the charcoal makes possible to distinguish areas with different temperatures. Thus, under the upper layer of charcoal there is an area of thermal maximum.



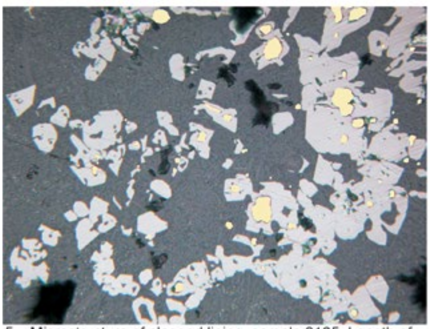
2 – Typical microstructure of ceramic slag. Sample 2155, experimental smelting 8, length of the photo is 0.54 mm. Light gray needles of fayalite crystallization and pores (dark) in the dark grey glass matrix.



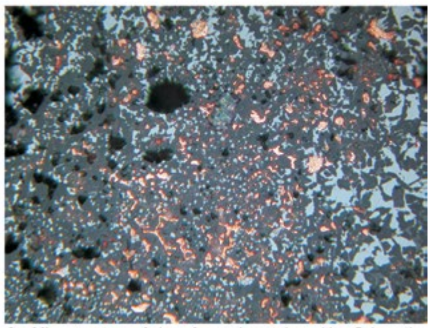
3 – Microstructure of slagged lining, sample 2165. Length of the photo is 0.54 mm. Light grey prisms of olivine, lighter particles of magnetite and small pink copper prills in the silicate glass matrix (grey background).



4 – Microstructure of slagged lining, sample 2165. Length of the photo is 0.22 mm. Copper prills in the glass matrix.



5 – Microstructure of slagged lining, sample 2165. Length of the photo is 0.54 mm. Grain of iron oxide disintegrating into particles and copper inclusions.



6 – Microstructure of slag of experimental smelting 5. Length of the photo is 0.54 mm. Accumulations of copper particles among the particles of iron oxide in glass matrix.

Fig. 1-IV. Experimental works: 1 – Smelting of oxidized ores is carried out almost without smoke and flame. Color of the charcoal makes possible to distinguish areas with different temperatures. Thus, under the upper layer of charcoal there is an area of thermal maximum. 2 – Typical microstructure of ceramic slag. Sample 2155, experimental smelting 8, length of the photo is 0.54 mm. Light gray needles of fayalite crystallization and pores (dark) in the dark grey glass matrix. 3 – Microstructure of slagged lining, sample 2165. Length of the photo is 0.54 mm. Light grey prisms of olivine, lighter particles of magnetite and small pink copper prills in the silicate glass matrix (grey background). 4 – Microstructure of slagged lining, sample 2165. Length of the photo is 0.22 mm. Copper prills in the glass matrix. 5 – Microstructure of slagged lining, sample 2165. Length of the photo is 0.54 mm. Grain of iron oxide disintegrating into particles and copper inclusions. 6 – Microstructure of slag of experimental smelting 5. Length of the photo is 0.54 mm. Accumulations of copper particles among the particles of iron oxide in glass matrix.

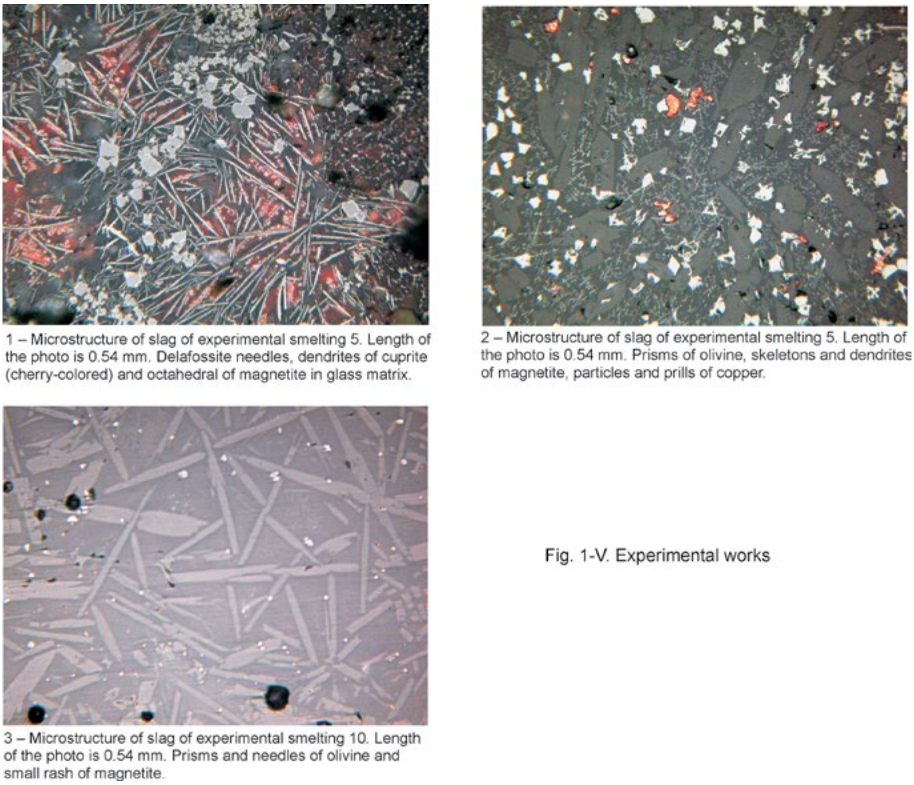


Fig. 1-V. Experimental works: 1 – Microstructure of slag of experimental smelting 5. Length of the photo is 0.54 mm. Delafossite needles, dendrites of cuprite (cherry-colored) and octahedral of magnetite in glass matrix. 2 – Microstructure of slag of experimental smelting 5. Length of the photo is 0.54 mm. Prisms of olivine, skeletons and dendrites of magnetite, particles and prills of copper. 3 – Microstructure of slag of experimental smelting 10. Length of the photo is 0.54 mm. Prisms and needles of olivine and small rash of magnetite.

Tab. 1-1. Bulk chemical analyses of sand, clay, lining, ore and slag of experimental works (weight %). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

№	Smelting №	Material	SiO_2	Al_2O_3	FeO
2029	5	Slag	18.64	15.01	1.45
2030	5	Slag	15.88	11.44	1.23
2031	6	Chalcopyrite before smelting	13.64	9.54	1.23
2033	6	Chalcopyrite before smelting	21.26	1.92	54.01
2034	6	Roasted ore	77.18	8.82	2.76
2035	6	Roasted ore	70.74	10.78	1.6
2038	6	Fragment of lining	67.16	10.88	2.03
2047	7	Slag	61.62	5.63	14.52
2074	11	Slag	70.4	10.78	1.23
2101		Granite sand	70.16	16,22	0.36
2103		Ore from Kargaly	33.96	6.19	1.31
2105		Clay	66.75	13.33	0.58

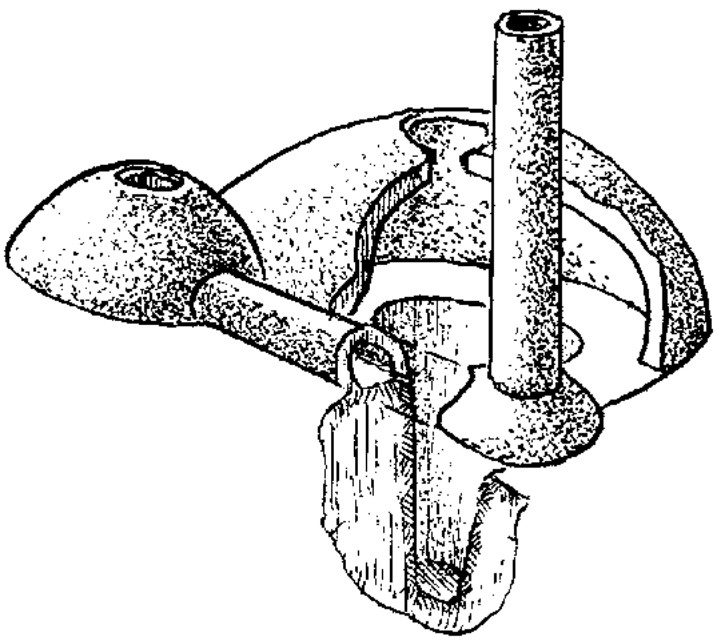


FIG. 1-2. FURNACE CONNECTED TO A WELL. IN SUCH FURNACES THE AIR CIRCULATES ALONG THE WALLS AROUND THE INTERIOR, UNIFORMLY WARMING THE FURNACE, AND THE AIR FROM BELLOWS GOES TO ITS CENTER. THEN THE AIR LEAVES THE FURNACE THROUGH A FLUE SITUATED NEAR THE WELL.

Tab. 1-3. Bulk chemical analyses of charcoal and ashes of experimental works (weight %). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

Material	№	SiO_2	Al_2O_3	FeO	CaO	K_2O	SO_3	Cu	CuO
Ashes from furnace	2199	57.4	11.72	1.52	4.86	3.5		1.75	
Ashes from open fire	2200	33.22	9.45	0.36	22.58	6.31		0.35	
Charcoal	2201	0.02	0.13	0.36	1.14	0.19	0.78		0.04
Charcoal from furnace	2202	0.06	0.14	0.36	0.57	0.23	0.91		0.3

Tab. 1-4. Emission spectral analyses of charcoal and ashes of experimental works (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).

Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Cu	Zn	Pb
Ashes from furnace	2199	0.007	0.01	0.05	0.1	0.005	0.3	<0.0005	1	0.1	0.02
Ashes from open fire	2200	0.005	0.003	0.015	0.15	0.0015	0.3	<0.0005	0.07	0.05	0.03
Charcoal	2201	0.002	<0.0003	0.01	0.05	<0.001	0.03	<0.0005	0.01	0.015	0.003
Charcoal from furnace	2202	0.003	0.002	0.02	0.05	<0.001	0.01	<0.0005	0.1	0.015	0.007
Sensitivity of the analysis		0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.001	0.003	0.0003

Material	Ag	As	Mo	Ba	Sr	Sn	Be	Zr	Ga	Y	Yb
Ashes from furnace	0.002	0.02	0.001	0.2	0.05	0.0007	0.0001	0.015	0.0015	0.0015	0.0001
Ashes from open fire	0.0005	0.01	0.0005	0.5	0.1	0.015	0.00015	0.01	0.0015	<0.001	<0.0001
Charcoal	<0.00003	0.01	0.0001	0.1	<0.01	0.0005	<0.00003	0.0015	<0.0005	<0.001	<0.0001
Charcoal from furnace	0.0001	0.03	0.0001	0.02	<0.01	0.0007	<0.00003	0.0015	<0.0005	<0.001	<0.0001
Sensitivity of the analysis	0.00003	0.01	0.0001	0.01	0.01	0.0005	0.00003	0.001	0.0005	0.001	0.0001

Tab. 1-5. Emission spectral analyses of components and products of experimental works (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).

Smelting	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Cu
Kargaly	Ore	2102	0.15	0.01	0.05	0.07	0.01	0.2	<0.0005	1
Turgoyak	Granite sand	2104	0.003	0.0007	0.03	0.02	0.0015	0.2	<0.0005	0.015
Turgoyak	Clay	2105	0.007	0.002	0.02	0.07	0.007	0.4	0.0005	0.02
Nikolskoye	Ore	2106	0.003	0.0005	0.02	0.1	0.003	0.15	<0.0005	1
1,2,3,4	Chalcopyrite	2107	0.003	0.07	0.0015	0.005	<0.001	<0.005	<0.0005	1
3	Slag	2116	0.005	0.07	0.0015	0.05	<0.001	<0.005	<0.0005	1
2	Slagged lining	2117	0.015	0.002	0.05	0.06	0.007	0.5	1	0.03
2	Roasted ore	2120	0.002	0.07	0.002	0.05	<0.001	0	<0.0005	1
2	Slag	2121	0.04	0.1/1	0.02	0.07	<0.001	0.15	<0.0005	1
4	Slag	2124	0.03	0.1	0.0015	0.05	<0.001	<0.005	<0.0005	1
5	Oxidized ore before smelting	2125	0.1	0.01	0.05	0.07	0.01	0.2	0.0005	1
5	Slag	2128	0.15	0.015	0.1	0.07	0.01	0.15	0.0005	1
6	Chalcopyrite before smelting	2133	0.003	0.1	0.003	0.01	<0.001	<0.005	<0.0005	1
6	Roasted ore	2134	0.004	0.1	0.001	0.01	<0.001	<0.005	<0.0005	1
6	Fragment of lining	2137	0.01	0.005	0.05	0.05	0.01	0.5	0.001	0.2
6	Fragment of red lining	2138	0.005	0.002	0.03	0.07	0.005	0.3	0.0005	0.015
6	Fragment of grey lining	2141	0.005	0.0015	0.03	0.03	0.005	0.3	0.0005	0.01
6	Slag	2142	0.005	0.1	0.003	0.15	<0.001	0.2	<0.0005	1
6	Slag	2145	0.005	0.1	0.001	0.07	<0.001	0.1	<0.0005	1
7	Slag	2147	0.007	0.01	0.05	0.05	0.05	0.3	<0.0005	0.4
8	Crucible bottom	2151	0.007	0.003	0.03	0.07	0.01	0.4	<0.0005	0.015
8	Slag, probably ceramic	2155	0.007	0.002	0.02	0.2	0.005	0.5	<0.0005	0.03
8	Slag from the surface of ore pieces	2156	0.15	0.03	0.1	0.1	0.007	0.3	<0.0005	1
9	Chalcopyrite before roasting	2158	0.07	0.07	0.1	0.05	<0.001	<0.005	<0.0005	1

Smelting	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Cu
9	Roasted chalcopyrite	2159	0.15	0.1	0.1	0.03	<0.001	<0.005	<0.0005	1
10	Ore from Nikolskoye	2162	0.1	0.005	0.2	0.02	0.007	0.1	0.005	1
10	Tuyere	2163	0.01	0.005	0.05	0.07	0.005	0.3	0.0005	0.15
10	Slagged lining	2165	0.01	0.02	0.07	0.07	0.003	0.3	<0.0005	1
10	Lining of the bottom	2168	0.01	0.003	0.05	0.07	0.005	0.3	<0.0005	0.05
10	Slag	2169	0.15	0.01	0.7	0.1	0.007	0.15	0.007	1
11	Slag from front part of the furnace	2172	0.1	0.07	0.2	0.05	<0.001	0.015	<0.0005	1
11	Slag from back part of the furnace	2176	0.15	0.1	0.15	0.1	<0.001	0.005	<0.0005	1
11	Fragment of furnace bottom	2181	0.007	0.002	0.03	0.05	0.007	0.3	0.0005	0.015
11	Roasted ore from back part of the furnace	2182	0.1	0.1	0.15	0.1	<0.001	<0.005	<0.0005	1
11	Roasted ore from main slag massif	2183	0.15	0.07	0.07	0.07	<0.001	<0.005	<0.0005	1
11	Slag from main slag massif	2185	0.15	0.1	0.07	0.05	<0.001	<0.005	<0.0005	1
11	Slag	2192	0.15	0.1	0.2	0.05	<0.001	0.02	<0.0005	1
12	Chalcopyrite from Tash-Tau	2196	0.005	0.0015	0.002	0.07	<0.001	0.005	<0.0005	1
12	Roasted chalcopyrite from Tash-Tau	2198	0.005	<0.0003	0.0015	0.05	<0.001	0.005	<0.0005	1
Sensitivity of the analysis			Ni	Co	Cr	Mn	V	Ti	Sc	Cu
			0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.001

Smelting	Material	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
Kargaly	Ore	0.1	0.007	0.00005	0.05	<0.003	<0.001	<0.001	0.001	0.01
Turgoyak	Granite sand	0.02	0.005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001	0.3
Turgoyak	Clay	0.01	0.003	<0.00003	0.005	<0.003	<0.001	<0.001	0.00015	0.15
Nikolskoye	Ore	0.007	0.003	0.003	0.2	<0.003	<0.001	0.005	0.005	0.7
1,2,3,4	Chalcopyrite	0.3	0.01	0.003	0.07	<0.003	0.003	<0.001	nd	0.015
3	Slag	0.3	0.02	0.003	0.01	<0.003	0.003	<0.001	nd	0.05
2	Slagged lining	0.015	0.003	0.00005	0.005	<0.003	<0.001	<0.001	0.0002	0.15
2	Roasted ore	1	0.07	0.003	0.015	<0.003	0.005	<0.001	nd	0.015
2	Slag	0.3	0.03	0.001	0.005	<0.003	0.005	<0.001	nd	0.2
4	Slag	1	0.15	0.002	0.01	<0.003	0.005	<0.001	nd	0.15
5	Oxidized ore before smelting	0.1	0.003	0.00005	0.05	<0.003	<0.001	<0.001	0.00015	0.01
5	Slag	0.1	0.005	0.00005	0.06	<0.003	<0.001	<0.001	0.001	0.01
6	Chalcopyrite before smelting	1	0.03	0.0015	0.05	<0.003	0.007	<0.001	0.0015	<0.01
6	Roasted ore	1	0.03	0.0015	0.03	<0.003	0.007	<0.001	0.0015	<0.01
6	Fragment of lining	0.015	0.005	0.0005	0.005	<0.003	<0.001	<0.001	0.001	0.1
6	Fragment of red lining	0.005	0.003	<0.00003	0.005	<0.003	<0.001	<0.001	0.0002	0.2
6	Fragment of grey lining	0.005	0.003	<0.00003	0.005	<0.003	<0.001	<0.001	0.0002	0.15
6	Slag	0.2	0.04	0.001	0.005	<0.003	0.003	<0.001	0.003	0.07
6	Slag	0.4	0.04	0.001	0.005	<0.003	0.003	<0.001	0.005	0.03
7	Slag	0.03	0.003	0.00015	0.005	<0.003	<0.001	<0.001	0.001	0.3
8	Crucible bottom	0.01	0.003	<0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.15
8	Slag, probably ceramic	0.005	0.002	0.00005	0.005	<0.003	<0.001	<0.001	0.0003	0.3
8	Slag from the surface of ore pieces	0.15	0.02	0.0002	0.05	<0.003	<0.001	<0.001	0.0015	0.2
9	Chalcopyrite before roasting	0.15	0.003	0.0001	0.1	<0.003	<0.001	<0.001	0.0002	<0.01
9	Roasted chalcopyrite	0.15	0.003	0.0005	0.015	<0.003	<0.001	<0.001	0.0002	0.01

Smelting	Material	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
10	Ore from Nikolskoye	0.06	0.003	<0.00003	0.7	<0.003	<0.001	<0.001	0.0001	0.015
10	Tuyere	0.02	0.003	0.0001	0.01	<0.003	<0.001	<0.001	0.0003	0.15
10	Slagged lining	0.4	0.01	0.002	0.02	<0.003	<0.001	<0.001	0.003	0.2
10	Lining of the bottom	0.01	0.007	0.0001	0.005	<0.003	<0.001	<0.001	0.0002	0.2
10	Slag	0.007	0.003	<0.00003	0.5	<0.003	<0.001	<0.001	0.0003	0.7
11	Slag from front part of the furnace	0.15	0.007	0.0007	0.02	<0.003	<0.001	<0.001	nd	0.2
11	Slag from back part of the furnace	0.15	0.003	0.002	0.1	<0.003	<0.001	<0.001	nd	0.015
11	Fragment of furnace bottom	0.005	0.003	0.00005	0.01	<0.003	<0.001	<0.001	0.0002	0.15
11	Roasted ore from back part of the furnace	0.1	0.003	0.001	0.15	<0.003	<0.001	<0.001	0.0002	<0.01
11	Roasted ore from main slag massif	0.1	0.003	0.001	0.07	<0.003	<0.001	<0.001	0.0002	0.01
11	Slag from main slag massif	0.15	0.003	0.001	0.05	<0.003	<0.001	<0.001	nd	0.01
11	Slag	0.2	0.003	0.001	0.07	<0.003	<0.001	<0.001	nd	0.01
12	Chalcopyrite from Tash-Tau	0.3	0.02	0.002	0.05	<0.003	<0.001	<0.001	0.001	0.07
12	Roasted chalcopyrite from Tash-Tau	0.4	0.03	0.002	0.05	<0.003	<0.001	<0.001	0.001	0.01
Sensitivity of the analysis		Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
		0.003	0.0003	0.00003	0.01	0.003	0.001	0.001	0.0001	0.01

Smelting	Material	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Kargaly	Ore	0.01	<0.001	0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Turgoyak	Granite sand	0.1	0.001	0.0015	0.0002	0.01	0.0015	0.0015	0.0015
Turgoyak	Clay	0.04	0.0005	0.0005	0.0002	0.015	0.0015	0.0015	0.0015
Nikolskoye	Ore	0.07	0.0015	0.0005	0.0001	0.007	0.0005	0.0005	0.0005
1,2,3,4	Chalcopyrite	<0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
3	Slag	<0.01	<0.001	<0.0005	<0.00003	nd	0.001	0.001	0.001
2	Slagged lining	0.05	0.001	0.0005	0.00015	0.015	0.001	0.001	0.001
2	Roasted ore	<0.01	<0.001	<0.0005	<0.00003	nd	0.001	0.001	0.001
2	Slag	<0.01	<0.001	<0.0005	0.00007	nd	0.0005	0.0005	0.0005
4	Slag	<0.01	<0.001	<0.0005	<0.00003	nd	0.001	0.001	0.001
5	Oxidized ore before smelting	0.015	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
5	Slag	0.015	<0.001	<0.0005	0.00003	nd	<0.0005	<0.001	<0.0001
6	Chalcopyrite before smelting	<0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
6	Roasted ore	<0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
6	Fragment of lining	0.03	<0.001	0.0007	0.0001	0.015	0.0015	0.002	0.00015
6	Fragment of red lining	0.03	0.001	0.0005	0.00015	0.015	0.0015	0.0015	0.0001
6	Fragment of grey lining	0.04	<0.001	0.0005	0.00015	0.015	0.0015	0.002	0.00015
6	Slag	0.015	<0.001	<0.0005	0.00007	nd	0.001	<0.001	<0.0001
6	Slag	0.01	<0.001	<0.0005	<0.00003	nd	0.001	<0.001	<0.0001
7	Slag	0.04	<0.001	<0.0005	0.00015	0.01	0.0015	0.0015	0.0001
8	Crucible bottom	0.04	0.001	0.0005	0.0002	0.015	0.0015	0.0015	0.00015
8	Slag, probably ceramic	0.05	<0.001	0.0005	0.00015	0.01	0.001	0.0015	0.0001
8	Slag from the surface of ore pieces	<0.01	<0.001	0.0005	<0.00003	nd	0.0005	<0.001	<0.0001
9	Chalcopyrite before roasting	<0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
9	Roasted chalcopyrite	<0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001

Smelting	Material	Sr	W	Sn	Be	Zr	Ga	Y	Yb
10	Ore from Nikolskoye	<0.01	<0.001	0.001	<0.00003	nd	0.001	<0.001	<0.0001
10	Tuyere	0.03	<0.001	0.0007	0.0002	0.015	0.0015	0.002	0.0002
10	Slagged lining	0.03	<0.001	0.001	0.00015	nd	0.0015	<0.001	<0.0001
10	Lining of the bottom	0.03	<0.001	0.0007	0.0002	0.015	0.0015	0.0015	0.00015
10	Slag	0.02	<0.001	nd	0.00015	nd	nd	<0.001	<0.0001
11	Slag from front part of the furnace	<0.01	<0.001	<0.0005	<0.00003	nd	0.0005	<0.001	<0.0001
11	Slag from back part of the furnace	<0.01	<0.001	<0.0005	<0.00003	nd	0.0005	<0.001	<0.0001
11	Fragment of furnace bottom	0.04	<0.001	0.0005	0.0002	0.015	0.001	0.0015	0.0001
11	Roasted ore from back part of the furnace	<0.01	<0.001	<0.0005	<0.00003	nd	0.0005	<0.001	<0.0001
11	Roasted ore from main slag massif	<0.01	<0.001	0.0005	<0.00003	nd	0.0005	<0.001	<0.0001
11	Slag from main slag massif	<0.01	<0.001	0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
11	Slag	<0.01	<0.001	<0.0005	<0.00003	nd	0.0005	<0.001	<0.0001
12	Chalcopyrite from Tash-Tau	<0.01	<0.001	<0.0005	<0.00003	nd	0.0005	<0.001	<0.0001
12	Roasted chalcopyrite from Tash-Tau	<0.01	<0.001	<0.0005	<0.00003	nd	0.001	<0.001	<0.0001
Sensitivity of the analysis		Sr	W	Sn	Be	Zr	Ga	Y	Yb
		0.01	0.001	0.0005	0.00003	0.001	0.0005	0.001	0.0001

Tab. 1-6. Bulk chemical analyses of ore (before roasting) and slag of experimental works (weight %). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

№	Smelting №	Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	MnO	Cu	SO_3
2152	8	Crucible bottom	62.54	12.51	3.7	9.43	1.78	2.25	0.07	0.09	0.12
2106	4	Oxidized ore	49.48	5.19	5.68	1.43	1.38	0.21	0.11	21.53	1.56
2126	5	Oxidized ore	30.64	5.94	17.67	1.43	9.5	0.07	0.07	17	0.13
2161	10	Ore	34.74	7.5	12.8	0.28	15.64	0.05	0.02	12.74	0.25
2112	1,2,3,4	Chalcopyrite	0.32	0.58	53.84	2.57	1.38	0.1	0.02	11.95	0.17
2132	6	Chalcopyrite	0.94	0.42	66.65	1.72	0.2	0.11	0.02	10.5	0.28
2158	9	Chalcopyrite	2.44	0.81	59.74	1.72	4.75	0.1	0.04	14.75	0.84
2195	12	Chalcopyrite	1.34	0.29	54.66	1.14	1.38	0.1	0.02	9.23	0.51
2116	3	Slag	5.54	0.67	69.49	2.86	1.98	0.11	0.03	7.8	0.87
2121	2	Slag	9.66	2.11	56.28	2.86	2.97	0.45	0.05	12.2	0.17
2123	4	Slag	13.22	1.64	55.06	1.72	1.58	0.27	0.06	11.85	0.33
2129	5	Slag	39.32	7.52	17.47	3.14	10.89	0.35	0.2	17.43	0.44
2144	6	Slag	30.5	6.59	40.03	2.29	1.58	1.46	0.11	10.28	0.22
2145	6	Slag	7.64	1.22	70.3	2	0.99	0.25	0.04	8.28	0.45
2146	7	Slag	64.64	13.87	3.54	6.86	2.38	4.59	0.27	0.09	0.22
2169	10	Slag	47.5	10.69	12.5	2.29	14.65	1.14	0.14	9.1	0.28
2173	11	Slag	2.42	1.05	69.5	1.43	2.38	0.14	0.03	13.46	1.16
2186	11	Slag	4.38	0.92	57.7	6.29	3.17	0.34	0.11	14.12	6.28
2193	11	Slag	3.5	1.52	60.96	2	4.15	0.22	0.07	16.72	2.61
2153	8	Ceramic slag	63.56	11.81	3.65	9.72	2.17	3.58	0.24	0.48	0.2

Tab. 1-7. Coefficients of basicity of slag and ore of experimental works.

Sample	Experiment	Material	Basicity	Group
2112	1,2,3,4	Chalcopyrite	64.53	Ultra-basic
2132	6	Chalcopyrite	50.72	Ultra-basic
2195	12	Chalcopyrite	35.47	Ultra-basic
2158	9	Chalcopyrite	20.67	Ultra-basic
2173	11	Slag	21.51	Ultra-basic
2193	11	Slag	13.95	Ultra-basic
2186	11	Slag	13.94	Ultra-basic
2116	3	Slag	12.13	Ultra-basic
2145	6	Slag	8.36	Ultra-basic
2121	2	Slag	5.33	Ultra-basic
2123	4	Slag	3.97	Ultra-basic
2144	6	Slag	1.23	Average
2126	5	Oxidized ore	0.79	Acid
2161	10	Oxidized ore	0.68	Acid
2129	5	Slag	0.68	Acid
2169	10	Slag	0.53	Acid
2153	8	Ceramic slag	0.26	Ultra-acid
2146	7	Slag	0.22	Ultra-acid
2106	4	Oxidized ore	0.16	Ultra-acid

Chapter 2.
Production in the Eneolithic, Early and Middle Bronze Age

In Northern Eurasia, as well as almost everywhere, the first metal artifacts appear in the Eneolithic. Unfortunately, for this time evidences of copper smelting from ore are almost unknown. Therefore, usually copper finds of this period were regarded either as imports or as objects forged from native copper. However now we have a series of indirect signs of that the Eneolithic production was more complicated. And, these evidences existed earlier, but they were usually out of scientific discussions.

The studied area is huge. Therefore, at the first stage of metal use the combinations of multidirectional impulses had to take place here, probably, somewhere a local origin of metallurgical production. Although when we deal with primitive forging of native copper, it is impossible to tell definitely – whether this phenomenon was of local origin or it was stimulated by any neighbors.

As in this work we discuss, mainly, analysis of slags and for the Eneolithic they are absent almost everywhere, this description will be short. Even in rather developed areas of the south of Central Asia it is supposed that metal was smelted from ore, but absence of convincing data on local production forced to assume that it came from the Iranian sources (Eneolith USSR, 1982, p. 54). In the west, the North Pontic area is included in the Eneolithic Balkan-Carpathian Metallurgical Province. Metallurgists of Tripolie culture used, mainly, pure copper, probably of the Balkan sources. However, although the Tripolie metal is chemically close to that in the Balkans, technologies and morphology of artifacts differ, that points to own metalworking production. The same can be also said about other Late Eneolithic group, Novodanilovka, where casting of artifacts in cold molds was carried out, a technique which was not used in other areas of this province (Ryndina, Degtyareva 2002, p. 61-64, 74).

To the east, in the Volga region, metal is revealed in the Khvalynsk burial ground. Its Tripolie sources are assumed (respectively, Balkan-Carpathian), but metalworking is much more primitive that points to own metalworking too (Ryndina, Degtyareva 2002, p. 79) [1].

Thus, to the east from the Balkans together with metal could spread also the metalworking, although it was technologically less perfect. But whether ore smelting could spread in the same way? Unfortunately, for the south of Eastern Europe such evidences are not present. However, for this period they are absent everywhere in Europe, as slag is not found (Pernicka, Anthony 2010, p. 171). In Europe even for the Bronze Age we know not so many sites with slag (Groer 2008, S. 39), although for the last period it can be explained by transfer of smelting to mining areas and difficulties in discovery and dating of such sites. Poor evidences on early metallurgy against the background of presence of copper objects led to conclusions that native copper was the main source of raw materials in the Eneolithic and Early Bronze Age. But it is rather problematic to confirm this conclusion as after melting it is difficult to distinguish native copper from that smelted from malachite. The latter can be pure too, and the native copper has sometimes impurities, especially arsenic and silver (Tylecote 1982, p. 99; 1987, p. 92). For example, in Iberia arsenic is present everywhere, and either existence or lack of impurities does not indicate native copper (Hunt Ortiz 2003, p. 322). But, if we will not consider specific areas, but the situation as a whole, although native copper can contain different impurities, including iron and sulfurs, only rare samples show it (Rapp 1982, p. 34, 35). This conclusion is confirmed by rather good series of analyses, therefore it is statistically reliable. Thus, having a sampling of rather pure

[1] Eneolithic cultures of the period Khvalynsk – Srednii Stog were dated initially, to the period after the first half of the 4th millennium BC. But within the calibrated radiocarbon dates their beginning was in the middle of the 5th millennium BC, and the end – in the interval 3865-3550 BC. The cultures like Novodanilovka have the same dates (Dryomov, Yudin 1992, p. 25, 26; Agapov *et al*. 1990, p. 85; Kuznetsov 1996, p. 56; Gimbutas 1992, p. 399, 401, 402).

copper objects from any area, we may assume their origins from native copper, but it is already recklessly to draw such a conclusion basing on a single samples.

Nevertheless, some rare slag samples are, nevertheless, found in Eneolithic Europe, but, in most cases, very small fragments. Therefore many scholars believe that in this period ones smelted pure ore; and it is difficult to distinguish this slag from casting slag (Hunt Ortiz 2003, p. 304). Experimental reconstructions of such production were carried out in Spain. Malachite (1 kg) mixed with charcoal was charged into an open furnace. As the ore was oxidized, and there was the direct blasting into the open furnace, in it the oxidizing conditions formed at a temperature of 1100-1200 °C. As a result of smelting the slag conglomerate (in which analyses revealed both delafossite and cuprite) was received, which should be crushed and pulverized for extraction of solid particles of copper. Probably, it is the main reason of lack of slag on the settlements of this epoch (Rovira, Guttierez 2005, p. 241).

Volumes of the Balkan production were colossal assuming large-scale ore smelting. In Bulgaria and Turkish Thrace the earliest metal objects appeared in the late Neolithic, in the late 6th millennium BC (Pernicka *et al.* 1977, S. 48; Makkay 1996, p. 37). Possibly, at this stage native copper was still in use. But already in the Early Eneolithic some copper objects contain increased concentrations of Pb, As, Sb that points to their origins from ore (Chernykh 1978a; Pernicka *et al.* 1997, S. 118-121, 127, 130). Studying of copper objects from the Varna necropolis showed higher concentrations of cobalt and nickel, than it expected in native copper, and this led to a conclusion about their smelting from ore. And, judging from lead isotope analysis, the Balkan metal was not a result of either Anatolian or Aegean imports (Gale *et al.* 2003, p. 162, 168).

A slag fragment from the settlement of Durankulak is an exception, but it was so small that it was sufficed only for the X-ray fluorescence (XRF) analysis (Glumac, Todd 1990). Possibly, it is a typical example when pure malachite was smelted producing metal, and not forming slag. It is confirmed also by rare analyses of ores from settlements. Ore samples from the settlements around Stara Zagora were presented by malachite and azurite (Gale *et al.* 2003, p. 162, 168). It is not excluded that the smelting was carried out in crucibles, and sometimes sulfide ores got to the furnace charge: in culture of Gumelniţa (Chatalka and Dolnoslav settlements) joint smelting in a crucible of the oxidized and sulfide ores at a temperature of 1100-1200 °C is identified (Yener 2000, p. 28). But oxides were a base of the production, of course.

To the west, in Serbia, the most known Eneolithic mine is Rudna Glava where is a series of pits of the Eneolithic period, in which malachite was extracted; it is considered that the operation of this mine began in the early Eneolithic, and it were not symbolical actions, but real extraction and production (Jovanovic 1971, p. 106; 1980, p. 32, 34). Recent studies show that the development of the mine of Rudna Glava had been started already about 6100 BC, although by analogy with Anatolia it is assumed that originally miners extracted malachite for jewelry, and extraction of ore took place between the middle of the 6th millennium BC and 4650 BC when settlements of Vinča culture disappeared in this area (Borić 2009, p. 206, 209, 237). The earliest copper objects are found here in the late phase of Vinča culture (Jovanović 1971, p. 105), therefore the initial extraction of malachite for jewelry is quite probable. However this mine is insignificant, and the composition of trace-elements in ores from Rudna Glava is another than that in the majority of Eneolithic copper objects. There are also no objects whose isotopic fingerprints would be comparable with those from Rudna Glava. It is not excluded that this mine was really operated in earlier time than these Eneolithic objects, for production of malachite which was used for jewelry. In Serbia there are more large-scale copper deposits (for example, Majdanpek) on which traces of ancient production could be destroyed by later mining (Begemann *et al.* 1990, p. 146-148). However, some researchers doubt that such large-scale production could be conducted only to extract malachite for jewelry or production of a painting pigment (that has no proofs too), and it is only a problem of lack of early metal objects that was a typical situation for initial stages of production everywhere (Jovanović 2009, p. 144, 145).

Some finds from the settlement of Belavode situated near Rudna Glava, malachite and azurite were smelted in crucibles (Borić 2009, p. 208). In Baden culture in Slovenia furnaces and fire-places of small sizes are known. On the settlement of Okukalj the copper prills and several slag pieces are found around a small (90×60cm) fireplace. On the settlement of Saloš-Donja Vrba the furnaces, fragments of crucibles, and casting molds are found. There is no strong evidence about the ore smelting here, although the stage of metalworking is documented quite reliably (Lozuk 1990, p. 55-57).

Thus, on the Balkans relatively pure oxidized ores were, mainly, used. Their smelting was carried out in the crucibles placed in small fireplaces. All this reflects rather primitive stage of development of metallurgy although there are individual finds which are out of this simple tradition. On the settlement of Gornja Tuzla in Serbia in a crucible the molten antimony is found that was either smelted, or it was an attempt to do it. On the Tripolie settlement of Mezvisko an awl containing 80% silver and 20% copper is revealed (Jovanović 1971, p. 110). Such silver content indicates either knowledge of ways of its extraction, or use of some more complex ores.

Actually, at early stages of metallurgical production rich ores were smelted only in crucibles. A function of a crucible was to hold together ore, reducing gases and temperature. The ore was mixed with charcoal. Often ones reduced copper in solid state. Reduced particles were isolated by charcoal, but during the smelting charcoal turned into ashes and was blown, and copper particles united and went down, being joined into small ingots at the bottom (Tylecote 1987, p. 107; Rehren 2003, p. 208).

The blasting was carried out not in the crucible wall, but from above (all early crucibles are slagged inside, and have no traces of active impact outside). It means there was no aspiration to isolate ore from surplus oxygen by the crucible walls, and this process did not essentially differ from the ore smelting directly in the furnace (Thornton *et al.* 2010, p. 305, 309). The reason is rather simple: early crucibles were made of usual clay, and could stand the temperature about 1100 °C, and blasting into them was conducted through the charcoal charge. A unique crucible of the middle of the 4th millennium BC from Tepe Hissar is an exception. Its external layer was made of steatite ceramics (with talc additions) that allowed it to stand temperature of 1600-1700 °C contrary to inside layer with the temperature limit of 1200 °C. But this crucible served, apparently, for metalworking although slag smelted from ore is found nearby (Thornton, Rehren 2009, p. 2701-2707).

It is doubtful that such way of smelting had been transferred to the Dnieper and Volga regions, but we have no strong evidence to state this idea, or to vice versa.

In Tripolie culture pure copper dominates, although in the late Tripolie the III chemical group with a high content of arsenic and nickel is known. This combination was typical in the Caucasus and the Near East. One object belonging to this group is the pickaxe from Veremie, having morphological analogies in the Transcaucasia, besides, it was cast in a bi-fold mould that distinguishes it from the Tripolie objects, but is known in the Caucasian (Chernykh 1966, p. 53-58; 1978; Ryndina 1971, p. 129, 132, 133). Therefore, it is not excluded that this group marks relations with the Transcaucasia, but in the Eneolithic the main relations of the region remained Balkan-Carpathian ones. In addition, since the EBA tanged tools with a stop, known earlier in Transcaucasia, spread through South-Eastern Europe from the Early Bronze Age onwards. There were also changes in metalworking. In the Balkan Eneolithic various forging operations dominated, hammering and welding took place, and metallurgists could define a necessary thermal range surely enough. But already in late Tripolie casting started play the main role (Ryndina 1961; 1971, p. 97-98). All these changes in types of raw materials and technology were connected with Caucasian impulses (Ryndina 1961, p. 208).

The same processes took place in Serbia where most of the Eneolithic objects of the 4th -3rd millennia BC were made of pure copper, but the flat axe from Leskov has 2% arsenic. The latest Eneolithic and EBA objects contain more impurities, especially arsenic (up to 3.9%). Therefore, researchers believe that there was an obvious change of ore material (Begemann *et al.* 1990, p. 143-146).

These processes were not limited by a single penetration, they lasted rather long within the Late Eneolthic and, so-called, Transitional period (within the first and, partly, second half of the 4th millennium BC, i.e., they coincided with formation of the Ural Eneolithic). The essence of cultural transformations on the Balkans was already described in detail (Grigoriev 2002, p. 345-347). They may be reduced to Transcaucasian impulses to the north, in the steppe, from where they reached the Balkans. At the same time, on the Balkans a certain role (although a secondary) was played also by Central European impulses. In the Urals from the all described above we can see parallels in smelting of the oxidized ore in crucibles and underlying use of pure copper. This means, if we see a chronological correspondence of the rise of Ural metallurgy with the above described events, we see neither sufficient typological nor technological reasons for discussion of their connections. As a last resort, we may discuss an early phase of this process when the arsenical bronzes were not so widespread on the Balkans. But it is interesting that during the formation of the Eneolithic in the Urals there were some large processes in both Anatolia and Central Europe which led to essential migratory processes and transformations in metallurgical technologies.

Many objects made from native copper by the method of cold forging are known to the north, in the forest zone, already at an early stage of the Eneolithic of Karelia. Dendrites of native copper are present in this area. At the late stage melting of native copper and its hot forging is fixed (Zhuravlyov 1990, p. 27). It is not excluded that in this case we really see a local origin of metallurgy, probably stimulated by knowledge of metal in the southern cultures, but neither ore smelting nor melting of metal did not arise here. This stage of metalworking of native copper could arise everywhere independently. It was more difficult to come to an idea of its melting as it demanded high temperatures and need to make crucibles that could hold the molten metal (Tylecote 1987, p. 92).

On the Upper Volga metalworking appeared only at the late stage of Volosovo culture. The most finds of metal (these are simple forged artifacts) are found in the east area of the culture. In the west and north metal is absent (Krainov 1987, p. 20). Therefore, taking into account a relatively late chronological position of these finds and their localization, the impulse from the Urals is most probable. However, it is not excluded that ore smelting was present in the Eneolithic of the Volga-Kama area since very early time: six small pieces of slag are found on the settlement of Arbashevskii Linozavod, belonging to Ilyinskaya culture. As they are too small, only spectral analyses have been done (Tab. 2-1.). Judging by the trace-elements composition, they mark smelting of copper ore, but it is difficult to tell something more certain about them.

E.N. Chernykh, having analyzed several copper objects from sites of the Ural Eneolithic[2], distinguished two metallurgical centers: Kysy-Kul in the Transurals and Garino-Bor in the Volga-Kama area. For both regions the conclusion was drawn about local raw materials and use of the “pure” unalloyed copper. The local origin of metallurgical production is supposed here, although with a reservation that this conclusion cannot be considered as reliable. The matter is that already in this small analyzed series some anomalous finds were revealed: a rode of the arsenical copper TK in the Transurals, and a copper prill from the site of Murat (Surtandy culture) made of a late group of the tin bronze VK. In the Kama area on the settlement of Bor 1 the knife showed the raised content of tin too. At that time, in this area the crucibles and copper prills indicating a developed stage of metallurgical production were known. Therefore these facts were designated as an anomaly, although it was carefully supposed the knowledge of tin bronzes (Chernykh 1970, p. 28, 108).

[2] Traditionally the Ural Eneolithic was dated from the beginning to the end of the 3rd millennium BC, but in system of the calibrated radiocarbon chronology it is dated to the 4th millennium BC (probably, between 3600 and 2400 BC). Nevertheless, it is impossible with confidence to speak about exact start and end date.

Unfortunately, subsequently these reservations were disregarded, and many authors wrote already only about melting of "pure" copper (Matyushin 1982, p. 292-293). Even discussing admixtures of arsenic and tin they preferred to consider them as natural[3] (Krizhevskaya 1977, p. 96-104).

Excavations around the Argazi Lake in the Southern Transurals led to discovery of several small crucibles with inclusions of slag on their surface and copper prills. The analysis of copper showed that it does not contain artificial admixtures. Therefore, it was suggested that these crucibles mark an archaic stage of melting of native copper (Nokhrina 1996, p. 52-58).

In the Eneolithic complexes of the Middle Transurals small simple copper objects, melting in crucibles, casting into closed moulds, and forging of objects are recorded. Arsenic admixtures are occasionally met, but more often the objects were made from "pure" copper. But also here we know one evidence indicating that the situation is understood too simply. In a burial of the cult place of Skvortsovaya Gora V in a copper ornament 1.6% lead was detected that is above a possible natural impurity. However this fact has been explained by that this object was not, possibly, connected with the burial, it was later (Chairkina 2005, p. 209-212). But a burial is, usually, a closed complex. As well as in the case with the copper prill from Murat, the decision about dating of metal has been made on the base of ideas that only "pure" metal had to be in this period. It is also necessary to pay attention that casting in the closed moulds is identified, and it was not an early stage of metallurgical production too.

Technological studies show different methods of metalworking. Sometimes metallurgists were making casting moulds by the imprint of a flint object in a clay matrix. But on the same settlement (Razboinichii Ostrov) more complicated technologies are also recorded, when an object was cast, and then forged with the reduction of 50-60%, and this forging run at the pre-melting temperatures of 900-1000 °C. The presence of this rather developed technology is explained by contacts with masters of Pit-Grave culture (Degtyareva 2010, p. 63, 68) whose traces and other remains, by the way, have not been found archaeologically.

To the east and south from the Urals knowledge of metal is traced definitely only on the settlement of Botai where on the remains of bone handles the green traces of copper are revealed, but traces of production and, respectively, copper sources, are not known. In Southern Siberia and to the south from Northern Kazakhstan similar facts are absent. The closest place of fixation of metal production is already mentioned Anau culture in Turkmenistan.

Thus, in the whole studied area only in the Urals we see strange signs of rather developed metallurgical production and a dominating presence of archaic features. And, these strange signs, as though, could not come from the neighboring areas. Some new data on the Ural metallurgy have appeared as a result of field works of the last time.

Metallurgical complex of the Vera Island

Archeological excavations on the Vera Island in Turgoyak Lake in the Transurals led to discovery of a large cult center with a series of Eneolithic megalithic objects. Along the shores of the island settlements are found, some with traces of metallurgical production. The metallurgical furnace of the settlement of Vera Island 4 became the most interesting find connected with this production. Owing to its uniqueness it will be described in more detail.

[3] In this book L.Ya. Krizhevskaya wrote about two objects with high tin content, but in the provided table there is a knife from the site of Kysy-Kul with the tin content of 0.3%. Therefore this knife can be considered as the third object with tin. Taking into account insignificance of the whole series, it is possible to speak about a rather good presence of tin bronzes in the Transural Eneolithic.

The furnace consisted of several main parts: smelting pit, exhaust channel with flue and pressure-blowing channel (Fig. 2-2.; Fig. 2-3.). The smelting pit was cut in bad rock. It was covered by two large horizontal granite plates.

In the north of smelting pit the rocky wall is inclined; probably, it was done specially because, in principle, it was convenient for creation of dome-shaped covering and promoted temperature reflection to the center of the lower part. On this wall traces of ledged cutting are visible. Traces of firing on this wall are fixed only in the east, but it probably is connected not with the furnace operating, but with the firing the granite rock to prepare the place.

In the southern wall the rock surface falls by a smooth ledge. The ledge and the wall here are burned to red color. Possibly, it was the furnace bottom. At this level and above brown soil was exposed to heat.

To the southeast and south from the smelting pit two fragments of friable granite of the burnt basis of the wall remained. They were standing on the burnt virgin rock and sand. As in the course of furnace operating firing under the wall basis was impossible, it was caused by the firing during preparation of the place for furnace. The need to do the wall in the south higher by means of granite blocks was caused by that the level of virgin rock was here 10-15cm lower, than in the north.

In northern part of the smelting pit, along edge of virgin rock below the bottom level, a channel is found, filled with dark sandy loam that was not burned. As the southern wall at this level has small traces of firing, it was, apparently, a result of the furnace building. As this channel was connected with a small opening in the east, it could serve for air supply by means of bellows. In this case the blasting was carried out from under furnace bottom. But this idea is not proved and must be checked by other similar finds.

As a whole, size of the smelting pit is 58×80cm, but its east extended projection used probably for blasting and inserting a tuyere. Therefore, taking into account the needed lining of walls and this projection, the size of the internal volume was insignificant – 45×45 cm. It is more difficult to determine height of the smelting cavity; probably, it was from 45 to 60 cm.

It is necessary to touch upon a question of walls lining. For granite walls it is absolutely needed as burnt granite disintegrates into small particles, and the lining reliably protects from it (Grigoriev 2005, p. 176). Therefore it is not excluded that the ledged cutting of the northern wall was made not intentionally. To the west in the exhaust channel such ledges are not present. The walls lining made of clay would keep better on these ledges. To the east of the furnace on the surface the pieces of gray plastic clay with greenish shade were found, and to the north – a layer of burnt clay. Possibly, the material for the lining was situated here, and this was a place where fallen pieces of lining could be thrown out.

To the west from the smelting pit a wide (30-40cm) deep channel is situated. Its western end is covered by a plate of the horizontal flue. The bottom of this channel gradually rises to the surface level. Lower in the south of the channel bottom, the red-colored traces of heating are found. The lighter traces of firing are present also on the channel bottom in the west. Possibly, this channel served for removal of exhaust gases which arrived further in the flue adjoining the channel in the west.

The flue consisted of two parts. The first, horizontal, is presented by a massive plate 1.35m length, directed along the line north – south. Just to the south from the exhaust channel on the edge of the virgin rock there is a layer of burnt friable granite. This layer was standing almost vertically under the fuel plate. Probably it was the end wall of the exhaust channel; therefore it was subjected to heating caused disintegration of the granite.

In the south under the fuel plate a small plate of a triangular form (Fig. 2-4.) was situated. It lies closely to the extended virgin rocky plate in the east. It was probably put as a basis of the southern part of the horizontal flue. The northern end of the flue was based on the virgin rock.

The surface of the fuel plate is non-uniform. Its southern end has a dense, firm and equal surface. The northern end has a friable, burned surface. This heat impact was stronger in the northeast, closer to the furnace. The transition from the friable burned surface to the firm one is very abrupt that is impossible to explain by gradual cooling of gases. Possibly, the south end of this plate was covered by soil fixing a vertical knee of the flue; this protected this part from the temperature impact. It demonstrates that passing to this part of the flue the gases were still rather hot; therefore the vertical part of the flue could not be made of easily flammable material, but we have no bases for more certain judgments about this.

Thus, the degree of firing gradually decreases from the furnace to the vertical part of the flue that is quite natural. Hot gases hit into the wall in the west, strongly burning it, further rose 20 cm up and passed south on the triangular plate, under the massive plate covering it.

To the south of the horizontal part of the flue a group of small plates erected vertically on the edge are situated. In the east some of them fell and lies on a massive virgin plate. These vertical plates surrounded a small empty space with the size of 60×40cm. Probably a vertical part of the flue was erected here.

The edge of the massive continental plate was treated additionally which is visible on a small depression on its edge. The impact of fire on the building stage is not excluded here too. On the surface of the depression traces of hammering by a stone tool are visible. This was needed probably for installation of some plates of the vertical flue. Additionally, to do this, the southern end of the horizontal flue was partly demolished (and pieces of granite were put of the flue surface).

Such thorough preparation of the basis shows that the vertical part of the flue could be high. It was made of any light material, but it was not too flammable. The basis was surrounded by small vertical plates and fastened by soil. Use of an easy organic material for superstructure is in this case quite possible as exhaust gases were already cool.

The need in this design arises only in the case of smelting of sulfide ores. At use of malachite notable gases do not, practically, escape.

To the east from the fuel a channel cut in the bad rock was excavated. In some places the channel was covered by small stone plates. This channel passes parallel to the flue and in the north adjoins the southern part of the smelting pit. Its length is 1.8 m, and the depth to 25 cm. Width of the channel is 14-18cm, but in the south, from the lake, the channel is considerably wider.

Small red traces of firing at the interfaces between the channel and southwest edge of the smelting pits is noteworthy. Such burnt areas are formed in a place of coming of air into the furnace. The border of this burnt area is parallel to a possible wall of the furnace (NW-SE). Therefore, air moved via this channel. As well as in a case with the blasting from Sintashta wells of the Bronze Age (Grigoriev 2000a, p. 256, 258), because of a small pressure air moved along the wall to the right. But the furnace would be pre-heated, and at the inlet an aircatcher, for example, a wall or skins, was necessary. It would provide the general heating of the furnace, but because the channel was narrow and long the air volume was insignificant. As well as in the Sintashta furnaces, it was not so essential, in comparison with possibility of intensification of blasting by pressure-blowing bellows. A possible lack of air would be easier to be compensated also by installation of additional bellows. Therefore, there were also other reasons of need of this channel.

The main reducing agent in ore smelting is carbon monoxide. If it is not formed, ore is oxidized and turns into cuprite. As it was already spoken at discussion of experimental works, in ancient furnaces the formation of carbon monoxide occurs at a distance of 10-15cm from the tuyere. In case of blasting intensification air passes through the furnace with greater speed that makes this process impossible.

It would be impossible to reduce ore in so small furnace, because air from the tuyere would quickly reach the furnace center. Contrary to this, oxygen blasted without strong pressure moved along the furnace wall, reacted with charcoal forming at first carbon dioxide, and then carbon monoxide. It was the main destination of this channel. Its existence testifies that smelting was conducted not in a crucible, but directly in the furnace as at crucible smelting such a construction is less sensible.

Three small pieces of cuprite are found in the smelting pit. Found in the upper part of its filling a small ceramic scoop (Fig. 2-5.1) specifies that casting operations also took place here. In other part of the settlement fragments of two casting moulds (Fig. 2-5.2,3) were found.

Stone tools

Near the furnace several tens of stone tools are found. A special article (Grigoriev 2010) is devoted to their analysis. Many of these tools were used at construction of the furnace and for various domestic needs. Here we briefly concern only those of them which were connected with metallurgical production. But it is necessary to remember that many tools could be multifunctional, and be used both in metallurgical operations, and for other needs.

Hammers are the most typical tool. They have various sizes probably depending on their function. The largest tools (6 items, Fig. 2-6.1,2,6), weighing between 2.5 and 10 kg, served for crushing of hard rock. For manufacturing of these tools large quartzite pebbles of a suitable form were more often used, which were adapted by chipping. One hammer was made of a crushed anvil: both its surfaces are even and smooth. Sometimes chipping technique was used to make waist for tool fastening to a handle. In one case (Fig. 2-6.6) it is visible that processing of the waist was made by a metal tool with a width of its edge about 1.5 cm. Less often granite pieces of a suitable form were used. They were less durable tools, but they did not need also considerable efforts to be manufactured. Similar hammers could serve, both for crushing granite, gangue and hard ores, for example, chalcopyrite.

More typical (9 items) are hammers of smaller size, with the weight of 0.2-1 kg (Fig. 2-6.3,5). For their manufacturing any elongated hard stone (quartzite, quartz, etc.) could be used. The manufacturing was limited by making of waist for handles by chipping and grinding. Often (in case the pebble had quite suitable form) this additional processing was not made.

The last and lightest group of hammers was made of more brittle quartzite (6 items, Fig. 2-6.4). The weight of these objects varies in the interval of 0.2-0.6 kg. They, practically, were not subjected to special processing. These tools were used for crushing of rather soft materials, for example, oxidized copper ores and gangue (iron hydroxides) or to strike on some soft material (wood, etc.). Some of these objects could be used also as pestles.

Thus, on the settlement the hammers with different functions are found. Possibly, it would be wrong to consider them exclusively as mining and metallurgical tools. Taking into account the presence on the island of the megalithic tradition, these objects could be used also for the megalithic building. So, even near the furnace on this settlement numerous traces of processing and crushing of stone plates are visible. At the same time, taking into account the metallurgical complex and many corresponding tools (completely absent, for example, on the settlement of Vera Island 7), their metallurgical function is undoubted too. Besides, character of these tools demonstrates that many pre-smelting operations took place on the settlement: trituration of ore before smelting, crushing of ore-bearing rock, i.e. primary crushing and sorting of ore and all subsequent cycles of copper object production. Respectively, these works weren't performed on mines that was, as a whole, characteristic for early stages of development of both mining and metallurgy.

Important indicators of metallurgical production are **stone anvils and abrasive plates**. As it was stated above, hammers could serve to crush any rock, but the ore processing (crushing and grinding) could executed only on special plates. The tools of this type found on the settlement are different.

The most massive are the anvils (Fig. 2-6.10,11) presented by two intact tools and three fragments. The intact objects are relatively long: 10 and 28.5 cm. The thickness of the anvils and their fragments varies between 5 and 12 cm. All of them are made of rather hard quartzite that allowed very hard rock on them to be crushed. Such their use may be demonstrated by small dents to their surfaces. At the same time, some tools have also traces of smoothing and grinding. One small heavy object (Fig. 2-6.11) in this series is different. It has traces of blows not only on flat surfaces, but also on angular parts. Therefore, this tool could be used as an anvil and a hammer. Possibly, as a whole, these objects were multifunctional, but they could be used also for crushing and grinding of hard ore and rock. For their manufacturing ones use thick flat pieces of quartzite which, if necessary, were chipped along the edges.

Two massive plates from hard quartzite have some differences from the anvils described above. It was impossible to crush large hard rock on them. The first is divided by a quartz vein and could not stand a strong blow (Fig. 2-6.7), and the second was adapted for placement on the knees. Both of them have shallow traces of hammering, but, at the same time, their upper work surfaces are smoothed and polished. Therefore, they were used for grinding of rather soft materials. They could serve in metallurgical production to pulverize ore, forge and whet copper tools.

Three objects are classical **abrasives** executed on small tiles of either quartzite slate or rather soft quartzite with polished surface (Fig. 2-6.8). One object is a grinding stone from pebble with a fillet formed by sharpening of small copper subjects, for example, awls (Fig. 2-6.9).

Thus, on the settlement a set of mining and metallurgical tools is revealed: tools for crushing and grinding of both oxidized and sulfide ore (including the massive objects suitable for crushing of chalcopyrite) and tools for metalworking. For this small excavated area on the settlement of Vera Island 4 the concentration of large stone tools is very high. For the Eneolithic settlements it is not, as a whole, typical.

As we saw, the functions of the tools are different. Even hammers belong to several types. They could be applied for processing granite, and in mining and metallurgical production. In the latter case the large hammers were necessary for crushing of gangue, and the smaller hammers – for ore crushing. However, it was needed to pulverize the ore, for what could serve pestles having both traces of hammering and rubbing.

The anvils had probably very wide range of application: crushing of ore and forging of metal (this operation was obligatory as tools from pure copper cannot be used to cut stone).

Character of stone mining tools depends on character of extracted ore. In the Alpine region where in the Bronze Age chalcopyrite was extracted, for its crushing massive tools were used, and for grinding tools of the smaller sizes. In Spain in the Eneolithic where slag is not present as the pure oxidized ore was used, mainly small tools are found; and in the area of Rudna Glava, the Eneolithic mine in Serbia, tools are unknown (Gale 1990, p. 51, 52). Therefore the complex of massive tools of the Vera Island indicates indirectly a possible use of chalcopyrite or ore from hard rocks.

There is one more interesting aspect of the problem. Practically everywhere from the Eneolithic and to the Middle Bronze Age, metallurgical production, including ore crushing and sorting, was carried out directly on settlements. It is noted for the Eneolithic sites in Levant, Anatolia, Iberia, Serbia (Hauptmann 2003, p. 97; Hunt Ortiz 2003, p. 382; Jovanovic 1980, p. 37).

Transfer of the production in areas of mines occur, mainly, since the beginning of the Late Bronze Age and especially active in the Early Iron Age. The settlement of Vera Island 4 is a striking example of this situation, and its materials allow us to understand reasons of this phenomenon. Manufacturing of some stone tools needed for ore crushing and sorting, was rather labor-intensive process, as well as the ore crushing itself and building of metallurgical furnaces. Besides, it would be quite burdensome to carry heavy multifunctional tools to the mines and back to the settlements. Production on the mines had a sense with a growth of its volumes. Therefore gradually, if corresponding social and economic conditions appeared, the structure of production changed and its separate stages were taken out of settlements. But during the Eneolithic this process did not start yet. Indirectly, the presence of production on settlements is, therefore, a sign of its rather small volumes.

Slag

However for our research slag and slagged fragments of vessels are more interesting. As it was discussed above, finds of the slagged fragments of vessels have been found earlier on the Eneolithic sites of the Transurals. A ceramic fragment with a strongly slagged rim and slagged internal surface was found in the Southern Transurals on the settlement of Bannoe-1 (Fig. 2-7.3, sample 2205). A fragment of rim of strongly slagged crucible was found on the settlement of Putilovskaya Zaimka. Its size was 3.3×2.5cm, the thickness did 1.6 cm; the external surface was dried by heat, and both internal surface and the rim were strongly slagged (Fig. 2-7.4, sample 2205). A fragment of slagged vessel is also present in the collection from the settlement of Vera Island 2 (Fig. 2-7.8). But the finds of slag and slagged copper prills are rare (Fig. 2-7.1,2,5-7). First of all, it is a dense and heavy shapeless slag (its size is 2.3 cm) from the settlement of Bannoe-23 (sample 2203). Some samples are found on the settlement of Vera Island 7: slagged copper prill of the size 14×4mm (sample 2210), small piece of dark brown finely porous slag with the size 13×9mm (sample 2211), piece of brown finely porous slag (the size is 17×8mm) (sample 2208). Some absolutely small slag fragments and pieces of iron oxides have been revealed on the settlement of Vera Island 4. It should be noted that excavations on the island were carried out with sieving and flotation that promoted detection of these finds. Therefore it is not excluded that use of this technique on other Ural settlement will lead to such finds.

Some of these samples have been investigated by means of microscope (Fig. 2-8.). The porous ceramic matrix of the slagged part of the vessel from the settlement of Vera Island 4 (sample 2206) copper prills have been revealed. This gives no strong evidence for judgments: it can be a result of either metal melting or smelting of ore in a crucible. XRF analysis of an inclusion (Tab. 2-9.) is of no use as mainly ceramic mass has been analyzed. But analyses of sample 2203 from the settlement of Bannoe-23 yielded unexpected results. Metal iron in patina crust has been revealed. Study of the crust showed that it was ilmenite-magnetite aggregate and metal iron with impurities of Mn, Cu, Sn, and Pb. The content of copper was 0.4-0.7% that means the slag was obviously connected with copper smelting. But the revealed dendrite-lattice structures of magnetite in combination with iron mark usually smelting of a primary sulfide, chalcopyrite, that is typical already for some complexes of the Late Bronze Age (in more detail about the nature of the process and formation of similar structures will be described further in chapters devoted to the LBA). The high tin content (0.5%) is also very remarkable. Tin in such concentrations, as a rule, does not contain in LBA slags. In the analyzed LBA series there are only 15 samples in which tin content reaches or exceeds this, because tin was added in metal. But this figure of 0.5% is in a limit of a natural impurity in ore.

However the analysis of two slag samples from the settlement of Vera Island 7 revealed the same impurity in one of them (Tab. 2-9., sample 2210). In a small slag ingot from the settlement of Vera Island 4 (sample 2218) the content of tin is 7.1%, against the background of copper content of 14.4%. The examination revealed that the most samples from this settlement are iron oxides without copper impurities; therefore it is not clear, whether they got to the furnace incidentally or were connected with metallurgical production. The last is more probable as such minerals have not been found in rocks of the island. But iron oxides are usual by-products of the chalcopyrite smelting.

Such high tin content considerably higher than possible natural impurities and against this background two other analyses with the increased tin concentration do not look as accident any more. Possibly, the identification of tin in Eneolithic copper artifacts which we discussed above, and also the presence of higher lead content in copper from the burial of Skvortsovaya Gora V is not casual too. Probably, we deal with attempts to produce tin alloys on the stage of ore smelting, a strange technology, and unknown in later metallurgy. The number of analyzed samples is too insignificant, but these paradoxical analyses of slag coincide with the paradoxical situation recorded by analyses of metal, therefore it is impossible to speak about a casual coincidence. At first sight it seems also to be strange the existence of a sample showing the smelting of chalcopyrite, although the basis of the production, of course, were oxidized ores, probably, relatively pure malachite at whose reduction slag is almost not formed. Only this can explain small number of slag on the Eneolithic settlements. Actually, more likely the studied furnace indicates also the smelting of oxidized ores as the channel for generation of carbon monoxide was essentially important to reduce oxides. In case of smelting of sulfides the reducing atmosphere is created simpler – due to reaction of oxygen with sulfur and sublimation of sulfur dioxide. But the presence of the flue indicates also the use of the furnace for smelting of sulfide ores.

Thus, as well as in the case of metalworking, we see again a strange combination of archaic and more developed features of the production: the furnace of a complicated design, the developed set of metalworking tools, attempts of smelting of primary sulfides and alloying with arsenic, tin and lead. All this is beyond ideas about initial stages of metallurgy when native copper or oxidized ores were used.

Problem of origins of Eneolithic metallurgy in the Urals

For a technological jump described above a long time and experience accumulation was necessary, it was a rather long process. A striking example is the history of metallurgy in the Near East where the development of technology was extremely slow. The first copper ornaments were detected in Shanidar in Iraqi Kurdistan where they are dated to the 9th millennium BC (Moorey 1975). However, these finds were completely mineralized, and it is not excluded that they made from malachite, but on later sites of the Pre-pottery Neolithic (Çayönü Tepesi), despite a similar problem, copper is already detected reliably (Muhly 1976, p. 83). Results of analyses of the objects (as a rule, copper beads) of the 8-7th millennia BC from Anatolian settlements (Çayönü Tepesi, Aşıklı Höyük, Nevalı Çori, Çatalhöyük, Hacilar, Khan Hassan) show that they were made by cold forging of native copper with intermediate annealing. Even the macehead from Can Hasan II (*ca*. 6000 BC) was made in this way. The earliest cast objects, probably made of copper extracted from ore, do not occur until the Mersin XVI level (*ca*. 5000 BC) (Yalcin 2000, p. 18-22; Birch *et al.* 2013, p. 307, 308, 315). Only in the 4th millennium BC in Anatolia smelting of chalcopyrite begin and there first objects with tin occur (see in details below). And, this stage of transition to sulfide ores lasted probably not too long, although it is considered that there was a long stage of smelting of pure malachite in crucibles. Its mixing with sulfides makes smelting easier. Soon also the alloys with arsenic occurred there, initially as casual smelting of copper ores with arsenical impurity, and then as a conscious choice of such ores (Roberts *et al.* 2009, p. 1017).

From Anatolia or Northern Mesopotamia the knowledge of metal gets into the Iranian Zagros at the end of the 8-7th millennia BC (a bead from Ali Kosh), and then to the Iranian Plateau at the end of the 6th millennium BC, but native copper is used. In the 5th millennium BC ore smelting begins (Thornton 2009, p. 308; Oudbashi *et al.* 2012, p. 155-156, 158). About 5000 BC it is noted in Tal-i-Iblis on the Iranian Plateau and in the 5th millennium BC in Ali Kosh (Thornton 2009, p. 308; Pigott 2004a, p. 28). Thus, these processes developed, practically, contemporary with those in Anatolia. And soon in Northeast Iran (Tepe Yahya, *ca*. 4300 BC) the first objects from arsenical copper appear (Thornton 2012).

Thus, the general dynamics of the process is as follows: the transition from use of native copper to smelting of ore was very long and difficult, but further innovations were carried out already quicker. In the Near East it took about 5000 years, but in the Urals metallurgists, as though, could do it for a short time. Therefore the appearance of metallurgical production in the Urals was stimulated too; however a question remains: from which area?

As we saw, in the neighboring areas only metalworking is recorded. It is possible to assume that it is a problem of weak study of the question, it is not excluded that somewhere in Eastern Europe people could smelt ore as slag is almost not formed when smelting malachite, but it is hardly necessary to expect discovery of so paradoxical situations, as in the Ural Eneolithic where E.N. Chernykh has designated these paradoxes many years ago (see above).

In addition to this, this problem cannot be separated from a problem of the Ural Eneolithic complex formation. Of course, the local Neolithic was in its base. But, along with metallurgy new types of ceramics and a megalithic tradition appeared. The analysis of new cultural features allowed me to draw a conclusion about two impulses: from Northwest Europe and from Anatolia, although it is impossible yet to determine a chronological correlation of these impulses (Grigoriev 2012). However, to specify sources of the metallurgical tradition it is necessary to apply a wider range of analogies out of Northern Eurasia where metalworking is identified only.

The earliest find in Transcaucasia are copper beads, pieces of malachite and azurite of the early 6th millennium BC (Aratashen). It was pure, probably, native copper (Meliksetian *et al.* 2011, p. 201). Possibly, the found oxidized ores were connected with their use for ornaments manufacture. In general, traces of ore smelting in Transcaucasia are absent in the Early Eneolithic which is understood as Shulaveri-Shomutepe culture, but they are known in the Late Eneolithic (Schachner 2002, S. 118). Since the Late Eneolithic (complexes like Alikemektepesi, the lower level of Kul-Tepe I and Tekhut in the second half of the 5th millennium BC) the first rare objects from arsenic bronzes appear. It is remarkable that awls had a small stop on the stem that became then characteristic of the whole Circumpontic zone (Teneishvili 1989; Selimkhanov, Torosyan 1969, p. 230-232; Meliksetian *et al.* 2011, p. 201). In this instance they were not probably imported from the south. Local mining and smelting is marked by the following facts: At ancient mines in the village of Zitelisopeli, pieces of slag and stone hammers with a waist, identical to hammers from Arukhlo and Kul-Tepe I, have been found (Kushnaryova, Chubinishvili 1970, p. 113). Possibly, the rise of metallurgy here was stimulated by the southern impulses that can be confirmed by arsenical ligatures and other parallels in material culture (Grigoriev 2002, p. 334, 335).

To the south evidences of metallurgy are more numerous, although for this period it is rather problematic to use such expression anywhere.

Eneolithic furnaces in Vadi Araba in Israel had internal diameter about 45cm, and a depth of 45-50cm. Thus, they were pit furnaces, as well as the furnace of the Vera Island. Slag was not tapped from these furnaces. The smelting atmosphere was, mainly, oxidized, therefore in such furnaces slag of spinel type was formed (Rothenberg 1990, p. 4-6, 9, 12, 19, 39, fig. 35, 40). In Levant in the Eneolithic, ones smelted, mainly, pure malachite; it is supposed that the smelting was carried out in crucibles, and such smelting almost did not produce slag. Finds of slag are extremely rare, the slag pieces were small containing up to 60% copper (Hauptmann 2003, p. 95, 98).

During a long time Anatolia was technologically most developed region. Here already in the Eneolithic a part of arsenic bronzes was high, about 31% of the whole complex of metal (Avilova 2008, tab. 9). On the settlement of Değirmentepe (5th – 4th millennia BC) arsenic is present not only in metal, but also in slag (Yener 2000, p. 40). However these limited data do not allow us to determine whether it was connected with artificial additions of arsenical minerals or reflects use of ore with natural arsenic impurity. Nevertheless, the purposeful manufacturing of arsenic bronzes in this case is undoubted. The oxidized ore was, mainly, used in smelting, although sometimes the sulfide ore got to furnace charge too. In some instances it is impossible to exclude completely a possibility of ore smelting directly in the furnaces, but reliable data in favor of it are not present. But on many settlements (Arslantepe, Değirmentepe, Mersin XVI, Tepechik, Norshuntepe and Tüllintepe) crucible smelting and metallurgical slag are well detected (Palmieri *et al.* 1999, p. 143; Yener 2000, p. 22, 34, 35, 39, 40, 61).

Furnaces are presented too. On the settlement of Nachi Nebe Tepe, in the Pre-Uruk layer, four dome furnaces, slag and tuyeres indicating artificial blasting are revealed (Yener 2000, p. 28). On the Eneolithic settlement of Hacinebi four furnaces had a diameter of 60-65cm and a depth of 45 cm (Yakar 2002, p. 20, 21). The furnaces found on the Anatolian Eneolithic settlement of Değirmentepe were usually about 60 cm in diameter, although sometimes their length reached 1 m. A very interesting feature is the presence of channels joined to furnaces. Their length could reach 1.2 m, with a width of 25 cm near the furnace and 10 cm at the other end, and a depth of 12 cm. It is supposed that these furnaces were used for metallurgical operations, but the purpose of the channels is not quite clear. They might have served to tap the slag or to blast air into the furnace (Müller-Karpe A. 1994, p. 17-19, Abb. 5, 6). However, investigation of Anatolian slag of this time has revealed microstructures which show that the slag cooled down directly in the furnace (Lutz *et al.* 1991, p. 64, 65). Furthermore, tapped slag cools quickly and would solidify immediately, blocking the beginning of this channel. Its use for blowing air into the furnace is not very likely either: it would be difficult to build up enough pressure to force air into the middle of the furnace in view the length of the channel and the greater size of the outlet than the inlet. Therefore it is more probable that these channels served as horizontal flues similar to that on the Vera Island. A further possible indication of this is that they terminated near the walls of dwellings. Temperatures reconstructed for slag from Değirmentepe are 1100 °C, but there are some samples showing a temperature of 1245 °C (Yener 2000, p. 34, 35, 39, 40). The last is quite probable if sulfide ore was charged into the furnace.

In neighboring Iran at this time arsenic bronzes are widespread too. Together with a group of metal containing nickel, they comprised 53%, but almost all this metal is found in Susa (Avilova 2008, tab. 32, 33). From this does not follow that Iranian metallurgy was more developed technologically, than Anatolian one. In Iran a lot of arsenic copper is known not only in the Eneolithic, but also in the Early Bronze Age, and this impurity is typical of Iranian copper deposits (Pigott 2009, p. 371; Oudbashi *et al.* 2012, p. 158). But, anyway, such deposits are rare, and the analysis of materials shows that a special selecting of ore is more probable. Often used as a proof of natural character of this alloys a deposit near Anarak, containing rare copper-arsenic minerals, not so surely was actively used. This idea is based not on analyses, but on its repetition (Thornton, Lamberg-Karlovsky 2004, p. 267; Thornton 2009, p. 317).

On the Iranian Eneolithic settlements of Tal-i-Iblis and Tepe Gabristan since the early 4th millennium BC ore was smelted in pedestalled crucibles, using simple hearths about 25 cm in diameter. A vessel with 20 kg of ore whose pieces were of the size of a nut is even found (Pigott 1999, p. 110-111; Thornton 2009, p. 312). But it hardly indicates such large charge. For ore smelting the ore should be pulverized. This ore probably was prepared for further crushing. But since the late 4th millennium BC in Iran we see a transition from the smelting in crucibles to smelting in furnaces, probably, use of fluxes started, and fluid slag occur (Thornton 2009, p. 319).

The ceramic scoops found on the Eneolithic Anatolian settlements of Büyükgülücek and Höyücek are identical to that found on Vera Island 4 (Schoop 2005, Taf. 11, 25). This analogy, as though, will be coordinated with the Anatolian parallel of the metallurgical furnace of this settlement, but a form of these scoops is dictated by a function, and it is rather simple.

In the Anatolian and Mesopotamian complexes of the 4th – 3rd millennia BC copper alloys with lead is known (Müller-Karpe 1990, p. 109; Yener *et al.* 1994, p. 378; Schmitt-Strecker *et al.* 1991; Riederer 1991, p. 88; Avilova 2008, p. 61). Slags with lead impurity are found in layers of this period also in Northeast Iran (Tepe Hissar) that marks mixing of copper and lead ores for the purpose of alloying (Thornton 2009, p. 317). A very high level of metallurgy was on the Balkans. In the context of Vinča culture lead and a galena are known. This agrees with discovery of a hoard in Greece (Alepotrypa Cave) with 100 silver objects of the same time (Radivojević *et al.* 2013, p. 1041). At discussion of Sintashta culture we will touch upon interconnection of both these metals. Thus, lead was known in a rather vast area. Therefore the find on the Skvortsovaya Gora V in the Urals was probably not accidental too.

Thus, we see some parallels of the Ural metallurgy in Anatolia. But these parallels reflect, mainly, universal parameters of this period (existence of small pit furnaces, crucible smelting, predominant use of oxidized ores, emergence of arsenic alloys, rarity of slag, a form of casting scoop). Unconditional exact parallel is the furnace with flue, smelting of sulfides and attempts to alloy with tin, but the last features as we will see further, were widespread during this epoch much more widely, than it is considered to be, and flues could arise independently, as a reaction against a need of removal of gases when smelting sulfide ore.

The European materials are most interesting to us because in this period besides metallurgy also megaliths occur in the Urals. The earliest center of their origins in Europe was Iberia. But in Iberia copper objects are seldom found in megaliths, and the context of these finds is not always unambiguous, especially as megaliths could be re-used in the Bronze Age. But in the period of Bell-Beaker culture (3rd millennium BC) copper objects in the Iberian megaliths were present quite definitely (Groer 2008, S. 52). A dolmen situated near Eneolithic copper mines in the Spanish province Huelva is interesting. That allowed scholars to assume that builders of the megaliths were the first metallurgists of Western Europe (Rothenberg, Freijeiro 1980, p. 45). But it, of course, is indirect evidence.

In Iberia, as well as in Anatolia, pure and arsenic copper was used (Rovira 2005, p. 177). The rise of metallurgy is dated here to very early time: on the settlement of Cerro Virtud in Almeria, excavations revealed metallurgical remains dated from the mid-5th millennium BC, i.e. 1000 earlier, than it was supposed before (Montero Ruiz 2005, p. 187). In Iberia 37 places with traces of metallurgical activity in the Eneolithic are known. On the well-known settlement of Los Millares (and this culture had the megalithic tradition too) ones extracted arsenic copper from arsenic-containing copper carbonates (Groer 2008, S. 53). Crucible slags with impurities of arsenic and arsenical copper minerals are found (Müller *et al.* 2006, p. 210, 212; Hunt Ortiz 2003, p. 295, 296). Sometimes there are not only slagged crucibles, but also slag (for example, from the settlement of Amarguillo), therefore, not always pure malachite was used in the smelting. These slags contain from 0.11 to 35% copper and, in some instances, arsenic has been found also in ore, and, in higher concentrations than in the slag. This is quite explainable: in slag the content of arsenic has to decrease. In metal the content of arsenic varies from insignificant to high. It is quite typical picture of the use of copper arsenic minerals. Therefore it is supposed that arsenic went together with copper ore (Hunt Ortiz 2003, p. 300-302, 306, 321, 380).

But there are other data on the settlement of Los Millares and some other, dated to the 3rd millennium BC according to which the arsenic concentration in ore is very insignificant. It is very high already in slagged crucibles that points to the alloying by arsenic into either ore or metal. The alloys on the ore smelting stage is, nevertheless, more probable because delafossite has been detected in the crucible slag. It is a copper and iron oxide, characteristic of archaic slags of the ore smelting. Besides, crucibles were subjected to much longer thermal impact than it was needed at metal melting (Hook *et al.* 1990, p. 67, 69, 70). Therefore it is not excluded that there was the alloying by arsenic, but copper ores with arsenic impurity were widely used too.

Copper oxides and carbonates were smelted (Groer 2008, S. 53; Hunt Ortiz 2003, p. 294). It is confirmed also by the above-mentioned Eneolithic mines in the province Huelva where malachite was extracted (Rothenberg, Freijeiro 1980, p. 45). As there is little slag and it is extremely rare, it is supposed that metallurgists smelted, mainly, pure malachite (Hunt Ortiz 2003, p. 304).

The smelting was conducted in crucibles with low walls and in furnaces. The open hearths are assumed, but it is necessary to consider that for ancient sites it is not always possible to determine a height of walls and existence of top covering. The analysis of crucibles from Los Millares has shown that the smelting lasted two hours at a temperature of 1100 °C, and then the contents of crucibles were sorted; copper was taken and melted (Hunt Ortiz 2003, p. 294-296, 298-302; Rovira 2005, p. 177, 178). The crucible smelting of oxidized ores is recorded also on the Almizaraque settlement (Müller *et al.* 2006, p. 209-211). As walls of crucibles were low (for example, the majority of crucibles in Portugal are only 10cm in diameter and 3 cm in height), it does not differ essentially from smelting in the furnace, and the crucibles probably served more for preservation of the furnace lining than for creation of specific chemical conditions. Almost always it was surface structures. One exception is known too: on the settlement of Chinflon in Huelva the furnace was represented by a simple pit in soil (Rothenberg, Freijeiro 1980, p. 52).

In some instances in the furnace charge inclusions of gangue are found: on the settlement of Chinflon slag of this period is porous and heterogeneous, with fayalite inclusions that indicates the reducing atmosphere in the furnace (Rothenberg, Freijeiro 1980, p. 52). But more often slag shows rather large losses of metal and oxidizing conditions of its formation: inclusions of magnetite, maghemite and spinel (Rovira 2005, p. 177, 178; Müller *et al.* 2006, p. 210).

Thus, all aforesaid reflects very early stage of metallurgical production. Both the preference of rather pure oxidized ore and smelting in crucibles are universal for this time. But the use of ores with the higher arsenic content can specify that the development of Iberian metallurgy had an impulse from the Eastern Mediterranean. But the Balkans can be excluded as there, as we saw, arsenic bronzes appeared much later, at the end of the Eneolithic. Therefore the most probable candidate is Anatolia. Certainly, in Iberia copper ore with arsenic was used, but metallurgists chose this ore probably purposefully, i.e. there was a tradition of the use and subsequent manufacturing of such metal. Now it cannot be considered as a reliable theory. But it is duplicated by other hypotheses, which are not connected with metallurgy. Müller-Karpe explained the appearance of fortifications with bastions like Los Millares by impulses from the Near East (Müller-Karpe 1974, S. 404, 405). The problem of origins of the European megaliths is connected with this too. There are two opposite points of view on this problem dividing the scholars into diffusionists and isolationists. The first assumed distribution of this tradition from the Eastern Mediterranean. Originally formulated quite simplified, with searching for starting point in Mycenae and Egypt, this theory was later developed in more careful forms (O'Riordan, Daniel 1964, p.131-134). However the isolationists also assume initial coming of populations from the East which resulted later in contemporary construction of megaliths in different parts of Europe owing to social reasons (Renfrew 1973, p. 143-145; 1976, p. 213-218). In relation to Iberia where megaliths appeared earlier than in other areas, this difference is not drastic, especially as together with the megaliths the metallurgy appeared there. Therefore the east impulse is most probable.

From the Mediterranean already in the Eneolithic the copper metallurgy penetrated into North Africa. In Nubia the first copper objects appeared about 3100 BC, in Algeria and Morocco from the 4th millennium BC too, and, it is probable, it was penetrated from Iberia judging from types of objects (Grébénart 1988, p. 40, 51-53, 60). It is necessary to remind that the megalithic tradition also penetrated here.

Into another megalithic area, France, metallurgy penetrated from Northern Italy at the early 3rd millennium BC, and spread to the north and west of France, and it was not connected with Iberia even in Western France (Strahm 2005, p. 26). Metal objects are known in dolmens here. And, the main producing centers were in the south, in Languedoc in the massif Cabriès where in mining areas fragments of slag, copper ingots and ore are found on settlements (Mille, Carozza 2009, p. 144-151).

On the basis of analysis of a large massif of artifacts several chemical groups of metal have been distinguished, and it has been demonstrated that allowed to claim that in this area ores of the fahlerz type were in use what is very similar to Rinaldone culture in Italy. Therefore the metallurgy, probably, spread from there, not from Iberia (Sangmeister 2005, p. 19).

According to the last data the mines of the massif Cabriès were exploited earlier, since the mid-4th millennium BC. Ore there is presented by tetrahedrite, chalcopyrite and malachite. Thanks to the tetrahedrite, copper objects have a specific composition with impurities of antimony, silver and arsenic (Ambert *et al.* 2009, p. 289). Taking into account the point of view given above that the metallurgical production came here from Northern Italy, it is possible to mention one remarkable parallel. In metal artifacts of the Copper Age of Northeastern Italy, in Liguria, strange compositions of copper have been detected: nickel (from 4.5% to 1.5%) and antimony (1.6%) in three awls; silver (5.2%) in an awl; and arsenic (2.1%), silver (3%) and lead (1.7%) in a plate (Delfino 2008, p. 233). It testifies, most likely, the smelting of ores of the fahlerz type too.

The presence of sulfide ores in Southern France led to their exploitation and, probably, it was a cause of that, unlike Iberia, slag occurs more often here. So, excavations in Saint-Véran, in the Alps, revealed several hundreds of kilograms of slag presented by flat cakes 10-20cm in diameter that points to considerable volumes of the production. Because 66% of copper artifacts contain more than 0.1% antimony and silver, and 7% of copper artifacts have up to 0.3% of these elements, the oxidized ore with impurity of fahlerz was used in smelting. It was not a result of alloying. It is difficult to tell something concrete about the technology of production, but, apparently, the smelting was carried out directly in the furnace, what was more reasonable when using sulfide ores. As the top part of slag cakes cooled very quickly, it has been supposed that slag was cooled by water with the purpose to begin a new smelting as soon as possible (Mille, Carozza 2009, p. 159, 163). But this assumption is doubtful.

On the settlement of La Capitelle du Broum a metallurgical complex of the first half of the 3rd millennium BC is revealed. Metallurgical installations are presented here by the hearths covered with clay, 50 cm in diameter and 15 cm in depth. Near the furnaces fragments of ore, slag and copper prills are found. Pieces of slag are small, no more than several grams, but there are a lot of such pieces (1 kg). Slag was viscous and probably crushed from larger pieces to extract copper. The slag analysis has revealed a partly oxidizing atmosphere: fayalite in slag is rare, there are many different silicates, prills of copper, pieces of ore. In some instances sulfides were used, producing a matte, but, as a whole, it was a direct production of copper. Fluxes, probably, were not used. It is supposed that the temperatures were 1000-1200 °C. Evidences about smelting in crucibles are not present; the crucibles appear later, in the period of Bell-Beaker culture. Subsequently the metal objects were manufactured by casting and cold forging with intermediate annealing (Rovira 2005, p. 177, 178; Ambert *et al.* 2009, p. 289, 290, 293). In this case it is possible to doubt only in conclusions about the open hearths as superstructures of furnaces remain extremely seldom, it is difficult to save high temperature in an open hearth, the smelting atmosphere would be so oxidized that slag would be extremely rich in cuprite, and, on the contrary, the cooling would be quicker.

In this area the smelting of malachite in crucible is detected since the 3rd millennium BC, and in Liguria and Corsica since the 4th millennium BC (Groer 2008, S. 56-63). In particular, the crucible smelting has been detected on the settlement of Al Claus. And, usual household vessels were used as crucibles. Smelting was conducted at a temperature above 1100 °C, judging by the presence of fayalite in the crucible slag (Mille, Carozza 2009, p. 155). This also testifies in favor of the reducing atmosphere.

Thus, we deal, apparently, with a rather paradoxical situation when at first more developed technology appeared. There are also no data on, whether these technologies coexisted after this. In other words, we can assume a combination of smelting in both crucibles and furnaces, but it is impossible to tell finally – whether it was connected with different periods or with use of ores of different types.

Similar level of metallurgical production is recorded in one more region of Europe with the megalithic monuments, in Ireland. Here ancient production of the period of Bell-Beaker culture (2400-2200 BC) in the area of copper deposits of Ross Island is studied. As well as in Languedoc, the fahlerz type of ores was used in smelting, therefore the most part of metal contain higher concentration of arsenic, antimony and silver. Therefore natural low-arsenic copper from rich in arsenic copper sulfates was widespread. Probably, ancient miners took such ore on purpose; later just it led to the transition to fahlerz ores that, in general, was characteristic of Bell-Beaker culture. The smelting was carried out in hearths and crucibles, without slag formation, what is considered as a tradition going back to smelting of oxidized ores (O'Brien 2005, p. 37; Groer 2008, S. 48).

In Britain metallurgy appears even later, at the late 3rd or early 2nd millennium BC. Its local origin on the British Isles is not excluded, because there were no others metals accompanying copper in the Near East, for example, lead. But objects from native copper are absent; therefore the transition had to be prompt. Slag is absent here too, and slag near mines can be dated also to later time. Besides, judging from a set of impurities, copper was delivered into southwest Britain from Ireland (Craddock, Craddock 1996, p. 52, 53, 61). But in here the impulse from the Near East should not had arrived either. However, because of scarcity of material it is impossible to discuss questions of origins of metallurgy here.

Into Central Europe where the megalithic tradition is known too, metallurgy penetrated in the early 4th millennium BC through the Balkans (in Slovakia the earliest metallurgical objects are dated to the period of 5400-4000 BC (Novotna 1990, p. 70) but, most likely, they belong to the end of the period), and from the southwest (where it had penetrated from the Mediterranean) in the 3rd millennium BC. In the 4th millennium BC in the north of this region the metallurgical production was present already in dolmens and rondel enclosures, however, to the north of the region metal import (including arsenic copper) was carried out, probably, from the Erzgebirge and subalpine zone (groups of Mondsee and Pfin) where already fahlerz ores were mined like in Languedoc. The growth of this import during 3500-3300 BC is detected, and ore mining appeared in the north (Krause 2003, S. 225, 226, 229, 233). Judging from excavation on the settlement of Brixlegg in Austria, smelting of ore was carried out in crucibles (Bartelheim *et al.* 2002, S. 42). In the following manufacture of metal artifacts dominated, as well as everywhere, forging technologies. Metallographic studies of materials of the Mondsee group showed that high temperatures were used, but it is impossible to determine whether it was cold forging with annealing or hot forging. Temperature impact depended on the content of impurities. So, the axe with a low content of arsenic was heated to low temperatures of 400-600 °C, degrees of reduction were different. There is a feeling that metallurgists perfectly understood properties of this or that metal (Budd, Ottaway 1990, p. 100-101).

Special problems are the alloying with tin and the use of chalcopyrite in smelting. As we will see, these problems can be interconnected. In Southeast Anatolia tin was known since the EBA (Yakar 2002, p. 18). As a whole in the EBA of the region a part of tin bronzes was 8% (Avilova 2008, p. 61). But for the early periods of the EBA they are rare finds. A stable presence of tin in the Near East begins since the periods of EBA III, Troy IIg, Ur III (2600-2400 BC) (Gülçur 2002, p. 35). The Eneolithic finds are also isolated instances. The Eneolithic in Anatolia is dated to 5500-3300 BC, and the transitional period to the EBA does to 3300-3000 BC. Tin occurs since the Late Eneolithic (Efe 2002, p. 50, 51). Sometimes one cast doubt on these finds. So, for Anatolia only a single case of alloy of copper with arsenic and tin is quoted in Mersin and it is supposed that this alloy was of a natural origin (Avilova 2008, p. 61). Actually, in Mersin in the Late Eneolithic context three objects made of this alloys containing more than 1% tin are known: pin (1.3%), awl (2.1%) and seal (2.6%) (Muhly 1985, p. 284). Therefore the conclusion about the presence of tin bronzes in the Anatolian Late Eneolithic (late 4th millennium BC) is probably lawful (Yalcin 2000, p. 27). There are also earlier finds. It is a pin from Tüllintepe with 5% tin content; it is supposed that it is the most ancient instance of such ligature in the Near East. But since the 4th millennium BC the tinning, i.e. covering of objects with tin, is also known. The silver covering recorded on spearheads from Arslantepe is considered as its technological analog. It was doing in prestigious or cult purposes and the tin covering gave the same visual effect (Yalcin, Yalcin 2009, p. 128, 129). An earlier case is the alloy with 2.9% tin content from Yumuktepe, dated to about 4300 BC (Kaptan 1990, p. 75). The most unexpected find is the copper wire from Suberde (the mid-7th millennium BC) containing 8.4% tin (Muhly 1985, p. 284). But the latter cannot be considered, as if it is not a result of analytical error, was an accident which had no further development as a technological tradition, unlike the use of tin in the Eneolithic. As we will see discussing the LBA, in Anatolia at the beginning of the EBA quite complicated production and enrichment of tin ore, and use of tin as a ligature were practiced. Naturally, the first attempts to use tin had to take place earlier. Therefore specialists in ancient Anatolian metallurgy believe that already in the 5th millennium BC experimental multicomponent alloys copper with arsenic, tin and lead had been practiced here. As a whole, tin starts to be used since the late 4th millennium BC. Besides, in Southeastern Anatolia a series of small tin deposits is known (Yener 2000, p. 32, 47, 71).

It is not excluded that the alloying was made at the ore smelting stage as on the settlement of Tall al-Judayda in Amuq valley (the late 4th – 3rd millennia BC) copper prills in crucible slag contain between 2 and 37% of tin (Yener 2000, p. 74).

To the east, in Luristan, in the cemetery of Kaleh Nissar of the same time the objects with tin are found that allowed to assume smelting of copper ore together with tin (Thornton 2009, p. 317).

But similar early finds present also outside the Near East. On Okukalj settlement of Baden culture in Slovenia slag contains from 5 to 20% of tin (Lozuk 1990, p. 56). The drill from Zlotska Pećina in Serbia contains 2.1% tin. It is assumed that this drill belongs to the late phase Baden-Kostolac (Begemann *et al.* 1990, p. 145, 146). But anyway it is dated within 4th millennium BC. But on the Balkans there are finds of tin bronzes even in an earlier context. Many of these finds came from multilayer settlements, and the attitude to them was mistrustful. The earliest (and from a clear context) is the foil piece from the Pločnik settlement of Vinča culture, dated to about 4650 BC. But today there are already 14 Eneolithic finds with the tin content from 1 to 8-12%. It is supposed that they were manufactured as a result of smelting of copper-tin ore. One of important proofs is the copper-tin slag in the Zengővárkony cemetery in Hungary (late 5th millennium BC). And, judging from the presence of sulfur and some other impurities, sulfide ores were smelted. On the base of contents of tin and other impurities these bronzes have been divided into three groups: stannite bronze, high-tin fahlore bronze and low-tin fahlore bronze. Early smelting of copper ore together with stannite (a sulfide of copper, iron, and tin) are known from Iberia to Iran. Subsequently, in 4th and 3rd millennia BC this tradition was forced out on the Balkans by the arsenic alloying and comes back again to the Balkans only in the 2nd millennium BC (Radivojević *et al.* 2013, p. 1030-1039).

Smelting of chalcopyrite and sometimes presence of tin in metal are noted in Languedoc in the context of Final Neolithic (3rd millennium BC) on the settlement of Al Claus (Mille, Carozza 2009, p. 155).

In Central Europe there are finds of tin bronzes in the Corded Ware cultures, the culture of Single Burials and Bell-Beaker (3rd millennium BC). Two artifacts of the 4th millennium BC are also known. The tin content in all these objects is 2-6% that is obviously more than that can be in copper ores, but frequently it is the low-alloyed objects, which cannot be related to the true tin bronzes. However, even the first experiences with the alloying or mixing of ores are not considered, and this situation is explained by contacts with Anatolian cultures of the EBA (Krause 2003, S. 210-213, 241). But during the whole Eneolithic period (5th – 4th millennia BC) contacts of South-Eastern Europe with Anatolia were absent that does not allow even to compare their schemes of periodization (Parzinger 1993, S. 253-263). It is possible to do for the next millennium, but for Central Europe such comparisons are indirect. Besides, in the 4th millennium BC tin bronzes were a rare phenomenon also in Anatolia. It is also noteworthy that these finds are situated near tin sources of the Erzgebirge. It is supposed that the beginning of tin alloys in Europe was connected with the Velika Gruda settlement in Montenegro, 2800-2700 BC, and in Central Europe this alloys spread already in the second half of the 3rd millennium BC as a result of influences from the Balkan-Carpathian region (Krause 2003, S. 242). But how to explain the earlier finds?

Analyses of the Eneolithic slag found near El Algarobillo in southern Iberia have shown copper, iron and 3.6% tin. Its microscopic investigation showed that it is rather a mix of partly reduced ore. The presence of tin is remarkable. Ore cannot contain more than 3% tin. Therefore, most likely, this slag was smelted from a mix of copper and tin ores, for the purpose to produce tin bronze, although in some instances copper ores are nevertheless rich in tin. But tin deposits are found in this area too. On the settlement of Llanete de los Moros partly roasted ores and slagged crucibles are also found. The analysis of crucible slag revealed copper, tin (0.6-5.8%) and iron, and in one instance 1.2% arsenic. It is supposed that metallurgists smelted primary sulfide ore, probably, with natural impurity of tin (Hunt Ortiz 2003, p. 305, 306, 376).

Thus, we see the presence of rare tin bronzes in the Eneolithic context on the Balkans, in Anatolia, Central Europe, Southern Iberia and Languedoc. It is possible to assume the alloying by tin ore at the stage of copper ore smelting, in other words, the same that we see in the Transurals. According to experimental data, it is easy to produce tin bronze at combined smelting of copper and tin ores (Rovira *et al.* 2009, p. 413).

At first sight, the transition to tin alloys can be explained simply. We see that in some instances it was contemporary with the transition to chalcopyrite smelting. From the technological point of view, it was quite explainable: when smelting chalcopyrite temperatures grow sharply, and duration of smelting increases. In these conditions the alloys by arsenic minerals into copper ore is impossible as arsenic vaporizes. In the Late Bronze Age it was probably a leading reason, but for this time it was hardly so, especially because on the Balkans it was earlier than arsenic alloys. And how there was an idea of a similar alloying? Charles assumed that originally ones started to use tin sulfide, stannite (Cu_2FeSnS_4), confusing it with copper ore with arsenic impurities (Charles, 1980, p. 172). And other authors agree that the first tin bronzes were made from stannite (Roberts *et al.* 2009, p. 1017). But this mineral is formed after replacement of an atom of iron by an atom of tin in chalcopyrite. Therefore, it is most likely, that just stannite got to smelting together with chalcopyrite, and its beneficial impact on properties of metal was noticed. As cassiterite is formed at disintegration of stannite, it resulted in use of this mineral. Probably the temporal coincidence of the beginning of chalcopyrite smelting with the first tin bronzes is explained by this.

In Anatolia smelting operations were based, above all, on the oxidized ores. On the majority of settlements chalcopyrite was not smelted. In slags of such settlements as Tüllintepe and Tepecik iron is absent, but on Değirmentepe smelting of sulfides is recorded already in the Eneolithic that allowed a conclusion to be drawn that although the wide use of chalcopyrite begins in Anatolia since the EBA, it was started in the Eneolithic (Yakar 2002, p. 18-21; Yener 2000, p. 40). By the way, probably, it explains the use of furnaces with flue on Değirmentepe. But on Değirmentepe the use of sulfides is detected by very rare samples.

This combination of use of both oxidized ore and chalcopyrite is also noted for the Late Eneolithic (3400-2900 BC), in particular, on such settlement as Arslantepe VI, and on the settlement of Norshuntepe in the Eneolithic layer the oxidized ores with chalcopyrite impurities has been found (Yener 2000, p. 45-47, 58).

Investigation of two small slag pieces from Tepe Hissar in Northeastern Iran (a layer dated to *ca*. 3600 BC) has shown that the smelting was low-temperature and short. But there is not so much cuprite in slag, but a lot of iron oxides, fragments of fused primary ore, bornite, with lead and arsenic impurities are found (Thornton 2009, p. 314).

Above we have mentioned the chalcopyrite smelting on the settlement of Al Claus in Languedoc in the context of discussion about tin. There are also indirect evidences of the occasional smelting of chalcopyrite in Europe. As we will see discussing metallurgy of the LBA, small iron pieces could be by-product of such smelting. At the end of the 19th century AD some archaeologists described a discovery of small pieces of iron and iron objects in megalithic tombs of Germany, the Netherlands and Scandinavia. A part of these objects, judging from the description, were probably too late, indicating reuse of the tombs. But in some instances the data look quite authentically as the iron objects were found in closed complexes, despite an obviously low level of excavation technique. Besides, the author has made an assumption that at the transition from the Neolithic to the Bronze Age metallurgists could use both meteoric iron, and the casual product received at smelting of copper ores (Olshausen 1893, S. 92, 89-121). Iron is also known in the Eneolithic context in Iberia. More frequently it is presented by small awls. Their analyses were not done and we know nothing about nickel impurities, but its meteoric origin is supposed (Hunt Ortiz 2003, p. 328).

Thus, in the Urals as well as in Anatolia and Europe, we see in the Eneolithic some unusual features: the first experience in smelting of chalcopyrite and bornite, alloying by tin minerals at the ore smelting stage, probably, the first experiences with iron (the latter for the Urals is unknown).

All this does not help with the understanding from which area the metallurgical technology came to the Urals. Its level is lower, but, as a whole, corresponds to that we see for this period in both Anatolia and Europe. For this early period it is impossible to solve reliably the question about origins of production: in all areas there are not enough data, the level of production is comparable, there are no specific refined local techniques yet, few metal objects, and they have inexpressive shapes, being made more often by forging; therefore fast regional transformations of any type were very probable. Unfortunately, even such specific to this period features as smelting of chalcopyrite and attempts of alloying with arsenic and tin at the ore smelting stage, do not help with determination of the initial area. Previously I thought that it allows me with confidence to speak about the Anatolian impulse (Grigoriev 2012), but as we saw, occasionally these features are also present in the Eneolithic context of different regions of Europe. The noted in the Urals crucible smelting took place in all regions during this period. There are some peculiar Anatolian features: alloys with lead, furnaces with a flue. But all this is presented by single objects, therefore, on the one hand, a fortuity is quite possible in this instance, on the other hand, against the background of a small quantity of the finds connected with metallurgical production of this period, unexpected single discoveries are possible everywhere, but individual similar features could also appear independently. Unfortunately, we do not see a complex of comparable features.

Therefore we may to state some positions. The nature of Ural metallurgy at its beginning is such that it does not assume a local stage-by-stage development. The production was introduced to the region from a remote area with the developed level of technologies. However, the data on the Eneolithic Ural metallurgy do not allow yet determining this area accurately. On the British Isles the production appears some later than in the Urals. Therefore, the most probable candidate is Central Europe especially as it is duplicated by a number of parallels in ceramics and megalithic structures. But a small group of parallels for the Ural megaliths is also known in the Near East; therefore a possibility of two impulses is not excluded: the first and the main, from

Europe, and the second from Anatolia (Grigoriev 2012). By the way, the metallurgical furnace on the Vera Island is stratigraphically later than the early Eneolithic layer of this site. Nevertheless, today we have not enough data on this second impulse.

Metallurgy and social relations in the Eneolithic

A very important problem of early stages in history of metallurgy is the reasons of the emergence and development of this production. In the Eneolithic in a majority of regions metal did not play an essential role in economy, it did not replace stone tools, and it was used, mainly, in areas of its production and was seldom removed out of these areas. Therefore it is considered that metal had rather a symbolical significance (Mille, Carozza 2009, p. 161, 167). Moreover, at the early stages all innovations in metallurgy were, probably, not the inventions caused by necessity. These were inventions in a pure form, trials with old technologies (ware burning) on a new material (Pigott 2004a, p. 28).

It is true. However, we have to remember that the degree of metal utilization differs sharply from the degree of utilization of stone. Therefore, the ratio of finds does not reflect the true ratio of their use. But even taking into account this circumstance, as smelting of both pure malachite and native copper cannot produce slag and demands no specialized furnaces, the found remains of metallurgical production in all regions are insignificant. Active use of stone is marked everywhere by a set of flint plates and chips, but vessels, even partly slagged, are presented everywhere extremely rare. Unfortunately, even it cannot be a reliable sign of small volumes of production, because in Bulgaria, with its plenty of massive copper tools and weapons, the remains of ore smelting are almost not found. Thus, we are not able to estimate these volumes realistically. They were obviously higher than it seems to us on the base of excavations of archaeological sites, but in any case very modest in comparison with the flint industry. And if not to consider Bulgaria, it is appropriately to ask: what lead to gradual development of metallurgical production and expansion of metal use?

First of all, we touch upon properties of metal. Its metallic lustre certainly attracted people when they for the first time got acquainted with native copper, and it was the main stimulus of production of copper ornaments. Not incidentally the most widespread early objects were ornaments. But important factors are also plasticity and hardness of copper. During the work with native copper the cold forging was the earliest stage, and then forging with annealing and melting appeared. After the forging the hardness of copper reaches 140 HV that (as well as occurrence of cracks) makes its further forging difficult, but the annealing reduces hardness to 60 HV (Tylecote 1987, p. 90). Eventually, everything depends on forging conditions. Pure copper forged in different conditions shows hardness from 55 to 130 HV. The maximum hardness of pure copper becomes after the cold forging. It is even higher than that of later alloys. It allowed to people to receive rather hard objects at early stages of the production. Therefore, the qualities of such tools as adzes, awls, and punches, could be better than that of tools made of stone and bone.

In different regions of the world the use of copper depended on different factors: accessibility, existence of tradition, a need for some specific tasks. In Anatolia 58% of copper objects are presented by ornaments and 39% by tools. However in Iran ornaments are presented much less (22%), but a part of tools and weapons reaches 71%, and they are presented not only by needles, awls and knifes, but also by rather massive forms – adzes, mattocks and axes (Avilova 2008, p. 41, 113). It is obvious that in the developed regions of the world metal was used also in the utilitarian purposes. However its quantity was insignificant. Obviously, the axes used in the fighting purposes, were not available for all people, and only for leaders or small groups of elite warriors. Therefore they could not turn an outcome of armed conflicts, and were, to some extent, the prestigious objects too. But awls and adzes were already definitely utilitarian tools.

In less developed areas, for example, in the Urals, owing to a rarity of copper objects, they for certain had the prestigious significance, and acted as a certain elite marker. But there are also signs of their purely utilitarian use. On the Vera Island where the large megalithic cult center was situated, a quarry is found where slabs and blocks for construction of megaliths were extracted. Many blocks have traces of splitting and small holes to insert wooden wedges. Studying of these holes have shown that for their cutting in granite an oblong edge of more than 5-6cm in length was used, and then a wide flat chisel. As the width of the holes was no more than 3 cm, the width of these tools could not be more than 2 cm, i.e., it could be only metal tools. And they were used for work with granite, whose hardness on the Mohs scale is 7, while hardness of copper is only 3. But, as we have discussed earlier, hardness of cold-forged copper tools increases sharply that did this work, although slow, but possible. It is also interesting that I saw similar traces on a block in the megalithic complex of Almendres in Portugal, although the softer limestone was used there. The same technique is recorded on another Portuguese megalithic complex, dolmens and quarries in Lapa da Orca. Identical holes cut by a chisel are present on a dolmen plate near Dakhovskaya (Markovin 1997, p. 201, fig. 98.1). Such technique applied to granite is noted in Carnac in France, and at Castelruddery in Ireland (a megalithic complex of the mid-3rd millennium BC). In the Maltese Hypogeum one footstep has wedge-shaped traces marking the same technique (Trump 2002). Thus, constructing of many megaliths required the use of copper tools. They were not necessary for simple dolmens made of boulders, but where it was necessary to do regular blocks, they were frequently needed. Therefore the megalithic tradition was partly connected with the metallurgical production, and sometimes they spread at the same time.

In this case we see purely utilitarian use of copper. But whether it was completely utilitarian? Discussing man-hours needed to build and serve the cult complex on the Vera Island, we have drown a conclusion that it was much more complicated society, than it seemed earlier for the Ural Eneolithic, that there was a certain social differentiation (Grigoriev 2011), and now it is a generally accepted point of view in the megalithic studies. Construction of the megaliths was one of the markers of a higher social group, although their main function was, of course, a cultic one. Therefore such significant efforts were made for this construction. In this regard the use of copper tools during this construction cannot be considered as a purely utilitarian action. It is also strange that metallurgical production was practiced within this cultic center. In this instance a lot of variations can be: it is possible to speak about sacrality of metallurgy, but it is possible also to remember both usual warehouses and workshops functioning within the Near Eastern temples (I do not mean, of course, internal sacral parts of the temple complexes). If to suppose the most probable variant when any elite group served in a cultic complex, existence of metallurgy here demonstrates, in some extend, its connection with this group. But metallurgy and access to copper deposits did not lead to changes in social structures (Krause 2003, S. 260). We have an inverse relation here: the elite part of the society could use achievements of metallurgy and promote thereby its preservation and development at the early stages.

But in the Eneolithic economy in the Urals metallurgy did not play an essential role. Even in a majority of agricultural and cattle breeding areas the situation was the same. Though sometimes it is possible to meet another point of view on that, for example, that metallurgy promoted a rapid progress of the Eneolithic groups in the Carpathians and Alps (Jovanović 1971, p. 115). But it is a naked assertion. The basis of the Eneolithic economy in Iberia, for example, was agriculture, and metallurgy was not so important. Even in mining areas with the metallurgical remains (Hunt Ortiz 2003, p. 382). The same is supposed also for the Eneolithic of France where, judging from territorial distribution of metal, it did not play any role in social transformations (Mille, Carozza, 2009, p. 165). In general, now nobody among archaeometallurgists believes that for development and spread of metallurgy at its early stages the elite was necessary, or that metallurgy supplied exclusively the elite (Thornton, Roberts 2009, p. 182). Metallurgy became an economic factor only after appearance of markets to sale its products that lead to the growth of specialization and exchange. In the EBA this phenomenon arises in Anatolia and in a majority of other regions only since the LBA.

Thus, for this early period it is possible to say that in a majority of regions the production had non-utilitarian character, although in some areas (probably, in Bulgaria) the situation started to gradually change.

Conclusions

For the Eneolithic of Northern Eurasia, owing to the scarcity of materials, it is difficult to construct a clear scheme of the spread of metallurgical production. It is the most probable that the first impulses resulted in the knowledge of metal and metalworking came from the west. Sometimes they led to local use of native copper as it took place in Karelia. From the territory of Circumpontic Metallurgical Province the expansion of metalworking went in the southern zone, up to the Volga, and from Central Europe to the Urals. Today with some probability it is possible to assume also an existence of a secondary, Anatolian impulse reached the Urals. The Transcaucasian impulses are also notable in the North Pontic area where in some instances the arsenic bronzes occur in the Eneolithic complexes. But this production did not have a rapid development in the Eneolithic. Even in the Urals with its rich ore sources and rather developed production, it fades away over time and becomes simpler. The emergence of developed metallurgy in any area does not mean at all that its further stage-by-stage development will take place here. New inventions can disappear and even do not appear again. It happened in Iran where in the Eneolithic refractory crucibles were invented (Thornton, Rehren 2009, p. 2710). The reason of this was quite simple: even the introduced production cannot find the development if there are no necessary social and economic conditions. Metallurgy develops, as a rule, in the conditions of agricultural and stock breading economy. In the conditions of the economy based on hunting and fishery, its need is not so great.

Metallurgy during the Early and Middle Bronze Age

In the Early and Middle Bronze Age the western part of Northern Eurasia was included into the system of the Circumpontic Metallurgical Province (CMP)[4]. Metallurgical production of this large system has been well studied and described (e.g. Chernykh 2007), and here we follow this newest generalizing work. In the south of the region during the Early Bronze Age metalworking of Pit-grave culture was a part of the CMP, and during the Middle Bronze Age – Catacomb and Poltavka cultures. In the forest zone Fatyanovo and Balanovo cultures relate to this province. Production of this zone includes thousands objects reflecting in morphological and chemical senses a certain Circumpontic standard. The origin of this standard was caused by migratory processes. A situation with Maikop metallurgy may be an example of these migrations, because earlier it has been supposed that the metal of this culture was imported from Transcaucasia which is marked by nickel impurities, characteristic of the Near East. But, recent studies of the Maikop metal (Ryndina *et al.* 2008; Ryndina, Ravich 2012) have shown that it was smelted from local ores, and higher concentrations of nickel should be explained by the use for alloying of an arsenic-nickel mineral, nickeline, and, in my opinion, taking into account a quality of the analytical work, this question is not debatable in spite of the fact that Maikop mines and remains of metallurgical production are not found yet. The matter is that the Maikop objects were made from arsenic and arsenic-nickel bronzes (53% arsenic bronzes, of them 38% contain nickel). There are low-arsenic bronzes (9%), but it is supposed that it was caused by repeated re-melting. Positive correlation between the content of arsenic and a type of objects is identified. Therefore, the metallurgists understood a difference of this metal, and this difference is well explainable from technological positions. The comparison of concentrations of trace-elements in metals from Iran, Transcaucasia and Anatolia has shown their difference, with unconditional morphological, chemical and technological similarity of the Transcaucasian and Near Eastern metal to the Maikop metal. Therefore this metal was not imported, it was locally produced. The most distinctly it is proved by the presence of uranium in both the Maikop copper objects and local ore deposits. And, these copper artifacts contain no sulfide impurity; therefore, the oxidized ore had been used in smelting (Ryndina *et al*. 2008; Ryndina, Ravich 2012, p. 5-18). As the nickel impurities are technologically conditional and known in the arsenic bronzes in Anatolia and Levant where also morphological parallels are, it is possible to assume the introduction of metallurgy into the North Caucasus from this region. It is

[4] Radiocarbon dates of the CMP are in the interval between 3300 and 1900 BC, but the border between EBA and MBA is not distinct. It falls in the period between 2700 and 2500 BC (Chernykh 2007, p. 37).

remarkable also that the genesis of Maikop culture was connected with these areas (Andreeva 1977; 1979, p. 33, 34; 1991, p. 46; 1996, p. 87, 93-99; Trifonov 1987, p. 20; Grigoriev 2002).

For the Pit-grave metalworking there are unconditional and generally accepted parallels with the North Caucasus. But here we can still discuss a diffusion of the tradition. However in the Catacomb time in the north objects appear having parallels in southeast part of this province (CMP), in the Near East. A part of these types (socketed hooks and chisels) was mentioned at discussion of the Near Eastern parallels of Sintashta metal (Grigoriev 2002, p. 70). Known on the Catacomb sites chisels with a forged socket were also typical in Anatolia and Northwest Syria where they are dated since the late 3rd – early second millennium BC (Müller-Karpe A. 1994, S. 170-173, Taf. 74, 75). Nevertheless, I had an impression that the knives of Catacomb forms evolved from the East European types of the EBA. This impression was, probably, false as typical Catacomb knives, including a knife with a pentagonal blade, are known in Susa. The date of these artifacts is not absolutely certain, only the knife No. 651 is dated to the 23rd century BC. The presence of 4.5% arsenic in the analyzed knife with the pentagonal blade is also remarkable, because it reflects similar technologies of metalworking (Talion 1987, p. 65, 256, 257). Therefore there was an impulse which had impact on metalworking. But the plenty of metal of this time is surprising against the total absence of information about ore smelting. Nowhere in this zone have we known any find of slag today.

The production of this period is characterized by use of pure copper and arsenic bronze. Besides, in all zones of the CMP a part of arsenic alloys grow from the Early to the Middle Bronze Age, although they play a noticeable role in the EBA too, especially in the North Caucasus. The mapping of these two groups of metal distribution shows that the "pure copper" was, mainly, distributed to the east, closer to the Southern Urals, and the arsenic bronze did to the Caucasus and Ciscaucasia, from what a conclusion has been drawn that the Ural deposits in sandstones (above all, the Kargaly mines) were a source of pure copper, and deposits of Transcaucasia supplied metallurgists with arsenic copper.

But for the Catacomb period it is impossible to exclude a possibility of ore smelting and mining in the North Caucasus. Proofs of this supposition are today absent. But there is also no proof that Catacomb arsenic bronzes were imported. The spectral analysis of metal cannot be considered as an instrument for such conclusions (we discussed it in the introduction). Besides, let us imagine this situation: a lot of metal was carried out during 700 years over large distances. During this long time trade ways and a lot of trade caravans existed. In the course of these trade operations some other imports had to be delivered and not only arsenic copper and single Egyptian scarabs of the Late Catacomb period. And something had to be delivered in exchange because I cannot imagine altruists in this field. In other words, the problem is not studied yet.

In the MBA of the Caucasus and Eastern Europe nickel impurities in the arsenic copper has not been detected and this break with the former technological tradition in the Northern Caucasus compels to think. It is a question of certain technological changes that against the emergence of types of copper artifacts known in the Near East, allows us to speak about a new impulse, but with the absence of ore smelting it is most evident only in the metalworking.

Thus, unlike the previous time, during this period we see a change of connections of the region from the Balkan-Carpathian area to the Transcaucasia and the Middle East. These connections almost did not extend to the Eneolithic cultures of the forest zone, the Transurals and Kazakhstan where the development of production, as it was discussed above, was stopped. But also within the northeastern zone of the CMP it is difficult to tell something certain about the ore smelting because of the lack of slag. The latter, however, makes it possible to assume that pure malachite was used in smelting, a process producing very insignificant amount of slag. Probably, the smelting operations were conducted on settlements, but the settlements of the Pit-grave, Poltavka and Catacomb cultures are poorly investigated in areas with copper deposits. Nevertheless, even despite the weak study, it is possible to state the lack of slag. Also both factors are, probably, lawful.

Perhaps, the production was not too intensive, and a part of metal was really imported. Now it is impossible to answer these questions.

The reliable support for judgments about the nature of metallurgical production appears only at the end of the MBA, with the formation of Sintashta and Abashevo metallurgy.

Tab. 2-1. Emission spectral analyses of slag from the settlement of Arbashevskii Linozavod (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).

Sample	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn	Pb
600	0.005	0.001	0.02	0.1	0.007	0.5	0.0005	<0. 0003	0.3	nd	0.0015
601	0.005	0.001	0.015	0.05	0.007	0.5	0.001	<0. 0003	0.7	nd	0.0007
602	0.015	0.001	0.02	0.05	0.007	0.7	0.001	<0. 0003	0.2	nd	0.003
603	0.005	0.001	0.01	0.1	0.005	0.5	0.001	<0. 0003	0.1	nd	0.001
604	0.005	0.001	0.02	0.1	0.005	0.5	0.001	<0. 0003	0.15	nd	0.0007
605	0.005	0.0015	0.015	0.1	0.007	0.5	0.001	<0. 0003	0.03	nd	0.003
Sensitivity of the analysis											
	0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.0003	0.001	0.003	0.0003

Sample	Ag	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn	Be
600	0.0001	0.005	<0.003	<0.001	<0.001	0.0001	0.1	0.03	<0.001	0.001	0.0001
601	0.0003	0.005	<0.003	<0.001	<0.001	0.0001	0.1	0.05	<0.001	0.0003	0.00015
602	0.0007	0.005	<0.003	<0.001	0.003	0.00015	0.15	0.03	<0.001	0.0007	0.00015
603	0.00003	0.005	<0.003	<0.001	<0.001	0.0001	0.2	0.03	<0.001	0.001	0.00015
604	0.00003	0.005	<0.003	<0.001	<0.001	0.0001	0.15	0.03	<0.001	0.0003	0.0001
605	<0.001	0.005	<0.003	<0.001	<0.001	0.0001	0.1	0.05	<0.001	0.0003	0.00015
Sensitivity of the analysis											
	0.00003	0.01	0.003	0.001	0.001	0.0001	0.01	0.01	0.001	0.0005	0.00003

Sample	Zr	Ga	Y	Yb
600	0.015	0.001	0.0015	0.0001
601	0.015	0.001	0.002	0.0001
602	0.015	0.0015	0.0015	0.0001
603	0.015	0.001	0.0015	0.0001
604	0.015	0.001	0.0015	0.0001
605	0.015	0.001	0.002	0.0001
Sensitivity of the analysis				
	0.001	0.0005	0.001	0.0001

Fig. 2-2. Furnace of the Vera Island. In the foreground a smelting pit from which the pressure-blowing channel goes to the south. On the right a flue plate with the cracked surface ended in the south with the basis of its vertical part.

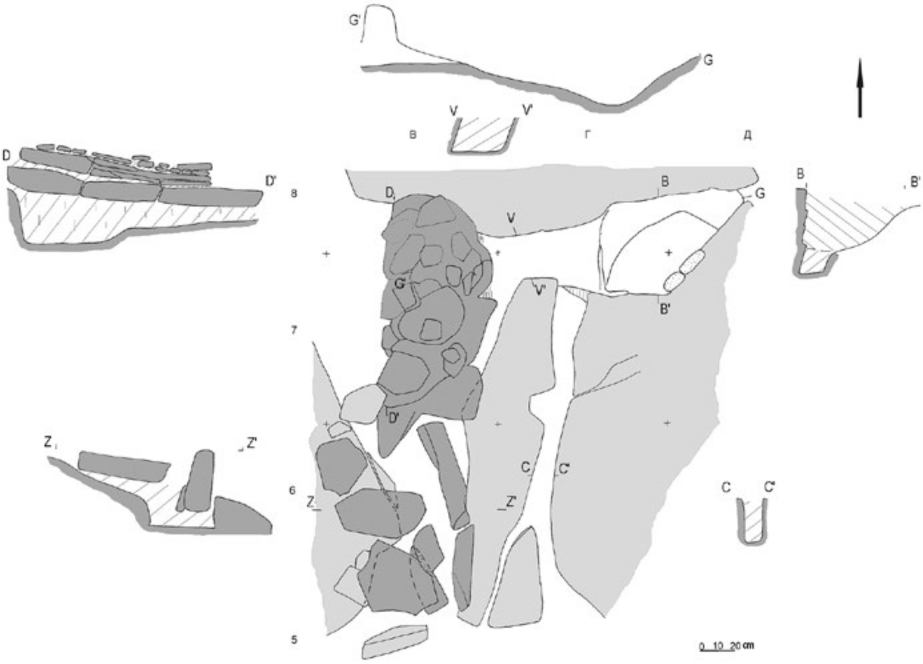


Fig. 2-3. Plan and cross-sections of the furnace of the Vera Island. Dark grey color – plates of the flue, light grey color – virgin rock, white color to the right of the flue – depressions of the pressure-blowing channel and smelting pit.

Fig. 2-4. Furnace of the Vera Island. Small plate of a triangular form at the end of the horizontal part of the flue.

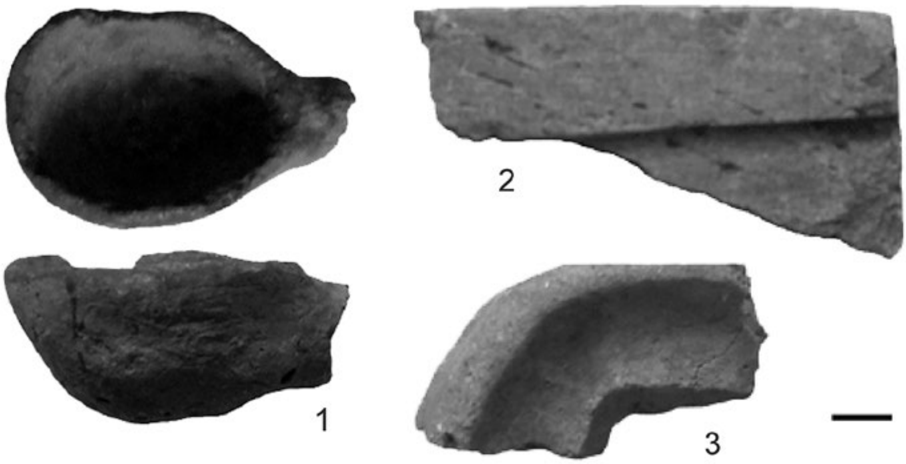


FIG. 2-5. SETTLEMENT OF THE VERA ISLAND 4: 1 – CERAMIC SCOOP; 2,3 – CASTING MOULDS.

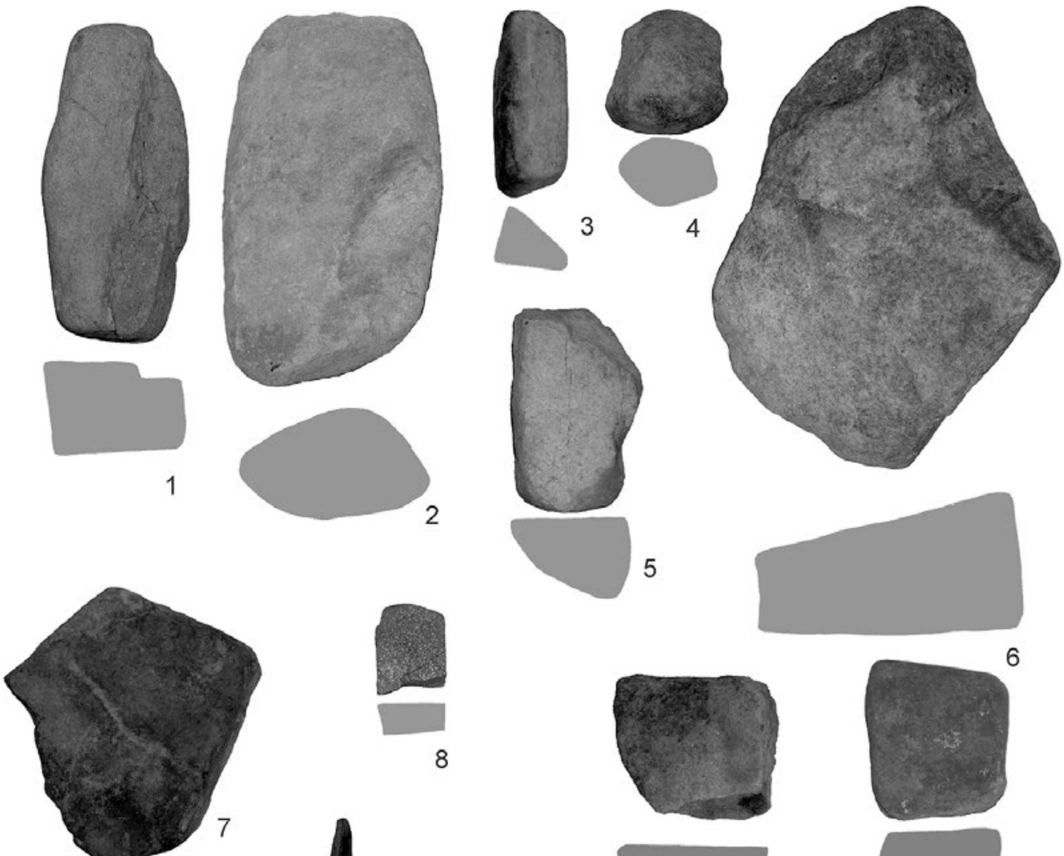


FIG. 2-6. SETTLEMENT OF THE VERA ISLAND 4, STONE TOOLS FOR MINING AND METALLURGY: 1-6 – HAMMERS; 7-9 – ABRASIVE PLATES; 10,11 – ANVILS.

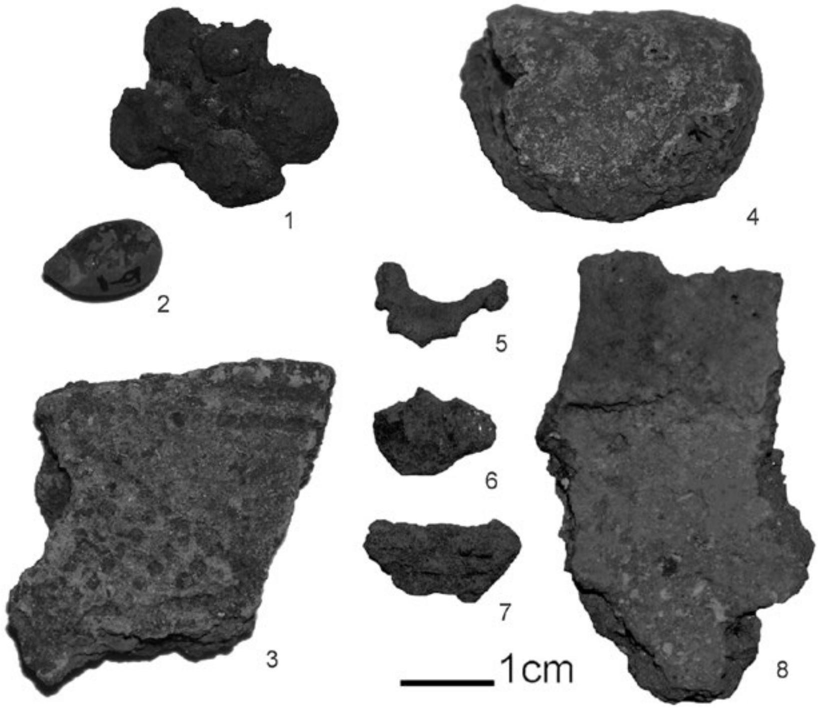


FIG. 2-7. ENEOLITHIC SLAG FROM THE URALS: 1 – SAMPLE 2203, BANNOE-23, SLAG; 2 – SAMPLE 2204, BANNOE-1, COPPER; 3 – SAMPLE 2205, BANNOE-1, FRAGMENT OF SLAGGED CERAMICS; 4 – SAMPLE 2207, PUTILOVSKAYA ZAIMKA, FRAGMENT OF SLAGGED CRUCIBLE; 5 – SAMPLE 2210, VERA ISLAND 7, COPPER; 6 – SAMPLE 2211, VERA ISLAND 7, SLAG; 7 – SAMPLE 2208, VERA ISLAND 7, SLAG; 8 – SAMPLE 2206, VERA ISLAND 2, FRAGMENT OF SLAGGED VESSEL.

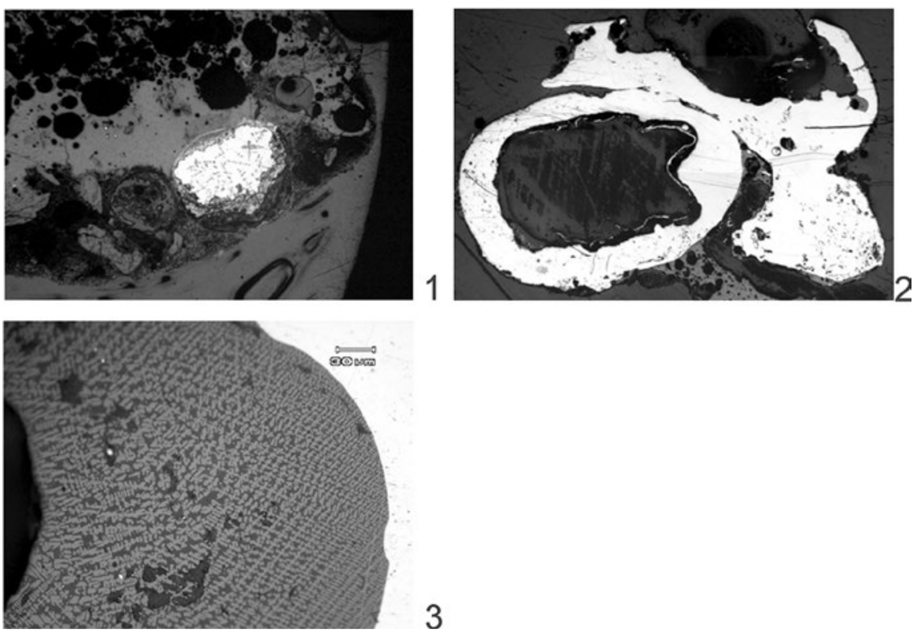


FIG. 2-8. 1 – VERA ISLAND 4, SAMPLE 2206, COPPER PRILLS IN THE CERAMIC MASS; 2 – BANNOE-23, VESICULAR STRUCTURE OF SAMPLE 2203, PATINA CRUST (GREY) ON THE SURFACE, IRON (WHITE); 3 – BANNOE-23, SECTION OF THE CRUST, SAMPLE 2203: MAGNETITE (LIGHT GREY) ILMENITE (DARK GREY) AND METAL IRON (WHITE). THE ANALYSIS IS DONE IN THE INSTITUTE OF MINERALOGY (MIASS) BY YU.M. YUMINOV.

Tab. 2-9. X-ray fluorescence analysis of the Eneolithic slags (%).The analysis is done in the Institute of Mineralogy (Miass) by Yu.M. Yuminov.

№	Material	Site	Fe	Ti	Mn	Cr	Co	Ni	Cu	Sn	As	Zn	Pb	Sb	Bi
2203	slag	Bannoe-23	38.1	22.3	5,5				0.7	0.05			0.11		0.03
2203	slag	Bannoe-23	20.2	22	10.5				0.4				0.03		0.01
2204	slag	Bannoe-1	0.02						2.9						
2206	copper in slagged ceramics	Vera Island 4-2	1.6		0.02	0.05		0.03	2.1			0.01			0.001
2208	slag	Vera Island 7	>50						0.1			0.03			0.01
2210	copper	Vera Island 7	0.04						2.3	0.05	0.004				
2212	iron hydroxide	Vera Island 4 Filling of furnace	>50	1.6		0.17	0.472					0.04	0.02		0.01
2213	iron hydroxide	Vera Island 4 Filling of fuel	43	2.4									0.005		0.004
2214	iron hydroxide	Vera Island 4 Filling of furnace	>50	1.5									0.02		0.01
2215	iron hydroxide	Vera Island 4 Filling of furnace	>50	1.1								0.01	0.01		0.004
2216	iron hydroxide	Vera Island 4	>50	2.9								0.04	0.06		0.02
2217	A piece of brown slag	Vera Island 4	>50	1.3	0.8								0.04		0.01
2218	slag	Vera Island 4	22.1		0.4				14.4	7.1	0.2	0.11			
2220	iron hydroxide of dark brown color	Vera Island 4	>50	3.6								0.02	0.03		0.007
2221	iron hydroxide	Vera Island 4	>50	3.1								0.03	0.02		0.01
2222	iron hydroxide	Vera Island 4	>50												0.01

Metallurgical Production of the Middle Bronze Age II and Transition to the Late Bronze Age

In Northern Eurasia metallurgical production of the end of the Middle Bronze Age is presented, above all, by materials of Sintashta and Abashevo cultures in the Southern Urals which are dated since the late 3rd millennium BC (below their chronology will be discussed in more detail). Remains of the Sintashta metallurgy are found on all settlements of this culture. In Northern Eurasia it is the earliest culture with the plenty of traces of metallurgical production. Slag and ore belong to the most widespread finds, but many metallurgical furnaces are known too. However on a number of settlements (Sintashta, Ustye) the metallurgical remains of this time are accompanied by the remains of the following Petrovka culture. It is possible to divide them only by means of the comparative analysis. Besides, partly Petrovka technologies are based on the Sintashta ones, and this analysis reflects dynamics of the production development. Therefore materials of Sintashta and Petrovka periods of the Transurals are considered here together. Some comparisons are made with some Abashevo sites (see a map, Fig. 3-1.).

Chapter 3.
Metallurgical Furnaces of Sintashta Culture

The basic criterion for determination of links of a particular installation with metallurgical operations was typological characteristics and discoveries of slag near it. Besides, it was taken into account that in many instances a furnace bottom could be not expressed, and its upper part could be completely destroyed. Our experimental works have shown that a furnace would have been built of clay or sand with clay cement. In case of destruction its remains could completely merge with a cultural layer of a settlement. On the floor we find only thin burnt place having a typical shape. Probably, not all furnaces were used exclusively for metallurgical activities. Most of types had, apparently, multifunctional character and served also for cooking, heating and other domestic needs. Similar installations have been found, practically, in all excavated dwellings of the Sintashta period, where the conditions of fixation allowed this to be done.

All excavated furnaces have been divided into two categories: single-sectioned and double-sectioned. The single-sectioned furnaces can be either deepened or placed on surface. There are only 4 deepened furnaces in the investigated sampling. Two of them have been found on the Sintashta settlement. They are dated to the Sintashta period, as were accompanied by corresponding ceramic materials, but they belonged, probably, to the late phase of this settlement's existence, because were built in the filled wells of the first building horizon. Owing this, contours of these furnaces have been seen very badly. This is a cause why this type of furnaces on Sintashta needs to be treated cautiously. Nevertheless, there is a basis to think that they were furnaces, as a 5-cm layer of burnt clay lining has been found at the level of the furnace's bottom in one of the constructions, as well as burnt fish bones and small pieces of slag.

Similar furnaces were excavated on Semiozerki II, a settlement of Petrovka culture (Evdokimov, Grigoriev 1996). They are represented by ring-shaped pits, 0.5 m in diameter and 0.3-0.4m in depth, with straight sides, slightly narrowing to the bottom (Fig. 3-2..2,3). In the fill of these furnaces small burnt clay bricks of the rectangular form have been found, and in the lower part a layer of burnt clay of the furnace's bottom. Very likely, a cupola of furnace was constructed of these bricks.

The single-sectioned surface furnaces have been divided into round (dome), trench-shaped and rectangular. Furnace's bottom of these constructions was, as a rule, slightly deepened; a depression was made sometimes at the building, sometimes at the erasures after operations. However, as a large part of the smelting hearth was above the floor level, these furnaces have been referred to the surface type.

The simplest type is a round dome furnace without flue (Fig. 3-3..2,4,7,10). A dome part of these furnaces did not remain, but there is evidence indicating such a variant of reconstruction. First of all, as metallurgical slag has been found near these furnaces, they could not be open hearths. In this case, as our experimental studies have shown, it was impossible to reach high temperatures and regulate smelting conditions. It was possible to construct a flat covering only by means of stone slabs; but such slabs have been not found. Occasionally on the level of furnaces' bottom thin horizontal concentric layers have been detected, which form usually after destruction of dome constructions.

The furnace's bottoms on the settlements of Arkaim and Sintashta are usually 0.7-1 m in diameter. They are remained well not everywhere. As a rule, the bottoms are fixed as a small shallow bowl-shaped depression or slightly burnt place on the floor of the dwelling. It was filled in furnaces of the Sintashta settlement by burnt clay, and on Arkaim by sandy soil. In the fill along the perimeter of furnaces on Arkaim in many instances the inclusions of clay have been found, but not enough to talk about clay cupolas of furnaces. As our experimental works demonstrated, the furnaces could be built of sand from the settlement, with small clay additions. In total, nine such furnaces have been revealed: five on the Arkaim settlement, three on the settlement of Sintashta and one on the settlement of Ustye (Tab. 3-4.). But the later belongs to the Petrovka period.

More complicated modification of this type of furnaces is a furnace attached to a well. Twenty-two such furnaces have been found: ten on the settlement of Arkaim, two on the settlement of Sintashta and ten on the settlement of Ustye (Fig. 3-3..1,3,5,6,8,9). The main difference of these furnaces is that they were built near wells and joined the wells by a small covered channel about 15 cm in width. Those furnaces of the Ustye settlement, which are dated to the Petrovka period, have some distinctive features. As a whole, they prolong here the Sintashta tradition. A distinctive feature of the Petrovka furnaces is the use at their building of small stones, although it could be a local feature of this settlement, which does not reflect a general tendency.

Furnaces of this type show one more constructional feature. Probably, it was typical of all furnaces of this period. A clay pressure-blowing nozzle was inserted in the furnace on the Arkaim settlement, at the level of the floor of dwelling (Fig. 3-3..9). The furnaces of the settlement of Sintashta have small trench-shaped juts served, probably, for the same purpose (Grigoriev 1996, fig. 2). These facts are very remarkable, because they demonstrate the existence of one-chambered bellows (bag bellows?). In two-chambered bellows the nozzle is set into the upper chamber. Therefore, it cannot be placed so low without a special depression under bellows. The irregularity of airflow from one-chambered bellows was compensated by air supply from the well. The latter was quite intensive. The natural draught here formed because of the thermal difference in the furnace and the well. This supposition has obtained a reliable experimental verification.

Thus, the discovery of the pressure-blowing nozzle in the furnace of the settlement of Arkaim, probably testifies to the use of bellows by the Sintashta metallurgists, although it is indirect evidence. But it is almost impossible to discover the bellows archaeologically. The evidences about bellows are absent in Europe, but they are known in the near East (Tylecote 1987, p. 115). But it does not mean that in Europe they were not used at all. At earlier stages of metallurgical production the blowing had been implemented by different ways. A relief of the tomb of Ank-Ma-Hor in Sakkara illustrates this process very expressive. This relief relates to the period of the fifth dynasty (2450-2359 BC). Three metallurgists are depicted on it. They blow in pipes on a crucible situated in a small heap of charcoal. Bellows appeared in Egypt only in the first quarter of the 2nd millennium BC, and were introduced into the country by the Hyksos (Zwicker *et al.* 1992, p. 103, 104). But the absence of nozzles does not demonstrate either presence or absence of artificial blasting. For example, in Feinan, Palestine, in the EBA, contrary to the Early Iron Age, there are no finds of nozzles (Hauptmann 2003, p. 93). But metallurgists should use the blasting, the nozzles could not save.

Another modification of the Sintashta dome furnaces is a type of construction with a horizontal flue. These furnaces may be positioned near wells or separately. Such furnaces have been discovered only on the settlement of Arkaim (Fig. 3-3.11,12; Fig. 3-5..2,3,9; Fig. 3-6.). They consisted of a dome furnace and a horizontal flue. The dome part is similar to those described above. The flues have saved as small trenches 10 cm deep, 35 cm wide and 120-180cm long. Small burnt rocks are found in the fuels. It is possible that in many instances the flues were placed on the surface without trenches. They were easier subjected to destruction and can be fixed only by elongated accumulations of small stones or long carbonaceous traces on the floors of dwellings. Frequently the dome part of furnaces was subjected to destruction together with the well. Taking into account these circumstances some new furnaces of this type have been identified.

The flues are oriented usually at a tangent to the wells. In one of the well preserved complexes the outlet of the flue joined closely the channel connecting the well with the furnace (Fig. 3-3..11). The practical rationality of such a construction has been clarified experimentally. If a flue and a well were positioned opposite one another, the airflow would cross the center of furnace fast enough and come out directly in the flue. At the arrangement found on the settlement, air moved along the furnace sides promoting an even heating in the furnace and supporting higher temperatures and formation of carbon monoxide.

Clay has been found also together with small stones in the flues. Usually, it was above stones. This, as well as rather small quantity of stones, testifies that an internal stone lining of the flue had taken place here. For the building of the clay flue ones used a frame of twigs situated over each 20 cm and burning out during the first operation. The clear carbonaceous traces which have identified on sides of the flue testify to this.

On the end the flues could have either a ring of stones or accumulation of them (Fig. 3-3.13; Fig. 3-5.3). They served, probably, as a base for a vertical part of the flue made of lighter material, probably of wood.

Trench-shaped or rectangular elongated furnaces are similar to the single-sectioned dome furnaces with the flue. On the settlement of Arkaim they are represented by trenches 2.2-2.5m in length, 0.3-0.5m in width, and 0.1-0.2m in depth. Their bottoms are slightly burnt, and small burnt stones have been found in the fill. There was no depression under such a construction in one of the Arkaim furnaces, and it was identified as masonry of the same size. Similar constructions have been discovered on the settlements of Sintashta and Ustye (Fig. 3-5.5,8,11). However, they are dated there, probably, to the Petrovka-Alakul period. It is notable that on the Sintashta settlement such a furnace was joined to the well.

Most likely, the constructions described above are one of modifications of the furnaces with flues, but the furnace had no special cavity here, and a cupola was remained almost nowhere. It was erected above one of the flue ends. On the Arkaim settlement remains of the cupola were identifiable by the accumulation of blocks made of clay and sand (Fig. 3-3.13). This furnace has features of both trench-shaped and dome furnaces with the flue. Accumulation of stones in the southern part of the flue in another furnace of the settlement of Arkaim indicates the former present of a cupola. Two furnaces covering one another (Arkaim) had, probably, cupolas overbuilt above wider ends of the trenches (Fig. 3-5.5).

One group of furnaces of the settlements of Sintashta and Arkaim differs from other single-sectioned furnaces. They are slightly deepened square constructions with the size 2.1×2.1 m. Their bottoms were burnt, the fill is carbonaceous. Metallurgical remains have not been found inside them. Most probably, these furnaces served only for heating of dwellings. Sometimes they were situated near entrances. In several dwellings on the settlement of Arkaim burnt sand was found near the entrances, but no structural details have been identified.

The next category is double-sectioned furnaces. It was accounted a few furnaces of such a type for the epoch under investigation. This circumstance does not allow us in the meantime to do a typological dividing within the category. Basic feature of these furnaces is the presence of two parts: a smelting hearth and a shallow pit for bellows. The presence of the latter marks, probably, an invention of double-sectioned bellows, where air was pumped to the upper section by means of the lower one, and therefrom, due to a weighted cover, went through an airhole into the smelting hearth. But this supposition is not reliable.

The earliest similar furnace is that on the Arkaim settlement. It is an almost oval shallow pit with the size of 1.6×1.2m. Its western part was cut in the floor on 35 cm. In the eastern part an oval hearth with the size of 75×55cm and depth of 38 cm, filled with burnt stones, has been found. Thus, bellows could be positioned in the western part. In the eastern one the smelting was implemented (Fig. 3-5.10).

On the Sintashta settlement two furnaces of this type have been discovered. They are dated to the Petrovka-Alakul period. It is difficult to do a more precise determination of their chronological position, as the accompanying ceramics have no clear characteristics allowing us to divide the late Petrovka and early Alakul materials correctly. These materials on the settlement, in contrast to those of the Sintashta period, may not be divided stratigraphically. The late chronological position of these installations relatively to the Sintashta complexes is illustrated even by that they covered the wells of the Sintashta period.

One furnace of this type has been traced poorly, as it was situated in the upper part of the Sintashta well (Fig. 3-5.4). The construction of another furnace has been investigated very well, although it was arranged above the level of the floor, in the layer of a destroyed Sintashta dwelling (Fig. 3-5.1). The smelting hearth of the furnace had an oval form and the size 100×60 cm and was deepened on 15 cm. Its fill consisted of burnt clay with inclusions of ashes, small crushed bones, small pieces of slag and copper prills. On the floor there was a layer of burnt lining 5 cm thick. A shallow pit with the size 120×60 cm adjoined the smelting hearth.

The furnaces of this type are found of the settlement of Semiozerki II dated to the Petrovka period (Evdokimov, Grigoriev 1996). They were placed in shallow pits with the size 1×0.6-1м, divided by earth partitions into two parts: a pit for bellows and a smelting hearth (Fig. 3-2.1,4). The sizes of the smelting hearths are usually 0.4×0.5 m. One furnace had more complicated construction (Fig. 3-2.5). In its center the pit for bellows had been arranged, to which two furnace hearths, 1m in length, 0.3-0.4m in width and 0.4m in depth, were attached. On their sides clay lining about 2.5-3cm thick has been identified. In the fill, the burnt bones have been found.

In conclusion of this chapter I would like to touch upon the process of development of the constructions of furnace. Unfortunately, the cases, when we have a clear stratigraphical situation with a recovering of a construction of one type by another, are extremely rare. Furthermore, they cannot serve as a proof of a 'genetic' continuity. It is also necessary to take into account that the furnaces of different types could coexist. Therefore, alongside stratigraphical situations, the connection of different types with a certain cultural layer and logic of the development of pyrotechnological installations have been taken into account (Tab. 3-4.; Fig. 3-6.).

Because an open hearth was a prototype of metallurgical furnaces, it is logically to suppose that simple dome surface furnaces were the earliest. Subsequently these furnaces were joined to the wells. The following stage was the appearance of flues and shallow depressions of the furnace's hearth. The latter resulted in the appearance of pit furnaces. Later furnaces with flues were transformed into the trench-shaped ones, and furnaces without flue with the invention of bellows of constant blast did into double-sectioned furnaces. However it was a general tendency of the development, and it is not the case that this tendency took place in the Urals as introduction of metallurgical technologies from outside is possible, which we will discuss below.

In the Sintashta period all the types of furnace were known. However, double-sectioned and pit furnaces were rather an exception. Dome surface furnaces of different types dominated. In the Petrovka period furnaces with flues were known in the form of their later modification, so-called trench-shaped furnaces. But the proportions of pit and double-sectioned furnaces increased.

Stratigraphical observations do not contradict these facts. On the settlement of Arkaim the overlapping of a simple dome furnace by a flue has been identified. On the Sintashta settlement, deepened furnaces, although accompanied by the Sintashta ceramics, were made in destroyed Sintashta wells, to which earlier dome furnaces were joined. Double-sectioned Petrovka furnaces were made in Sintashta wells too.

Said above allows us to reveal dynamics of the development of pyrotechnological installations in studied period. However, it is necessary to remember that meanwhile, owing to the absence of detailed chronological ordering of the investigated epoch, the conclusions mentioned below may be considered only as a hypothesis.

The Sintashta population had practically no specialized metallurgical furnaces. They used multifunctional furnaces. These installations, accompanied by metallurgical remains are, as a rule, the single in each dwelling.

Originally these were the surface dome furnaces 0.7-1m in diameter. Air was blasted into them by simple one-chambered bellows. The use of blowing from the well was an important step forward. Ones began adjoin the furnaces to the wells that made blowing more equal and intensive. When using the furnace for domestic needs the good draught was provided. But in metallurgical operations this design carried out one more important function. As we already discussed earlier, the creation of reducing atmosphere in the furnace was a serious problem of early metallurgy. In order to achieve it, air had to pass through a charcoal layer. Air from the well arrived without pressure and revolved along furnace walls that promoted the generation of carbon monoxide.

The invention of flues was very important. There is no necessity in flue at smelting oxidized ores. Combustion of charcoal, which was used in metallurgical operations, practically, does not produce smoke and fire, and the heating of ore does not result in the appearance of injurious gases. However, if a little quantity of sulfide ore is charged into the furnace, a flue is already necessary, as pungent smell of sulfur dioxide begins to diffuse around it. The necessity of its removing resulted in the appearance of flues.

The specificity of the flues construction was conditioned by the absence of a good technique of vertical brickwork or masonry in the Sintashta period. Therefore, first a horizontal part had been constructed, passing through which gases were cooling down, heating a dwelling at the same time. A vertical part made of non-refractory materials, for example wood, was further erected.

The latest modification was trench-shaped furnaces. Their basic difference from the furnaces with flue is a decreasing smelting hearth that allowed higher temperatures to be reached, but it limited the use of the furnaces for domestic needs. The same task was realized also in constructions of pit furnaces. However, an optimal construction appeared, when the two-chambered bellows appeared, providing intensive blowing and heat. On the Sintashta sites such a construction is single, but already on the Petrovka settlements they make a large part of metallurgical installations.

It is necessary to note that in other regions metallurgical furnaces had in most instances smaller sizes. In India the Eneolithic furnaces (2nd millennium BC) are rather small: 35 cm in height and 18 cm in diameter at the bottom, and 14 cm in diameter at the middle part (Hegde, Ericson 1992, p. 64). In Sinai and Negev furnaces of the 14-11th centuries BC had usually a diameter about 20 cm. However, furnaces 40-60cm in diameter are known too, but to obtain temperature needed for smelt, air into them was blasted by several nozzles (Bachmann 1980, pp. 110, 111). In Israel furnaces dated to the 14-12th centuries BC had smaller diameter (30-40cm) and a pit for the slag tapping. The furnace's bottom was placed above the slag pit. Between the furnace's bottom and the pit a ground partition was kept. Slag, obtained in furnaces of this type, belongs to the fayalite type (Rothenberg 1990, p. 4-6, 9, 12, 19, 39, fig. 35, 40; Rothenberg 1992, p. 124, 125, 127). Probably, the installations of this type can be comparable with some furnaces of the Petrovka period but we have no tapped slag. The large sizes of the Sintashta furnaces may be explained, mainly, by their multifunctionality, while all constructions described above fall into the category of specialized metallurgical furnaces.

Simple dome furnaces have been investigated in the Early Bronze Age layer of the Norşuntepe settlement in Anatolia. Furnaces of the late Uruk period of the Tüllintepe settlement are dome-shaped too. In addition, a furnace of the 2nd millennium BC, excavated on the Tepecik settlement, had a size 1.5×0.8m, which is close to the largest furnaces of the Sintashta period (Müller-Karpe A. 1994, p. 23, 25, 90, 91). Small dome furnaces have been found in Hissar, in North-Eastern Iran (Thornton, Rehren 2007, p. 315).

There are very many experimental researches, reconstructing processes of copper smelting in antiquity. In particular, on the ground of these researches it is supposed that an indispensable condition of a successful smelt could be a rather small diameter of a furnace (20-40cm) and the use simultaneously of up to six nozzles. Greater diameter fails to achieve infiltration of air into the central part of furnace and combustion of charcoal (Bamberger 1992, p. 152, 157). However, our experiments with constructions of the Sintashta type have shown that even at a greater diameter of furnaces and using only one nozzle it is possible to achieve heating of the whole furnace, with the thermal maximum in its central part. In the Sintashta furnaces blowing from the well provided this process. The furnaces, which had been not attached to wells, are usually somewhat smaller, but they are, nevertheless, more than 40 cm. Probably, a correct selection of size of charcoal promoted to successful smelts, because it made easier infiltration of air into the center of furnace.

In most instances ethnographic furnaces for smelting of oxidized copper ore of the African continent are small. Venda tribes to the south from the Zambezi had furnaces 45 cm in diameter, and 45 cm in height. It allowed them to extract copper, but losses, probably, were very high. In Botswana the furnaces of the 19th century AD were oval, 50-60cm long and 40 cm width with a depth of 25 cm. Metallurgists smelted also malachite at temperatures of 1200 °C. On the both ends nozzles were inserted (Bisson 2000, p. 101, 102). It is probable when gases made longer way through the furnace, the recovery atmosphere was formed better. It is not excluded that at the end of Sintashta time the emergence of extended furnaces was caused by the same reasons.

A.D. Degtyareva has stated her doubts that Sintashta furnaces were used for smelting as direct evidences of it (inserted nozzles or slag inside the furnace) are rare. But similar finds are rare everywhere, especially large slag pieces which were taken from furnace. Besides, almost all Sintashta furnaces have been excavated without sieving and flotation, therefore small slag pieces could not be found. The only attempt of the flotation on the settlement of Arkaim has led to discovery of small particles of both slag and copper.

Degtyareva also believes that smelting/melting of ore and metal with arsenic in all dwellings is extremely doubtful, "taking into account high degree of sublimation of arsenic oxides at melting, annealing and even in the process of cooling of alloys. Volatile arsenic oxides are very toxic and have very notable garlic smell" (Degtyareva 2010, p. 79). However the presence of slag in all dwellings is the archaeological fact, and, usually on the floors of dwellings. A very important characteristic of deposits formation on the Sintashta fortified settlements is that inside the dwellings the deposit was not accumulated, and in the course of destruction already parts of walls fell on the floor; it does not allow us to admit a free migration of materials in the layer. Casual occurrence in rare cases is not excluded, but it is a question of regularities. And nobody could bring slag to each dwelling from outside too. Therefore, the smelting was conducted inside the dwellings. It is not necessary to forget that on the Sintashta settlements free spaces between dwellings were absent.

As it will be shown further, neither pure arsenic nor pure arsenic minerals were used in charge, but compounds of arsenic with nickel. Nickel in this alloy prevents volatilization of arsenic (Ryndina *et al.* 2008, p. 210). A part of arsenic, certainly, was not connected with nickel. It left a furnace through a flue, but another part probably got also to rooms. As these rooms were not specialized working areas, smelting in them was conducted not permanently. In case of an unpleasant smell the people who had not been involved in the production, could also leave the dwelling. And they were guided by the smell, and not by danger to health at all, as the modern people. Let us remember that Dr. Semmelweis insisted on need to wash hands before surgeries only 150 years ago, and first his colleagues mocked at him. It is possible to imagine ecological and hygienic competence of people of the Bronze Age! And this ignorance, of course, affected the health. An interesting fact is that the anthropological comparisons of Sintashta-Potapovka complexes with other Volga-Ural complexes have shown very high level of child mortality and shorter life duration of the Sintashta population. Scientists looked for different reasons to it: epidemiological, social, etc. (Khokhlov 2010, p. 141-146). Incidental vapors of arsenic in the dwellings could be also one of the reasons. So, Needham notes that vapors of arsenic cause distension of blood vessels, conduct to nausea, a muscular atrophy, perspiration, edemata, loss of appetite, polyneuritis (cit. after Charles 1980, p. 177). A principal difference of the Sintashta population from other populations of the Bronze Age was also in that they lived in warm, but badly ventilated rooms in which, in addition to this, the entire metallurgical cycle was carried out. Naturally, it badly affected the health, especially if the alloying was made by arsenic. Therefore sometimes it is assumed even that the replacement of arsenic with tin, probably, happened not for technological, but for medical reasons (Muhly 1976, p. 90). But from this does not follow that copper smelting with arsenic could not be practiced in dwellings especially as these smelts have been identified not only in the Transurals, but also everywhere, in Anatolia, for example.

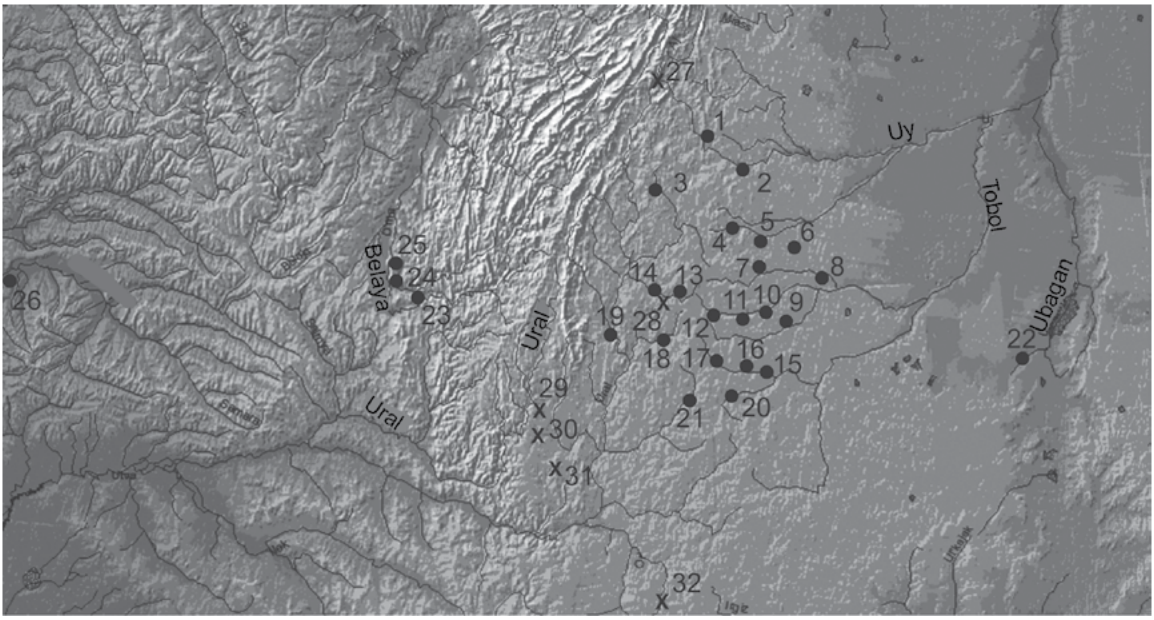


FIG. 3-1. MAP OF SITES OF THE SINTASHTA PERIOD (• – SINTASHTA SETTLEMENTS, X – MINES): 1 – STEPNOE, 2 – CHERNORYECHYE III, 3 – BAKHTA, 4 – PARIS, 5 – USTYE, 6 – CHEKOTAI, 7 – RODNIKI, 8 – ISENEI, 9 – KAMYSTY, 10 – KAMENNIY AMBAR, 11 – ZHURUMBAY, 12 – KONOPLYANKA, 13 – SARIM-SAKLA, 14 – KUYSAK, 15 – ANDREEVSKOYE, 16 – SINTASHTA II, 17 – SINTASHTA, 18 – ARKAIM, BOLSHEKARAGANSKIY, 19 – KIZILSKOYE, 20 – BERSUAT, 21 – ALANDSKOYE, 22 – SEMIOZERKI II, 23 – TYUBYAK, 24 – BEREGOVSKOE I, 25 – BEREGOVSKOE II, 26 – UTYOVKA, 27 – TASH-KAZGAN, 28 – VOROVSKAYA YAMA, 29 – IVANOVKA, 30 – DERGAMYSH, 31 – ISHKININO, 32 – ELENOVKA.

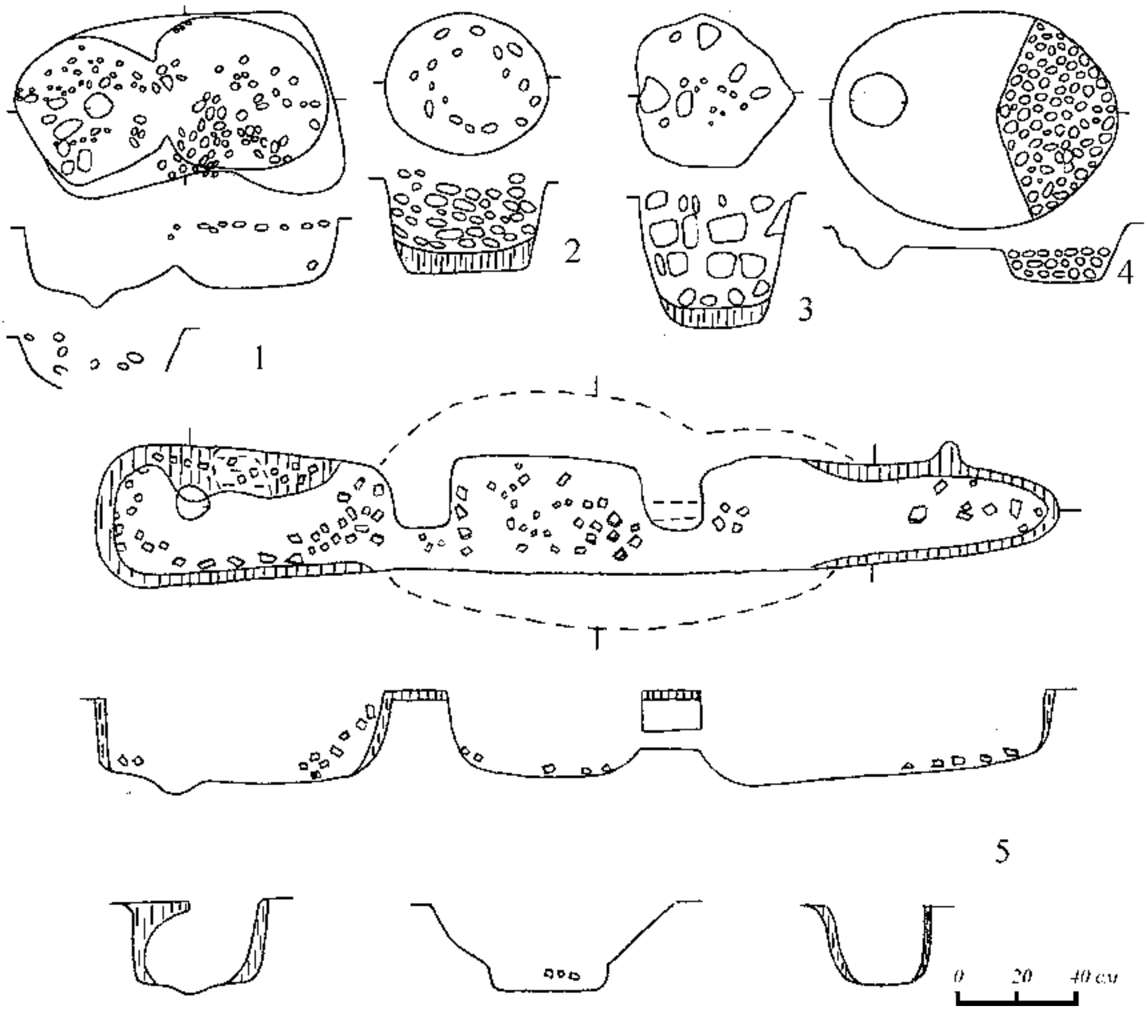


FIG. 3-2. PIT FURNACES (2, 3) AND DOUBLE-SECTIONED FURNACES (1, 4, 5) OF THE SETTLEMENT OF SEMIOZERKI II.

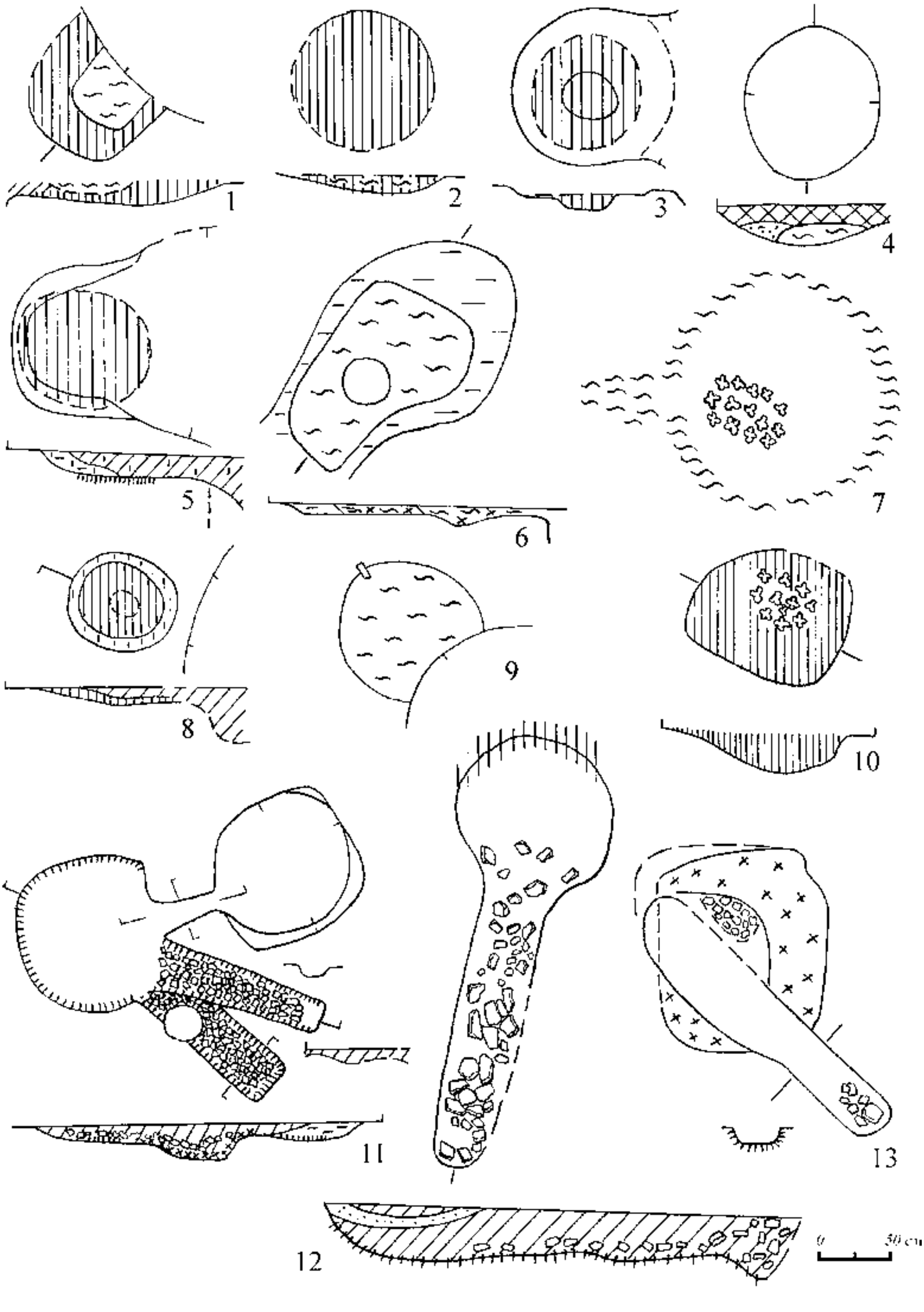


Fig. 3-3. Single-sectioned furnaces (2,4,7,10) and those joined the wells (1,3,5,6,8,9) and furnaces with a flue (11-13) from the settlements of Arkaim and Sintashta.

Tab. 3-4. Distribution of furnaces over settlements.

furnaces	single-sectioned							double-sectioned
	surface						pit furnaces	
	square	round				trench-shaped		
		without flue		with flue				
sites		separate	at a well	separate	at a well			
Arkaim	1	5	10	3	9	5		1
Sintashta		3	2			1	2	2
Устье		1	10			1		
Semiozerki							2	5
Sintashta settlements								
Arkaim	1	5	10	3	9	5		1
Sintashta		3	2				2	
Ustye			5					
%	2.17	17.36	36.89	6.51	19.53	10.85	4.34	2.17
Petrovka settlements								
Sintashta						1		2
Ustye		1	5			1		
Semiozerki							2	5
%	0	5.88	29.4	0	0	11.76	11.76	41.16

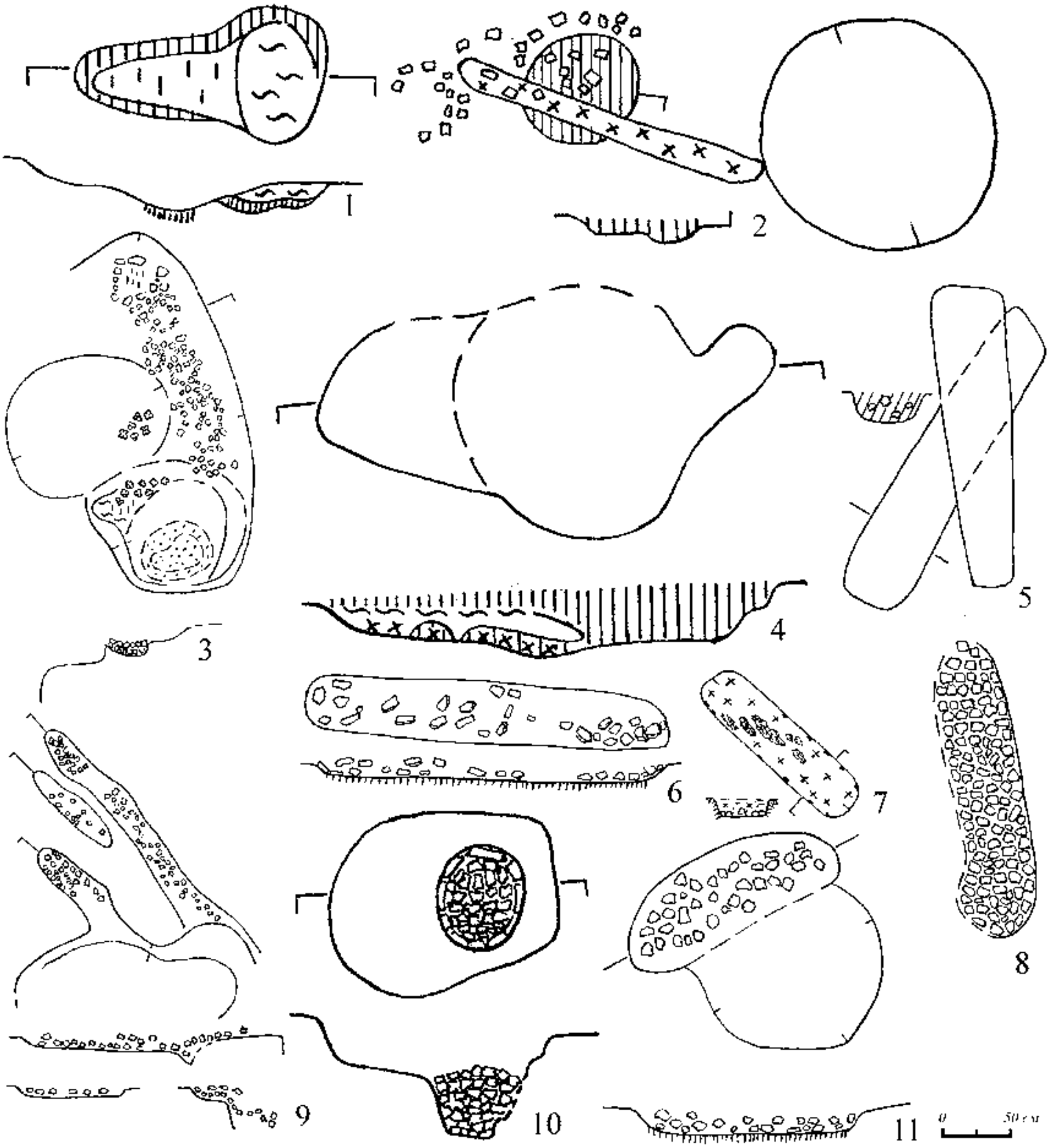


FIG. 3-5. FURNACES OF THE SINTASHTA CULTURE.

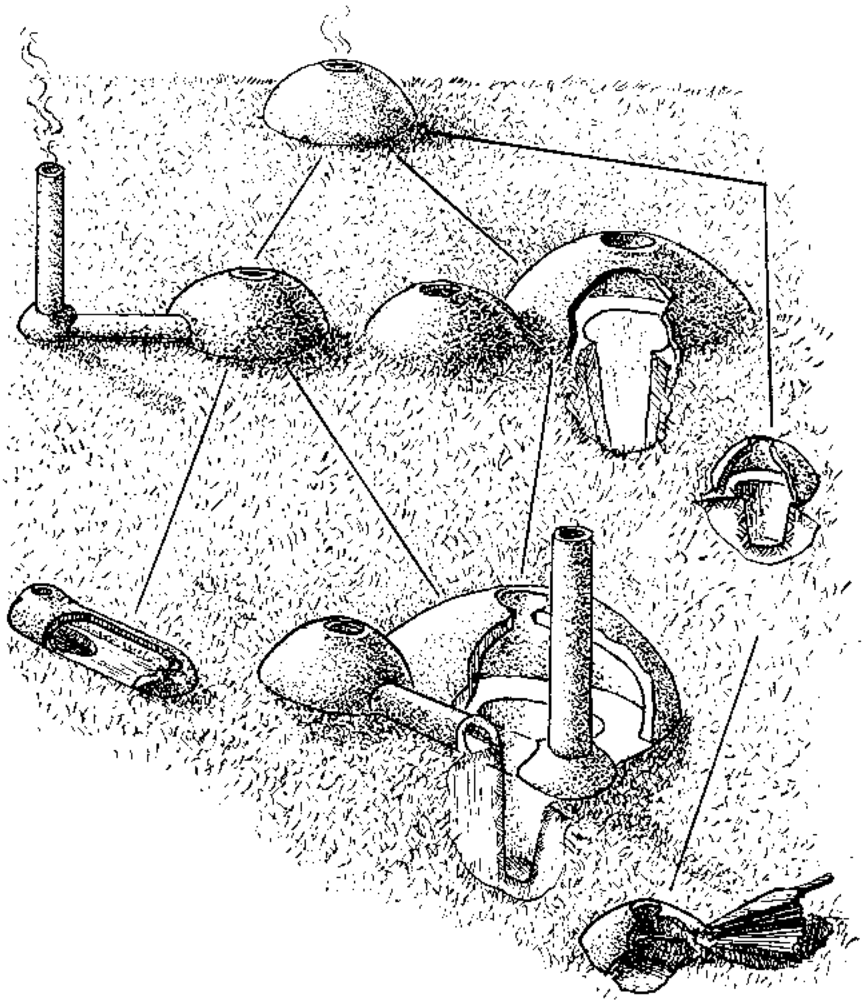


Fig. 3-6. Scheme of development of metallurgical installations of the Sintashta culture.

Chapter 4.
Copper Ores of Sintashta and Petrovka Sites in the Transurals

One of the most complicated problems in archaeometallurgical studies is the identification of sources formed the ore base of a particular archaeological culture or settlement. In the case of Sintashta culture this work was based on analysis of a large series of ore. However, this work was extremely hindered by a lack of information on geochemistry of the most Ural copper mines. Therefore, the work was limited by the distinction of chemical groups of ores found on sites, not attempting to link them with concrete deposits. However, it is necessary to mean, that the distinguished groups subsequently will not be linked with different ore fields.

A large series of ores (113 samples) had been studied by means of the emission spectral analysis (Tab. 4-1.). In addition to samples from Sintashta and Sintashta-Petrovka settlements (Sintashta, Arkaim, Ustye, Yagodnii Dol), samples from some other sites have been included in the study: from the settlements of Rodniki and Petrovka of Petrovka culture, the post-Eneolthic settlement of Sergeevka in Northern Kazakhstan, the Eneolthic settlement of Burli, and the site of Tamat-Utkul of the Pit-Grave culture. Besides some samples from mines (Tash-Kazgan, Mayli-Yurt, and Ust-Kabanskii) have been analyzed.

For analyses large samples of ore (about 3-5g) were selected and pulverized to avoid errors determined by heterogeneous nature of the material. At the first stage diagrams of distribution of trace-elements concentration in ores from the Transural sites (Fig. 4-2.) were made. The asymmetric diagram of silver, double-peak diagrams of nickel, zinc and lead, three-peak diagram of cobalt pays attention. The following processing of this information has been made by the Brookhaven Date Handling Programs. This allowed the all sampling to be divided into eight clusters (Tab. 4-1.). Clusters 1, 2 and 3 are very close to each other and differ from the all others. In addition, cluster 3, having lower concentrations of Zn, may be easy distinguished from clusters 1 and 2 (Fig. 4-3., Fig. 4-4., Fig. 4-5., Fig. 4-6., Fig. 4-7.). But, as a whole, these clusters belong to the same geochemical and mineralogical type. Two last clusters have very close characteristics and the samples which have been included into them could originate from different zone of the same deposit. The distinction between them is most visible on the diagram Pb-Cr, because of lower Cr concentrations and higher Pb concentrations in samples of cluster 3 (Fig. 4-4., Fig. 4-6., Fig. 4-8.). All samples of these clusters have been found on the Sintashta settlements. The exclusions are: one sample from Mayli-Yurt (cluster 1) and one from Arkaim (cluster 2), which may be explained by either an analytical error or heterogeneity of the material. Cluster 3 consists of samples from the Mayli-Yurt mine and the settlement of Sintashta (Tab. 4-10.). Therefore, it is possible that the people of the settlement of Sintashta used ore from this mine, although this conclusion demands special investigations by other analytical methods.

In addition to the spectral analysis, mineralogical studies of these ores were conducted. From the samples studied 40 were malachite in serpentine, 3 – malachite in siliceous serpentine, 1 – serpentine with malachite veins, 3 – malachite in carbon-siliceous slates, 13 – malachite in limonite, 2 – malachite in limonite and iron hydroxides, 1 – malachite in siliceous limonite, 1 – azurite in iron hydroxides. Besides, 27 samples are presented by malachite and 2 by azurite without gangue inclusions. As carbon-siliceous slates are often connected with serpentinized ultrabasic rocks, it is possible to relate 47 samples to deposits in these rocks. Another group of 20 samples is connected with iron hydroxides, but these hydroxides can form both on deposits in the ultrabasic rocks and on deposits of any other type. And 29 samples without impurity of rocks can belong to any type of deposit too. Nevertheless, even despite these reservations it is sufficiently obvious that the production was based, above all, on the oxidized ores, and these ores originated, mainly, from the ultrabasic rocks.

Correlation of the date of spectral analysis with the mineralogical determinations of ores has shown the following. Cluster 1 consists of 23 samples presented by malachite in serpentine and 3 samples by malachite in siliceous serpentine (Tab. 4-11.). Cluster 2 consists of samples represented by malachite in serpentine (two samples), malachite in serpentine with limonite veins (one sample), malachite with limonite and hydroxides (one sample) and malachite in limonite (one sample). Therefore, as said above, samples of both these clusters could have been mined from the same deposit, but samples included in cluster 2 could be mined from the upper level of the mine, which resulted in lower Cr and higher Pb concentrations. All samples of cluster 3 are presented by malachite in serpentine.

Cluster 4, with the exception of one sample from Arkaim, originated from the Ustye settlement (Tab. 4-10.). The cluster is distinguished by high concentrations of Mn, Pb, Ti and Ba (Fig. 4-4., Fig. 4-7., Fig. 4-9.). It is very difficult to say somewhat convincing about a mineralogical nature of this cluster because all of the samples are represented by small pieces of malachite (17 samples) and azurite (2 samples), malachite in limonite (1 sample) and malachite and azurite in acid effusive (1 sample) (Tab. 4-11.).

Clusters 5 and 6 are the most interesting for our problem. Chemically these clusters are very close. They are distinguished by high As concentrations and could be used for production of arsenic bronzes. The proportion of these samples in the whole sampling is insignificant (Tab. 4-10.). There are only 11 such samples, or 10% of the total. Besides, three of them belong to the Tash-Kazgan mine, which in the opinion of E.N. Chernykh was mined at this time and was the main source for metal production of the Sintashta and Abashevo cultures.

Samples of cluster 5 are presented by malachite in limonite and could be mined from the deposit of any type (Tab. 4-11.). The samples contain very high concentrations of Zn, Ge, Pb, As and Ag and low concentrations of Ni, Co and Cr (Fig. 4-3., Fig. 4-5., Fig. 4-6.). All of them originate from the Arkaim settlement (Tab. 4-10.).

Cluster 6 consists of samples from the Tash-Kazgan mine (three samples), and the settlements of Ustye (two samples), Burli (one sample) and Sergeevka (two samples) (Tab. 4-10.). This cluster is characterized by very low concentrations of Cr, Ni and Co and relatively high concentrations of Pb (except for samples from Tash-Kazgan[1]), As and Ag (Fig. 4-3., Fig. 4-5., Fig. 4-6., Fig. 4-7.). But there is no assurance that all these ores had been actually mined from Tash-Kazgan because As concentrations in samples from Ustye are low, and samples from Burli and Sergeevka are very rich in Zn, which is not typical of Tash-Kazgan ore. Besides, the gangue on Tash-Kazgan is quartz.[2] The samples from Sergeevka and Burli are represented by malachite and malachite in limonite, which does not allow us to judge about a nature of the rock in the mine. The samples from Ustye are represented by malachite in quartzite and malachite in effusive (Tab. 4-11.). Thereby the question of the exploitation of the Tash-Kazgan mine is yet open, although we may discuss the use of ores rich in arsenic in the area.

Cluster 7 consists of samples from Sintashta (malachite in serpentine or carbon-siliceous slate accompanying serpentine) and Arkaim (epidote-plagioclaz aggregate and malachite with chlorite and iron hydroxide) (Tab. 4-10., Tab. 4-11.). Three samples from Mayli-Yurt, Tamar-Utkul and Petrovka fell in this cluster because of either analytical or statistical error, heterogeneity of the ore, etc. So, we can say that this cluster belongs to serpentine or rocks accompanying it.

Cluster 8 consists of samples from different sites and with very different mineral nature. This is explained by that this statistical program includes in the last cluster those samples, which with some difficulties can

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[1] However, SEM investigations demonstrated the presence of metal consisting of Fe and Pb in Tash-Kazgan ore (Tab. 5-4., Tab. 5-5., sample 2179, an. 1).

[2] This is confirmed also by SEM investigation of ores from Tash-Kazgan and Nikolskoe that is situated near Tash-Kazgan (Tab. 5-4., Tab. 5-5., sample 1980, 2175, 2179).

be included in other clusters. Therefore, some of these samples can relate to other clusters discussed above, some to new clusters, which have been not determined by the program.

Intermediate conclusions

Thus, the investigated ore materials have been divided into eight clusters. Clusters 1, 2, 3 and 7 can be connected with deposits in serpentine and carbon-siliceous slate accompanying it. These clusters are characterized by higher concentrations of Cr, Ni and Co. Other clusters can be connected with any type of deposit, although some samples of these clusters, represented by malachite in limonite, may be related to ultrabasic rock.

The contents of arsenic in ore from settlements are, as a rule, insignificant. Only clusters 5 and 6 show high concentrations of this element. Besides, we may undoubtedly connect with Sintashta metallurgy only three samples from Arkaim. The main massif of ore is low-arsenical.[3]

The most of ores from the Sintashta settlement was mined from some deposit in serpentine. Some part could be mined from the Mayli-Yurt mine. These clusters (1-3) do not almost include samples from other sites. Similarly, people of the Ustye (cluster 4) and Arkaim (cluster 5) settlements mined any deposit that was not mined by people from other Sintashta settlements. Indeed, some deposits were, probably, exploited by miners of different settlements and maybe at different time: cluster 6 (Ustye, Sergeevka, Burli), cluster 7 (Sintashta, Arkaim). But the number of analyses is too small that does not allow us to say with confidence about this. Studies of new materials from new settlements can change this picture. However, today we can say about a certain correlation between ores from mines and settlements, and about the presence of clusters which are typical for individual settlements. This allows the belonging of mines to particular populations to be discussed (Tab. 4-10.). Besides, at all problems of the spectral analysis we see a certain correlation of the distinguished clusters with mineralogical characteristics of ores. Therefore we may apply this method to large samplings, although its results cannot be absolutized. The belonging of ores from any settlement and mine to one cluster means the proximity of their chemical and mineralogical types, but do not mean at all that ore is brought on the settlement from this mine.

In general, the preference of ores from the ultrabasic rocks is obvious. But it is a poor type of ore fields. In the previous period in the Volga-Ural region the mining of ores in sandstones was known only. It is quite reliably documented by researches on the Kargaly mines and identifications of ores from burials (Chernykh *et al.* 1999; Chernykh 2002). Conclusions about the belonging of the MP group of metal exclusively to the fields in sandstones are less reliable, as the spectral analysis of metal does not allow it to do with high degree of reliability. But, the overall chemical picture of metal of the Early and Middle Bronze Age does not contradict it, therefore within this chemico-metallurgical group the proportion of metal smelted from ore from these sandstones was certainly great. After the expansion of metallurgical production to the east where similar fields were absent, the transition to new types of raw materials is quite explainable. But why just the fields in the ultrabasic rocks were chosen? They have absolutely another balance of acid and basic oxides which required transformation of technological schemes? And why such poor type of ores started to be mined if richer deposits were available?

It should be noted that exploitation of these ores was practiced very seldom. In Northern Eurasia it is known, with rare exceptions, only on the Sintashta sites. The exploitation of these ores was rather typical phenomenon in Eastern Anatolia as such ores are widespread in this region (Tylecote 1981, p. 41; Seeliger *et al.* 1985, p.

[3] This conclusion has been confirmed by SEM analyses, which revealed no As in investigated ore samples from settlements and deposits (Tab. 5-4., Tab. 5-5.). In general, oxidized ores, the main source of the Sintashta metallurgists, contain usually few arsenic.

629-631; Palmieri *et al.* 1993, p. 586). The same ophiolite complex has its continuation on the Cyprus where is a lot of the serpentinized rocks with copper ores (Constantinou 1982, p. 13).

Tab. 4-1. Emission spectral analyses of ore from the Transural settlements and mines of the Middle Bronze Age and the transition to the Late Bronze Age (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).

Site	№	Cluster	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Sintashta	6	8	0.005	0.005	0.15	0.15	0.01	0.2	0.001	<0.0003	0.07
Sintashta	45	8	0.0015	0.015	0.002	0.01	0.007	0.1	<0.0005	<0.0003	1
Rodniki	323	8	0.0015	0.0003	<0.001	0.02	<0.001	0.02	<0.0005	0.00015	0.01
Petrovka	596	7	0.05	0.002	0.007	0.02	0.0015	0.07	<0.0005	<0.0003	1
Burli	597	6	0.0015	0.0005	0.001	0.015	0.001	0.03	0.0005	<0.0003	1
Tamar-Utkul	598	7	0.005	0.0005	0.02	0.05	0.01	0.5	0.001	0.00015	1
Arkaim	713	7	0.01	0.003	0.02	0.05	0.01	0.3	0.002	<0.0003	0.05
Arkaim	714	4	0.015	<0.0003	0.005	0.15	<0.001	0.1	0.0005	<0.0003	1
Arkaim	715	8	0.001	<0.0003	0.005	0.02	0.01	0.3	0.0015	<0.0003	1
Arkaim	716	8	0.0015	<0.0003	0.0015	0.15	0.003	0.1	0.0005	<0.0003	1
Arkaim	717	7	0.1	<0.0003	0.02	0.03	<0.001	0.1	<0.0005	0.0007	1
Arkaim	718	5	0.005	0.0007	0.001	0.05	0.005	0.15	<0.0005	0.001	1
Arkaim	719	5	0.005	0.0007	0.0015	0.02	0.01	0.03	<0.0005	0.001	1
Arkaim	720	8	0.005	<0.0003	0.005	0.03	0.01	0.07	0.001	0.00015	1
Arkaim	721	8	0.001	<0.0003	0.007	0.03	0.003	0.2	0.001	<0.0003	1
Arkaim	722	2	0.1	0.02	0.0015	0.05	<0.001	0.05	0.0005	0.00015	1
Arkaim	723	8	0.005	0.003	0.003	0.2	0.01	0.2	0.0005	0.00015	1
Arkaim	724	5	0.015	0.002	0.002	0.5	0.007	0.07	0.0005	0.001	1
Sintashta	827	7	0.02	0.005	0.015	0.05	0.015	0.2	0.002	<0.0003	1
Yagodniy Dol	834	8	0.03	0.02	0.005	0.3	<0.001	0.3	0.001	<0.0003	1
Ustye	880	4	0.005	0.0007	0.007	0.3	0.007	0.3	0.001	<0.0003	1
Ustye	881	4	0.005	0.0007	0.007	0.07	0.015	0.3	0.001	<0.0003	1
Ustye	882	8	0.015	0.03	0.007	0.05	0.015	0.3	0.0015	<0.0003	1
Ustye	884	6	0.002	<0.0003	0.002	0.015	0.003	0.1	<0.0005	<0.0003	1
Ustye	885	8	0.003	<0.0003	0.002	0.02	0.01	0.15	<0.0005	<0.0003	1
Ustye	886	8	0.005	0.0003	0.015	0.15	0.015	0.7	0.001	<0.0003	1

Site	№	Cluster	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Ustye	887	6	0.0015	<0.0003	0.002	0.015	<0.001	0.07	<0.0005	<0.0003	1
Sergeevka	1108	8	0.01	0.003	0.015	0.3	0.01	0.3	0.001	<0.0003	0.07
Sergeevka	1112	6	0.0015	<0.0003	0.0015	0.05	0.007	0.15	<0.0005	0.0005	1
Sergeevka	1113	6	0.001	<0.0003	0.001	0.015	0.007	0.015	<0.0005	0.0005	1
Sintashta	1127	2	0.02	0.07	0.015	0.1	0.003	0.15	0.0005	0.0005	1
Sintashta	1128	2	0.1	0.05	0.02	0.15	0.007	0.07	0.0005	0.0003	1
Sintashta	1129	2	0.1	0.03	0.01	0.02	0.0015	0.01	<0.0005	0.00015	0.5
Sintashta	1130		0.007	0.015	0.07	0.07	0.01	0.2	<0.0005	0.01	1
Sintashta	1131	7	0.03	0.0015	0.015	0.05	0.02	0.2	0.001	<0.0003	1
Tash-Kazgan	1136	6	0.001	0.0003	0.007	0.03	<0.001	0.07	0.0005	<0.0003	1
Tash-Kazgan	1137	8	0.0015	0.0003	0.003	0.005	0.005	0.3	0.0005	<0.0003	1
Tash-Kazgan	1138	6	0.003	0.0003	0.005	0.015	0.007	0.15	<0.0005	<0.0003	1
Tash-Kazgan	1139	6	0.0015	<0.0003	0.007	0.03	0.0015	0.15	0.0005	0.0003	1
Maily-Yurt	1170	3	0.05	0.015	0.003	0.03	<0.001	0.03	<0.0005	<0.0003	1
Maily-Yurt	1171	3	0.15	0.02	0.015	0.03	0.0015	0.03	<0.0005	<0.0003	1
Maily-Yurt	1172	3	0.15	0.03	0.03	0.1	0.003	0.05	0.0005	<0.0003	1
Maily-Yurt	1173	3	0.3	0.03	0.01	0.07	0.0015	0.03	0.0005	<0.0003	1
Maily-Yurt	1174	3	0.15	0.085	0.02	0.1	<0.001	0.02	<0.0005	<0.0003	1
Maily-Yurt	1175		0.85	0.03	0.007	0.1	0.0015	0.02	<0.0005	<0.0003	1
Maily-Yurt	1176	7	0.15	0.03	0.007	0.1	<0.001	0.05	<0.0005	<0.0003	1
Maily-Yurt	1177	3	0.3	0.05	0.07	0.1	<0.001	0.03	<0.0005	<0.0003	1
Maily-Yurt	1178	1	0.05	0.03	0.07	0.07	<0.001	0.02	<0.0005	<0.0003	1
Maily-Yurt	1179	3	0.2	0.03	0.05	0.01	<0.001	0.015	<0.0005	<0.0003	1
Sintashta	1200	8	0.003	0.01	0.003	0.05	0.015	0.5	0.0015	0.00015	0.1
Sintashta	1201	1	0.15	0.015	0.1	0.03	0.003	0.03	<0.0005	0.00015	1
Sintashta	1202	8	0.003	0.003	0.007	0.07	0.015	0.5	0.002	0.00015	1
Sintashta	1203	1	0.15	0.01	0.05	0.1	0.005	0.05	0.001	0.00015	1
Sintashta	1204	8	0.01	0.007	0.01	0.05	0.005	0.05	0.001	<0.0003	1
Sintashta	1205	3	0.07	0.01	0.01	0.05	0.003	0.05	<0.0005	<0.0003	1
Sintashta	1206	1	0.07	0.015	0.05	0.03	0.003	0.03	0.001	<0.0003	1
Sintashta	1207	1	0.15	0.01	0.05	0.05	0.0015	0.03	0.0005	<0.0003	1

Site	№	Cluster	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Sintashta	1208	1	0.07	0.01	0.07	0.03	0.003	0.03	0.0005	<0.0003	1
Sintashta	1209	1	0.2	0.015	0.15	0.05	0.007	0.015	0.001	0.00015	1
Sintashta	1210	1	0.2	0.02	0.03	0.07	0.003	0.02	0.0005	0.00015	1
Sintashta	1211	2	0.05	0.015	0.01	0.02	0.003	0.1	0.0005	0.00015	1
Sintashta	1212	1	0.15	0.02	0.03	0.1	0.0015	0.03	<0.0005	0.00015	1
Sintashta	1213	1	0.15	0.02	0.03	0.1	0.003	0.05	0.001	0.00015	1
Sintashta	1214	1	0.15	0.015	0.03	0.3	0.003	0.05	0.0005	0.00015	1
Sintashta	1215	8	0.02	0.01	0.005	0.15	0.015	0.15	0.0005	0.00015	1
Sintashta	1216	7	0.01	0.0015	0.02	0.1	0.05	0.15	0.0015	<0.0003	1
Sintashta	1217	8	0.005	0.0015	0.002	0.1	0.01	0.05	<0.0005	<0.0003	1
Sintashta	1218	8	0.015	0.03	0.005	0.07	0.005	0.07	<0.0005	0.00015	1
Sintashta	1219		0.1	0.015	0.05	0.1	0.0015	0.03	<0.0005	<0.0003	1
Sintashta	1220	1	0.1	0.015	0.05	0.2	0.003	0.05	0.0005	0.00015	1
Sintashta	1221	8	0.015	0.007	0.015	0.2	0.007	0.1	0.001	0.00015	1
Sintashta	1222	1	0.2	0.02	0.05	0.3	0.003	0.05	<0.0005	0.00015	1
Sintashta	1223	1	0.15	0.015	0.05	0.07	0.0015	0.03	0.0005	0.00015	1
Sintashta	1224	1	0.15	0.02	0.07	0.15	0.003	0.03	<0.0005	0.00015	1
Sintashta	1225	1	0.07	0.02	0.07	0.07	0.007	0.1	0.0005	0.00015	1
Sintashta	1226	1	0.1	0.02	0.1	0.05	0.0015	0.03	<0.0005	0.00015	1
Sintashta	1227	1	0.15	0.01	0.05	0.07	0.0015	0.05	0.0005	0.00015	1
Sintashta	1228	1	0.2	0.02	0.03	0.07	0.0015	0.05	<0.0005	0.00015	1
Sintashta	1229	1	0.1	0.015	0.03	0.15	0.005	0.03	0.0005	0.00015	1
Sintashta	1230	1	0.15	0.02	0.02	0.07	0.003	0.02	0.0005	0.00015	1
Sintashta	1231	1	0.1	0.015	0.02	0.15	0.005	0.05	0.0005	0.00015	1
Sintashta	1232	1	0.1	0.015	0.05	0.05	0.005	0.015	0.0005	0.00015	1
Sintashta	1233	1	0.3	0.03	0.1	0.05	0.005	0.015	<0.0005	0.0003	1
Sintashta	1234	3	0.15	0.03	0.015	0.07	0.003	0.05	<0.0005	0.00015	1
Sintashta	1235	3	0.07	0.007	0.01	0.1	0.003	0.015	0.0005	0.0003	1
Sintashta	1236	1	0.1	0.007	0.1	0.03	0.005	0.015	0.0005	0.00015	1
Sintashta	1237	1	0.3	0.1	0.15	0.3	0.005	0.015	<0.0005	0.00015	1
Sintashta	1238	3	0.15	0.02	0.02	0.1	0.0015	0.07	<0.0005	0.0003	1

Site	№	Cluster	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Sintashta	1239	7	0.07	0.02	0.015	0.07	0.003	0.1	<0.0005	0.0003	1
Ust-Kabanskii	1357	8	0.003	0.001	0.002	0.03	0.015	0.3	0.001	<0.0003	0.7
Ustye	1358	8	0.002	0.002	0.007	1	0.01	0.3	0.0005	<0.0003	1
Ustye	1359	4	0.007	0.005	0.015	1	0.02	0.7	0.001	<0.0003	1
Ustye	1360	4	0.003	0.0015	0.01	0.2	0.01	0.3	0.001	<0.0003	1
Ustye	1361	4	0.005	0.002	0.01	1	0.015	0.5	0.001	<0.0003	1
Ustye	1362	4	0.005	0.001	0.01	0.07	0.015	0.5	0.001	<0.0003	1
Ustye	1363	4	0.007	0.001	0.01	0.3	0.01	0.5	0.001	<0.0003	1
Ustye	1364	4	0.005	0.001	0.007	0.07	0.007	0.15	0.0005	<0.0003	1
Ustye	1365	4	0.005	0.001	0.01	0.15	0.015	0.3	0.001	<0.0003	1
Ustye	1366	8	0.001	0.0015	0.007	0.015	0.015	0.05	<0.0005	0.0003	1
Ustye	1367	4	0.005	0.001	0.007	0.03	0.007	0.15	<0.0005	<0.0003	1
Ustye	1368	4	0.005	0.0015	0.01	0.15	0.01	0.3	0.0005	<0.0003	1
Ustye	1369	4	0.01	0.003	0.015	1	0.02	0.7	0.001	<0.0003	1
Ustye	1370	4	0.01	0.002	0.003	0.15	0.007	0.07	<0.0005	0.0003	1
Ustye	1371	8	0.05	0.03	0.015	0.7	0.015	0.5	0.002	0.0002	1
Ustye	1372	4	0.005	0.0015	0.05	0.1	0.05	0.5	0.002	<0.0003	1
Ustye	1373	8	0.003	0.005	0.01	0.3	0.01	0.3	0.0015	<0.0003	1
Ustye	1374	4	0.005	0.003	0.01	0.1	0.015	0.3	0.001	<0.0003	1
Ustye	1375	8	0.003	0.01	0.01	0.2	0.007	0.2	<0.0005	<0.0003	1
Ustye	1376	4	0.003	0.001	0.01	0.1	0.01	0.2	0.001	<0.0003	1
Ustye	1377	4	0.002	0.001	0.007	0.2	0.03	0.2	0.0015	0.00015	1
Ustye	1378	4	0.01	0.001	0.007	0.3	0.01	0.1	0.0005	0.00015	1
Ustye	1379	4	0.002	0.001	0.015	0.2	0.02	0.2	0.001	<0.0003	1
Ustye	1380	4	0.001	0.02	0.7	0.02	0.2	0.001	<0.0005	1	0.1
Sensitivity of the analysis			Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
			0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.0003	0.001

Site	№	Cluster	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo
Sintashta	6	8	nd	0.0003	0.00003	0.005	<0.003	<0.001	<0.001	0.0003
Sintashta	45	8	0.2	0.015	0.00003	0.005	0.0015	<0.001	<0.001	0.0001
Rodniki	323	8	0.015	0.0015	0.00003	0.03	<0.003	<0.001	<0.001	0.0005
Petrovka	596	7	0.015	0.03	0.003	0.005	<0.003	<0.001	0.03	0.0001
Burli	597	6	1	0.03	0.0005	0.07	0.015	0.005	0.0015	0.0001
Tamar-Utkul	598	7	0.01	0.003	0.0015	0.01	<0.003	<0.001	<0.001	<0.0001
Arkaim	713	7	0.007	0.003	<0.00003	0.005	<0.003	<0.001	<0.001	0.00015
Arkaim	714	4	0.3	0.2	0.00005	0.01	<0.003	<0.001	0.001	0.0001
Arkaim	715	8	0.05	0.002	0.00015	0.005	<0.003	<0.001	<0.001	0.0005
Arkaim	716	8	0.05	0.003	0.0015	0.015	<0.003	<0.001	0.005	0.0001
Arkaim	717	7	0.05	0.005	0.01	0.07	<0.003	<0.001	0.001	0.0001
Arkaim	718	5	1	1	0.01	0.15	0.005	0.007	0.005	0.005
Arkaim	719	5	1	1	0.0015	0.15	0.0015	0.001	<0.001	0.0015
Arkaim	720	8	0.02	0.02	0.00015	0.005	<0.003	<0.001	<0.001	0.0002
Arkaim	721	8	0.5	0.02	0.0002	0.005	<0.003	<0.001	<0.001	0.0001
Arkaim	722	2	0.15	0.002	0.00015	0	<0.003	<0.001	<0.001	0.0001
Arkaim	723	8	0.15	0.007	0.0005	0.005	<0.003	<0.001	<0.001	0.0007
Arkaim	724	5	1	1	0.003	0.2	0.005	<0.001	<0.001	0.003
Sintashta	827	7	0.005	0.0015	<0.00003	0.02	<0.003	<0.001	<0.001	0.0001
Yagodniy Dol	834	8	0.15	0.0015	<0.00003	0.005	<0.003	<0.001	<0.001	<0.0001
Ustye	880	4	0.15	0.15	0.0001	0.01	<0.003	<0.001	<0.001	0.0001
Ustye	881	4	0.15	0.2	0.0005	0.01	<0.003	<0.001	<0.001	<0.0001
Ustye	882	8	0.03	0.003	0.0001	0.01	<0.003	<0.001	<0.001	0.0015
Ustye	884	6	0.007	0.015	0.003	0.01	<0.003	<0.001	<0.001	<0.0001
Ustye	885	8	0.015	0.02	0.0001	0.01	<0.003	<0.001	<0.001	<0.0001
Ustye	886	8	0.03	0.005	0.00003	0.01	<0.003	<0.001	<0.001	<0.0001
Ustye	887	6	0.005	0.03	0.003	0.01	<0.003	<0.001	<0.001	<0.0001
Sergeevka	1108	8	0.2	0.0015	<0.00003	0.005	<0.003	0.001	<0.001	0.0003
Sergeevka	1112	6	0.15	0.03	0.0007	0.3	<0.003	<0.001	0.02	0.0001
Sergeevka	1113	6	0.1	0.02	0.003	0.2	<0.003	<0.001	0.05	0.0001
Sintashta	1127	2	0.3	0.003	0.0003	0.005	<0.003	0.001	<0.001	0.0001

Site	№	Cluster	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo
Sintashta	1128	2	0.15	0.0015	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1129	2	0.1	0.0015	0.0002	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1130		0.15	0.03	0.003	0.01	<0.003	0.001	<0.001	0.005
Sintashta	1131	7	0.015	0.002	0.0003	0.05	<0.003	<0.001	<0.001	0.0001
Tash-Kazgan	1136	6	0.02	0.003	0.003	0.07	<0.003	<0.001	0.015	0.00015
Tash-Kazgan	1137	8	0.007	0.002	0.00015	0.01	<0.003	<0.001	<0.001	0.0001
Tash-Kazgan	1138	6	0.02	0.005	0.003	1	<0.003	<0.001	<0.001	0.007
Tash-Kazgan	1139	6	0.01	0.005	0.003	0.15	<0.003	<0.001	<0.001	0.0003
Maily-Yurt	1170	3	0.01	0.0003	<0.00003	<0.01	<0.003	<0.001	<0.001	<0.0001
Maily-Yurt	1171	3	0.01	0.0003	0.00003	<0.01	<0.003	<0.001	<0.001	0.0001
Maily-Yurt	1172	3	0.015	0.0003	0.0003	<0.01	<0.003	<0.001	<0.001	<0.0001
Maily-Yurt	1173	3	0.015	0.0007	0.0001	<0.01	<0.003	<0.001	<0.001	<0.0001
Maily-Yurt	1174	3	0.02	0.0003	0.00015	<0.01	<0.003	<0.001	<0.001	0.0001
Maily-Yurt	1175		0.01	0.0003	0.00003	<0.01	<0.003	<0.001	<0.001	<0.0001
Maily-Yurt	1176	7	0.01	0.0003	0.002	<0.01	<0.003	<0.001	<0.001	0.0001
Maily-Yurt	1177	3	0.02	0.0003	0.0001	<0.01	<0.003	<0.001	<0.001	<0.0001
Maily-Yurt	1178	1	0.1	0.0007	0.0001	<0.01	<0.003	<0.001	<0.001	0.0001
Maily-Yurt	1179	3	0.02	0.0003	0.0001	<0.01	<0.003	<0.001	<0.001	0.0001
Sintashta	1200	8	nd	0.07	0.0001	0.05	<0.003	<0.001	0.007	0.03
Sintashta	1201	1	0.15	0.0015	0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1202	8	nd	0.007	0.00003	0.005	<0.003	<0.001	0.0015	0.01
Sintashta	1203	1	0.15	0.001	0.00003	0.005	<0.003	<0.001	<0.001	0.0002
Sintashta	1204	8	0.2	0.0015	0.0015	0.01	<0.003	<0.001	<0.001	0.0001
Sintashta	1205	3	0.07	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1206	1	0.2	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1207	1	0.2	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1208	1	0.1	0.001	0.00003	0.01	<0.003	<0.001	<0.001	0.0001
Sintashta	1209	1	0.1	0.0007	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1210	1	0.2	0.0007	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1211	2	0.3	0.005	0.0001	0.015	<0.003	<0.001	<0.001	0.0003
Sintashta	1212	1	0.1	0.0005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001

Site	№	Cluster	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo
Sintashta	1213	1	0.15	0.0005	<0.00003	0.005	<0.003	<0.001	<0.001	0.00015
Sintashta	1214	1	0.15	0.0007	<0.00003	0.005	<0.003	<0.001	<0.001	0.00015
Sintashta	1215	8	0.3	0.02	0.0002	0.02	<0.003	<0.001	0.003	0.01
Sintashta	1216	7	0.007	0.005	0.0015	0.03	<0.003	<0.001	<0.001	0.0002
Sintashta	1217	8	0.1	0.0015	0.00005	0.1	<0.003	<0.001	<0.001	0.0002
Sintashta	1218	8	0.3	0.002	0.00003	0.005	<0.003	<0.001	<0.001	0.003
Sintashta	1219		0.3	0.0005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1220	1	0.3	0.0007	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1221	8	0.3	0.0015	0.0002	0.01	<0.003	<0.001	<0.001	0.0001
Sintashta	1222	1	0.3	0.0007	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1223	1	0.15	0.0007	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1224	1	0.3	0.0015	0.00007	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1225	1	0.2	0.001	0.00007	0.02	<0.003	<0.001	<0.001	0.0001
Sintashta	1226	1	0.5	0.0007	0.00015	0.01	<0.003	<0.001	<0.001	0.0001
Sintashta	1227	1	0.2	0.0005	0.00003	0.01	<0.003	<0.001	<0.001	0.0001
Sintashta	1228	1	0.2	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1229	1	0.1	0.0005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1230	1	0.3	0.0005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1231	1	0.2	0.0005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1232	1	0.2	0.0005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1233	1	0.2	0.0005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1234	3	0.02	0.0015	0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1235	3	0.007	0.0007	0.00005	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1236	1	0.1	0.0005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1237	1	0.1	0.001	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1238	3	0.02	0.0015	0.00005	0.005	<0.003	<0.001	<0.001	0.0001
Sintashta	1239	7	0.02	0.0015	0.0015	0.005	<0.003	<0.001	<0.001	0.0001
Ust-Kabanskii	1357	8	nd	0.0015	0.0001	0.005	<0.003	<0.001	<0.001	0.007
Ustye	1358	8	0.07	0.003	0.00003	0.03	<0.003	<0.001	<0.001	0.00015
Ustye	1359	4	0.15	0.5	0.0002	0.005	<0.003	<0.001	<0.001	0.0002
Ustye	1360	4	0.2	0.05	0.0005	0.005	<0.003	<0.001	<0.001	0.00015

Site	№	Cluster	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo
Ustye	1361	4	0.05	0.05	0.00007	0.015	<0.003	<0.001	<0.001	0.00015
Ustye	1362	4	0.05	0.07	0.0001	0.005	<0.003	<0.001	<0.001	0.0002
Ustye	1363	4	0.15	0.05	0.0002	0.005	<0.003	<0.001	<0.001	0.00015
Ustye	1364	4	0.15	0.15	0.0015	0.005	<0.003	0.0005	<0.001	0.0002
Ustye	1365	4	0.07	0.3	0.003	0.005	<0.003	0.0005	<0.001	0.0003
Ustye	1366	8	0.015	0.001	0.00015	0.005	<0.003	<0.001	<0.001	0.003
Ustye	1367	4	0.03	0.05	0.001	0.005	<0.003	<0.001	<0.001	0.00015
Ustye	1368	4	0.07	0.1	0.0007	0.005	<0.003	<0.001	<0.001	0.00015
Ustye	1369	4	0.15	0.7	0.002	0.005	<0.003	<0.001	<0.001	0.0007
Ustye	1370	4	0.7	0.7	0.002	0.015	<0.003	<0.001	<0.001	0.00015
Ustye	1371	8	0.7	0.02	0.0001	0.02	<0.003	<0.001	<0.001	0.0015
Ustye	1372	4	0.05	0.3	0.00015	0.01	<0.003	<0.001	<0.001	0.0003
Ustye	1373	8	0.1	0.005	0.0001	0.015	<0.003	<0.001	0.003	0.00015
Ustye	1374	4	0.1	0.3	0.0015	0.005	<0.003	<0.001	<0.001	0.00015
Ustye	1375	8	0.03	0.002	0.0005	0.005	<0.003	<0.001	<0.001	0.0003
Ustye	1376	4	0.1	0.03	0.0003	0.005	<0.003	<0.001	<0.001	0.00015
Ustye	1377	4	0.01	0.2	0.0007	0.005	<0.003	<0.001	<0.001	0.00015
Ustye	1378	4	1	0.1	0.0003	0.03	<0.003	0.02	<0.001	0.00015
Ustye	1379	4	0.1	0.2	0.0005	0.01	<0.003	<0.001	<0.001	0.00015
Ustye	1380	4	0.7	0.0007	0.005	<0.01	<0.003	<0.001	0.0003	0.5
Sensitivity of the analysis			Zn	Pb	Ag	As	Sb	Cd	Bi	Mo
			0.003	0.0003	0.00003	0.01	0.003	0.001	0.001	0.0001

Site	№	Cluster	Ba	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Sintashta	6	8	0.05	0.01	<0.001	<0.0005	0.002	0.007	0.0005	0.005	0.0005
Sintashta	45	8	0.01	0.01	<0.001	<0.0005	0.00003	nd	<0.0005	<0.001	<0.0001
Rodniki	323	8	<0.01	0.01	<0.001	<0.0005	0.00003	0.002	<0.0005	<0.001	0.0001
Petrovka	596	7	0.02	<0.01	<0.001	<0.0005	0.0003	nd	<0.0005	<0.001	<0.0001
Burli	597	6	0.01	<0.01	<0.001	<0.0005	0.0002	nd	<0.0005	<0.001	<0.0001
Tamar-Utkul	598	7	0.05	0.02	<0.001	<0.0005	0.00015	nd	0.001	0.001	<0.0001
Arkaim	713	7	0.3	0.2	<0.001	<0.0005	0.0003	0.003	0.001	0.002	0.00015
Arkaim	714	4	0.07	0.015	<0.001	<0.0005	0.003	nd	<0.0005	0.005	0.0005
Arkaim	715	8	0.015	0.01	<0.001	<0.0005	<0.00003	nd	0.0015	0.005	0.00015
Arkaim	716	8	0.01	0.01	<0.001	<0.0005	0.00005	nd	<0.0005	<0.001	0.0001
Arkaim	717	7	<0.01	0.01	<0.001	<0.0005	<0.00003	nd	0.001	<0.001	<0.0001
Arkaim	718	5	0.01	0.01	<0.001	<0.0005	0.0007	nd	0.001	0.007	0.0007
Arkaim	719	5	0.01	0.01	<0.001	<0.0005	0.0007	nd	0.001	0.003	0.00015
Arkaim	720	8	<0.01	<0.01	<0.001	0.0005	0.00007	nd	0.001	0.001	<0.0001
Arkaim	721	8	0.2	<0.01	<0.001	<0.0005	0.00007	nd	0.001	0.003	<0.0001
Arkaim	722	2	0.01	0.01	<0.001	<0.0005	0.00003	0.0015	<0.0005	<0.001	0.0001
Arkaim	723	8	0.03	0.01	<0.001	0.0003	0.0001	0.003	0.0015	<0.001	0.00015
Arkaim	724	5	0.02	0.015	<0.001	0.0003	0.0003	nd	0.001	0.002	0.00015
Sintashta	827	7	0.01	<0.01	<0.001	0.0005	0.00007	0.007	0.0005	0.003	0.00015
Yagodniy Dol	834	8	0.02	<0.01	<0.001	<0.0005	0.003	nd	<0.0005	<0.001	<0.0001
Ustye	880	4	0.02	0.01	<0.001	<0.0005	0.0003	0.007	0.001	0.03	0.0015
Ustye	881	4	0.015	0.02	<0.001	<0.0005	0.0003	0.007	0.0005	0.03	0.003
Ustye	882	8	0.15	0.01	<0.001	<0.0005	0.0002	0.007	0.0005	0.007	0.0003
Ustye	884	6	0.02	0.01	0.001	<0.0005	0.0015	nd	0.0005	0.0015	0.00015
Ustye	885	8	0.01	0.015	0.001	<0.0005	0.0015	nd	0.0005	0.03	0.0015
Ustye	886	8	0.02	0.01	<0.001	<0.0005	0.0005	0.015	0.001	0.003	0.0001
Ustye	887	6	0.01	0.01	<0.001	<0.0005	0.00007	nd	0.0005	0.02	0.002
Sergeevka	1108	8	0.07	0.01	<0.001	<0.0005	0.00007	0.005	0.001	0.0015	0.00015
Sergeevka	1112	6	0.01	0.01	<0.001	0.007	0.00003	<0.001	0.0005	<0.001	<0.0001
Sergeevka	1113	6	0.01	0.01	<0.001	0.005	<0.00003	<0.001	<0.0005	<0.001	<0.0001
Sintashta	1127	2	<0.01	0.01	<0.001	<0.0005	0.00003	<0.001	0.0005	<0.001	<0.0001

Site	№	Cluster	Ba	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Sintashta	1128	2	<0.01	0.01	<0.001	<0.0005	<0.00003	<0.001	0.0005	<0.001	0.0001
Sintashta	1129	2	<0.01	0.01	<0.001	0.0003	<0.00003	<0.001	0.0005	<0.001	0.0001
Sintashta	1130		0.3	0.01	<0.001	0.0005	0.00005	0.007	0.0015	<0.001	<0.0001
Sintashta	1131	7	0.01	0.01	0.001	0.0003	0.00003	0.015	0.0005	0.003	0.0002
Tash-Kazgan	1136	6	<0.01	<0.01	<0.001	<0.0005	0.00005	nd	0.0005	<0.001	<0.0001
Tash-Kazgan	1137	8	<0.01	0.03	0.001	<0.0005	0.00003	0.01	0.0015	<0.001	<0.0001
Tash-Kazgan	1138	6	0.01	0.01	0.001	0.0003	0.00007	0.007	0.0005	0.001	<0.0001
Tash-Kazgan	1139	6	3	0.15	<0.001	<0.0005	0.00015	0.007	0.001	<0.001	<0.0001
Maily-Yurt	1170	3	<0.01	0.01	<0.001	<0.0005	0.00005	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	1171	3	<0.01	0.01	<0.001	<0.0005	<0.00003	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	1172	3	<0.01	0.01	<0.001	<0.0005	<0.00003	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	1173	3	0.01	0.01	<0.001	<0.0005	<0.00003	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	1174	3	0.01	0.01	<0.001	<0.0005	<0.00003	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	1175		<0.01	0.01	<0.001	<0.0005	<0.00003	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	1176	7	<0.01	0.01	<0.001	<0.0005	<0.00003	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	1177	3	0.01	0.01	<0.001	<0.0005	<0.00003	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	1178	1	<0.01	0.01	<0.001	<0.0005	<0.00003	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	1179	3	<0.01	0.01	<0.001	<0.0005	<0.00003	<0.001	<0.0005	<0.001	<0.0001
Sintashta	1200	8	0.015	0.015	<0.001	0.003	0.0002	0.007	0.003	0.002	0.00015
Sintashta	1201	1	0.01	0.01	<0.001	0.0003	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1202	8	0.02	0.015	<0.001	0.005	0.0002	0.015	0.002	0.001	0.0001
Sintashta	1203	1	<0.01	0.01	<0.001	<0.0005	<0.00003	0.003	nd	<0.001	<0.0001
Sintashta	1204	8	<0.01	<0.01	<0.001	<0.0005	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1205	3	<0.01	0.01	<0.001	<0.0005	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1206	1	0.015	0.01	<0.001	<0.0005	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1207	1	0.03	0.01	<0.001	<0.0005	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1208	1	0.01	0.01	<0.001	<0.0005	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1209	1	0.01	0.01	<0.001	0.0003	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1210	1	<0.01	0.01	<0.001	<0.0005	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1211	2	<0.01	<	<0.001	<0.0005	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1212	1	0.01	0.01	<0.001	<0.0005	<0.00003	nd	nd	<0.001	<0.0001

Site	№	Cluster	Ba	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Sintashta	1213	1	0.01	0.01	<0.001	<0.0005	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1214	1	0.01	0.01	<0.001	0.0003	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1215	8	0.01	0.01	<0.001	0.0015	0.00007	0.003	0.001	0.0015	0.0001
Sintashta	1216	7	0.07	0.01	<0.001	0.0003	0.0002	nd	0.0005	0.003	0.0002
Sintashta	1217	8	0.015	0.01	<0.001	<0.0005	0.00003	nd	0.0005	0.0015	0.0001
Sintashta	1218	8	<0.01	0.01	<0.001	<0.0005	<0.00003	nd	0.0005	<0.001	<0.0001
Sintashta	1219		<0.01	0.01	<0.001	<0.0005	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1220	1	0.01	0.01	<0.001	<0.0005	<0.00003	nd	nd	<0.001	<0.0001
Sintashta	1221	8	0.01	0.01	<0.001	<0.0005	<0.00003	nd	0.0005	<0.001	<0.0001
Sintashta	1222	1	<0.01	0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1223	1	<0.01	0.01	<0.001	0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1224	1	0.01	0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1225	1	0.01	0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1226	1	0.01	0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1227	1	0.01	0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1228	1	0.01	0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1229	1	<0.01	<0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1230	1	<0.01	<0.01	0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1231	1	0.015	<0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1232	1	0.01	<0.01	0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1233	1	0.01	<0.01	<0.001	<0.0005	<0.00003	0.003	<0.0005	<0.001	<0.0001
Sintashta	1234	3	<0.01	<0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1235	3	<0.01	0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1236	1	<0.01	0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1237	1	<0.01	<0.01	<0.001	0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1238	3	<0.01	0.01	<0.001	0.0003	<0.00003	nd	<0.0005	<0.001	<0.0001
Sintashta	1239	7	<0.01	<0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Ust-Kabanskii	1357	8	0.1	0.015	<0.001	<0.0005	0.00015	0.01	0.0015	0.0015	0.00015
Ustye	1358	8	0.05	0.01	<0.001	<0.0005	0.0005	nd	<0.0005	0.0015	0.0001
Ustye	1359	4	0.15	0.015	<0.001	<0.0005	0.001	nd	0.001	0.01	0.001
Ustye	1360	4	0.02	0.01	<0.001	<0.0005	0.0005	nd	<0.0005	0.01	0.0007

Site	**№**	**Cluster**	**Ba**	**Sr**	**W**	**Sn**	**Be**	**Zr**	**Ga**	**Y**	**Yb**
Ustye	1361	4	0.15	0.01	<0.001	<0.0005	0.0005	nd	0.0005	0.005	0.0002
Ustye	1362	4	1	0.03	<0.001	<0.0005	0.0007	0.01	0.001	0.01	0.0015
Ustye	1363	4	0.1	0.01	<0.001	<0.0005	0.0007	0.007	0.001	0.01	0.0007
Ustye	1364	4	0.02	0.01	<0.001	<0.0005	0.0015	nd	<0.0005	0.015	0.002
Ustye	1365	4	0.03	0.02	<0.001	<0.0005	0.003	0.01	0.0005	0.01	0.002
Ustye	1366	8	0.015	0.01	<0.001	<0.0005	0.00015	nd	0.001	0.0015	0.00015
Ustye	1367	4	0.1	0.03	0.001	<0.0005	0.0015	0.007	0.0005	0.01	0.001
Ustye	1368	4	0.015	0.02	<0.001	<0.0005	0.0005	0.01	0.0005	0.015	0.002
Ustye	1369	4	0.2	0.01	<0.001	<0.0005	0.0007	0.015	<0.0005	0.007	0.0007
Ustye	1370	4	0.015	0.015	<0.001	<0.0005	0.003	nd	<0.0005	0.015	0.001
Ustye	1371	8	0.2	0.015	<0.001	<0.0005	0.0007	0.01	<0.0005	0.007	0.0007
Ustye	1372	4	0.1	0.02	<0.001	<0.0005	0.0007	0.015	<0.0005	0.03	0.003
Ustye	1373	8	0.03	<0.01	<0.001	<0.0005	0.0007	0.007	<0.0005	0.002	0.0007
Ustye	1374	4	0.03	0.03	<0.001	<0.0005	0.001	0.007	<0.0005	0.03	0.003
Ustye	1375	8	0.1	0.01	<0.001	<0.0005	0.0002	0.01	0.001	0.002	0.0002
Ustye	1376	4	0.02	0.01	<0.001	<0.0005	0.001	0.007	<0.0005	0.02	0.003
Ustye	1377	4	0.01	0.01	<0.001	<0.0005	0.005	nd	<0.0005	0.01	0.0007
Ustye	1378	4	0.02	0.01	<0.001	<0.0005	0.002	nd	<0.0005	0.01	0.00015
Ustye	1379	4	0.15	0.03	<0.001	<0.0005	0.002	nd	<0.0005	0.03	0.003
Ustye	1380	4	0.03	<0.01	<0.001	0.001	nd	<0.001	0.03	0.003	
Sensitivity of the analysis			Ba	Sr	W	Sn	Be	Zr	Ga	Y	Yb
			0.01	0.01	0.001	0.0005	0.00003	0.001	0.0005	0.001	0.0001

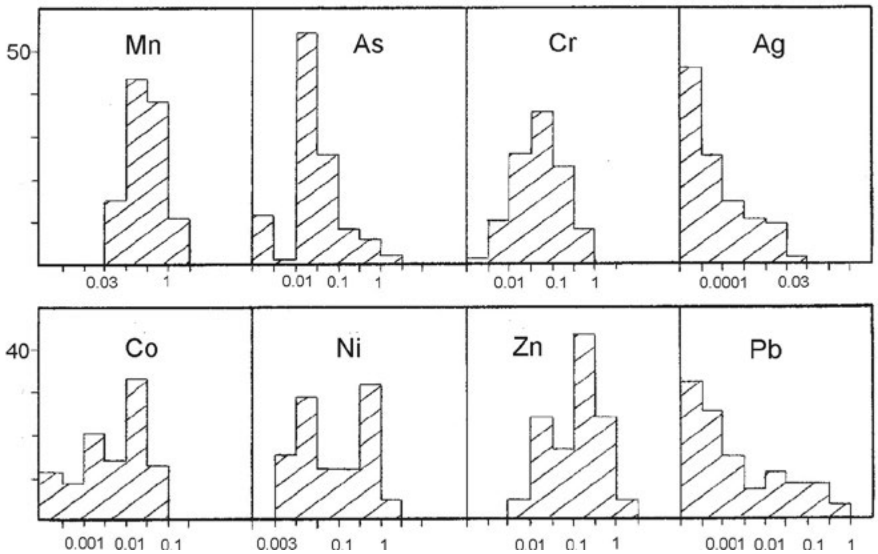


FIG. 4-2. DIAGRAMS OF DISTRIBUTION OF TRACE-ELEMENTS' CONCENTRATIONS IN ORE (%).

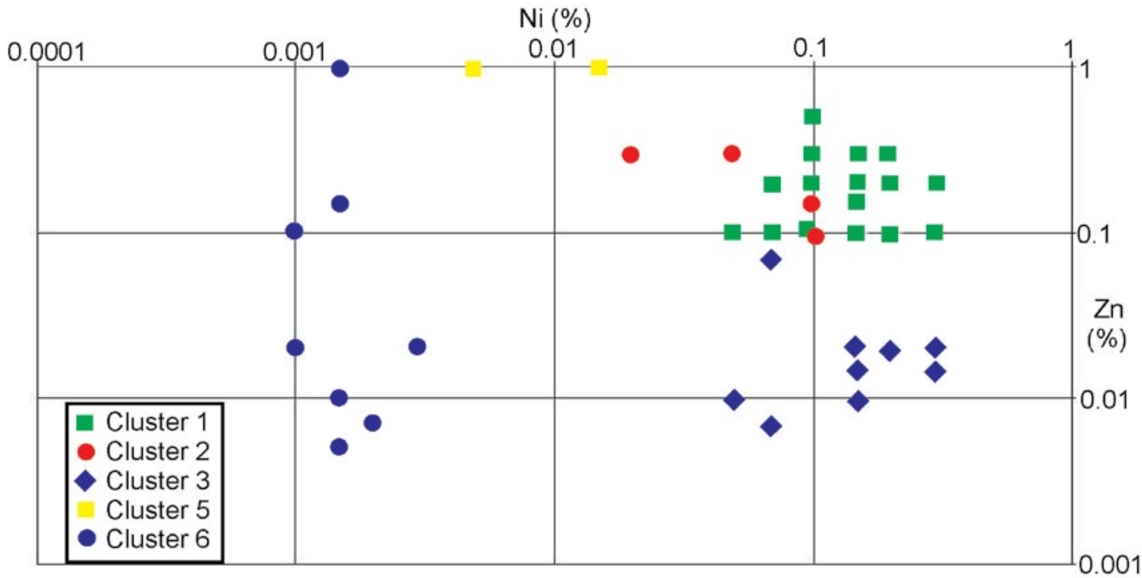


FIG. 4-3. CORRELATION OF CONCENTRATIONS OF NI-ZN IN ORE.

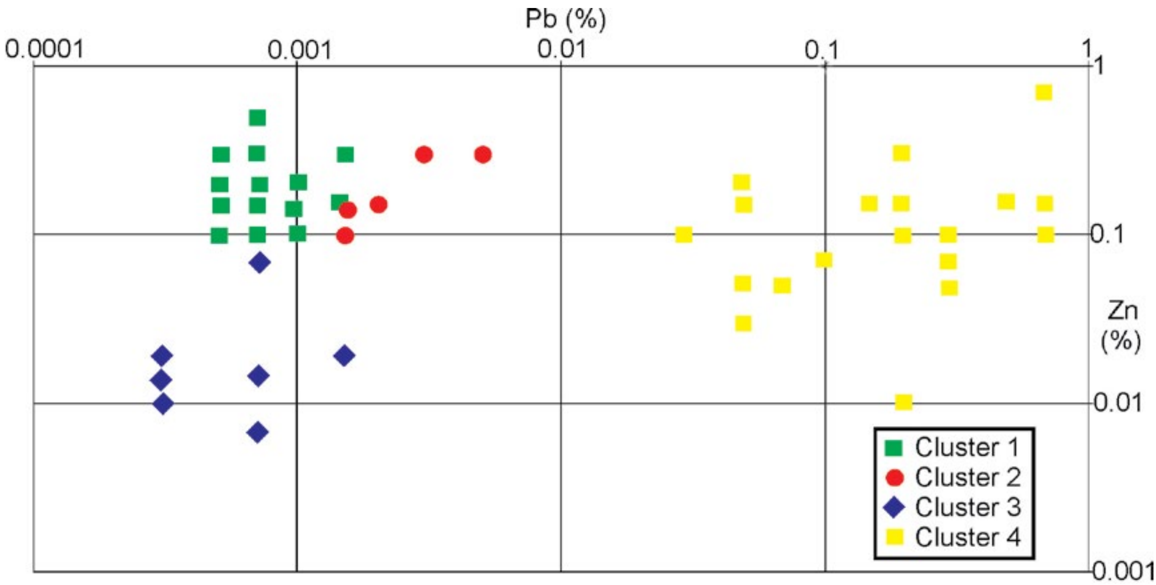


FIG. 4-4. CORRELATION OF CONCENTRATIONS OF PB-ZN IN ORE OF CLUSTERS 1-4.

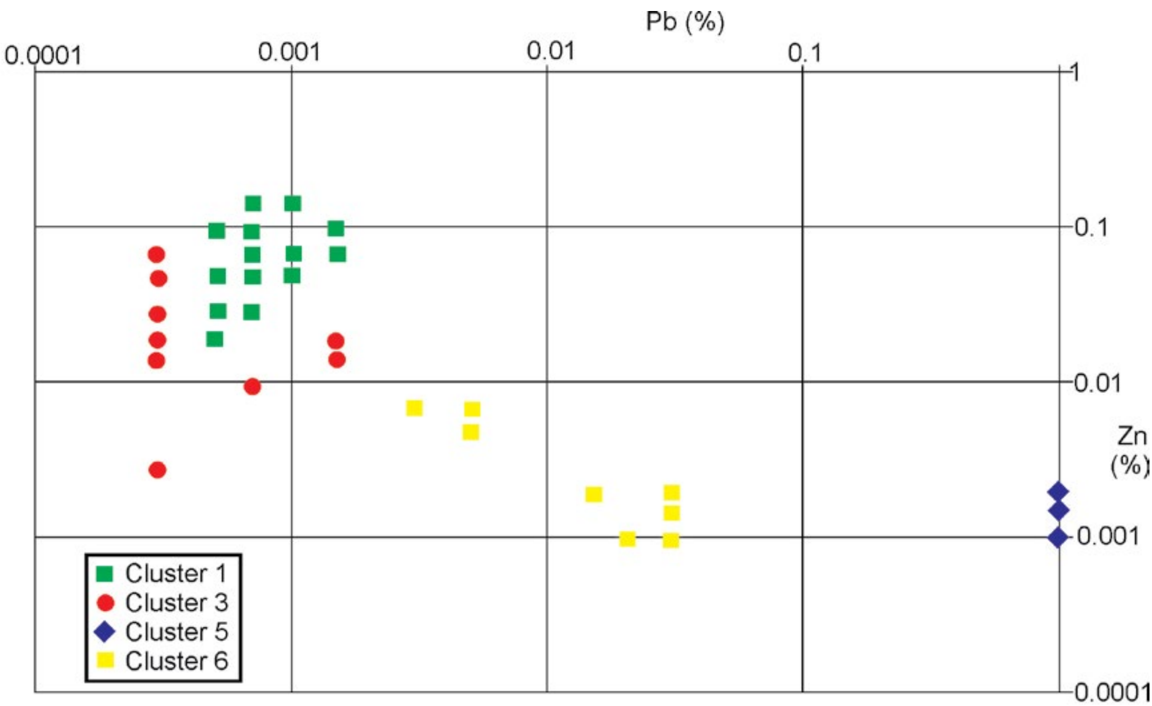


FIG. 4-5. CORRELATION OF CONCENTRATIONS OF PB-CR IN ORE OF CLUSTERS 1, 3, 5, 6.

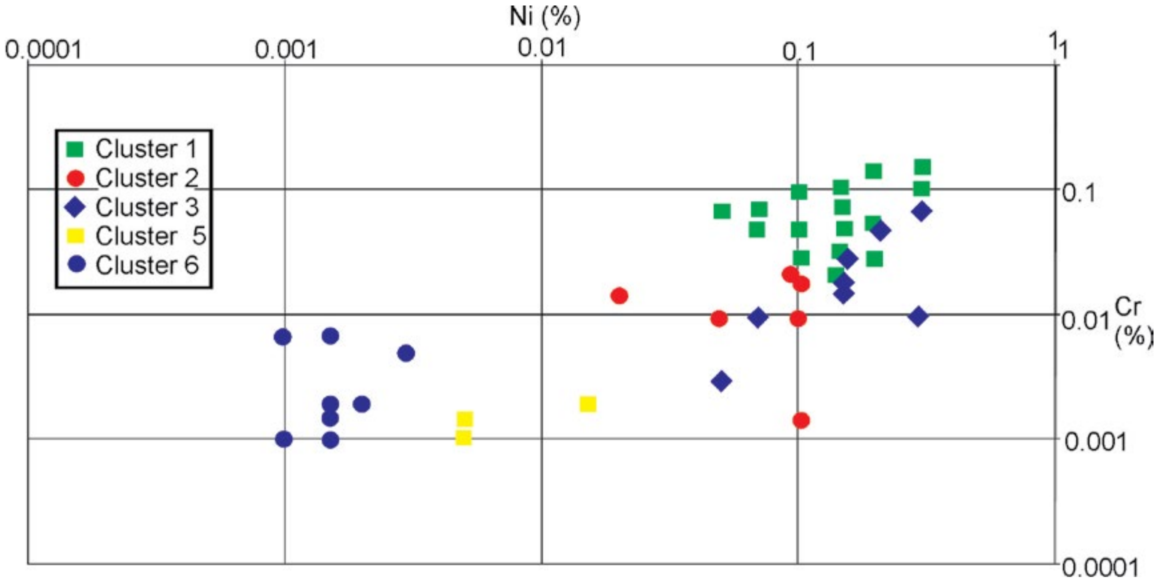


FIG. 4-6. CORRELATION OF CONCENTRATIONS OF NI-CR IN ORE.

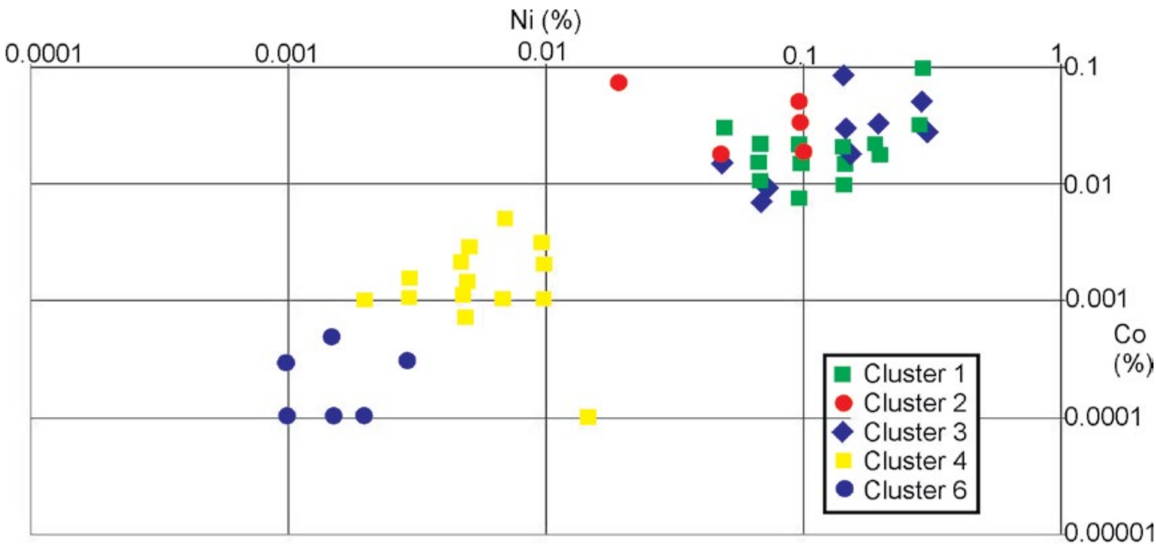


FIG. 4-7. CORRELATION OF CONCENTRATIONS OF NI-CO IN ORE.

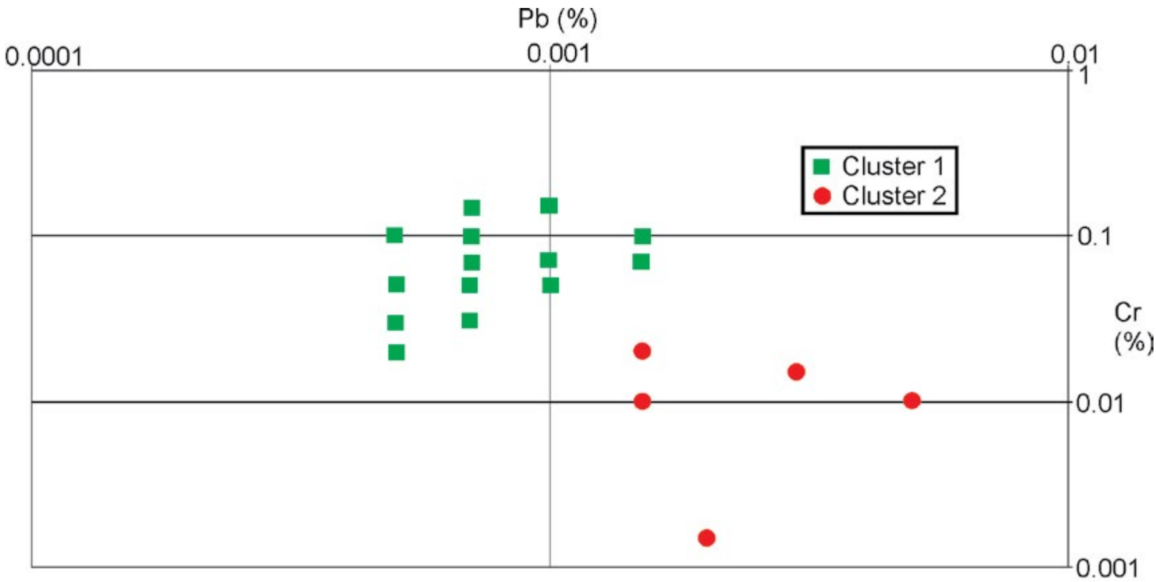


FIG. 4-8. CORRELATION OF CONCENTRATIONS OF PB-CR IN ORE OF CLUSTERS 1, 2.

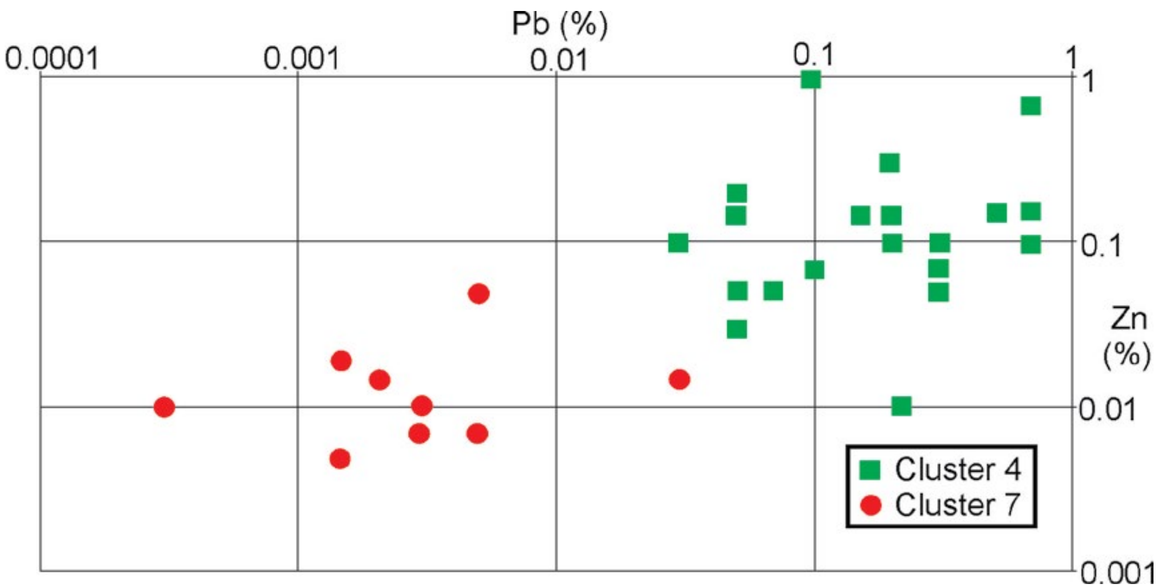


FIG. 4-9. CORRELATION OF CONCENTRATIONS OF PB-ZN IN ORE OF CLUSTERS 4, 7.

Tab. 4-10. Distribution of clusters of ores over sites.

Site \ Cluster	1	2	3	4	5	6	7	8
Sintashta	25	4	4				5	9
Ustye				20		2		8
Arkaim		1		1	3		2	5
Sergeevka						2		1
Burli						1		
Rodniki								1
Yagodniy Dol								1
Tamar-Utkul							1	
Petrovka							1	
Maily-Yurt	1		7				1	
Tash-Kazgan						3		1
Ust-Kobanskii								1
Total	26	5	11	21	3	8	9	27

Tab. 4-11. Correlation between chemical clusters and mineralogy of ores.

Mineralogy \ Clusters	1	2	3	4	5	6	7	8
Malachite in serpentine	23	2	11				2	2
malachite in siliceous serpentine	3							
Malachite in serpentine, limonite veins		1						
malachite, chloride, iron hydroxide							1	2
malachite in carbon-siliceous slate							3	
malachite, limonite, hydroxides		1						1
malachite in limonite		1		1	3	2		6
malachite in siliceous limonite								1
azurite, iron hydroxide								1
malachite				17		1	1	8
azurite				2				

Chapter 5.
Mineralogical and Chemical Composition of Sintashta Slag

Visual description

The most widespread find linked with metallurgical production on settlements of the Southern Urals of the Sintashta period is slag. It is present everywhere in cultural layers, but the most of finds concentrates in economic parts of dwellings, where the furnaces and wells were situated. Some samples occur in burials.

Quantity of slag found in Sintashta dwellings is not too large. Usually it varies from several small pieces to 300-1000g. But it is necessary to note that quantity of other finds in the dwellings is also not too ample and differs sharply from the picture that can be seen on the Late Bronze Age settlements of the Eurasian forest-steppe. Because of the density of constructions the waste was removed from the area of settlements. Besides, although ore smelting took place in all the dwellings, they were, nevertheless, just the dwellings, and did not specialized workshops.

Visually slag can be divided into two groups. Circular, less often semi-rectangular slag cakes about 10-17cm in diameter relate to the first (Fig. 5-1.7-11). All samples are presented by fragments, as the cakes were broken after cooling of furnaces in order to extract copper ingots. Rims of the cakes are usually thick and rounded of inside. This slag is dense and heavy. Its color varies from dark-brown to dark-gray, and the latter occurs much more often. The top surface of the slag is smooth, irregular and lustrous. In some instances the imprints of charcoal are visible on it. The bottom surface is very flat and has many small pores. As a rule, this surface has metallic luster. In some instances prolonged small crystals formed from smelt are viewed on this surface. It was directly adjoined the metal ingot and its cooling, therefore, was slower. Only some samples differ from this standard. They are presented by very thin, dense black colored slag plates (Fig. 5-1.4,5).

Sometimes this lustrous surface of the Sintashta slag cakes misleads. It is supposed that such texture of surface was caused by very fast water cooling (Hanks, Doonan 2009, p. 347). The same opinion was suggested about some Eneolithic slags from France, because of weak crystallization (Mille, Carozza 2009, p. 159, 163). But it is not confirmed by our analysis of slag. Besides, if to pour water in the heated furnace, due to instant evaporation the furnace lining and, partly, the furnace itself will be destroyed.

The 2nd group includes shapeless lumps of slag (Fig. 5-1.1-3,6). They are always coated by thin fused crust. Their internal parts differ very much in weight and porosity. There are samples, which almost do not contain pores, but there are also those supersaturated by them.

The formation of slag cakes was connected, above all, with that this slag was more fluid than the second type. Among the all examined materials it makes 62.5% (Tab. 5-2.; Tab. 5-3.). On the proper Sintashta sites its proportion is somewhat higher (73%). On sites of Petrovka culture there is only 38% of such slag. Such a situation is observed also on sites containing both Sintashta and Petrovka levels. The cake-shaped slag makes there 70%, which is somewhat less than on the proper Sintashta settlements. The reason of this phenomenon has been clarified by means of mineralogical analyses of slag.

It is necessary to note that the form of Sintashta slag cakes is unique for Northern Eurasia. Among a significant number of Late Bronze Age samples similar slag is almost unknown (with the exception of several later samples of the Early Timber-Grave period). At the same time, such slag has been found at excavations of settlements in Eastern Anatolia, Northern Iraq and Iran. Slag, identical in the form has been found on the settlements of Nevali-Chori, Shahr-I-Sokhta, Chayönü Tepesi, Tell Hueyra, Hissar. This slag is very specific and very legibly differs from the early Eneolithic and later slag of the Late Bronze Age. Slag from Nevali-Chori, dated to the period of the Early Bronze Age, has weight from 150 to 250 g, which is less than the weight of the Sintashta slag (Hauptmann *et al*. 1993, Abb. 2.3,4, S. 546-549; Lutz *et al.* 1991, S. 60; Hauptmann et al. 2003, p. 202; Thornton 2009, p. 316). In Murgul the diameter of slag cakes is 15-20cm, the depth 4-5cm, and the weight 1.5-3kg. This slag is more thick and heavy than that in Sintashta, which is explained by the use of fluxes resulted in the increase of volumes and weights of charges. But in other respects this slag is typologically close to that in Sintashta. On its bottom surface the imprint of ingot has been identified, the top surface is partly smooth (Hauptmann *et al.* 1993, Abb. 2.3,4, S. 546-549; Lutz *et al.* 1991, S. 60; Hauptmann et al. 2003, p. 202; Thornton, 2009, p. 316).

Mineralogical analysis

As a result of microscopic investigations of polished sections of slag the samples have been divided in several mineralogical groups.

Slag of 1st mineralogical group

Chromite

The presence of chromite grains in slag was a diagnostic sign for their including in the 1st mineralogical group (Fig. 5-I.5,6; Fig. 5-II.2,4-6; Fig. 5-III.3; Fig. 5-IV.1,5,6). The content of chromite is usually insignificant and varies within the limits of 1-5%. However, this mineral indicates the belonging of initial ore to the ultrabasic rocks. These grains are quite large. Frequently there is a magnetite border on their rims, as chromite is usually replaced by magnetite (Fig. 5-II.2).

The analysis of the border on the edge of chromite grains by means of the scanning electron microscope has shown that it consists of magnetite with very low contents of chromium (Fig. 5-VI.3; Tab. 5-6., sample 252, an. a). Therefore, as said above, a part of magnetite was formed by the replacement of chromite.

Serpentine

In some instances disintegrating serpentine grains have been identified, in which the chromites were included (Fig. 5-I.4-6; Fig. 5-II.1,4,5; Fig. 5-IV.3). The investigation of the serpentines by the scanning electron microscope has shown that in many cases their composition is quite close to forsterite.[1] Besides, in all samples the contents of magnesium in rock notably prevails over the content of iron. In sample 680, serpentine contains 7% Fe, 17% Mg and has been determined as chrisolite (olivine) (Fig. 5-VI.4; Tab. 5-4.; Tab. 5-5., sample 680, an. 2). In sample 751 there was 3.1% Fe, 12.8% Mg, which corresponds to such serpentine as forsterite (Fig. 5-VII.2; Tab. 5-4.; Tab. 5-6., sample 751, an. 2)[2]. Serpentine in sample 252 (Fig. 5-VI.1; Tab. 5-4.; Tab. 5-5., sample 252, an. 1) contains 5.3% Fe and 26.9% Mg. This also allows us to relate it to forsterite.

Olivine

Olivine crystals are the main inclusions in slag of this group (Fig. 5-I. - Fig. 5-IV.). Their form varies from large polygonal to long prismatic, long-skeletal and acicular (needle-shaped) crystals, among which the growing nucleation centers of the olivine crystallization are visible. A tendency is identified that the small

[1] The evidence presented in this description, obtained on the scanning electron microscope, relates also to slag of the 2nd and 3rd mineralogical groups. They are collected here together to avoid repetitions, and in the conforming descriptions of groups only their main differences from each another will be given.

[2] This analysis has also revealed a high content of As (7.2%). But a new analysis has not identified arsenic, but the content of Mn was higher.

acicular and skeletal crystals gravitate to the top surface of slag cakes. This is connected with a faster smelt cooling in this zone. Frequently a zonal structure is typical of large olivine crystals. Their rim is lighter than an internal part (Fig. 5-II.6; Fig. 5-III.3; Fig. 5-IV..1). Quantity of olivine is very high. In most samples its content varies from 50 to 70%, reaching occasionally 80%. Only in a small series of samples the olivine is present in quantity of 35-45%. It has elongated, frequently skeletal forms or needles. The decrease of the olivine content in slag conducts to the increase of its viscosity and, as a result, to the increase of metal losses. So, if there is 24% olivine in sample 198 (settlement of Ustye) the contents of copper and cuprite globules in slag increase to 2.7%. The losses of copper increase also when olivine is presented by elongated skeletal and needle crystals, marking a fast smelt cooling. This leads to a situation when copper simply has no time to accumulate. Olivine in slag was formed from the ultrabasic rocks. This is indicated also by chromite inclusions.

These dates were detailed by the SEM investigation of olivines. Depending on ration of Mg and Fe, the olivines form a series between forsterite (Mg-rich member) to fayalite (iron-rich member). It has been demonstrated that in olivines, crystallized from the smelt in the same samples where the serpentine grains have been identified, the contents of magnesium are notably reduced; it is also noteworthy the decreasing content of silicoius component and the increase of iron (Fig. 5-7.). The most olivines have been related to the hortonolithe type, olivines in two samples have been related to fayalite, and one sample has shown compound similar to hyalosiderite and Fe-hortonolithe.[3]

In sample 839 olivine, as well as in many others in the Sintashta slag, has a zonal structure (Fig. 5-VIII.5; Tab. 5-4.; Tab. 5-5., sample 839, an. 6, 7). Its external part is lighter. This part does almost not contain Mg. Therefore, this segment of the crystal has fayalite composition. In the centre of the crystal, Mg content reaches 8.1% (hortonolithe). Thus, the rock of olivine or forsterite type was used for smelting. Therefore, originally the slag rich in Mg was crystallized. Then, when temperature fell, on the rim of the crystal the formation of fayalite started. In this zone a little admixture of Ca (0.9%) has been identified. The latter came from slag (glass enriched in some samples by this element owing, probably, to additions of fluxes, but more frequently from ash).

The analysis of a central part of another crystal in the same sample has been made too. There is a higher Fe content and lower Mg content than in the centre of the previous crystal (Tab. 5-4.; Tab. 5-5., sample 839, an. 8). Therefore, this olivine falls in the group Fe-hortonolithe. The same concerns also a lighter periphery of a crystal, in which the content of iron is higher than on the periphery of the previous sample and it has a fayalite composition (Tab. 5-4.; Tab. 5-5., sample 839, an. 9).

A similar composition of olivine, but with a higher Mg content (8.6%) has been found in another sample (Fig. 5-VIII.6; Tab. 5-4.; Tab. 5-5., sample 846, an. 1). Initially it has been determined as hortonolithe. But the repeated analysis has revealed higher content of iron, and the crystal was identified as Fe-hortonolithe (Tab. 5-4.; Tab. 5-5., sample 846, an. 1 Wdh).

[3] In olivine of sample 680 36.7% Fe, 10.8% Mg have been detected and it is, therefore, hortonolithe (Fig. 5-VI.4; Tab. 5-4.; Tab. 5-5., sample 680, an. 3). Olivine of sample 751 contains 38.7% Fe, 3.7% Mg, 1.9% As, which is typical of such olivine as Fe-hortonolithe (Fig. 5-VI.4; Tab. 5-4.; Tab. 5-5., sample 751, an. 4). The repeated analysis has corrected the situation: 36.24% Fe, 10.29% Mg, and the absence of As (Tab. 5-4.; Tab. 5-5., sample 751, an. 4 Wdh). This olivine has been identified as hortonolithe. In olivine of sample 252 (Fig. 5-VI.1; Tab. 5-4.; Tab. 5-5., sample 252, an. 3) 33.8% Fe and 11.6% Mg have been detected. In addition, more magnesian center of the crystal, having darker tint, has been analysed. Olivine in sample 822 contains 34.8% Fe and 7.4% Mg (Fig. 5-VIII.1; Tab. 5-4.; Tab. 5-5., sample 822, an. 2). Both these olivines are the hortonolithes too. A lighter border in the last olivine to the greater degree is enriched with iron. Olivine of sample 740 contains 8.6% Mg and 11.1% Fe. There are also admixtures of Al (4.6%) and As (5.2%) (Fig. 5-VI.6; Tab. 5-4.; Tab. 5-5., sample 740, an. 3). It is the most magnesian olivine of the investigated series (hyalosiderite). It is very indicative that the crystal is needle-shaped, undeveloped. This means that at the decrease of temperature the development of the crystal due to iron components did not happen. The last element (arsenic) has been identified, as in other olivines, by mistake. Aluminium could originate from the lining of furnace. In some instances the qualitative analyses of olivine have revealed a rather pure fayalite (Fig. 5-V.2; Tab. 5-6., sample 173, an. b; Fig. 5-IX.3; Tab. 5-6. sample 873, an. h).

Thus, all this shows rather clear regularity: forming olivines are richer in iron than the basic gangue, serpentine. In the course of cooling there was at first the crystallization of the Mg-rich olivines, and later the Fe-rich olivines. This regularity is visual on the phase diagram for olivine, serpentine and glass (Fig. 5-8., Fig. 5-9.). In comparison with the serpentine in the olivines the contents of Mg and SiO_2 decrease and the content of Fe grows. And glass contains not enough magnesium, this means that the serpentine, if melt, do it weakly, only superficial parts of the grains that is well visible under microscope. Possibly, its considerable presence in slag reflects almost all its content in the furnace charge as the magnesian component poorly passes into glass and olivines. Respectively, in the process of ore sorting ones tried to avoid adding the serpentine in the furnace charge, and its presence had casual character.

In the olivine, in comparison with glass, the essential difference in the ratio of iron and silicate components is visible, that is quite logical. The silicate slag reacts with iron components provoking the crystallization of olivine. If their ratio in slag changes in favor of the silicates, the slag becomes viscous and it solidifies and forms glass. On the diagram (Fig. 5-8.) it is well visible that at the end of crystallization in the same crystal at the edges the formation of richer in iron olivine (points 2, 4) than in the center (points 1, 3) took place.

Glass

Qualitative analyses of glass have revealed identical compositions in different samples: Si, O, Fe, Al, K, Ca (Fig. 5-V.3; Tab. 5-6., sample 173, an. e; Fig. 5-VIII.6; Tab. 5-6., sample 846, an. a; Fig. 5-VII.3; Tab. 5-6., sample 751, an. b). Similar compositions of glass have been found also by quantitative analyses. In glass of sample 252, apart from Fe, O and Si, analyses have identified also 5.1% Al, 1% K and 12% Ca. In this instance the use of calcite or bones is probable, at that in large quantity (Fig. 5-VI.1; Tab. 5-4.; Tab. 5-5., sample 252, an. 5, Fig. 5-9.). In other samples the calcium contents are low, and it originated, perhaps, from ashes. In this case its significant additions were connected, probably, with refractoriness of serpentine used in this smelting. There are small admixtures of Mn, Ca and K in glass of sample 740. They could be used, probably, as fluxes, although the admixtures were insignificant. There is Al originating from the lining of furnace. The ratio of Fe (10.5%) and Si (24.8%) is notable. The content of Mg is low (Fig. 5-VII.1; Tab. 5-4.; Tab. 5-5., sample 740, an. 5). In principle, at this chemical composition the formation of fayalite could be continued. Its termination was caused by cooling. By the way, olivine crystals have here the extended form that demonstrates a high speed of cooling in this case.

In glass of sample 822 the content of Fe is 16.2%, and there is no Mg (Fig. 5-VIII.1; Tab. 5-4.; Tab. 5-5., sample 822, an. 3). Therefore, the situation here was identical. Slag began to cool down quickly after the formation of magnesian olivine. Some part of richer in iron olivine, nevertheless, formed as edges of crystals have lighter shade. Besides, 5.9% Al, 1% K and 6.9% Ca have been found. Perhaps, bones were used as fluxes.

Magnetite

The second leading component in slag of this group is magnetite (Fig. 5-II.1,2,4-6; Fig. 5-III.1; Fig. 5-IV.2,3,5,6). It is represented by octahedra of different sizes, skeletons and dendrites. Frequently magnetite forms a border around the chromite grains. In several samples the replacement of chromite by magnetite had taken place completely. This has been found in several samples of the Ustye settlement. It is unlikely that this replacement was connected with metallurgical processes. It is most probable that ultrabasic ore-bearing rock, used for smelting, was extracted from the crust of weathering. As a result of metallurgical processes, particles of magnetite separated from chromite and formed octahedra, frequently fused on the surface.

This conclusion has been confirmed also by investigations of magnetite conducted by the SEM. Its separate grains have compositions, which are intermediate between magnetite and chromite: In sample 680 a small magnetite grain contained 44.3% Fe and 25.9% Cr (Fig. 5-VI.5; Tab. 5-4.; Tab. 5-5., sample 680, an. 4, Fig. 5-10.). In sample 822 magnetite contained 4.8% Cr and 3.1% Al (Fig. 5-VIII.1; Tab. 5-4.; Tab. 5-5., sample 822, an. 4). In crystals of magnetite in sample 740 Al and Mg have been detected, which is typical of chromites of the investigated series (Fig. 5-VI.6; Fig. 5-VII.1; Tab. 5-4.; Tab. 5-5., sample 740, an. 1,4). Frequently this concerns small crystals, instead of dendrites or larger grains.

The magnetite presence with impurity of arsenic allows us to assume a thought that in some instances it was introduced also with alloying components. But the existence of chromites with this impurity, allows another assumption to be done, that this component comes from the same deposit as ore (or from a deposit of the same type).

Frequently magnetite falls from the smelt in the form of small skeletons or nucleation centers. The contents of magnetite vary usually within the limits of 1-7%. Only in single samples up to 20% magnetite has been detected. In these cases it can form the large fields from small grains originated, probably, from pieces of limonite, occurred in the charge. On segments containing a significant amount of magnetite the quantity of copper prills increases too, which was conditioned by the increase of viscosity here.

Investigations of samples by the scanning electron microscope are not contradicted with these conclusions. Magnetite, crystallizing from slag has, as a rule, light color and contains admixtures of 5.7% Al, Ti and V (Fig. 5-V.3; Tab. 5-4.; Tab. 5-5., sample 173, an. 2). The admixtures of aluminum have been identified also by the qualitative analysis (Fig. 5-V.2; Tab. 5-6., sample 173, an. c). In another sample (Fig. 5-VIII.6; Tab. 5-6., sample 846, an. b) magnetite is pure enough. Probably, it did not crystallize from the slag, as aluminum is present in glass of these samples. The pure magnetite occurs also in sample 873 (Fig. 5-9.3; Tab. 5-6., sample 873, an. e). Here magnetite forms due to dissociation of a grain of iron oxide.

Copper and cuprite

The losses of metal in slag of this group are usually insignificant (about 0.1-1%). Extremely rare the losses reach 2%. Slag contains copper in the form of small prills (Fig. 5-I.3,5; Fig. 5-II.2,4,6; Fig. 5-III.1-4; Fig. 5-IV.2,3,5,6).

Cuprite is represented by small prills, occasionally by dendrites. It can also replace ore minerals (Fig. 5-I.4; Fig. 5-IV.1,2,5). As a whole, the contents of cuprite in investigated samples are insignificant in comparison with copper. However, the most part of the investigated cuprite is, apparently, secondary and has been formed already in cultural deposits of settlements. It is difficult to judge about small cuprite prills. They could form as a result of metallurgical reactions (Fig. 5-IX.3; Tab. 5-6., sample 873, an. f, g). However, a part of the analyses indicates undoubtedly that cuprite was of the secondary formation. This is quite apparently if cuprite formed around a pore (Fig. 5-VIII.6; Tab. 5-6., sample 846, an. c). In other cases admixtures indicate this.

The qualitative analysis of a large globule (Fig. 5-IX.1; Tab. 5-6., sample 846, an. d) has allowed it to be determined as pure copper. On its edge a border has been found. Its darker phase consists of copper and 36% Cl. A lighter phase consisting of copper with a small amount of oxygen is, probably, cuprite. Apparently, it is already a secondary formation because chloric compounds disintegrate at high temperatures.

The qualitative analysis of another large globule (Fig. 5-IX.2; Tab. 5-6., sample 873, an. a) has revealed pure copper. There is a large cuprite inclusion in them (an. b). On the edge two phases have been identified: darker and lighter. The darker phase is cuprite with admixture of chlorine (an. d), the lighter one contains more oxygen, and it is very likely tenorite (an. c). The internal cuprite inclusions indicate that it was not a secondary oxidation. But the oxidation on the border could be formed already in the deposit of settlement. The iron and chlorine admixtures have been identified also in cuprite of sample 252 (Fig. 5-VI.2; Tab.

5-4.; Tab. 5-5., sample 252, an. 6). As tenorite and chlorides cannot be formed as a result of metallurgical reactions, we can speak about secondary mineralization. The compounds of copper with chlorine (CuCl, $CuCl_2$) can be formed at low temperatures. At higher temperature (250-340 °C) these formations disintegrate again and, because of oxidation, tenorite (CuO) forms. At temperature of 500°C CuCl sublimates (Tafel, 1951, p. 234, 235, 245, 246).

Analysis on the scanning electron microscope has identified occasionally essential admixtures of iron in copper and cuprite (Fig. 5-V.1; Tab. 5-4.; Tab. 5-5., sample 3, an. 2; Fig. 5-V.2; Tab. 5-6., sample 173, an. a; Fig. 5-VI.6; Fig. 5-VI.6; Tab. 5-4.; Tab. 5-5., sample 740, an. 2; Fig. 5-VIII.1; Tab. 5-6., sample 822, an. b; Fig. 5-VIII.5; Tab. 5-6., sample 839, an. b). Subsequently obtained metal required, probably, refinement. In this case the compounds of copper with iron do not indicate, apparently, the smelting of primary sulfide ores. Very likely, these compounds formed from smelting of copper ores from ultrabasic rocks.

Ore minerals

In most instances ore minerals are represented by oxidized ores: malachite and cuprite. Only in several samples of the Arkaim settlement secondary sulfides in the form of covellite and chalcocite grains have been detected. In samples from the cemetery of Krivoye Ozero chalcocite is represented in the form of small prills. In one sample from Arkaim a grain of chalcopyrite has been identified. However, in their primary kind such minerals as chalcocite and covellite are very rarely preserved in slag. As a rule, burning-out of a part of sulfur resulted in the formation of isotropic copper sulfides, similar by their optical characteristics with cuprite, but having no internal reflexes. These minerals occur in Sintashta slag, but in the 1st group very rarely. More often they are represented by solidified melt, because, as well as other secondary sulfides, they have very low melting point.

Smelting of sulfides (apparently, the secondary sulfides) has been detected also by analysis on the scanning electron microscope. The copper sulfides have been identified by qualitative analyses (Fig. 5-V.3; Tab. 5-6., sample 173, an. d; fig. Fig. 5-VIII.1; Tab. 5-6., sample 822, an. a). Sometimes sulfides formed a border around copper. This border contains 73.2% Cu, 3% Fe and 23.7% S (Fig. 5-V.2; Tab. 5-4.; Tab. 5-5., sample 173, an. 1).

The described mineralogical group is represented by cake-shaped slag and was a result of smelting of ore from serpentinized ultrabasic rocks.

The microstructure of this group of Sintashta slag is very specific for Northern Eurasia. In the Late Bronze Age, slag containing chromites with well crystallized olivine crystals is very rare. The parallels to this slag are known in South-Eastern Anatolia, on the settlement of Norşuntepe (Hauptmann *et al.* 1993, Abb. 10, 13), which indicates the same raw material and smelting technology.

Slag of 2nd mineralogical group

Slag obtained from smelting ore from quartz was included in the 2nd group. Quartz is represented, predominantly, by small grains. In some instances cracked quartz grains contain inclusions of cuprite and copper. In a number of cases quartz has also malachite inclusions. In some samples there are a great number of quartz grains. Above all, it is samples, extracted from the mine of Tash-Kazgan. Chromite in samples of the 2nd group is absent.

The olivine crystallization is also carried out much worse. Here the formation of olivine was caused by the reaction of iron oxides with quartz. It is good visible, because the grains of quartz are usually surrounded by the olivine reactionary border.

Olivine is represented usually by elongated skeletal and needle crystals. Often it is only centers of nucleation. On many segments the olivine crystallization has been not found at all. The content of olivine varies usually between 15 and 25%, and very rare reaches 40-50%. Only in two samples from the Arkaim settlement its content reaches 60-70%. Almost all samples of this group fall in the type of the shapeless lumps of slag. The exception is the samples with the higher content of olivine. In these instances slag was less viscous, and in the course of solidification the slag formed a cake shape.

Magnetite in samples of this group is extremely rare. It is represented by small skeletons, dendrites and hardly noticeable nuclei of crystal. Only in several samples from Arkaim larger crystals have been found. Quantity of magnetite usually does not exceed 1-5%. Only in several samples from Arkaim its quantity is above 10%. Very likely, so little quantity of magnetite is explained by its reaction with quartz, when fayalite slag formed. It is possible that magnetite was formed from the replacement of some iron oxide, probably, limonite, as there is several large magnetite grains.

The presence of magnetite and the olivine crystallization indicate a possibility of the use of iron oxide fluxes to reduce the viscosity of the slag at smelting of quartz-containing ore. But, on the other hand, iron oxides could originate from gangue. Because of a low viscosity the metal losses in the form of copper prills are small (0.2-2%). There is also no much cuprite in slag. It is present in the form of prills and grains, fills up cracks and replaces ore minerals. Extremely rare cuprite occurs in the form of dendrites surrounding needles of delafossite. Only four samples from the Ustye settlement look anomalously, because the contents of cuprite reach 3.5-7.5%.

Ore in all samples of this group is represented by malachite. Only in three samples from the Ustye settlement prills and grains of chalcocite and covellite have been detected. Frequently there are also isotropic copper sulfides described above.

Slag of 3rd mineralogical group

In the 3rd group samples containing both quartz and chromite grains have been included (Fig. 5-I.2; Fig. 5-II.3). The presence of quartz was confirmed by the analysis on SEM (Fig. 5-V.2; Tab. 5-6., sample 173, an. c). It allows us to guess a bicomponent composition of charge with the use of ore from serpentine and quartz lodes, because in some instances ore inclusions are presence in quartz. But it is necessary to emphasize that ore associations with quartz have been found not often, the amount of quartz is not great, and its part could get to furnace charge incidentally, while the slag classification is based on the qualitative characteristics. Therefore, this slag does not differ essentially from slag of the 1st mineralogical group.

The main inclusions in slag of this group are crystals of olivine in glass matrix. The olivine crystallization is represented, above all, by elongated skeletal and needle-shaped structures. The elongated prismatic forms are less often. Sometimes olivine formed a slag reactionary border around grains of quartz and serpentine. The content of olivine crystals is usually 40-60%, less often 20-40%. In several samples from Arkaim there is much more olivine (60-70%).

Magnetite was formed from chromite grains, replacing them on edges. It is represented by small octahedra, skeletons and nuclei of crystal (Fig. 5-I.2). In some instances there are also dendrites of magnetite. Quantity of magnetite in slag of this group is insignificant. Usually it does not exceed 1% and extremely rarely reaches 3%. It is explained by that the magnetite, interacting with quartz, formed fayalite slag, which results in the formation of fayalite crystals. In several cases the contents of magnetite in slag is 8-15%. However, its most part formed not by the replacement of chromite, but by the separation from large broken up magnetite grains originated, probably, as a result of metallurgical reactions from limonite.

The prills of copper in slag of this group occur rarely. Copper losses vary within the range of 0.1-1%. There is a little cuprite too. It fills cracks, forms prills, replaces ore grains. Indeed, it is most likely, the cuprite filling in cracks is of secondary formation, a result of oxidization already in cultural layers.

Ore minerals are represented, above all, by malachite. In one sample from the settlement of Ustye grains and a small ingot of chalcocite have been found. The ore spectrum in slag of Arkaim is some wider. In addition to malachite and chalcocite, which are present everywhere, here tennantite, bornite and chalcopyrite have been detected, but in single cases and very small grains. In some instances there are isotropic copper sulfides.

Slag of 4th mineralogical group

The 4th mineralogical group includes oxidized slag with a high content of cuprite (Fig. 5-III.6; Fig. 5-IV.4). The crystallization in samples of this group was realized rather poorly. Glass matrix contains a great number of cuprite prills and small nuclei of the cuprite crystallization, discernible only at the magnification ×950. In some instances there are cuprite dendrites and borders of cuprite and copper sulfide around the copper globules. The greatest quantity of cuprite is in samples from the settlements of Sintashta XIII and Ustye. Its content here reaches 50%. Somewhat less cuprite is present in samples of other sites (30-50%). A minimum quantity of cuprite (10-15%) has been detected in four samples from the Sintashta settlement. Cuprite in samples from the settlement of *Semiozerki* II is also somewhat different. It is represented by dendrites, deformed prills and globules of various sizes. Delafossite needles have been identified among the accumulations of cuprite.

The phase analysis conducted by the optical microscope has been tested by means of the scanning electron microscope. The analysis of one sample from the settlement of *Semiozerki* has revealed delafossite (Fig. 5-V.5; Tab. 5-4.; Tab. 5-5., sample 221, an. 1). Some cuprite dendrites were identified initially by this method as silicates (Fig. 5-V.5; Tab. 5-4.; Tab. 5-5., sample 221, an. 2, 3), however, as the investigated inclusions were too small, it has been ascertained that the silicate compound was given by glass. These dendrites are cuprite and were formed, therefore, during metallurgical processes as a result of the crystallisation from smelt. Glass contains copper (12.2%) and admixtures of As (1.6%) (Fig. 5-V.5; Tab. 5-4.; Tab. 5-5., sample 221, an. 4). Larger cuprite inclusions, which were not crystallised from the slag, can contain small admixtures of iron (Fig. 5-V.6; Tab. 5-4.; Tab. 5-5., sample 221, an. 5). Besides, in this slag hematite has been found (Fig. 5-V.6; Tab. 5-4.; Tab. 5-5., sample 221, an. 6). All these dates undoubtedly indicate oxidizing conditions of smelting.

There is much more copper in slag of the 4th group than in samples of other groups (3-5%). The copper prills are very deformed which indicates considerable viscosity of smelt. The magnetite grains and nuclei of the olivine crystallization have been detected only in some samples of the Sintashta settlement. In these samples and those from the settlement of Sintashta XIII a full absence of ore surprises. Therefore, it is impossible to exclude that this slag was obtained at the casting. Crystals of cuprite in this slag are also smaller and saturate slag more densely. In glass matrix the very small detrital material occurs, which is not identifiable in the reflected light. But in samples from other sites the ore material is well presented. Above all, it is malachite.

It is rather difficult to determine the ore base of this group. Probably, it was not uniform. In slag of the settlements of Sintashta and Sintashta XIII the gangue has not been detected. There are only small separate grains of quartz sand. In slag of the settlements of Ustye and Semiozerki II inclusions of quartz have been found.

All described mineralogical group falls in the type of shapeless lumps of slag.

Slag that out of the groups

Finally, several samples did not fall in any of the main groups. Sample 8 from the settlement of Sintashta is represented by magnetite slag. Magnetite in it forms dendrites, skeletons and octahedra. Its amount (30-35%) resulted in higher metal losses. In slag, 3-4% copper was entrapped.

Two light, porous, shapeless samples from the Arkaim settlement differ from others too. The crystallization in them had not carried out at all. The nuclei of fayalite and magnetite are rarely identified. There are also prills of copper and cyprite. This cuprite is, most likely, a secondary mineral. Remains of gangue have not been found in this slag. Probably, this slag is a result of casting, or, which is quite possible too, it is the fused furnace lining.

A shapeless slag from the settlement of Petrovka II in the Ishim basin relates to Petrovka culture. The main components in slag are needle-shaped, skeletal and elongated prismatic crystals of olivine, among which the crystallization of skeletons, octahedra and dendrites of wüstite and magnetite is visible. Sometimes they reach rather large sizes. Copper in the form of small prills are situated among large accumulations of iron oxides. In some instances the ore grains replaced by copper have been detected. Originally it was, probably, malachite, sometimes malachite with sulfide.

Disintegration of magnetite octahedra from larger grains is well fixed. The source of ore is unclear, but both iron and silicate components are present in the slag. At this stage it is impossible to tell if it was caused by initial parameters of ore or fluxes. Molten sulfide and occasionally small sulfide grains replaced at the edges by cuprite are detected. This slag is close to that of Sintashta, but lack of reliable indicators of gangue did not allow it to a particular group to be related.

Chemical analysis

Thus, as it is follows from mineralogical analyses of ore and slag, deposits in serpentinized ultrabasic rocks were the main ore sources of this time. Such deposits with traces of ancient mining are known in the Transurals: Mayli-Yurt, Vorovskaya Yama, Ishkinino, Ivanovka, Dergamysh (Zaykov *et al.* 2005). Chemical analyses of ore and slag contribute to understanding of some questions of ore base and smelting technology.

In different years and in different laboratory (Chemical laboratory of the Chelyabinsk geological expedition, and Activation Laboratories Ltd. Ancaster, Ontario, Canada) a series of chemical analyses of ancient Ural slags of the Bronze Age was done (Tab. 5-11., Tab. 5-12.).

Studies of Sintashta ores have revealed the primary use of ore from the serpentines. This mineral is very refractory and has magnesian olivine composition. Therefore there was a need of more careful selection of ore from gangue and use of fluxes. It was necessary to increase a proportion of iron component. It has not been excluded that for this purpose the iron-containing Chagray sandstone was used, whose finds are very typical of the settlement of Sintashta. But this hypothesis could be checked only the chemical analysis.

Ratio of components of furnace charge

All analyzed samples were subjected to additional statistical processing and divided into the oxides influencing increase and decrease of the viscosity, and the coefficient of basicity has been calculated (see Introduction, Tab. 5-13.). For each sample the sum of these oxides has been estimated. In the table are brought not only Sintashta samples, but also Abashevo and Petrovka samples from neighboring adjacent areas that allows comparison between them to be done.

At calculations under the formulas stated in the Introduction, we receive the following picture of groups of slag and ore based on their chemical compositions. The majority of slag of the Sintashta period has the basic composition. Only rare samples belong to middle, acid and ultra-acid groups. In the ore from the Sintashta settlements and used mines we see other regularity. The ore belongs usually to acid and middle groups. Such changes are impossible without a special compositing the furnace charge or ore sorting.

The ratio of the groups is shown in table 5-13. Unfortunately, the small number of ore samples has been used. The received coefficient of basicity for ore varies within 0.16-1.74. For slag of the Sintashta and Abashevo (Tyubyak) settlements this coefficient is higher fluctuating within 0.1-2.52. The average coefficient for ore is 0.82, and that for slag is 1.4. Thus, this situation could not be improved by the addition in the furnace charge of the Chagray sandstone whose coefficient is 0.78. Therefore, other components, for example, crushed bones and iron oxides could be added in the furnace charge. The use of crushed bones by Sintashta smelters has been identified. However these additions could not change the situation so drastically because the sum of K_2O and CaO in slag of this time varies between 2.47 and 6.22%.

The coefficient of a ratio of iron and magnesian components shows also an interesting picture (Tab. 5-14.). In smelting of this period ores from serpentine which is rich in magnesian component were actively used. Actually, in ore this coefficient usually fluctuates from 0.56 to 3.38. It is higher in a sample from carbon-siliceous slates (10.15) and is abnormally high in a sample from the mine of Vorovskaya Yama (157.15). In slags this ratio fluctuates within 3.26-23.48. Thus, the average value for ore is 1.2, and for slag it is 12.14. In other words, in slag in comparison with ore the ratio of iron and magnesian components changes drastically.

Discussing the optical analysis of slag we noted that magnetite in slag was usually formed from any iron oxide.

At first sight, it indicates the use of iron fluxes. But strong archaeological and analytical data in favor of it are absent. Based on the above-stated table the Chagray sandstone whose pieces are very often found on the Sintashta sites could be used as such fluxes. But in it the proportion of silicate components is great, and from ore to slag we see invariable drift from the acid to basic compositions. For these purposes it would be possible to choose other rich in iron oxides. It is not excluded that this situation may be explained by that Sintashta metallurgists carefully sorted ore, selecting the ore inclusions from richer in iron olivines. Plenty of ore in magnesian chrysotile serpentine on the settlement of Sintashta was just connected with that it was the waste which was not used in smelting. Contrary to it, on Arkaim ore is presented by rare small pieces in iron oxides. It is difficult to explain, what caused so contrast picture. As a hypothesis it is possible to assume that the population of Arkaim sorted ore on mines more carefully, and the Sintashta's population made final ore sorting on the settlement. It could be caused by that the settlement of Sintashta was situated closer to the exploited mines in comparison with Arkaim, but as we will see further, it was not so. Therefore, the problem is caused by a difference in the organization of works on the mines.

In slag of the settlement of Arkaim the silicate component varies from 22 to 51%, and in slags from Sintashta it does from 10 to 43%. However the average value for both sites is 33%. It is quite close to the content of silicate components in the mines of Ishkinino and Dergamysh that forces to doubt in the use of iron oxides as flux too, and points to exploitation of deposits of this type.

The content of Al_2O_3 in slag in comparison with that in ore even slightly decreases (4.79% in ore and 3.78% in slag) (Tab. 5-15.). In principle, as we saw from analyses of experimental works, due to fused furnace lining its content in slag increases, but it is insignificant (if not to consider ceramic slag). The decrease may be explained by both ore sorting and fluxes. Apparently, the lining of furnaces was rather strong and was seldom molten.

In slag the content of potassium grows (0.15% in ore and 1.19% in slag). But, as it follows from our experimental works, the small growth of the content of calcium and potassium in slag is well explained by their transition from ashes.

The use of bones and calcite pieces as fluxes has an archaeological confirmation. It had to make impact on the content of calcium, and the use of bones did also on the content of calcium and phosphorus.

The content of calcium in ore on the average is even slightly higher than in slag (2.88 and 2.72%), but it was caused by that in this small sampling of ore the analysis of ore from Vorovskaya Yama with very high content of this component is taken into account. Without it the average content of calcium in ore is 1.25%, and we see its small increase in slag that, as a whole, corresponds to the expected result. However the growth of calcium and potassium may be explained by their transition from ashes and also by metallurgical processes as these elements do not go into metal, and their growth in slag is expected. But the artificial character of calcium additions is confirmed by the growth of the content of phosphorus (the average value is 0.07% in ore and 0.59% in slag). At that, a clear dependence between the content of potassium and phosphorus is not observed that specifies that potassium went into slag from ashes. But the dependence between the content of calcium and phosphorus is traced (Fig. 5-16.). All this obviously indicates the use of bones as fluxes.

Slag of the settlement of Arkaim contain slightly more manganese oxide, than the slag from Sintashta, however at this stage it is difficult to explain these distinctions. Most likely, they are connected with some distinctions in ore base.

Conclusions:

On the basis of data processing of chemical analyses it is possible to say about legitimacy of the conclusion drawn about the use by the Middle Bronze Age metallurgists of ores from mainly basic and ultrabasic rocks. The difference in ore base of metallurgy of Sintashta and Arkaim is felt. Metallurgists of Arkaim either extracted ore from more rich in iron rock, or carried out a careful ore sorting directly on mines. Metallurgists of the Sintashta settlement brought ore from the serpentines to the settlement and sorted it there. The most part of ore samples found on this settlement is, apparently, wastes of the production.

The obvious insufficiency of the use of Chagray sandstone by Sintashta's metallurgists for fluxing is revealed. Data on use of iron fluxes are absent; probably a careful ore sorting took place. Crushed bones of animals as fluxes are more preferable. However, if even the iron component was present initially in the rock and was left when sorting, it was left purposely as metallurgists understood its usefulness in the smelting process. From this point of view, irrespective of its origin, it can be considered, nevertheless, as a flux.

In principle, a similar chemical composition of slag has been recorded on many Anatolian settlements (Murgul, Nevali Chori, Norşuntepe), on sites of Oman, on Tepe Hissar in Northeastern Iran. The sites in Levant (Feynan) and also Sialk in Iran contain less rich in iron slag (Thornton 2009, p. 315, fig. 6).

X-ray crystallographic analyses

Supplementary evidence, which has permitted to reconstruct the smelting technology, has been obtained by means of the X-ray diffraction method. In total 40 samples were subjected to this analysis, but only 13 analyses relate to the Sintashta-Petrovka period (Tab. 5-17.).

This method identifies predominantly phase compounds of a material on the ground of studying its crystal lattice. In slag, different modifications of iron oxides (wüstite, hematite, and magnetite), copper and quartz have been detected. Quartz is most interesting in this case, as other minerals may be well diagnosed by a microscope. The analysis of quartz in the reflected light does not allow its modification to be determined authentically. In many cases it was notably that quartz was not uniform. The edges of grains had often a lighter border. However, it was not possible to attribute it with confidence to either tridymite or cristobalite.

In all samples from the Tash-Kazgan mine the X-ray analysis detected exclusively proper quartz. Other modifications have not been found. It is possible to say the same also about samples 5 and 83 from the settlement of Sintashta, relating to the 4th mineralogical group. In samples 1,7,43,87 of this settlement, relating to the 1st, 2nd and 3rd mineralogical groups, apart from quartz, tridymite has been detected. Finally, in a samples from the settlement of Petrovka, apart from quartz and tridymite, the high-temperature modification of quartz, cristobalite, has been identified. The latter, by the way, is present in samples of the Late Bronze Age and Early Iron Age.

Smelting technology

Smelting temperature

Technological characteristics of slags of the 1st, 2nd and 3rd mineralogical groups are very similar. All of them are characterized by the presence of well-formed olivine (fayalite) crystals. This indicates temperatures higher than 1209°C. In all samples apart from molten copper there are cuprite globules, and in a number of instances prills of chalcocite and covellite. These globules and prills are well shaped, have a regular spherical form, which indicates a low viscosity of slag and may testify to overheating of cuprite, which usually takes place if the smelting temperature almost reached 1300°C. Besides, there is no confidence in all cases that cuprite was not a result of a secondary replacement of molten copper minerals (chalcocite, covellite) or copper either at the time when slag was in a cultural layer of the settlement. If cuprite formed in a pore, this creates an illusion of a molten prill. The absence in slag of another copper oxide, tenorite (CuO), which transforms at the temperature of 1026°C into cuprite (Hauptmann *et al.* 1994, p. 6), is very notable. The presence in slag of crystallizing magnetite, probably, does not allow us to talk about higher temperature, as the magnetite crystals originate, above all, from the replacement of grains of chromite and limonite. Some dendrites, skeletons and nuclei of the magnetite crystallization is connected with falling from the liquid olivine slag at lower temperatures than the melting point of magnetite (Perepelitsin 1987, p. 84). Small size of crystals testifies in favor of this too. This supposition is confirmed also by tridymite, well presented in slag of these groups, and cristobalite missing completely. Therefore, temperature could not by above 1470°C. On the face of it, all said allows us to conclude that the temperatures varied from 1200 to 1400°C. And, in a high temperature zone the smelting was conducted a short time, as alongside the tridymite in all samples also quartz is presented which had no time to develop completely into its high-temperature modification.

The determination of temperature is a rather difficult task, however, the majority of specialists dealing with this question, understands that the achievement of high temperatures was not a problem for ancient metallurgists. It was more difficult to create reducing smelting conditions (Hauptmann *et al.* 1994, p. 6). The experimental smelting operations, realized in Anatolia, have shown that it is possible even to reach the temperature of 1600°C (Caneva, Giardino 1994, p. 454). As said above, cuprite prills, detected in the Sintashta slag, allow us to talk about temperatures, reached or exceeded 1300°C.

This conclusion can be confirmed by the temperature phase diagram constructed for olivines on the base of SEM analyses (Tab. 5-4.; Fig. 5-18.). On the solidification curve all samples are situated in a high temperature zone. Some olivines (samples 839, an. 7, 8, 9; 846, an. 1Wdh; 1870, an. 5) solidified within the temperature range 1200-1300 °C. Besides, two of them (sample 839, an. 7, 9) are rims of crystals and were formed at the end of the smelting process at the temperature about 1300 °C. So, the most part of samples demonstrates the temperature interval of 1270-1350 °C. There is an analysis (sample 740, an. 3) which shows the temperature of solidification about 1500°C. It is a very thin crystal rich in magnesium. All this is not sure evidence, because of two reasons. Such high temperatures could not be achievable, because of the absence of cristobalite in slag. On the other hand, smelting process is not limited by chemical and thermal reactions. There is also gas phase, which plays an important role in it. This phase promotes the decrease of melting points. Probably, this explains two analyses of molten serpentine, which show in the liquidus curve the temperatures of 1415°C and 1680°C (samples 1870, an. 2 and 1780, an. 4). But all non-melted serpentines lay above.

The presence of arsenic, which cannot be preserved at the temperature above (Pollard *et al.* 1990, p. 130-132), is also contrary to this. Individual particles of magnetite with molten surface cannot also testify the high temperature, as during the smelting process they could be formed from wüstite having a lower melting point. In this case, we can speak about temperatures of 1200-1300 °C, although on some stages of smelting the temperatures could be higher. It is not excluded that the additions of arsenic-containing minerals were made not at the beginning of smelting, although this is a doubtful assumption. As a whole, all this corresponds to present conceptions of archaeometallurgists about temperatures achievable in the antiquity.

Rate of smelt cooling

Temperature was falling slowly, as the rate of smelt cooling was in the most cases obviously insignificant. It is possible to conclude this from olivine crystallized very well. From its microstructure we may suppose that the Sintashta slag formed directly in furnaces. Technologically it is an earlier stage than a metallurgical process with slag tapping. The latter has been identified in Palestine on objects of the 14-11th centuries BC (Bachmann 1980, p. 110). For settlements of the Anatolian Early and Middle Bronze Age the smelting method similar to that of Sintashta has been reconstructed. For example, slag of the Murgul settlement contained rather large crystals of fayalite testifying quite slow rate of smelt cooling, and the formation of this slag directly in the furnace at the temperature of about 1200°C (Lutz *et al.* 1991, pp. 64, 65). And although when the airflow was stopped, the temperature fell quickly (Hauptmann *et al.* 1994, p. 6), the rate of the cooling of the smelt was, nevertheless, considerably lower than the rate of the cooling of tapped slag, and the large crystals of fayalite had time to be formed. The presence in some samples of small needle-shaped olivine is explained by their acid composition. But essentially the same scheme of smelting was used also in other places of the Middle East, for example, in Northeastern Iran where already in the Eneolithic metallurgists smelted previously in crucibles began to smelt in furnaces.

Smelting atmosphere

Smelting had been conducted under reducing conditions. Hematite absent in slag, small quantity of cuprite and well-presented magnetite testify this.

The reducing condition of smelting is rather characteristic of the Sintashta technology of metal extraction. Sintashta metallurgists could achieve this condition in full measure, despite the use of predominantly oxidized ores and rather intensive blasting, without which it was impossible to reach high temperatures indispensable for obtaining liquid slag at smelting ore from serpentine.

The type of Sintashta blasting, when air moved in a circle along walls of a furnace, promoted more intensive formation of carbon monoxide (CO), which is a very important reducing agent. Another probable reducing agent was phosphorous, that easily reacts with oxygen and vaporizes. Its sources were bone and, in some instances fish bones found in one of the furnaces.

When the secondary sulfides were added in the charge too, the reducing reaction was more successful.

However, we are not able to appreciate a role of particular factors in the creation of reducing atmosphere, as we do not know now, and, probably, we will not know in the future the volumes of interacting components.

Losses of metal and slag viscosity

The smelting technology can be estimated as quite perfect. The losses of copper were very insignificant. Usually they vary within the limit of 0.1-1%. Early Bronze Age slag from Murgul in Anatolia, having considerable parallels with that from Sintashta, contains copper oxides within the limit of 1-2.7%, which is similar to the Sintashta situation (Hauptmann *et al.* 1993, p. 551). Only in slag of the 2nd group of Sintashta culture the losses of copper can be a little higher and reach 2%. It is explained by more viscous slag, because of the presence of silicates. The decreasing viscosity was reached, above all, by the careful ore sorting with removal of silicates. It is impossible to exclude iron fluxes, but there is no strong evidence confirming them, as we have discussed in the part about chemical analyses.

At first sight, the SEM investigations of serpentine, olivine and glass demonstrate the use of iron fluxes. As it has been already mentioned at the description of mineralogy of slag, in the course of smelting the composition of olivines changed towards the increase of iron. And magnesium (containing in serpentine) is absent in glass of studied samples. Therefore, iron fluxes could be used in charge. Serpentine is a refractory material, and it was necessary for decreasing melting point and viscosity of slag. Originally the magnesian olivines formed marking high smelting temperatures. Then at the edges of the formed crystals the formation of fayalite began. Soon after that the viscosity of slag started to increase as after partial removal of iron the liquid slag became richer in silicates, and in the solidified glass the proportion of SiO_2 became higher than that of FeO. The increase of this component is recorded in many samples. But the same result could be received also in case of ore sorting, when iron components of rock were smelted with the formation of olivine slag, and then the olivine crystals. In glass they did not remain, and not smelted magnesian remains do not reflect an initial composition of the furnace charge.

Slag from the settlement of Shakhr-I-Sokhta in Central Iran (2700-2500 BC) has been similarly interpreted. In slag of this settlement the content of iron oxides in comparison with ore also grows. And it is explained not by fluxes. Metallurgists chose for smelting just richer in iron ores. Therefore, usually archaeometallurgists analyze the ores which had been rejected by ancient metallurgists (Hauptmann *et al.* 2003, p. 203, 204). Thus, this situation is identical to that we reconstructed for the settlement of Sintashta.

A possibility is also not excluded, that calcite, found near one furnace of the Arkaim settlement, was added. In other cases calcite could be replaced by small bones, which occur everywhere in filling of furnaces. The small pieces of burnt bones, included in slag, are found too. The use of calcium-containing materials as fluxes can be demonstrated by the presence in some slags of increased concentrations of this element. However this type of fluxing was not, apparently, obligatory as high calcium concentrations have been not recorded in all samples. Besides, a part of calcium could appear from ashes.

Nevertheless, the evidence of use of fluxes is not enough today. However, it should be noted that purely theoretically it was quite possible as fluxes were used in metallurgy, probably, from the 4th millennium BC (Tylecote 1980a, p. 5). However it was not a general situation. Everything depended, probably, on character of ore used in smelting. So, in Wadi Feinan in Palestine, in the Eneolithic ones used malachite from limonite rock, and flux additions has not been recorded. The iron component arrived into the furnace charge directly from the ore. In the EBA of this region metallurgists began to smelt copper-manganese ores which can be considered as self-fluxing too (Hauptmann 1987, p. 123, 129-131; 1994, p. 4, 5). The smelting experiments with this ore carried out at Arslantepe in Eastern Anatolia have allowed a conclusion to be drawn that it is possible to smelt this ore without fluxes (Palmieri *et al.* 1993, p. 588). Therefore, in case of use of ore from limonite (and such, for example, has been found on Arkaim), fluxes could not be used. At the same time, studies of metallurgical remains from the Sinai Peninsula and the Negev Desert dated to 14-11th centuries BC allowed to draw a conclusion that here, depending on type of ore, both silicates and iron oxides were used as fluxes (Bachmann 1980, p. 110). Additions of quartz and iron oxides for creating the fayalite slag took place also in the Eneolithic period of the settlement of Murgul in Northeastern Anatolia (Lutz *et al.* 1991, p. 64). On other East Anatolian settlement of Norşuntepe the use of chloride fluxes is recorded (Zwicker 1980, p. 17). On Cyprus where the ores close to those in Sintashta culture were used, heaps of burned bones have been found which probably were used as fluxes (Tylecote 1982, p. 81).

Studies of the tapped knebelite slag from the south of Palestine revealed the use of manganese fluxes which allowed to receive liquid slag at the temperature about 1300 °C (Bachmann 1980, p. 111).

For the Sintashta metallurgy the use of quartz for fluxing doubtfully as slag of the 2nd and 3rd mineralogical groups contains quartz as gangue, and slag of the 1st mineralogical group contain silicates from serpentine.

A low viscosity of Sintashta slag has been verified by calculations. At the temperature 1300-1400 °C the viscosity varied from 0 to 5.94 Pa·s with the average value of 2.82 Pa·s (Tab. 5-19.). The Abashevo slag of this period was more viscous: between 2.18 and 9.91 Pa·s (the average value is 5.88 Pa·s). The ore from the Nikolskoe mine in quartz rock would produce slag with the maximum viscosity. The furnace charge received from ores of the Dergamysh and Ishkinino ultrabasic fields, in case of smelting would have viscosity of between 3.46 and 4.50 Pa·s that is slightly higher than the average Sintashta values and was compensated probably by ore sorting and small additions of fluxes. The ore from Nikolskoe mine in quartz rock would give the maximum viscosity.

There was one more factor reducing the slag viscosity, but it is hardly calculated. The furnace charge contained some quantity of sulfides (covellite and chalcocite). They easily melt and reduce viscosity, promoting the removal of copper as it took place on Shakhr-I-Sokhta (Hauptmann *et al.* 2003, p. 211). But, as these sulfides are easily melted, it is hard to determine their real role in the decrease of viscosity. But for some later slags it is quite true.

Weights of charges and products

The form of slag cakes (Fig. 5-1.) allows weights of the charges and finished products to be calculated. At a significant amount of slag pieces on settlements it has been not found any whole slag cake, as metal was extracted after the complete cooling of the furnace, when slag had time to solidify and grasp by its edges an ingot. Therefore, it was necessary to crush it to extract metal from slag cakes. The fragments have various sizes and thickness. However, it was possible to clear up that the diameter of slag cakes varied more often within the range of 13-15cm, sometimes within the range of 10-17cm, their weight was 300-900g, but, as a rule, 400-600g. The diameter and thickness of copper ingots were calculated by the subtraction of the corresponding parameters of thick edges from the diameter and thickness of slag. The diameter of copper ingots varied within the range of 8-13cm, and the thickness was 0.5-1cm. Taking into account that density of copper is 8.9 g/cm^3 (Gulyaev, 1986, p. 509), weight of the ingots fall into the interval of 50-130g. Summarizing it with weight of slag, we can state that the weight of the charge varied within the limits of 0.5-1kg. Thus, the copper contain in the charge was 10-15%. Certainly, the ore before sorting was much poorer. The conditions of mineralization in serpentines are those that ore belong to the porphyry type.

As it was mentioned above, the samples of slag identical in the form are known in the Near East. Some of them, for example, slag from Morgul in Eastern Anatolia, differ by the greater thickness and weight, reaching 1.5-3kg, which was conditioned by the intensive use of fluxes. However, weight of copper extracted in Murgul was quite comparable with weight of copper extracted by the Sintashta metallurgists. It was about

100 g (Lutz *et al.* 1991, p. 60). The same form of slag is known on the settlement of Shakhr-I-Sokhta in Iran, where the weight of extracted copper was 150g (Hauptmann *et al.* 2003, p. 211).

Cleared up the volume and weight of the charge, we may admittedly talk also about quantity of charcoal necessary for each smelting. Smelting experiments in furnaces of small diameter have shown that the ratio of ore and fuel should be 2:1 (Bamberger, 1992, p. 157; Bamberger, Wincierz, 1990, p. 123). Therefore, the weight of charcoal needed for one Sintashta smelting, taking into account greater diameter of furnaces, was about 0.3-0.7 kg.

The copper extracted at ore smelting required refinement because of iron impurities in some instances. However, archaeological traces of such refinement are not known.

Technology of the 2nd type

Thus, slag of the 1st, 2nd and 3rd mineralogical groups relates to the same technological type. Against its background slag of the 4th mineralogical group, characterized by a great number of cuprite inclusions, differs. It testifies an oxidizing condition in the furnace and higher intensity of blasting, which resulted in large losses of copper. It was possible to reconcile with such losses only using richer ores.

Temperatures achieved during the smelting varied between 1200 and 1300 °C. It is indicated by nuclei of the olivine crystallization and molten cuprite. However, in some instances the temperatures did not exceed 1000 °C. The confirmation to this is the absence of high-temperature quartz modifications in two samples from the Sintashta settlement, investigated by the XRD method. Low temperature of some smelts on the settlements of Sintashta and Sintashta XIII may be indicated also by that the copper and cuprite form seldom regular prills here. More often they are deformed or presented by particles. Therefore, it is most likely, that this group of Sintashta slag is a product of casting.

On such sites, as Tyubyak, Ustye, *Semiozerki* II, the temperature detected by slag of this group was much higher. As it was already spoken, it varied in the range of 1200-1300 °C.

The viscosity of this slag was higher. For slag from the settlement of Sintashta it is explained by lower temperatures, for slag from other sites by the presence of more refractory components, such as cuprite, and by the acid composition. This resulted also in the higher rate of smelt solidification.

The almost full absence of olivine confirms that flux components were seldom used, although smelting of quartz rocks, in contrast to smelting of ultrabasic ones, required this.

As a whole it is possible to discuss this technology as imperfect. The change of raw material and the use of a new, more refractory raw resulted in the attempt to solve the problem by the intensification of air-blow to increase the temperature, which resulted in losses of copper. It is, probably, a break from the former technological tradition.

The metallurgists of Petrovka settlements in Northern Kazakhstan, apparently, solved this problem. The temperatures, achievable here, were very high, as in all samples cristobalite is present. They reached, probably, 1500 °C. It was possible only at a very intensive airflow. Nevertheless, there was the reducing atmosphere in furnaces. Cuprite has not, practically, been detected. The charge was good prepared. The ratio of iron oxides and silica allowed a good fayalite slag to be formed. Due to this, and to high temperatures as well, the furnaces cooled down very slowly, providing the crystallization to large crystals of fayalite and the separation of copper particles. The losses of copper, in outcome, were small. They are somewhat higher

(2.98%) on Petrovka II, where it is explained by too high silica content (53.46%). However, also in this case because of the high temperature the smelt was not too viscous.

The most representative mineralogical group in the whole sampling is the first (44.1%). The samples of other groups are represented much less (Tab. 5-20.). So, the 2nd group is represented by 15.2% of samples, the 3rd by 23.3%, the 4th by 15.9%. The predominance of the 1st and 3rd groups in this sampling is conditioned by their predominance on the Sintashta sites (Tab. 5-21.), where samples of 1st group make 59.2%, and together with samples of 3rd group, which contain chromite too, 81.6%. Thus, it is necessary to take into account that quartz not always got to charge only with ore bearing rock, and not in all samples its associations with ore are revealed. Therefore, the proportion of slag of the 1st group was, probably, somewhat higher, which is not so important for this problem, as has no effect for the ratio with slag of the 2nd group, which were marked, mainly, by the absence of chromite in their structure. Slag of the 4th mineralogical group has not been detected on the proper Sintashta sites.

On the settlements containing both Sintashta and Petrovka materials the ratio of mineralogical groups changes. Although the proportion of slag of the 2nd and 3rd groups either does not change, or even slightly increases, the quantity of slag of 1st group decreases to 37.1%. Metallurgists more often use ores from quartz. This ore could be represented by separate ore sources and inclusions in ultrabasic rocks. This problem is very difficult; however, the tendency detected is obvious. It is indicated also by the occurrence on the Sintashta-Petrovka sites of slag of 4th mineralogical group supersaturated with cuprite (17.6%).

The use of other raw sources started in the Petrovka period. Here 13% of slag is connected with the exploitation of ores from ultrabasic rock. The remaining ore originated, above all, from quartz rocks.

The detected tendency in distribution of raw groups is duplicated by the gravitation of particular technological schemes to particular cultural types of sites. Sintashta sites are the most uniform in this respect (Tab. 5-22.). Practically all samples of slag (97.3%) from these settlements were obtained after smelting, referred to 1st technological type. On the settlements containing both Sintashta and Petrovka layers, the technology of 1st type dominates, but there is technology of 2nd type, with its expressed tendency to increase temperature by the intensification of blasting. The proportion of this technology is 17.5%, and, apparently, all this slag relates to the Petrovka period of the settlement. On the Petrovka sites the technological scheme of the 2nd type becomes basic. However, it is possible to talk also about a further development of metallurgical production, connected with the appearance on the Late Bronze Age sites in Northern Kazakhstan of the technology of 3rd type.

Chemical groups of slag

For the determination of probable ore base of the region, alongside the mineralogical analyses of slag described above, the emission spectral analysis has been conducted (Tab. 5-23.). Its purpose was the dividing slag into chemical groups and an attempt to correlate these groups with chemical groups of ore. There are larger difficulties than at the correlating ore groups, because the problems arising at the analysis of ores and already described were redoubled by problems caused by metallurgical processes. Their kernel may be reduced to several points. Trace-element compositions of slag could be changed by the use of various fluxes and ligatures, charging different ores, furnace lining, and change of the trace-element compositions in the metallurgical reactions. Information about the mineral analyses of slag made the understanding of this analysis considerably easier.

As a result of the mineralogical analysis, slag has been divided in three basic groups distinguished by initial row materials: 1st group – slag from ore in serpentines; 2nd group – slag from ore in quartz; 3rd group – slag containing remains of serpentine and quartz ore-bearing rocks.

As well as the ore sampling, the processing of dates has been done by the Brookhaven Date Handling Programs. For this work Ti, Mn, As, Ba, Sr, Ni, Co, Cr, V, Pb, Sn, Ga, Ge, Ag and Mo have been used.

In total six clusters have been distinguished, but cluster 4 has been divided in three sub-clusters and cluster 5 in two sub-clusters (Tab. 5-23., Tab. 5-24.). Taking into account that the use of alloying materials (ores or other minerals) could take place, we may admit that the chemical composition could be hardly transformed. If ores from serpentine were used for such alloying, it should result in increased concentrations of As, Cr and some other elements. Therefore, a new processing by the same programs has been done. I have not used the elements having long intervals of distribution in all of the former clusters. As a result for the processing another set of elements has been used: Ti, Zn, Sr, Ni, V, Sc, Sn, Ga, Y, Ge, Ag, Mo, Be. This has allowed thirteen clusters to be distinguished. The correlation between the first clusters and the second ones shows very interesting results. Clusters 1, 2, 3, 4a, 4b and 4c show a good enough correlation with clusters 1-6. The single samples only have occurred out of this correlation (Tab. 5-25.).

Clusters 5a, 5b and 6 show another picture. The samples from these clusters are irregularly distributed over clusters 7 – 13. Most likely slag of these clusters was obtained from either the smelting of mixed ores or more intensive use of alloying components.

Clusters 1 and 2 are presented by slag found on the Abashevo settlement of Tyubyak. Only one sample from the Ustye settlement falls in cluster 2. Cluster 3 is presented by five samples from Ustye and two from Tyubyak (Tab. 5-24.). It is difficult to say now either metallurgists of both these settlements used the same ore sources or different mines with similar chemical characteristics. The first supposition seems strange as these settlements are divided by a long distance. However, up to the obtaining of other dates such a supposition may be discussed.

These clusters are characterized by very high concentrations of Ag and As (except for cluster 1) and low concentrations of Co, and clusters 1, 3 differ also by low concentrations of Ni (Fig. 5-26., Fig. 5-27., Fig. 5-28.). The difference between both last clusters is visible on the diagram Ti-Sr (Fig. 5-29.)., and, at the lesser extent, at the diagram As-Pb (Fig. 5-27.). Besides, cluster 3 is characterized by higher concentrations of Pb, which is typical, as a whole, of ore from Ustye (Tab. 4-10., Fig. 4-4., Fig. 4-9.). Except for one sample, slag of cluster 1 relates to the 2nd and 4th mineralogical groups and had been obtained from the smelting ores from quartz rock (Tab. 5-30.). Cluster 3 falls, as a whole, in the same mineralogical groups, but one sample relates to 1st group (from serpentine or ultrabasic rock) and one more sample does to 3rd group, which demonstrates the use of both ores: from quartz and serpentine. The first of these samples may be explained by analytical or statistical error. The samples of cluster 2 relate to the 1st and 3rd mineralogical groups and they are distinguished from other two clusters by higher concentrations of Cr (Fig. 5-28.). Chemically cluster 3 is comparable with ore from the Tash-Kazgan mine because of low concentrations of Ni, Co, Pb, Zn, Cr and high concentrations of Ag and As. Samples of these clusters are dated to the Sintashta-Abashevo period.

Sub-clusters 4a, 4b and 4c are very similar and this does not allow to separate three different clusters on this base (Fig. 5-31., Fig. 5-32.). This dividing has been obtained on such small differences, which could not allow in other cases sub-clusters to be separated. This cluster is characterized by high concentrations of Pb, Zn, Mn and low concentrations of Cr. In addition, sub-cluster 4a is characterized by high concentrations of Co and Ag and low concentrations of Ni; sub-cluster 4b differs by high concentrations of Co and Ba, and sub-cluster 4c does by high concentrations of Ge, Ag and As and relatively low concentrations of Co and Ni.

But in this case the sub-clusters obtained can be well correlated with sites and epochs (Tab. 5-33., Tab. 5-34.). Sub-cluster 4a is represented by eight samples from Arkaim. Therefore, all these samples belong to the Sintashta period. Sub-cluster 4b consists of eight samples: five from Ustye, two from Semiozerki and one from Rodniki. Besides, all samples from Ustye were found in the Petrovka layer of this settlement.

Therefore, all samples are dated to the Petrovka period[4]. Sub-cluster 4c consists of seven samples: three from the Sintashta levels of the Ustye settlement, one from Sintashta, one from *Burli* and two from Sergeevka. This means that this sub-cluster is to be dated to the Sintashta period.

Sub-clusters 4a and 4b belong mainly to 2nd mineralogical group and this slag was obtained at the smelting of ores from quartz rock. The samples of sub-cluster 4c (all from Ustye) investigated mineralogically relate to 1st group, but they are somewhat differ from other samples of this group because instead of chromite grains they include magnetite grains with similar shape (Tab. 5-30.). So, the ore could originate from deposits of any type, but most probably from the ultrabasic rock.

Chemically the whole this cluster is close to the clusters 5 and 6 distinguished for ore. The distribution of slag and ore samples over sites allows us to connect cluster 4a (slag) with cluster 5 (ore) and cluster 4c (slag) with cluster 6 (ore), except for samples from Tash-Kazgan, whose relation to this group is unclear (Tab. 4-10., Tab. 5-24.). However, it is quite possible because the ores of the clusters 5 and 6 are represented by malachite and malachite in limonite, which does not allow them to be related to any concrete type of deposits (Tab. 4-11.). And, as we have seen, slag of the described cluster was either connected or can be connected with a deposit in quartz rock. Only low concentrations of Pb and Zn in Tash-Kazgan ores are contrary to such a supposition. So, we may speak in this case about the use of the Tash-Kazgan mine and/or one or two mines with similar chemical characteristics.

Cluster 5 has a very broad distribution of elements and this slag was obtained, probably, as a result of mixing different ores. This cluster is the larger in the whole sampling and consists of 76 samples (Fig. 5-35., Fig. 5-36., Fig. 5-37.). The samples of this cluster are present on all Sintashta sites (Tab. 5-24.). They show high concentrations of Cr, which may be explained by that all of them belong to the 1st and 3rd mineralogical groups, and this slag was obtained at smelting ores from serpentine and ultrabasic rocks (Tab. 5-30.).

Two sub-clusters have been separated within this cluster. Sub-cluster 5a is characterized by low concentrations of Pb, Zn and Ag. Sub-cluster 5b shows high concentration of Ni and Co and relatively higher As concentrations. This may be explained by more intensive alloying with minerals having high concentrations of these elements.

Cluster 6 may be distinguished from cluster 5 because of lower concentrations of Ni, Co, Cr, Ag and As (Fig. 5-37.). As well as in the case with ore, the reliability of separation of this cluster is little because the program throws into it those samples whose relation to other clusters is questionable. The cluster includes samples belonging to both serpentine and quartz types (Tab. 5-30.). Therefore, very likely a part of the samples should be related to cluster 5.

Thus, only the clusters 1, 2, 3 and 4 may be connected in the future with particular deposits. The clusters 5 and 6 are, probably, products of mixing ore (for example, copper ore and some arsenic minerals). These clusters include the majority of slag materials (70 %) (Tab. 5-33.).

Clusters 1 and 3 being comparable chemically with Tash-Kazgan ores allow us to discuss a possibility of the use of this ore by metallurgists of the Tyubyak and Ustye settlements. Two ore samples from Ustye have fallen in the same cluster as Tash-Kazgan ores. Besides, the ore samples from Burli and Sergeevka have been included in the same cluster, although they have higher concentrations of Zn. Therefore, it is necessary to pay an attention to that the sub-cluster 4c distinguished for slag includes samples from Ustye, Sergeevka and Burli too (Tab. 5-24.). Thus, the distribution of ores from Tash-Kazgan or from any mine with similar geochemistry to the east is quite possible. Finally, we may speak about connections between metallurgy

[4] We remember also that ore cluster 4, presented by ores from Ustye, has shown higher Ba, Mn and Pb concentrations too.

of the Ustye settlement of the Sintashta period with metallurgy of the Eneolithic (Burli) and Early Bronze Age (Sergeevka) settlements in Kazakhstan, which is quite explainable against a background of eastern localization of the Ustye settlement inside Sintashta culture and Sintashta impulses to the east, resulted in the appearance of Petrovka culture in Kazakhstan.

The presence of slag of the same sub-cluster (4b) in the Petrovka cultural levels in the Transurals (Ustye, Rodniki) and Kazakhstan (Semiozerki) shows the continuation of these communications, though this may be also explained by impulses from Kazakhstan during the formation of Petrovka culture in the Transurals, which took place, above all, in the Tobol basin.

Discussing the distribution of different clusters over cultural groups, we can say that clusters 1, 2, 3, 4a, 4c, 5 and 6 were most typical of the Sintashta-Abashevo period. Clusters 4b, 5 and 6 were typical already of the Petrovka period. The last two clusters allow us to emphasize a certain succession between Sintashta and Petrovka metallurgy, although the latter was based already on other technological principles (Tab. 5-33., Tab. 5-34.).

It is also possible to discuss long-distance connections between metallurgists from Tyubyak and Ustye. The slag of clusters 2 and 3 are common for these settlements. Besides, slag of sub-cluster 4b (Ustye and some other sites) demonstrates high concentrations of Ba, which is not typical of other clusters, except for cluster 1, presented by slag from Tyubyak. Unfortunately, ore from Tyubyak has been not investigated by spectral analysis, but investigation by SEM of ore sample from Tyubyak (Tab. 5-4., Tab. 5-5., 1921, an. 1) has detected a mineral with 16.79% of this element. On this stage we are not able to explain this probable connection.

Conclusions

The analysis conducted allows us while in the most general features to reveal some regularities. The ore fields in ultrabasic serpentinized rocks were exploited as the main ore source during the Sintashta period. Alongside them on all settlements of the area small ore sources in quartz, and on the Ustye settlement also in iron hydroxides were used. It is now very difficult to link any distinguished clusters with concrete ore mines. Probably, it is necessary to refuse the ore mine of Maily-Yurt as the main source of the ore in serpentine. As it has been shown by the investigations of ores used on the settlement of Sintashta, the exploited ore deposit related to the porphyry type. Therefore, there is a lot of barren rock, but the waste heaps on Maily-Yurt are rather small. Only cluster 3 can be connected with this mine, and we may suppose that people from the settlement of Sintashta exploited it. It is much more likely to search for the main sources of ore in serpentine in the Transurals: in the southern zone of the Chelyabinsk area or in neighboring regions.

The sources serving as raw for the occurrence of other groups of slag are, apparently, very small and were located nearby settlements. One of these sources was the ore mine of Vorovskaya Yama (Zaykov *et al.* 1995). According to calculations, about ten tons of copper had been extracted from this mine, although this seems to be an overvaluation. By the same calculations a coefficient of metal extraction from ore of this mine was 10%, which corresponds to evidence calculated in this work on the basis of the slag investigation. It is possible that not a single slag cluster was connected with this mine, as the nature of ore and gangue varies on its different levels. However, a verification of this position requires a special analysis.

It is problematic to connect slag, obtained from smelting ore from quartz rocks, with the mine of Tash-Kazgan, as this slag has low arsenic concentrations. In the result of the spectral analysis of ore from settlements the high concentrations of arsenic and silver has been detected only in several ochre samples from the settlements of Arkaim, Ustye, Sergeevka, Burli and samples from the Tash-Kazgan mine itself. However, they are not fully identical to the Tash-Kazgan ore.

Analysis of chromite in slag

As it was discussed in the Introduction, it is a serious problem in archaeometallurgy to link ore, slag and metal found on sites, with concrete mines. In relation to Sintashta culture it has been succeeded to outline a solution of this problem based on analysis of chromite in slag and ores connected with the ultrabasic rocks[5]. Because, as the above described mineralogical investigations have demonstrated, the most part of slag of this culture was connected with fields of this type. Studies of specialists of the Institute of Mineralogy (Miass) have revealed in the Transurals several deposits of this type with traces of ancient mining: Vorovskaya Yama, Dergamysh, Ishkinino, Ivanovka, Elenovka (Zaykov *et al.* 1995, 1999, 2000, 2002).

Initially, for this purpose 17 analyses of chromite inclusions in slag from settlements and ore of some mines have been used (Tab. 5-4.). Besides, published data on chromites of some deposits were used (Melekestseva *et al.* 2001).

Based on these analyses phase diagram Fe_2O_3 – Al_2O_3 – Cr_2O_3 for chromites has revealed a partly disperse picture, although all samples belong probably to very similar deposits. Comparison of this diagram with the diagram received on the basis of analyses of chromites in ore from Ishkinino, Ivanovka and Dergamysh deposits has shown that the studied samples differ from samples of the Dergamysh field, but can be compared with samples from Ishkinino and Ivanovka (Fig. 5-38., Fig. 5-39.). Thus, chromites from Ivanovka, although are similar, nevertheless differ by lower contents of Cr_2O_3. Chromites from the Ishkinino field entirely correspond to chromites in slags from Arkaim, Sintashta and Semiozerki II (Grigoriev, 2003a). Besides, many chromites from Ishkinino and Ivanovka fields have a magnetite border (Melekestseva *et al.* 2001) that we have repeatedly observed in Sintashta slag.

However, the comparison of other chemical characteristics has demonstrated not so unambiguous picture. Chromites from the Ishkinino field contain some higher concentrations of titan that seldom is present in chromites of slag from the Sintashta settlements. But in the chromites of Ishkinino field higher concentration of titan are found on edges of grain, and analyses of chromites from the Sintashta settlements have been done in the grain center. Nevertheless, in some samples the titan has been revealed (sample 3, an. 1Wdh.; sample 751, an. 1Wdh.) (Tab. 5-4.). In addition to this on this field arsenical minerals have been also found. This field shows higher concentrations of nickel in ore that is quite characteristic of the Sintashta slag connected with the ultrabasic rocks. Besides, ore bearing rocks of the field are presented not only by serpentine, but also carbon-siliceous slates which in some instances accompany serpentines, and such samples have been found on the settlement of Sintashta.

All this has given the grounds for an assumption about primary connection of Sintashta metallurgy either with this field or with a field of this type. As the method has turned out rather perspective, on its basis in collaboration with scientists of the Institute of Mineralogy (Miass) a project on studying chromites in ore and slag of this period has been realized (Grigoriev *et al.* 2005; Zaykov *et al*. 2005, 2005a; Dunaev *et al.* 2006, 2006a). Within this project 269 analyses of chemical composition of chromites on the electronic microscope have been made. For the correctness of comparison the grains were analyzed in the center. Besides not only chemical comparison has been carried out, but also the comparison of shapes of chromites in slag and ore from particular fields.

In all studied slags chromites are presented by euhedral and subhedral, seldom round grains, with the size of 0.1-1mm, frequently with silicate inclusions. Many crystals have a magnetite border, up to 75 µm. In most cases the border has a simple structure, with regular internal borders with the chromite. As it was noted above, at the description of slag mineralogy, the content of chromite inclusions fluctuates within 1-5%. Ores of the

[5] The author is thankful to Khachatur Meliksetian from the Armenian Institute of Geology who suggested this way.

Ishkinino field contain inclusions of the euhedral and subhedral chromites of the octahedral crystal habit with prevailing sizes of 0.5-1mm. The amount of grains is from 1 to 4% of the volume. For them magnetite and chrom-magnetite borders tens microns thick are typical and roundish inclusions of silicate materials of molten rock. All this completely corresponds to the character of chromites in slag. Moreover, their slightly lesser content in ore is well explained by metallurgical processes as copper does not go so actively into slag. Therefore, this indicator of ore from this field is identical to that of Sintashta slag.

Chromites of the Ivanovka fields have similar morphology and sizes, but practically do not contain silicate inclusions and magnetite borders. In ores of the Dergamysh field the chromite inclusions are rare, they have the sizes of 0.1-0.3mm. Chromites from serpentines of the mine of Vorovskaya Yama are, mainly, presented by subhedral and amoeba-shaped grains, the sizes about 0.3 mm. Often the grains are broken by microcracks. They differ from the majority of chromites studied in slags too.

The comparison of such large series of microprobe analyses has shown some regularity. From the analyses it follows that the chemical composition of chromites shows strong fluctuations (Tab. 5-40., Tab. 5-41.). And, it is shown as at the comparison of analyses from different places, as well as at the comparison of chromites in one slag/ore sample. Therefore, as well as in the case with any other chemical analyses, this method does not allow us to identify authentically the belonging of a concrete individual sample to a concrete individual field. Any conclusions are possible only on the base of comparisons of a statistically reliable sampling.

In ore from the Ishkinino field the fluctuation of ratio 100Cr / (Cr+Al) is rather insignificant: 62.98-74.91%, with the average value of 69.78%. In ore from Vorovskaya Yama this fluctuation is much higher – 26.68-70.95% (the average value of 62% because only single samples show low values). On the Ivanovka field the ratio varies within 58.86-89.98%, and on Dergamysh – within 60.12-83.77%.

In slags this indicator is characterized by certain dispersion too. It is not as large as in the ore from Vorovskaya Yama, and is closer to ores from the Ishkinino, Ivanovka and Dergamysh fields. The larger dispersion is shown by the samples from Ustye (48.92-82.35%) and Kuysak (58.72-82.90%). Another indicator is ratio of 100Mg / (Mg+Fe2 +): chromites of Ishkinino ores get to the range of 38.90-57.00% with the average value of 46.03%, chromites of Vorovskaya Yama ores are in the larger range of 6.30-84.40%, showing the close average values of 47.15%, and the indicators of Ivanovka is 29.50-68.20%, and those of Dergamysh – 22.11-65.35%. In slag the larger dispersion is shown by the chromites from the settlements of Ustye, Rodniki, Kuysak and Sintashta, where are also the layers of the beginning of the Late Bronze Age. It creates a possibility of exploitation of the mine of Vorovskaya Yama or chemically similar mine, mainly, during this period. The coefficients of ferruginosity demonstrate a similar situation: low values of this indicator in samples from Vorovskaya Yama, Kuysak, Rodniki and Ustye. The total values of all these indicators for actually Sintashta sites are rather similar to Ishkinino (to a lesser extent to the Ivanovka and Dergamysh fields), but after all, they are not completely identical. The chemical proximity of chromites from Ishkinino to the chromites in slag is well shown by diagrams of distributions of chromity (Cr#) and magnesity (Mg#) of chromites in slag from settlements and ores from the Ishkinino field (Fig. 5-42., Fig. 5-43.), in which the sulfide and oxidized ores are considered separately. Peaks of intervals of Cr# of the chromites in ores from the Ishkinino field and those of slag coincide completely. The Mg# indicator demonstrates the wide range of fluctuations; however it is in the common limits, excepting the Alandskoe settlement for which more magnesian chromites are typical.

An important indicator is the content of titan. On the Ishkinino field it is rather stable within 0.25-0.35%. On Vorovskaya Yama the titan is absent. On the Ivanovka and Dergamysh fields titan reaches 0.28% and 0.39% respectively. In slag the dispersion of the titan content is larger, and on all the sites it begins from zero values (Fig. 5-44.). The above-mentioned fields fall within this range, but nowhere we see such great dispersion.

From this it is possible to draw a conclusion that the ore base of the settlements was not, usually, limited by any single deposit in the ultrabasic rock. Especially it concerns such settlements as Sintashta, Kuysak and Ustye where are not only Sintashta, but also later layers. It does not mean, of course, that during each separate period more than one deposit was exploited. They could be exploited one after another. We have, nevertheless, a total picture.

As it follows from tables 5-24 and 5-30, the spectral analyses has also allowed to believe that more than one deposit in the ultrabasic rock was exploited, and, samples of the same sub-cluster connected with the ultrabasic rock, can be distributed over different settlements, but, at the same time, on one settlement there are the samples related to different sub-clusters. At the comparison of chemical compositions of chromites in slag from Sintashta and Ustye with compositions of chromites from the mines (Fig. 5-45.) the difference in the configuration of fields for these two settlements is quite distinctly visible. Besides, if for miners of the settlement of Ustye it is possible to assume the exploitation of all compared mines, the miners of the settlement of Sintashta obviously did not use the mines of Vorovskaya Yama and Dergamysh. At the same time, the fields for chromites from the settlements leave areas of fields of all mines in the ultrabasic rocks known today. From this it is possible to draw a quite sure conclusion that the ore base of the Sintashta time was not limited by these fields known to us, and in this area there are any others while unknown mines which have to fill these unmatched fields.

Conclusions

Summarizing everything told above about the shape, inclusions and chemical compositions of chromites, it is possible to draw the following conclusions. The most acceptable candidate for consideration as the main ore base in the ultrabasic rock of Sintashta culture is the mine of Ishkinino. However, the exploitation of mines of Dergamysh and Ivanovka in more limited scales is possible. The exploitation and the mining of Vorovskaya Yama are probable too, but since the transition to the Late Bronze Age. In addition to the above-mentioned mines, some other unknown mines of this type were obviously exploited.

The mines of the Sintashta period

As it was already spoken above, in recent years within the area of Sintashta culture a series of copper deposits in the ultrabasic serpentinized rocks have been found, with traces of ancient mines.

Vorovskaya Yama ("The Thieves' Pit") became the first such mine (Zaykov *et al.* 1995, 2000; 2005a). It was named so for the reasons that in this mine the stolen cattle was hided. The mine is situated on the left bank of the Zingeika River, directly within the area of the Sintashta settlements. The ore bearing rocks on the field are serpentine, talc, epidosite, basalts and siliceous rocks, and the ores are, mainly, malachite.

The open pit is 30-40m in diameter and 3-5m in depth. As it is partly filled with late deposits, its initial depth is about 6-7m. The dumps 5-15m in width and 0.8-1.5m in height are situated around the pit.

The studies of the mine have revealed that it was exploited three periods, because the dumps are divided by layers of buried soil that formed during the periods when the mine was not used.

Near the east end of the northern dump a cultural layer has been found covered by the dump. It consists of two horizons containing ashes, bones of animals and Alakul-Timber-Grave ware of the beginning of the Late Bronze Age. On the surface the Sintashta-Petrovka ceramics has been collected. Respectively, the transition from the Middle Bronze Age to the Late Bronze Age is the most probable period of work on the mine, which corresponds to the conclusions drawn on the base of the analysis of chromites.

Dergamysh deposit (Zaykov *et al.* 2001, 2005a) is situated on the left bank of the Tashla River near the village of Akjyar (Bashkortostan). The ore-bearing zone with the thickness from 6.5 to 40 m is situated on the contact of serpentine and pyroxenite plates. On the deposit an ancient open pit, 70-80m long and 10-12m deep, surrounded with a dump up to 3m high has been found. The dumps have been found also on the bottom of the pit. The copper mineralization (malachite and chrysocolla) is shown in northern and eastern sides of the pit, in serpentine detritus. Judging from the presence of the pit and the analysis of chromites, the mine could be used in the Sintashta time, although archeological finds confirming it have not been revealed.

The **Ivanovka deposit** is situated 10km to the north, on the river Dergamysh. It is connected with the contact of serpentine and basalt plates. The ore has chalcopyrite-pyrrhotite compound, there are as compact ores as well as in small veins and inclusions. The ancient mine on the deposit is presented by a trench 50m in length and 1-2m in depth. Respectively, the volumes of works were not too significant. The dating material has not been found.

The largest ancient mines have been found on the **Ishkinino deposit** (Zaykov *et al.* 2001, 2005a; Yuminov, Zaykov, 2002, 2002a). It is located 20 km to the west of the town Gay (Orenburg region) in a hilly terrain on the left bank of the river Sukhaya Guberlya. The field is connected with serpentines, carbonate and talc-carbonate apodunite-serpentinitic metasomatites. There are pyrite-pyrrhotite, chalcopyrite-pyrite-pyrrhotite and sulfoarsenic-sulfidic ores.

On several places of the field eight ancient open pits have been revealed. The largest of them was 120 m in length, up to 40 m in width and 5-15m in depth. One of the pit dumps has been investigated by a trench in which bones of animals have been found only. In the dump the excavations revealed three horizons divided by buried soils pointing to interruption of mining for some long time. In addition to this, the dumps contain ashes layers which testify the use of fire for rock crashing.

In the lowest horizon of the dumps the ore store has been found, that sheds light on the organization of works on the mine. It is represented by a lens put from small (from 1 to 15 cm) pieces of oxidized ore. The thickness of the lens is 0.6m and the length more than 4 m (it can be longer because has not been unearthed completely). The analysis of ore has shown that it contains a lot of iron (this means, that in case of smelting of this ore it should be easier to form the basic slag) and high concentrations of arsenic (Tab. 5-46.). In principle, the presence of arsenic is characteristic of this field, and when smelting the ore of similar compound it would be quite possible to produce arsenic bronzes, characteristic of Sintashta metallurgy, but we will consider this question below in more detail. There are also the increased concentrations of nickel, characteristic of the Sintashta slag smelted from ores of this type.

This ore-store was covered by barren rock that points to aspiration to hide the ore, and a layer of buried soil was formed above. The store of ore testifies that ore was extracted and stored during a certain season. Its export had been carrying out, apparently, after the end of these seasonal works; it is possible at the same time when miners came back to the settlements. It should be also noted that this ore was not taken out because of any crisis events which interrupted works on the mine, and the people knowing about this store, could not return to it.

A similar ore-store (No. 2) has been found also above, on the middle horizon of the dumps that points to the repetition of the situation. Thus, on the Ishkinino mine we see the same situation of three phases of its exploitation and double cessation of the work, as on the mine of Vorovskaya Yama. Possibly, it was connected with some crisis phenomena which grabbed rather wide area of Sintashta culture. As the smelting of this type of ores took place in this area only during the Sintashta period and at the very beginning of the Late Bronze Age, the last crisis was obviously caused by coming of tribes from the east and formation of the Petrovka, early Timber-Grave and early Alakul cultures here. But there was also some previous event of similar character that is not caught yet archaeologically. Therefore it is not excluded that some internal conflict inside the Sintashta tribes or an epidemic of catastrophic character took place.

Taking into account the revealed similarity of chromites from ores of the Ishkinino field with chromites from the most Sintashta slags, and also taking into account the considerable amount of works carried out on this mine, it is necessary to recognize that it was the main mine in the Sintashta time.

One more mine used, probably, in the Sintashta period, is the well-known **Elenovka mine** in Eastern Orenburg area, near which E.E. Kuzmina has realized an archaeological project (Kuzmina, 1962). Around the mine she has found traces of metallurgical production and ceramics of the Alakul period. Therefore the mine was exploited, mainly, during this period, however recently some evidences appeared that this exploitation was started here already in the Sintashta period. This deposit differs from the above described fields in the serpentinized ultrabasic rocks. The ore is situated in quartz-chlorite-tourmaline rocks and basalts. The ore body has a large extent up to 130 m in length and 120 m in depth, the oxidation zone is well developed, and the richest mineralization is located, as usual, in the zone of secondary sulfide enrichment (Bushmakin, Zaykov 1998; Zaykov *et al.* 2005a).

As the tourmaline-containing ores, similar to those in Elenovka, have been found on the settlement of Arkaim, and in slags of this settlement impurity of boron present in tourmaline has been detected, the assumption about the use of this mine by metallurgists of this settlement seems to be quite reasonable, especially as it is a rather rare type of deposits (Bushmakin, Zaykov 1998). As the boron has been detected in many slags of this settlement, it is very probable that a very large proportion of slag of the 2nd mineralogical group (connected with quartz rocks), was smelted from ore of this deposit. Unfortunately, we cannot assert the same in relation to slags of other settlements as the huge number of the analyses was not capable to catch this element. We can only allow a similar thought, as well as a possibility of exploitation of other fields in quartz rocks widespread in the Urals.

Near the settlements no mines have been found. Recently the attempts to search for such mines have been done, being guided by small pits and dumps near the settlement of Olgino and by known small deposits to the north from the settlement of Stepnoe. But in the first instance there was no copper mineralization, and in the second no traces of mining have been found (Hanks, Doonan 2009, p. 344, 350).

Conclusions

All above-mentioned fields (Ivanovka, Dergamysh, Ishkinino, Vorovskaya Yama, and Elenovka) have large ancient pits, and their ores correspond to the both ore and slag found on the Sintashta settlements. The carried-out analysis has shown that all of them were exploited during this period, although some other fields, both in ultrabasic and quartz rocks were used too. But these fields, most likely, played a supporting role. Ishkinino was the main mine during this period.

It is an intriguing fact that except for Vorovskaya Yama all these mines are situated on a large distance from the area of Sintashta settlements, although in their areas Sintashta cemeteries are known. It suggests an idea of any special, seasonal way of exploitation of these territories that is confirmed also by the presence of ore-stores on the Ishkinino mine.

On two rather remote mines three phases of exploitation have been recorded, divided by long periods when the works were stopped. It is not excluded that it was connected with some crisis processes: one at the transition to the Late Bronze Age, and another in some earlier time. However, it is possible to assume a possibility that the interruption of works, recorded by particular trenches, means only a temporary termination of production in these concrete places, and its transfer to other places of the same mine. And the existence on two mines of identical quantity of phases of production and cessation of work may be explained by an accidental coincidence. It is less probable variant, but we have to allow it, nevertheless, until radio-carbon dating of buried soils will be made and won't be shown that the periods of cessation of works on both mines coincide.

Problem of arsenic bronzes

Everywhere the earliest type of bronzes was arsenic alloy (Muhly 1976, p. 90). For Northern Eurasia this thesis is true too. In the Sintashta-Abashevo period a large proportion of metal here contains arsenic. This metal has been combined by E.N. Chernikh in the group TK (Chernikh 1970, p. 15). He divides the metal of this chronological horizon into two chemico-metallurgical groups: TK and MP. It has been supposed that the former was obtained from smelting ores from the deposit of Tash-Kazgan, and the latter from sandstones of the Western Urals. The quantity of artifacts, referred to each of these groups, is approximately identical (Chernikh 1970, p. 28). However, as ornaments were made predominantly of the MP copper, and tools and weapons of the TK copper, the weight proportion was different.

Because our research of slag and ore of this period has shown, they are connected with absolutely other deposits; therefore the question arises about the nature of the TK group. I have already written that it was not connected with the mine of Tash-Kazgan (Grigoriev 1994, 2000, p. 500-510). This conclusion was based, in particular, on that the main part of ores used in this time was delivered from mines in the ultrabasic rocks, but the Tash-Kazgan mine does not belong to this type. However the above-stated conclusions that the Ishkinino mine was one of the main sources, and also that this mine has higher concentrations of arsenic in ore or in the form of arsenic minerals actualize this problem again and forces us to return to it.

The basis for further reasoning is the conclusion of E. Chernykh that during smelting the contents of arsenic increases ten times in metal and, accordingly, decreases in slag Chernykh (1970 p. 11). Earlier analyses of slag of modern metallurgical production gave similar results: 65.2% arsenic remains in copper, 16.8% in slag, 18% is sublimated (Tafel 1951, p. 405). R.F. Tylecote carried out a very interesting research of arsenic at ore smelting. As a result of smelting experiments with oxidized ores the contents of As and Ni in copper increased. At smelting of sulfides the contents of all trace elements decreased. Even arsenic left the metal almost fully. This was a reason of the purity of metal of the Late Bronze Age in Western Europe. In view of a greater pollution of sulfide ores, the purity of metal may be explained by higher temperatures and subsequent refining in a crucible (Tylecote 1980, p. 7). The important observations have been made also by another group of English scientists. It was clarified experimentally that at the temperature below 950 °C the contents of arsenic in copper in comparison with ore does not change essentially. Further the contents of arsenic start drastically to increase. At temperature about 1300°C almost all arsenic passes into metal (Pollard *et al.* 1990, p. 130-132).

Our experiments have shown invariable decrease of the content of arsenic in slag too. However, the comparison of all available analyses of ore discussed in the Introduction with the analyses of slag allows us to assume that the coefficient of this transition is not 10 as assumed by E.N. Chernykh; it is 1.31 that is closer to the coefficient suggested by Tafel. But it is not excluded that it is the case when statistical studies does not reflect as adequately a picture as the concrete ones do. Nevertheless, despite the imperfect analytical equipment E.N. Chernykh analyzed ore, metal and slag from the same slag pieces. But irrespective of the fact which figures are closer to the truth (they vary depending on smelting parameters) it is possible to note with confidence that in case of smelting of the oxidized ore the content of arsenic in slag considerably decreases, and in metal increases.

According to state above, the approximate limit of the arsenic contents in ore, which was necessary to obtain arsenic bronze, should be 0.1% (if to be based on the coefficient of Chernykh). Among the investigated ores only samples from Tash-Kazgan and limonite ore from Arkaim correspond to this condition. All other ores contain arsenic less of this limit. In case of assumption of other coefficients (for example, 1.31 as it is supposed for the oxidized ores in the Introduction) only one ore sample from Tash-Kazgan is capable to give arsenic bronze.

For slag this limit of arsenic bronzes should be about 0.01% (at the base on the same coefficient of Chernykh). However, we see the inverse relationship here. Considerably smaller quantity of samples demonstrates low concentrations of arsenic. The most part can be connected with arsenic bronzes.

The presence in slag of more than 0.003% arsenic corresponds to the arsenic concentrations in copper above 0.3%, which is also characteristic of the TK group. In this case almost all investigated slag samples fall in this group. At the same time, it is unlikely to guess that all ore deposits, exploited at this time, had such chemical composition as that of Tash-Kazgan. Low concentrations of arsenic in ore have been indicated also by the emission spectral analysis of ore from settlements.

The comparison of frequency diagrams of slag and ore shows that the pyramid of arsenic contents in slag is shifted to the right relatively to the pyramid of ore (Fig. 5-47.). It is possible to see from the diagram of ore that with the exception of samples from Tash-Kazgan and limonite samples from Arkaim almost all samples are within the range of 0-0.03%, which at smelting could not give metal, in which the concentrations of arsenic exceed 0.3%.

This situation with ore is contrary to the metal of the Sintashta sites. Scholars have already distinguished a group of arsenic bronzes, but the most part of metal which has not been related to this group, contains, nevertheless, the higher concentration of arsenic (Zaykova 1995). We have carried out XRF analyses of metal objects of the Sintashta-Abashevo time (Tab. 5-48.). It is possible to divide these objects into three groups (Fig. 5-49.): low-arsenical (0-0.3%), middle-arsenical (0.3-1%) and high-arsenical (more than 1%). Two first groups contain 28.41% of samples, and the third – 43.18%. Respectively, 71.59% of the analyzed objects correspond to chemico-metallurgical group TK that fully corresponds to the parameters of Sintashta metallurgy known earlier. Degtyareva relates to the group alloyed with arsenic about 80% of metal, but she supposes that the lower limit of this group is 0.1% (Degtyareva 2010, p. 83)[6].

However, analyses of metal look slightly differently (information has been kindly presented by S.A. Agapov and S.V. Kuzminikh). On the settlement of Sintashta artifacts made of arsenic bronzes account 53.9%, and on the cemetery they reach 67.3%. A similar picture has been revealed also by other investigators (Zaykova 1995), but it is necessary to note that there is a cultural layer of the Late Bronze Age on the settlement, and the arsenic bronzes were not so typical of this period. On the settlement of Ustye a part of arsenic bronzes is much less: 17%, which is explained by the presence of the Late Bronze Age layer.

But anyway metal of the Sintashta settlements sharply differs from ore of the same settlements. This metal cannot be smelted from this ore. Thus, as it was already discussed, Tash-Kazgan's ore has different mineralogy than the ores used on these settlements. Should we assume a wide use of ores from the Ishkinino mine containing arsenic too? Certainly, it took place. But there is a question: whether it was enough for smelting arsenical bronzes? Three analyses of this ore given above (Tab. 5-46.) has shown that the content of arsenic in the ore which has been selected for smelting fluctuates in the range of 0.6-1% that allowed to produce this metal. But it is single analyses, besides, XRF analyses giving a weak representation about the composition of such heterogeneous system as ore. And if to be based on the made above conclusions from

[6] Probably, it is true, but the definition of exact borders for arsenic concentrations is really difficult challenge taking into account the way of alloying which was applied in Sintashta metallurgy, partial sublimation of arsenic at metalworking, alloy of different metal scrap, etc. Therefore the concrete figures of the alloyed metal can vary, depending on an assessment of this or that researcher, but it does not influence in any way upon the general situation of the production.

analyses of chromites, the ore of the Ishkinino mine is well presented on the Sintashta settlements. And we come back to the fact of total lack of arsenic in the ore of settlements.

If we assume that high-arsenical ores from Tash-Kazgan or Ishkinino were highly appreciated and were not left in a settlement layer, they were added to other ores as an alloying component, this assumption will not be true too. Such mixes would reduce concentration of arsenic in bronzes therefore arsenical ores would be well presented in furnace charge, and they would get to our rather large series of analyses. Single samples of ore show really high content of arsenic, and one of the ways of these bronzes production could be really this, but the part of this way was insignificant.

It is possible to suppose that high-arsenical ore (from Tash-Kazgan, Ishkinino and other probable mines) had been smelted anywhere on other settlements; and after this this metal was distributed over the Sintashta-Abashevo area. On the investigated settlements only limited smelting ores for domestic needs took place.

Such an approach is partly fair, but only partly. On the Abashevo settlements of Balanbash and Malokizilskoye slag and ore, comparable with those of Tash-Kazgan have been found (Chernikh 1970, p. 171). However, capabilities for a sure connection of ore with a particular mine by means of the emission spectral analysis are more than limited. Investigated samples of slag from the settlement of Malokizilskoye, are identical in the microstructure to the samples from Tash-Kazgan, but a similar microstructure could be obtained from smelting ore from any field in quartz rock. On the Urnyak settlement only one of seven analyzed ore samples has shown the high contents of arsenic. In others arsenic misses. However, slag of this settlement invariably demonstrates the high contents of this element (Chernikh 1970, p. 171, tab. XVI), which resembles a situation in the Transurals. And this is fundamentally important.

Slags of the Transural settlements contain arsenic. So, we come nearer to the last variant of this problem solution, which seems the most reasonable. The presence of arsenic bronzes on the Sintashta sites against a background of the absence of ores with arsenic may be explained only by the use of the corresponding ligatures. The local production of these bronzes is indicated by the presence of arsenic in slag. This is a testimony that the alloying was made at the stage of ore smelting. At the Fig. 5-47. it is well visible that contrary to an anticipated decrease of arsenic concentrations in slag, in comparison with ore, they increase. In case of displacement of the frequency diagram of distribution of concentrations of arsenic in slag in the direction of increase, we obtain a diagram corresponding to concentrations of arsenic in arsenic bronzes. And that, as a whole, corresponds to regularities of the dividing of arsenic between slag and metal during the smelting, which has been repeatedly discussed above. At any coefficient of this transition, the content of arsenic has to decrease in slag, but it grows.

Thus, it is possible to talk about the conformity of the Transural slag of the Sintashta period to the Transural metal. If we accept 0.01% of the arsenic contents as a conditional limit marking slag obtained after producing arsenic bronzes (namely this value has been indicated by the double-peak diagram of arsenic for slag of the Tyubyak settlement), the proportion of produced bronzes will be following: Arkaim – 71.7%, Tyubyak – 62%, Ustye – 82%, all Ural sites of the Sintashta-Abashevo period – 63%. However, as a part of the interval 0.01 – 0.03% may mark the smelting of pure copper, the proportion of As-bronzes can some decrease.

Above we have seen that the proportion of arsenic metal fluctuates in the range of 50-70%. Therefore, this evidence corresponds to the general picture of the Sintashta-Abashevo metalworking. But on the settlement of Ustye, where the proportion of arsenic bronzes is only 17%, so significant amount of arsenic slag, on the face of it, raises doubts. Apparently, it may be explained by the follows: if the largest part of slag is dated, as said above, to the Sintashta period, the metal relates more often to the Petrovka period. This, as a whole, corresponds to the nature of both Sintashta and Petrovka settlements. If on the formers metal occurs rather as an exception (the significant proportion of metal of the settlement of Sintashta concerns, apparently, to the layer of the Late Bronze Age), there is a great number of metal artifacts on the Petrovka settlements.

Thus, arsenical metal was produced, mainly, by alloying at the stage of ore smelting, and less often by smelting of copper-arsenic ores. But what could be used as an alloying component? It is a very difficult question as this component is not presented in the analyzed series where slags and copper ores were selected only. It could remain initially on settlements in the form of rare samples, but could also be not identified during the excavations and not taken in the collection. Several years ago even slags often have not been taken in the collections.

In slags this alloying component could be strongly changed and therefore it has not been identified by mineralogical analyses. Therefore it is necessary to consider attentively the available analyses which can allow us this component to reveal.

The fact attracts attention that the 2nd mineralogical group (from deposits in quartz) takes a boundary position and its arsenic content do not falls out of the limit 0.01-0.03% (Fig. 5-50.). The highest concentrations of arsenic are observed in the 1st mineralogical group (Fig. 5-51.). However, they vary here from 0 to 0.15%, reaching in some instances 0.5%. The mineralogically mixed 3rd mineralogical group shows the same picture. Samples of this group can contain both low and high concentrations of arsenic (Fig. 5-52.). This comparison is visually shown on the diagram of Cr – As where samples with the high content of chrome that characterizes ore from the ultrabasic rocks, show usually also high arsenic concentrations (Fig. 5-53.).

This connection between the contents of arsenic and chrome is shown also by the analysis of individual chemical clusters, although this connection is not strong. More chromium slags show higher concentrations of arsenic which is possible to see on the corresponding correlation diagram for chemical clusters 1-3 (Fig. 5-28.). In this case the cluster 2 correlated with ore from ultrabasic rocks contains more arsenic. It demonstrates that the source of arsenic could be connected with ores in the ultrabasic rocks. There is no evidence of such connections with ores from quartz, and Tash-Kazgan belongs just to the last type of deposits.

Therefore, the presence of arsenic is more typical of smelting ores from the ultrabasic rocks. If arsenic was present in ore, it would allow returning to the Chernykh's former theory, having replaced Tash-Kazgan by the Ishkinino mine. But, as it has been already discussed, the ores from Ishkinino are insufficient for producing high-arsenical bronzes in such large quantity. But it is impossible also to ignore the connection of high concentrations of arsenic with the ores from ultrabasic rocks. As in these deposits with the higher arsenic concentration there are also proper arsenical minerals, it is possible to assume that they were got there, together with copper ore, and used then for alloying at the stage of ore smelting.

Correlation of arsenic and nickel concentrations in slag and ore are indicative for the following discussion. In ore from settlements any connection between these elements are absent (Fig. 5-54.), although in ores of the Ishkinino deposit both arsenic and nickel are present (Tab. 5-46.). In metal this connection is visible rather clearly (Fig. 5-55.). There is only small number of samples which do not show this regularity. All others reflect a strong ratio of arsenic to nickel as 10:1. The increase of 10 parts of arsenic one part of nickel increases too. Therefore it is possible to assume an alloying by a mineral containing, in addition to the arsenic, a considerably smaller quantity of nickel.

The positive correlations between nickel and cobalt (Fig. 5-36.), at first sight, allow us to assume the presence of cobalt in this mineral too, however the same connection is seen also in ore (Fig. 4-7.). Therefore cobalt, apparently, did not play a large role in the alloying component.

Very important results have been obtained from the analysis of metal, included in slag, carried out by the scanning electron microscope. During this investigation a question of the way of alloying with arsenic was especially interesting to us. The analyses have confirmed the conclusion presented above.

The investigated ore grains represented by malachite (sample 751, an. e) and cuprite (sample 751, an. f) did not contain arsenic, while in other inclusions of this sample it has been identified (Tab. 5-4., Tab. 5-5., Tab. 5-6., Fig. 5-VII.4). There is also no arsenic in investigated gangue (serpentine). However, in the same sample the prills of metal separating from a serpentine grain, have been studied. They consisted sometimes of two zones. In the inner zone the qualitative analysis has revealed Cu, Fe, Si and As (sample 751, an. a). In the external zone the analysis has revealed 9.9% Cu, 38.3% Fe, 44.8% As, 6.4% O, and 0.7% S (sample 751, an. 3) (Fig. 5-VII.3). But the repeated analysis has detected heterogeneity of the metal surface very similar composition, but sulfur was absent and some impurity of nickel was present (1.15%) (sample 751, an. 3 Wdh).

It is possible to assume that this arsenic-nickel mineral was sulfide and this analysis is a good luck as usually sulfide minerals if they do not compose the basis of the furnace charge, lose sulfur quite easily. We remember from the description of our experimental works that sublimation of sulfur begins already at insignificant heating. It is probable, but is not proved, that a considerable iron component comparable with the arsenical one, was present, probably, in this mineral.

The interesting results have been obtained from the investigation of new metallurgical formations (Tab. 5-4., Tab. 5-5., Tab. 5-6., Fig. 5-VII.5,6). A light inclusion, considered originally as metal, has been analysed. At a large magnification it has been clarified that it consists of two phases: light and dark. The analysis of the dark phase revealed the presence of 7% Cu, 79.9% Fe and 13.2% As (sample 751, an. 5). The analysis of the light phase has revealed copper with small admixtures of iron (sample 751, an. d). A similar inclusion, consisting of two phases, demonstrated the same picture, but it was an oxide. The dark phase contained 40.6% Fe, 16.1% Cu, 6% As, 35.4% O, 1.8% Si (sample 751, an. 6). Re-examination of this result has shown similar values (sample 751, an. 6 Wdh). The light phase: 96.8% Cu, 3.2% Fe (sample 751, an. 7). Arsenic has not been initially detected in it. But the second analysis (sample 751, an. 7 Wdh) has revealed a lower content of copper (87.86%), more iron (7.02%) and arsenic (5.06%). Probably, this difference of two analyses has been caused by heterogeneity of the alloy; therefore the average content of arsenic in it is lower.

But in this case nickel has not been recorded by the analyses. Therefore, it is not excluded that in some instances any oxidized iron-copper-arsenic minerals were used for smelting. It is difficult to say whether they were used purposefully for the alloying or got together with copper ore.

But a series of other analyses has demonstrated that arsenic was connected with nickel (Tab. 5-4., Tab. 5-5., Tab. 5-6., Fig. 5-V.1, Fig. 5-VI.5, Fig. 5-VIII.2-5). A prill of copper in sample 3 contained 12.5% As (sample 3, an. 2). The retest of this inclusion revealed the presence of two phases: a light in centre and a dark on the edges. The analysis of the light phase (sample 3, an. 5) has shown that it is copper with admixtures of Fe (4.17%), As (9.8%) and Ni (1.26%). The dark phase contained similar admixtures of iron, lower of Ni (0.66%) and As (4.93%), and sulphur (11.4%) was present there. The presence of Se (2.76%) is very remarkable, but cannot be explained.

A prill of copper in another sample contained 31.6% As (sample 680, an. 5) which indicates that it was formed in a zone of a mineral with high arsenic content.

At the investigation of sample 839 the large molten inclusions consisting of three phases have been identified: a light metal phase, a blue phase and a grey-blue phase. All these phases were formed here already as a result of metallurgical reactions. The grey-blue phase consisted of 6.9% Cu, 44.5% Fe, 10.5% As, 2.1% Ni and 36.1% O (sample 839, an. 1). In the same inclusion the light phase, distributing on the edge, has been analysed (qualitative analysis). Its composition was the same, but the content of iron was somewhat higher.

Another similar inclusion contained 6.4% Cu, 40.6% Fe, 5.9% As, 9% Ni, 33.5% O, 4.6% Cl (sample 839, an. 3). The re-examination has slightly changed these figures, but not fundamentally. A blue phase in the same grain had 11.2% Cu, 82% Fe, 3.8% Ni, 2.9% O (sample 839, an. 4). The repeated analysis has revealed a similar composition (with variation of some elements), the presence of As (4.45%) and full absence of oxygen. Consequently, it was not oxide, it was metal. In the same grain a light phase has shown 89.4% Cu, 4.6% Fe, 4.4% As and 1.7% Ni (sample 839, an. 5).

In these analyses it is interesting that the ratio of arsenic and nickel is close to that has been identified for the hypothetical alloying component by the spectral analysis, although in some instances their ratio is 5:1 here. And we see two phases with arsenic and nickel: one with the iron, and the second with sulfur[7].

Some analyses have not revealed a presence of arsenic in copper prills (sample 173, an. a; sample 822, an. b). Basically, a part of the Sintashta metallurgical production was directed on smelting of pure copper. However, it is necessary to take into account the marked above instability of diagnostic of arsenic in the first series of analyses, and that arsenic can be distributed in slag irregularly.

Conclusions

Thus, the most part of arsenical metal of this period had not been smelted from ores of the Tash-Kazgan mine. It had been smelted from ores in ultrabasic rocks; and the alloys with arsenic were produced by arsenical minerals on the ore smelting stage. The presence of arsenic is steadily accompanied by nickel which is absent in the analyzed ore, rock and olivine. It is possible to claim with confidence that this mineral contained, along with arsenic, high concentration of this element, and also iron and in some cases sulfur.

Nickel is often present in sulfide and arsenic-containing copper-nickel ores, which quite corresponds to the characteristics of Ishkinino, Ivanovka and Dergamysh deposits in which nickel arsenide, nickeline, has been found (Zaykov *et al.* 2001). Therefore, most likely, the alloying components were extracted on the same mines. At discussion of SEM analyses of inclusions of magnetite and chrome in some Sintashta slags, it has been demonstrated that some inclusions contain arsenic; therefore, it was brought from a deposits in the ultrabasic rocks, where from also the copper ore was brought. It is impossible to precisely define the mineral, being based on studies of the minerals which had been re-born as a result of metallurgical processes. Besides, there is a series of similar minerals in which the ratio of components varies. And all of them can be present in the same deposit. The ore, that could be used to produce the arsenic bronzes, could be present in the same deposit too, but it obviously was not a base of the production. This assumption imposes some restrictions on our conclusions about connection of many slags with ore of the Ishkinino mine, as chromites in slag can indicate inclusions of the alloying component taken on this deposit, and ore of any particular settlements could origin from other sources. It is not quite probable version, but it is admissible.

The conclusions made are not a ground to refuse an idea of a probable exploitation of the Tash-Kazgan mine. It could be quite used. It is possible also that some other copper deposits rich in arsenic were exploited. However, their role was obviously more limited than it has been thought earlier, and their exploitation was possible only due to a stereotype of production of arsenic bronzes. In some cases the ores of such deposits could be used as ligatures. In antiquity the alloying could be realized by arsenic minerals, and by arsenic-containing copper ores.

[7] Identical evidences have been obtained by the same method at study of copper inclusions in Sintashta slag by another group of scientists (Zaykov *et al.* 2008, 2008a).

In connection with the above-stated, it is necessary to consider the TK group of metal as having a broader sense. Most likely, it is necessary to include into it the samples smelted from the ores of Tash-Kazgan (and it is a very hypothetical supposition), as well as those alloyed with arsenic at the smelting ores from different deposits of the Urals (the most part of this metal was produced on the Sintashta settlements). But to it is necessary remember that strong evidences about the exploitation of the Tash-Kazgan mine in this period are absent, as well as the possibilities to correlate its ore with ore and metal of this period.[8]

Arsenic bronzes

The content of arsenic in the Sintashta metal is not too high. It provokes a question of the need of this alloying. The matter is that there is an opinion that at the arsenic concentration of 1-2% the hardness of the alloy is almost the same as the hardness of copper. Only 4% give to metal the characteristics which are close to tin bronze. But for ancient technologies it was difficult to produce an alloy with more than 8% arsenic. Besides, it was difficult to control the content of arsenic at alloying (Northover 1987, p. 111,113,114). Therefore some scholars suppose that this alloying was senseless, and it was a casual metal. In Iberia, besides, there is no connection between the types of object and the content of arsenic (Hunt Ortiz, 2003, p. 324). But it is necessary to remember that at high-temperature metalworking, especially at re-melting, the content of arsenic decreases. Therefore the lack of this connection can reflect also a high degree of metal utilization, and this feature cannot be reliable in the solution of question on the premeditation of the alloying.

It is not excluded that the aspiration to get more fluid metal was sometimes the reason of this ligature, as arsenic promote reduction of melting temperature of copper to 830 ˚C (Palmieri *et al.* 1993, p. 597). It is impossible to forget also about the esthetic features of arsenical alloys to which the segregation and migration to the surface is peculiar that lead to formation of a silver covering (Charles 1980, p. 171). But the esthetic motives were obviously insufficient for stimulation of mass production, and the aspiration to reduce the melting temperature was not so important for the Sintashta metalworking too as the forging operations dominated.

Usually it is considered that copper with the content of arsenic less than 1% was an accident, if more – it was a deliberate alloy with arsenic or deliberate melting of copper-arsenic ore because of convenience of further casting and forging or working qualities of this copper. Its hardness increases at cold forging, but even at small additions the arsenic works as de-oxidizer that improves mechanical properties of the object. In the Alpine zone and Northern Italy the content of arsenic in different types of object differs that is evidence of the premeditation. But actually, there is not enough studies about properties of arsenic alloys, and some scholars even think that in scientific literature the data are provided not quite correctly, wandering from one publication to another (Budd, Ottaway 1990, p. 95).

8 Recently E.N. Chernykh (2007, p. 82, 83, fig. 5.9) has published comparison of arsenic concentration in the TK copper of Sintashta-Abashevo sites with its concentration in the North Caucasian arsenic bronzes, claiming that this comparison is so striking that it does not make sense to continue discussion about the question of artificial character of the TK group. In his opinion, this copper was of natural origin and was connected only with the Tash-Kazgan mine. The given drawing really shows much higher concentrations of arsenic in the North Caucasian metal, but it, nevertheless, requires to be discussed, as there is no sense to discuss only religious dogmas. The matter is that in Sintashta culture the metal is presented mainly by tools and weapons, a proportion of ornaments is insignificantly small. Contrary to it, in the MBA metal of the North Caucasus ornaments dominate (Avilova, Chernykh 1989, p. 73; Černykh *et al.* 1991, p. 604). And the comparison of arsenic concentration in metal of North Caucasian culture shows rather contrast picture: in cast objects (mainly, ornaments) the arsenic concentrations fluctuate within 1.6-40%, and in forged objects they do within 0.25-6.3%, and among the latters the proportion of the objects with very high concentration is not so high (Chernykh 1966, p. 42, fig. 14). And it is already quite comparable with the Sintashta situation. As all metal is included in the discussed drawing totally, there is so contrast picture. In case of more correct selection, with a close ratio of tools and weapons to ornaments, this picture will be not so contrast and cogent. Though, it is possible to assume that on the average the arsenic concentration in metal of the North Caucasus will be slightly higher. But it is already obvious insufficiently for judgments about either artificial or natural character of bronzes, and has to be discussed within a problem of distinctions of the alloying, the subsequent methods of casting and forging, a proportion of re-melted metal (all this could lead to decrease in concentration), etc.

It is some exaggeration too. Besides, recently the information has appeared that is based on analytical and experimental data. At the increase of arsenic content the hardness of metal also gradually increases. It is observed up to 3-4% of the arsenic content, and at higher values the hardness smoothly decreases. Up to 3% of the arsenic concentration the malleability of metal does not change, and then it decreases drastically (therefore at higher contents it is more preferable to cast than to forge). But the master could feel this increase in hardness only since 1% of the contents (after S. Rovira). The presence of nickel in the arsenic bronzes of some regions (Maikop and Sintashta cultures) was also very important. Nickel "gives to the alloy ability for hardening and tempering that after additional forging leads to its essential hardening" (Ryndina, Ravich 2012, p. 5, 6).

In the case with Sintashta metallurgy the reason was, apparently, the aspiration to improve working properties of tools as we see in metal of this time the correlation between the type of objects and the presence of arsenic. Besides, as it follows from the evidences of other authors, the correlation between the type of objects and contents of arsenic is expressed less clearly (see Zaykova 1995; Chernykh 1970; Kuznetsov 1983) that was caused by character of alloying at the ore smelting stage, although it could have also the second reason: repeated hot forging and re-melting.

Being based on our XRF analyses of Sintashta-Abashevo metal, we have tried to consider this question in more detail. It is noteworthy that average value of arsenic concentration for each individual type demonstrates that average value of the arsenic content increases in those types of object which are subjected to larger dynamic load (Tab. 5-56.). Exceptions are bracelets, but their higher arsenic content could be caused either technological reasons (better flexibility and castability) or esthetic reasons. At the same time, all types of objects show essential dispersion of these concentrations[9]. In some cases it could be caused by casual reasons, for example, lack of alloying components or production of a new object from scrap. But a more typical reason was that at that way of alloying which was used in Sintashta time, it was impossible to achieve an accurately controlled arsenic content in metal. Besides, after the metal was smelted even if the metallurgist could appreciate approximately its arsenic content basing on metal qualities, this metal was not used for manufacturing of objects of some single type. Something similar would be possible in case of craft production for the market, but the nature of Sintashta production was obviously different. Therefore the metallurgists had, of course, general ideas of properties of the alloyed metal, but the aspiration to achieve strong concentrations by any way was absent.

Problem of arsenic alloys in archaeometallurgy

The conclusion drawn allows us to turn to the problem of arsenic bronzes, in general. This problem is discussed for a long time in archaeometallurgy and is formulated exactly so as this has been discussed above with reference to the Sintashta metallurgy. In other words, the problem may be reduced to a question, whether the arsenic bronzes were an outcome of deliberate alloying or they were obtained from smelting copper ores containing high concentrations of arsenic. For different cases both approaches are assumed: smelting this metal from arsenic-containing copper ore (Tylecote 1982, p. 99) and by artificial additions (Tylecote 1987, p. 193).

The essence of this problem has been expounded in detail by Riederer who adduced arguments of both parties (Riederer 1991, p. 87, 88). Arguments in favor of copper ores alloying with arsenic ores in his statement are the following:

1. High contents of arsenic in some objects.

[9] Comparable results have been received also from analyses of the Sintashta metal by A.D. Degtyareva, although she writes about high degree of correlation between the type of object and arsenic contents (Degtyareva 2010, p. 138, 144). In this case the difference is only in the verbal assessment, the results are comparable.

2. Conformity of definite contents of arsenic to groups of objects.
3. Improvement of quality of copper at the alloying with arsenic.
4. Presence of arsenic sulfides in Anatolia and neighboring areas.

   Arguments in favor of arsenic-containing ores:
   1. Variation of arsenic contents in the majority of groups.
   2. Very often objects content from 0.5 to 1% arsenic, which is not enough for alloying.
   3. Universality of this alloying from antiquity to the New Time.
   4. Arsenic-containing copper ores occur more often than realgar or orpiment.
   5. Empirical knowledge of ores, which allowed the eligible ores to be selected.

Riederer himself was inclined to the second position. It is easy to see that the arguments presented by him in its favor are more convincing. This point of view is also confirmed, in his opinion, by analyses of metal (arguments 1 and 2). Besides, in Mesopotamian written sources only lead and tin were mentioned as ligatures. This, however, cannot be a sufficient argument in framework of this problem, as in case of alloying at the ore smelting stage in these sources the mentions of these ligatures could not be reflected (it is necessary to say that not ore, but metal was delivered into Mesopotamia).

But in all areas the data are contradictory. In Britain copper minerals with the higher content of arsenic are known. They are widespread not so widely, as the fahlores containing arsenic and antimony. It is impossible to confirm their use in the EBA (it was contemporary to Sintashta culture) in view of lack of slag, but it is supposed because arsenic bronzes are presented rather well (Ixer, Patrick 2003, p. 14,15). Probably, in this case reliable data for any sure judgments are today absent.

It is more likely that everywhere, even inside one region, different schemes of alloying could be used. For example, on some Spanish settlements malachite with admixtures of arsenic was found. As a rule, arsenic concentrations in artifacts are less than 1%. Very rarely they exceed 2%. There is no direct correlation between concentrations of arsenic and types of artifact (Fernandez-Miranda *et al.* 1994, p. 23, 26). This evidence rather unambiguously confirms that arsenic was introduced together with arsenic-contained ore. But it is not also excluded that the metal was repeatedly re-melted. Nevertheless, in Iberia already in the MBA arsenic in metal is typical, in some cases in high concentrations, but it has been explained by properties of Iberian ores, as ores with the high arsenic content are present there everywhere, even in the upper parts of deposits (Hunt Ortiz 2003, p. 323, 329-332). Discussing the Eneolithic metallurgy of this region, we cited the evidences of use of the arsenic-containing copper ores and alloying at the stage of ore smelting.

In Iran a situation was more homogeneous. On many sites, dated to the late 4th – early 3rd millennium BC (Geoy Tepe, Shah Tepe, Hissar, Sialk, Giyan) copper-arsenic minerals, domeykite (Cu_3As) and algodonite (Cu_5As) have been found (Palmieri *et al.* 1993, p. 596). It is supposed that a source of this ores was the Anarak deposit, whose copper minerals contain a lot of arsenic. Its contents in ore of the deposit are very variable which also resulted in a variation of the arsenic contents in copper artifacts (Zwicker 1987, p. 192).

The situation in Anatolia is more intricate. On the settlement of Ikiztepe the direct correlation between types of artifact and contents of arsenic has been found, indicating a deliberate alloying. On the other hand, in the Middle Bronze Age layer of the settlement of Achemhöyük, ore with high content of arsenic has been identified (Yener *et al.* 1994, p. 379). On the settlement of Nachi Nebe Tepe, arsenic (less than 1%) in slag is accompanied by nickel. But these impurities are noted also in ore; therefore the use of polymetallic ores is supposed (Yener 2000, p. 28). On the Arslantepe settlement in Eastern Anatolia the direct correlation between the types of artifact and contents of arsenic is observed. So, spearheads contained 2.5-3% arsenic and swards 4.5-5%. However, arsenic is present also in ore of this settlement. The minerals with the high contents of antimony and nickel occur too. Sometimes, the content of arsenic in metal reaches 3-10%, which could not be achieved without artificial additions of minerals with arsenic (Palmieri *et al.* 1994, p. 447; Palmieri *et al.*

1993, p. 574, 577). All this indicates smelting of copper-arsenic minerals and alloying with such minerals at the smelting of other ores. However, ore in the Early Bronze Age IB layer of this settlement do not contain arsenic, although arsenic copper has been found there, which is the evidence of artificial alloying (Caneva, Giardino, 1994, p. 455). The situation in areas of Malatya and Trabzon is similar. Minerals contained small quantity of arsenic have been collected there, but on settlements many arsenic bronzes are found (Palmieri *et al.* 1993, p. 591). Slags of the Eneolithic settlements of Tüllintepe and Tepecik contain up to 2-5% of arsenical minerals therefore the ore smelting with addition of these minerals is supposed (Yakar 2002, p. 18). Very exponential is the evidence obtained on the settlement of Noršun tepe, where two types of ore have been found: in quartz, containing considerable admixtures of arsenic and antimony; and in sandstone, in which these admixtures almost missed. But high concentrations of these elements have not been detected in slag from these layers, as the slag was smelted from ore in sandstones. The ore in quartz, because of very high concentrations of antimony, was useless for smelting at all. This ore was suit only as a ligature to ore from sandstones (Zwicker 1980, p. 13, 14, 17). As a matter of fact, these elements in case of this alloying could partly remain in slag, but if temperatures were not too high.

Thus, for Anatolia we can guess not only smelting copper-arsenic minerals, but also a method of alloying with copper-arsenic and arsenic minerals. And, it is not excluded that it was not a regional feature, but a general phenomenon. Arsenopyrite which was added to ore is found in the EBA2 and MBA layers of the settlement of Değirmentepe (previous to Sintashta culture), but there are also copper ores with the high content of arsenic (Yener 2000, p. 55). Possibly, both variants took place. Metallurgists could perfectly determine the presence of arsenic in ore by a smell from the furnace and used these ores. In other cases they alloyed with arsenical minerals. These minerals in Anatolia are situated in regions of Kars and Sivas. They also could serve as a source of similar ligatures (Palmieri *et al.* 1993, p. 591).

But it is not excluded that the situation in the Middle East was even more complicated. For example, against a background of the abundance of arsenic bronzes in Iran, quantity of the deposits containing such ores is not as great as it is considered to be. And this against a plenty of other deposits (Pigott 2004a, p. 29, 31). But a historiographic myth has been created (Thornton, Lamberg-Karlovsky 2004, p. 267). At the analysis of materials from Shakhr-I-Sokhta in a layer of 2700-2500 BC speiss has been identified, an iron arsenide. It has been originally supposed that malachite was smelted with arsenopyrite that would provide the reducing atmosphere and the production of the arsenic bronze. Materials from Tepe Yahya and Namazga allowed the authors to assume the same process (Thornton, Lamberg-Karlovsky 2004a, p. 51, 53). In process of accumulation of data it became clear that there is a series of sites (for example, Shakhr-I-Sokhta) where arsenic in slag is absent, but in metal the arsenic content is high that allowed to draw a conclusion about the use of speiss for alloying with metal (Thornton, Rehren 2007, p. 316). A special research program revealed a deliberate alloying with arsenic on many Iranian sites of the late 4th – 3rd millennia BC (Shakhr-I-Sokhta, Arisman, Hissar). The finds of speiss specify that it could be produced from arsenopyrite, in aim to alloy it then with metal. Taking into account that speiss melts at a low temperature, about 700 ˚C, it is quite simple operation. At the same time, there are copper finds with 20% of arsenic that is close to copper speiss. Also it is impossible to fully exclude additions of arsenopyrite to copper ore. Apparently, this method was very widespread in the Middle East, and was not limited to Iran. Moreover, at the early 3rd millennium BC everywhere the production of pure copper grows, which could then be alloyed with speiss. It is not excluded that the absence of arsenic in slag and its presence in metal is explained in some instances by this (Thornton 2009; Thornton et al. 2009). This problem has been additionally studied on slags from Shakhr-I-Sokhta. As though the lack of copper in samples of speiss shows that this speiss was not a casual result of smelting chalcopyrite enriched with arsenic, and the lack of arsenic in ore and in copper of slag allow to assume this way of alloying. But the use of the speiss as a ligature would lead to growth of iron content in copper that is not detected. Therefore additional studies of the problem are necessary (Hauptmann *et al.* 2003, p. 201, 203, 208, 211). Possibly, there was the metal refinement.

Our analyses of Sintashta slag have not identified metal phases containing only iron and arsenic (Tab. 5-5.); all of them contain some quantity of copper, or only copper, although in one of phases the content of arsenic exceeded 32%, i.e. it is iron and copper speiss, but formed, probably, as a result of alloying of copper ore with an arsenic mineral. Besides, arsenic is present everywhere in our slags of copper smelting. But also in the Middle East the alloying with speiss cannot be considered as the base of the production. It is possible that it took place, but the finds of speiss are rare. The alloying of ore with minerals was, nevertheless, a basis.

From huge quantity of the Caucasian deposits (about 500) less than 10% is inspected archaeologically, but there is no evidence of mining copper-arsenic deposits. However, the artificial nature of copper-arsenic alloys of the Caucasus is doubtless since the Eneolithic (Palmieri *et al.* 1993, p. 593, 594). But there are also some strange facts. Arsenic is a volatile element; therefore it is difficult to achieve its content in copper higher than 3-4%. Samples with its content of 7-20% are usually strongly oxidized, and just this oxidized zone of objects is enriched with arsenic. In uncorroded metal its contents is usually lower than 5%. And, the EBA metal in Armenia contains more arsenic than ore, which repeats the Sintashta situation. Besides, in metal the ratio of arsenic to antimony is higher than in ore from what a conclusion has been drawn about the use of arsenic minerals added to ore to smelt the alloyed metal (Meliksetian *et al.* 2003, p. 602; Meliksetyan, Pernicka 2010, p. 47). But there are objects containing high arsenic concentrations: 15.8-27.6%. In some instances their surface is gray, silvered, but it was not a result of the known effect of segregation of arsenic on the surface, the objects have the same composition inside. It has allowed an assumption to be done about existence of some special technology of alloying (Meliksetian *et al.* 2011, p. 204; Meliksetian *et al.* 2011a, p. 211, 212). It is not excluded that it was alloying by speiss, recorded in Iran. In Sintashta culture such alloying was absent.

Thus, the Sintashta metallurgy by a way of alloying is very similar to metallurgy of Anatolia and the Caucasus. It is less clear, how this alloying was put into practice in these regions (if not to consider the objects with high arsenic contents). We may discuss two ways: into the ore and metal. Tylecote wrote that it is possible to add arsenic directly in the copper in form of either metal or arsenopyrite. In the latter case the iron sulfide will separate, will be oxidized and slagged (Tylecote 1987, p. 193). On the base of analysis of a slagged crucible from the Cyprus it has been supposed that arsenic ore was added to molten copper (Zwicker 1982, p. 67). Palmieri, Sertok and Chernykh suppose that both of these ways were used, but the alloying into copper was applied more often, as it promotes the decrease of its melting temperature (Palmieri *et al.* 1993, p. 597). In our point of view, it is not so essential, as if before arsenic-containing copper had been smelted from ore, its melting point was lower, and such element, as sulphur, contained in arsenic minerals, promoted a rise of temperature in a smelting process of ore, but at the additions into metal, sulphur can worsen its quality. It is possibly, perhaps, to achieve also the full removal of sulphur from metal, but this could put to the unjustifiable increase of the duration of melting.

A probability of alloying with arsenic-containing minerals into metal is doubtful too. On the first hand, there is no reliable evidence testifying such alloying; on the second hand, a technological possibility of this process is unclear, despite the opinion of Tylecote given above.

Therefore it was more legitimate to produce such bronzes by addition of arsenic ores (Muhly 1976, p. 90). Experiments show that the production of the arsenic bronze by joint smelting of the oxidized copper ore with arsenic minerals is a rather simple process (Yener 2000, p. 57-59). And in some regions metallurgists probably used speiss.

This problem, probably, requires a special analysis, nevertheless, the way of alloying, which was applied by the Sintashta metallurgists (at the composition of charge) seems more preferable. This way is also more legitimate from the point of view of the logic. This alloying could have its origin in smelting copper-arsenic minerals. Therefore, we have no ground to separate the Sintashta technology of alloying from that in Anatolia.

Thus, four ways of producing arsenic bronzes were used: from arsenic-containing copper ore; by the additions of arsenic-containing copper ore to copper ore (the most doubtful way, and if it took place, it was quite rare); by the additions of arsenic-containing minerals to copper ore; and by the speiss into metal. In each area different ways were used. This depended on ores that were close to hand.

Exotic alloys and metals in Sintashta culture

As a result of analysis of metal objects of Sintashta culture carried out by A.D. Degtyareva (2010, p. 83) the metal has been divided into some groups: copper and copper-based alloys (88.1%), billon and silver (7.8%), gold (4.1%). In turn, inside the copper and copper alloys some groups have been distinguished: a small group of pure copper, the leading Sintashta alloy of copper with arsenic discussed above, a copper alloy with zinc, and several multicomponent alloys: tin-arsenic, lead-arsenic, antimony-arsenic, zinc-arsenic, tin-lead-arsenic and a rare alloy with tin, lead, zinc and arsenic. It should be noted that in our analysis of metal, except for isolated cases, the alloys with zinc, lead and tin have not been identified (Tab. 5-48.). It is explained by that the ornaments have not been almost included in our sampling, and these alloys were used, mainly, at their production. Therefore at further discussion we will be based on the classification made by A.D. Degtyareva.

We will not discuss the gold here as technological problems of its extraction are absolutely incompatible with that is discussed in this book. Besides, the proportion of gold in Sintashta metal is absolutely insignificant. These 4.1% of objects mean actually thin gold foil on rings and pendants. Therefore the weight of these finds is small.

The deliberate character of multicomponent alloys is very doubtful too. Most likely, these single objects are result of melting metal scrap. Antimony-arsenic alloys are rare and are a result, apparently, of sulfide ores smelting. In the introduction we have discussed that antimony often replaces sulfur in sulfide minerals of arsenic and other elements. Tin or tin-arsenic bronzes do not provoke special problems too as such ligature as tin was not characteristic of Sintashta metallurgy and it is a sign of contacts with the Seima-Turbino producing centers. And the problems of presence of zinc, nickel, lead and silver in copper will be considered below.

Copper with zinc

The collection contains four objects from arsenic-zinc bronze in which the content of arsenic strongly differs, and one object from brass (a copper alloy with zinc). The content of zinc in them varies from 0.4 to 5%.

Brass could be an attractive alloy as it has golden color and it is easily casted and forged. However, this color appears at the contents from 8% of zinc when it is really possible to speak about premeditation of this alloy. Besides, it is very difficult to smelt zinc for the alloy. It vaporizes at a temperature of 906 °C, which is lower than the temperatures of its smelting from ore. But it is possible to alloy by the cementation method, heating copper at a low temperature with zinc oxide in a closed crucible, and then melt the product to receive a homogeneous alloy (Khavrin, Chugunova 2004, p. 352, 354; Thornton 2007, p. 124).

As in the Sintashta collection an accurate correlation between zinc and types of object is absent, the deliberated production of this metal is doubtful. Therefore it is supposed that its source were some deposits in the Southern and Middle Transurals, in areas of Kyshtym, Pyshma and Klyuchevsk, which were exploited by Sintashta metallurgists (Degtyareva 2010, p. 89, 148). However these deposits are far in the north, in the forest zone which was not developed by the Sintashta population (Grigoriev 2008). Deposits with high concentration of zinc have to be somewhere closer to the area of the Sintashta settlements. It can be demonstrated, in particular, by the presence in our collection of individual samples of ore and slag with higher zinc concentrations. So in individual samples of ore of the settlements of Arkaim, Ustye and Burli the spectral analysis revealed 1% of zinc and more (Tab. 4-1.). Taking into account that, according to our calculation, zinc goes into slag with the decreasing coefficient 0.392 (see Tab. 0-6. in Introduction), such ores can give more than 0.25% zinc in slag. There are eight such samples (Tab. 5-23.): on the settlements of Semiozerki, Arkaim, Burli, Ustye, Sergeevka and the cemetery of Krivoe Ozero. In three samples the content of zinc is 1% and more. All this, as a whole, corresponds to the weak presence of alloys with zinc on the Sintashta sites from what follows that sources of this copper were somewhere nearby.

But it is hardly justified to assume the deliberate character of these alloys. For this period such alloys are unknown. In the Late Bronze Age in the Near East some brass objects with the content of 5-15% zinc are known. But they too are considered as the casual product formed because zinc was present in ore, and smelting temperature was low and the conditions were reducing. Purposeful production of the brass begins only since 500 BC (Craddock, Eckstein 2003, p. 216, 217). In China, the earliest brass object is a plate of the 5th millennium BC. Several later brass objects have been found too. But the most of researchers agree that three brass objects from Shanxi (Yangshao culture) and one more of the Longshan cultures cause questions too. Most likely, zinc was present in ore (Lin Yun 1991, p. 78, 79; Mei, Li 2003, p. 112).

At the same time, it is possible that it was not always the ore impurity. The brass in the Near East appears since the 3rd millennium BC, at the same time with the appearance of tin. And brass objects more often contain tin, instead of arsenic, although in deposits zinc and tin are not connected (Thornton, Ehlers 2003, p. 3-5; Thornton 2007, p. 123, 130-132). Therefore the attempts of alloying are not excluded, but in our case when there are slags with the higher content of zinc and the copper objects contain arsenic, this variant is excluded. This group of metal can be considered only as ore impurity. But this conclusion is reliable for the most part of metal. In cases of the high zinc content we have no confidence, after all, as single brass objects from Iraq and Iran (Nuzi, Tepe Yahya) are dated to about 1700 BC, and one object is known in Armenia in the period of the Middle Bronze Age that was just before Sintashta culture (Meliksetian *et al.* 2011, p. 205). But, anyway, it is a question of the Transcaucasian and West Asian parallels.

Lead and silver

Many years ago K.V. Salnikov discussing a lead bracelet found on the settlement of Malo-Kizilskoe of the Ural Abashevo culture, wrote that it was a proof of existence of local smelting of lead (Salnikov 1962, p. 66). This settlement is situated in the Chelyabinsk region where sites of Sintashta culture have been subsequently discovered. As well as the Sintashta settlements, it was surrounded with a defensive ditch, but its ceramic material differs from that of the Sintashta sites, although has with them much in common. During a long time similar finds did not repeat, and this bracelet was not mentioned by researchers, being considered as something casual. However from the beginning of works on the Sintashta settlements, the new find has been made – a lead wire found on the settlement of Kuysak (Zaykov *et al.* 1999, p. 194, 195). It is possible to add to this the presence of copper-lead-arsenic and copper-tin-lead alloys in the Sintashta metal, mainly, in ornaments (Degtyareva 2010, p. 83, 87, 133).

In principle, our experimental works have shown (see appropriate chapter), it is not difficult to smelt metal lead from the lead ore, but there is a vital question – for what purpose to do it? Lead in antiquity was used seldom, sometimes for manufacturing of weights or ligature to copper, in aspiration to produce fluid metal; and its broad application begins only since the classic antiquity, i.e. the Early Iron Age. And such objects and ligatures are single in Sintashta culture.

Curiosity of these finds against huge scope of excavation of the Sintashta sites as though emphasizes a rarity of lead during this period. The reasons of presence of this metal on the sites were unclear until the SEM analyses of slag. These analyses revealed two samples from the settlements of Arkaim (FG1788) and Sintashta (FG1817) in which lead has been detected that confirms Salnikov's opinion on his local production.

Visually these slags were not different from the majority Sintashta slags of copper smelting, being flat slag cakes formed on metal.

Qualitative and quantitative analyses of samples have been made (Tab. 5-4., Tab. 5-5., Tab. 5-6., Fig. 5-IX.6, Tab. 5-X..1). In the table of qualitative analyses those elements are marked, whose essential presence was recorded by the analysis. These analyses in slag have detected prills of pure lead; lead silicates with considerable impurity of iron are rarer. In principle, occasionally metal lead, in some instances with iron impurity, can be also present in copper ore. That is found, for example, by analyses of samples from the Tash-Kazgan mine and the settlement of Sintashta (Tab. 5-4.). Therefore we may raise a question of possibility of receiving a small amount of lead as a by-product, at smelting copper ore, what would explain a rarity of its finds on the sites. However the study of the lead prills has not revealed copper impurity. Proper copper prills or inclusions of copper ore have not been found in these samples too. Besides, the described inclusions in ore are very small and can give only micro-impurity in metal, but they are not enough to extract metal lead. The presence of native lead in ore only indicates a possible existence of a limited lead mineralization on the mines exploited for copper. In some instances the corresponding minerals could be used for smelting for the purpose of extracting lead, although they could be also mined on other deposits. It is more difficult to tell what kind of minerals were these? Their remains in slag have not been identified.

There is no definiteness also with smelting technology. The presence of wüstite in the studied samples indicates the reducing smelting conditions. And, these conditions were, probably, more reducing, than those of copper ore smelting in Sintashta metallurgy as wüstite was less typical for slags of copper smelting, than magnetite.

The main raw material for smelting lead is the galenite (PbS). Its smelting is described by two consecutive chemical processes. The first is the ore roasting in the oxidizing conditions:

$$2PbS + 3O_2 \rightarrow 2PbO + 2SO_2$$

The second process is the reduction of metal lead in the reducing conditions:

$$PbS + 2PbO \rightarrow 3Pb + SO_2$$

In principle, if almost all galenite turns into oxide, the metal reduction by means of charcoal is possible. The presence of metal lead and its oxides in the slag indicates both these processes, but the second was not completed.

It is possible to assume also quite high temperatures of smelting as the analysis of fused quartz revealed a refractory composition (Tab. 5-4., an. FG1817-1, Tab. 5-6., an. FG1817-a). And this composition has a low viscosity. Oxides of calcium, magnesium, iron, manganese, and titan and sulfides influence on the decrease of viscosity, and silicon dioxide and alumina influence on its increase (Bachmann u.a. 1987). In the studied probe the sum of Fe+Ca+K+Ti is only 12.55%, and the sum of Si+Al, increasing the viscosity, is 49.25% (weight percent). It is rather problematic to calculate, at what temperature this composition melts. In vitro this substance melts at a temperature about 1600 °C. In furnaces, at a temperature of 1400 °C, the viscosity of this composition is about 19-20 Pa·s. But in the conditions of slag reactions, in particular in the presence of molten lead and its oxides, the temperature of melting will be much lower. However, anyway, there was a rather high temperature in which there was no need at smelting lead, because lead melts at a temperature of 327.4 °C, and boils at a temperature of 1750 °C. Oxide of lead melts at a temperature of 890 °C, and boils at 1470 °C. However already at temperatures above 750 °C galenite (PbS) and lead oxide (PbO) start to vaporize (Zimmerman, Gunter 1982, p. 354, 360, 876). The melting point of galenite is 1115 °C (Deer *et al.* 1966, p. 205).

Thus, the chemical composition of the described substance shows senselessly high temperatures which led to the substance evaporation. Studies of slags of lead ores smelting from the island of Thasos located near the coast of Greece, allowed to assume much lower temperatures. According to the differential thermal analysis (DTA) these slags melt in the interval of 820-960 °C. As a whole, the temperatures were below 1100 °C (Hauptmann *et al.* 1988, S. 106).

For this reason, it is not excluded that in this case another process took place: extraction of silver. In antiquity and today the raw for this production was galenite enriched with silver, because lead and silver are the interconnected metals. In ancient Anatolia silver was extracted by roasting galenite to lead oxide, and then metallurgists melted the oxide in a bowl to separate silver from lead oxides. For example, on the Anatolian settlement of Nachi Nebe Tepe, in the Pre-Uruk layer, ore (galenite) contained up to 43% lead and impurity of silver (Yener *et al.* 1994, p. 380; Yener 2000, p. 28).

Recently the reliable analytical data appeared, allowing this process to be reconstructed. At excavation of the Eneolithic settlement of Fatmali-Kelecik dated to the 4th millennium BC, and located in Southeast Anatolia near Keban, it was found 50 g of slag and 200 g of lead oxides in ingots. This slag is similar to that of Sintashta, but its size is smaller. These are the flat cakes formed on metal. Pieces of the lead oxide were 1.5-5cm in diameter (Hess *et al.* 1998, p. 59-62). The main inclusions in the slag are SiO_2, FeO, and PbO. The amount of silver is insignificant: 0.08-0.17%. It is close to the EBA slag from Sifnos, but in slag from the settlement of Arslantepe in Anatolia the concentration of silver was only 0.01%. The quantity of sulfur is not high; therefore, more likely, the oxidized ore was used. The latter is also specified by low concentration of zinc which usually accompanies lead, but it is not characteristic for upper zones of deposits. Slag of such composition melts at a temperature of 800 °C that is much lower, than melting point of copper slag. At the same time, crystallization of hedenbergite (Ca-Fe-clinopyroxene) specifies that the slag solidified at a temperature of 1100 °C. It, however, does not mean at all that more high temperatures were not reached. Thus, this slag is close to that from the Sintashta sites.

In the analyzed ingots from Fatmali-Kelecik the lead oxide (PbO) contains 63-70%. But its majority was transformed into a carbonate cerussite ($PbCO_3$) and hydrocerussite, which led to the contents smaller than 100% revealed by the analysis. In the top part of ingots small silver inclusions have been identified. But as a whole its contents fluctuates within 0.01-0.2%. Therefore, the oxidation of lead and separation of silver as a result of the secondary melting were almost fully completed (Hess *et al.* 1998, p. 63; Pernicka *et al.* 1998, p. 128).

Hess and coauthors believe that galenite was insufficient for smelting. The use of cerussite or jarosite in ore-bearing rock from iron oxides, silicon dioxide and lead arsenates is more probable (Hess *et al.* 1998, p. 64). Pernicka with coauthors suppose that now serious analytical data for judgments about initial ore are absent as when at smelting of galenite and cerussite identical methods were applied and similar processes took place. However the presence in some lead oxide ingots of such elements as arsenic and antimony, not characteristic for the galenite, indicates more likely minerals from a group of secondary sulfides (Pernicka *et al.* 1998, p. 123, 128).

Besides, lead easily reacts with quartz, forming silicates. If there is a lot of quartz, they can be formed and stop the process as a higher temperature and reducing conditions are required. The sulfur is also undesirable, bringing to formation of matte from which it is difficult to extract lead (Kassianidou 2003, p. 198, 199).

Our studies of slag have not found initial ores for this smelting process. The presence of silicates in this slag confirms the situation given above. But it seems to me that the analyses discussed above allow us to assume the use of different minerals in different territories. For Sintashta culture it is possible to assume, nevertheless, the smelting of galenite as the presence of wüstite indicates the reducing atmosphere at very high temperatures. Their achievement demanded intensive blasting which in case of smelting of cerussite would lead to creation of the oxidizing atmosphere. It is not excluded that the achievement of high temperatures was promoted also by the exothermic reaction of combustion of sulfur from galenite. During this reaction oxygen combines with sulfur and vaporizes from the furnace, and it hampers the matte formation. But the process was, apparently, not absolutely classical.

In modern archaeometallurgy it seems as follows. Lead-bearing minerals (galenite or cerussite) were smelted in the conditions of slightly reducing atmosphere with receiving slag and the alloy of lead with silver. Then the ingot of lead was subjected to the secondary melting in the conditions of oxidizing atmosphere, to produce lead oxide and silver. This process is named "cupellation". During it a part of lead oxide evaporated and was absorbed by furnace walls. Besides Southeastern Anatolia and Northern Syria (Fatmali-Kelecik, Arslantepe, Habuba Kabira), this technology is recorded in ancient Iberia, since the MBA, and also on the Aegean island Sifnos from the first half of the 3rd millennium BC. And it was the unique method of silver production (Hess *et al.* 1998, p. 65; Pernicka *et al.* 1998, p. 123; Kassianidou 1988; Hunt Ortiz 2003, p. 345, 346; Wagner *et al.* 1980, p. 77).

The investigated Sintashta slags belong to the first stage of this technology. However, high temperatures of this process identified by the Sintashta slag demonstrate that metallurgists already in this stage tried to evaporate a part of lead oxides that characterizes, as a whole, the second stage of this process. The melting point of silver is 960.8 °C, and its boiling point is 2212 °C that much more exceeds the temperature of boiling of lead and its oxide. The lead was only the by-product used in rare instances. It, and also its physical characteristics, explains the rarity of the lead objects found on the Sintashta settlements. On the contrary, ornaments from silver are well-known on the Sintashta and Abashevo sites. In particular, two sets of silver ornaments have been found in the cemetery of Sintashta (Gening *et al.* 1992, p. 324). Actually, just the details of these two sets raise a proportion of silver in the Sintashta complex of metal. A silver pendant with essential copper impurity is found in barrow 25 of the Bolshekaragansky cemetery (Bushmakin 2002, p. 138). From the Abashevo sites we know a series of silver ornaments (Chernykh 1970, tab. 5). But, taking into account a small weight of these products, the proportion of silver in Sintashta metal is very insignificant.

The first silver occurs in Anatolia in the 4th millennium BC[10]. Originally, probably, the native silver was used, and it was also smelted from silver chloride (Yener 1983, p. 8). But this situation changes quickly enough as native silver and silver ore are extremely rare. But silver is present also in copper fahlores and in lead ores (Kassianidou 2003, p. 198). The extraction of silver from the lead ore and from the silver ore by the method of cupellation has been identified on the Anatolian settlement of Arslantepe VI in the Late Eneolithic where lead and silver have been found, and, the silver can be pure or have lead impurity (Yener 2000, p. 54). However, ones could extract rather pure silver also from the lead ore. And, probably, the transition to the method of cupellation happened just at this time.

The emergence of lead objects on the Sintashta sites was connected with the Near Eastern metallurgy (Grigoriev 2000, p. 509). It remains unclear, since what time the lead metallurgy begins in the Near East, as beads from Chattal Höyük and a bracelet from Yarim Tepe I (Müller-Karpe 1990, S. 107) are made, probably, from galenite (Muhly 1987). Concerning the beads it is more probable, but concerning the bracelet there is no confidence as determination has been carried out by means of the spectral analysis. But already in the Eneolithic and Early Bronze Age proper lead objects and use of lead as a ligature to copper are known. The well-known figure of lion from Uruk of the Jemdet Nasr period contains 9% lead. A similar alloy was often used in the 4th – 3rd millennia BC (Müller-Karpe 1990, p. 109). The higher lead concentration is present

[10] In chapter 2, we have discussed the Eneolithic finds of lead and galenite in Vinča culture. And in Greece there is a hoard of early silver objects (Radivojević *et al.* 2013, p. 1041). Taking into account the early finds of tin bronzes on the Balkans it is not excluded that a number of technological innovations came to the Near East from there. But in the period previous to the Sintashta culture I do not know these metals on the Balkan Peninsula. Therefore, the Anatolian parallels are more essential.

in copper objects from Kusura B and Troy II in Anatolia (Yener *et al.* 1994, p. 378). In some cases the alloys have very high lead concentrations. In the Anatolian EBA2 cemetery Hassek Höyük one cylindrical seal contained 27.5% lead (Schmitt-Strecker *et al.* 1991). In Mesopotamian written sources the lead is often mentioned as a ligature (Riederer 1991, p. 88). At the same time, in the Near East lead objects are known also very early. Three lead objects are found in the already mentioned above cemetery of Hassek Höyük (Schmitt-Strecker *et al.* 1991).

It is remarkable that the most ancient silver objects are known on sites of this region since the Eneolithic too, which shows the technological connection of these metals. They always accompany the lead occurrence. It is also noteworthy that ingots of lead oxide and slags indicating the technological process discussed here, are dated since the 4th millennium BC too (Pernicka *et al.* 1998, p. 123; Hess *et al.* 1998, p. 59). However the lead metallurgy had, anyway, earlier chronological position, than the extracting silver, that is quite natural against the extraction of the latter from the lead ores.

In Turkey the silver deposits are rather great, especially in the lead ores. One of areas in Anatolia with the lead deposits is Keban and the Central Taurus in Southeastern Anatolia where also a considerable number of finds of silver objects is done (Yener 1983, p. 2; Yener *et al.* 1994, p. 380). It is remarkable that lead and silver were delivered to Mesopotamia of the Old Babylonian period, apparently, from the Taurus region (Reiter 1999, p. 168).

Possibly, studies of silver of the Sintashta-Abashevo time will allow its origin as a result of the described technological process to be shown. Lead impurity will act as its indicator. However they can be very insignificant. In silver inclusions in ingots of lead oxide (litharge), received as a result of the secondary melting (cupellation), microanalyses show lead impurity of 4-8% (Hess *et al.* 1998, p. 64). However in the silver produced by such a way the lead contents are usually much lower. As a rule, such silver contains some tenth of a percent of lead. It characterizes almost all analyzed silver objects in the Near East, with rare exception. It allows to suppose that almost all silver was produced exactly so. Besides, lead oxides easily evaporate and are present usually in the lining of furnaces or walls of used for this crucible that can be a diagnostic sign too. At this smelting metallurgists could use a vessel or a small pit in the earth. The hearth could be covered with clay, to absorb the lead evaporations (Pernicka *et al.* 1998, p. 124, 125). At last, this process can be also testified by analysis of lead objects. In case of incomplete separation of silver, its content in lead can be about 0.1%. The content of silver lower than 0.07% can testify the exploitation of enough pure lead ores. Higher concentrations (0.4-0.6%) indicate, as a rule, weak qualification, problems with fuel, etc. (Reher, Prange 1998, p. 189).

Thus, the finds of lead and slags containing lead, testify, first of all, the silver production. Rare finds of lead objects in comparison with silver objects also testify to it. Besides, up to the Hellenistic time there are no data that after silver extraction the lead was reduced from lead oxide. And the lead production could be incomparably larger at its larger content in the initial ore. Some amount of lead could be smelted as by-product, and be occasionally used in arsenic-lead and tin-lead alloys.

Initial ore could contain not so much silver. Researches show that in the ores used in the Early Bronze Age, the content of silver was above 0.5%, and in the Roman time it was already above 0.1%. Individual lead objects can be a result of casual reduction from oxide in the process of silver production or test smelting of lead ore (Pernicka *et al.* 1998, p. 128). This picture, as a whole, corresponds to that which we see in the Sintashta-Abashevo time, where, besides the rare alloys with lead, silver objects and billons (copper alloy with silver) are known. It is supported also by Chernykh's data. In his study of the Volga-Ural metal 12 silver objects and only one of lead are recorded (Chernykh 1970, tab. 5). Besides Abashevo culture, silver objects are found in the Seima-Turbino cemeteries in which also copper-silver alloys are known (Chernykh, Kuzminykh 1989, tab. 10). Therefore it is not excluded that the concept suggested here can be extended also on this group of Northern Eurasian sites; especially as in the Near East billons are known (Hauptmann, Palmieri 2000, p. 77).

Judging from the rarity of finds in the Urals, the volumes of this ore smelting, as well as the volumes of silver extraction, were insignificant. But, except for Anatolia where silver was necessary to supply the Mesopotamian trade, these volumes were insignificant everywhere. The situation drastically changed only in the classical antiquity. Smelting of galenite and use of the method of cupellation for producing silver are recorded in Phoenician colonies in Spain (Kassianidou 2003, p. 204; Hunt Ortiz 2003, p. 358). But the Athenian mines in Laurion are the best-known ancient production of silver, of course. Thanks to large furnaces, smelting of silver were very economically effective there, slag contained small lead concentrations, and this lead contained less silver, than usually. This production was technologically perfect. The ore was roasted and oxidized in the large furnace. A small hearth for cupellation was constructed separately (Tylecote 1987, p. 138). The same technologies, although in more modest kind, was practiced in Roman colonies (Rehren, Kraus 1999).

Copper with nickel

The analysis of metal of the Arkaim settlement by the specialists of the Institute of Mineralogy (Miass) has revealed an object made of nickel bronze with the nickel content of 1.1% (Zaykov *et al.* 1999, p. 194, 195). As our studies of the Sintashta metal have shown, nickel impurity in copper is not something unique. 16 objects have been revealed with nickel concentration within the range of 0.3-1.16% (Tab. 5-48.). As a rule, these objects are also characterized by high arsenic concentrations[11].

The connection of nickel with arsenic identified in slag, caused by alloying components, forces us to see in it the reason of the presence of such copper. As the same way of alloying took place in the Near East, it is lawful also to look for analogies of this impurity in copper there. In Eastern Europe such metal is known only in one group of the EBA Maikop metal of the Northern Caucasus, and E.N. Chernykh assumed its origin from some areas to the south from the Caucasus (Chernykh 1966, p. 49, 50), but V.A. Galibin suggested to consider it as a result of alloying of copper with the nickel-arsenic mineral nickeline (NiAs) (Galibin 1991, p. 60, 61). There are also objections against this point of view and the suggestion to consider these arsenic bronzes with nickel impurity in the Caucasus as a result of smelting fahlores which can contain also nickel (Egorkov 2002). But this last assumption is not supported by any analytical data. Moreover, although in the Maikop metal containing higher concentration of nickel, the content of antimony is really slightly higher, it is nevertheless too insignificant to speak about the use of fahlores (see Chernykh 1966, fig. 12, 13).

There are really many objects with higher content of nickel in the Near East. The collection of copper artifacts from the layer Amuq F is the most known; the artifacts contain from 0.39 to 2.73% nickel, and in exceptional cases up to 10%. The high nickel content was detected by studies of metal from some Anatolian sites: Hassek Höyük, Tarsus and Tepecik. One ornament from Ikiztepe has shown even 22.7% nickel. In addition to Anatolia, similar objects are present in the well-known Israeli hoards Kfar Monash and Nahal Mishmar, in Suse, Habuba, Egypt, Luristan and Mokhendjo Daro (Tylecote 1981, p. 45, 50; Yener *et al.* 1994, p. 378; Schmitt-Strecker *et al.* 1991; Riederer 1991, p. 89). In Mesopotamia and Iran the higher nickel content is observed in half of arsenic bronzes (Avilova 2008, p. 86, 87, 124). At last, the higher contents of nickel and cobalt are revealed in some objects of the Middle Bronze Age of Armenia, although this impurity is not characteristic of copper ores of the region. Therefore, it has been suggested that the difference in the nickel content is caused by different smelting temperatures (Meliksetyan, Pernicka 2010, p. 49).

[11] Similar result has been received by A.D. Degtyareva (2010, p. 87) who determined that about 20% of objects had nickel concentration between 0.2 and 0.96%, and they were accompanied by higher concentrations of arsenic.

Nevertheless, so wide distribution of the metal enriched with this element, provokes to look for sources of this copper because in Turkey and on the Cyprus such deposits are absent. Earlier it was supposed that the higher nickel concentrations are a reliable sign of the origin of copper from Oman (Tylecote 1981, p. 45). As deposits in Oman are connected with ophiolites, it was supposed that the same impurity can be present also in the ophiolites and ultrabasic rocks in Anatolia, and it is a natural impurity (Hauptman, Palmieri 2000, p. 80). However, the recent studies have shown that similar ores in Oman are absent too (Müller-Karpe 1990, p. 107, 108). Nevertheless, in Anatolia where copper with arsenic and nickel occurs since the end of the Eneolithic, but it is typical already for the Bronze Age, the deposits in the ophiolites and serpentines enriched with these elements are really found, in particular, the well-known large deposit of Ergani Maden (Yalcin, Yalcin 2009, p. 130-133).

It is also impossible to assume an alloying with nickel into metal because of so high concentration in some instances. Therefore the source of this copper is unclear. But its southern origin is unconditional. The most probable explanation is (by analogy with the Sintashta situation) the smelting of copper ore with minerals containing arsenic and nickel. It is confirmed, in particular, by that in objects from the Anatolian settlement of Ikiztepe the distribution of arsenic and nickel is bimodal, a part of objects does not show correlation between these elements, and another part shows. And, near the Galis there are ancient mines with arsenical mineralization (Gülçur 2002, p. 44-45).

Metallographic analyses of the Maikop artifacts are very important for the solution of this problem. Noticeable impurities of nickel in copper after smelting of complex fahlores is improbable as they do not contain it in noticeable quantities, but their smelting leads to the sublimation of arsenic. Deposits with nickeline are known in the area of Maikop culture, and, these deposits contain also impurity of uranium oxide, and traces of uranium are present in the Maikop bronzes. Smelting of nickeline with malachite makes possible to produce arsenic bronze of the corresponding composition and with identical inclusions. Thanks to strong compound of arsenic with nickel the sublimation of arsenic does not happen, which was the main factor in the choice of this mineral for alloying: "Results of experiments have shown that smelting of malachite or copper with nickeline allows at heating to 1100-1200 °C to receive high-quality bronze without slags and defects, and the main thing, without loss of arsenic. It is known that at heating of double copper-arsenic alloys there is an active volatilization of arsenic, or rather its oxides (As_2O_3) which has an effect already at a temperature of 457 °C" (Ryndina *et al.* 2008; Ryndina, Ravich 2012, p. 5-9).

Important results have been also received at studying physical properties of the arsenic-nickel bronzes. Distinctions in the hardness of these alloys, in comparison with arsenic bronzes, have not been revealed. But the presence of nickel demanded changes in forging technology. Annealing was necessary to increase the malleability in a narrow range of temperatures 600-750 °C. At higher temperatures the hardening of the alloy occurs, delay deceleration of both recrystallization and cracks formation. At the temperatures between 400 and 600 °C it is possible to reach the maximum hardness of the product. In case of high arsenic contents it is not possible to increase the malleability by the annealing. Therefore, high arsenic concentration are absent in these bronzes.

Taking into account this research, it becomes clear comparatively low contents of arsenic in the Sintashta copper. It is interesting that the chosen method of alloying was dictated by the aspiration to avoid arsenic sublimation, but it demanded also special forging operations avoiding too high temperatures.

It is not excluded that a similar way of alloying took place sometimes also later. Analyses of slag and metal ingots from the settlement of Klingelberg near to Mitterberg in Austria have shown that copper sulfides in slag contain little arsenic and nickel, but in copper ingots they are presented, and nickel can be present in high concentrations (up to 5%). From this a conclusion has been drawn that nickel was not an ore impurity, it was the result of alloying (Moesta 1995a, p. 331). But the alloying with nickel is hardly possible. The alloying variant by an arsenic-nickel mineral is not excluded as it took place in Sintashta culture, although in this case the sense of this alloying against the wide distribution of alloying with tin in the Middle Bronze Age of Europe (it is later than Sintashta culture) is not quite clear.

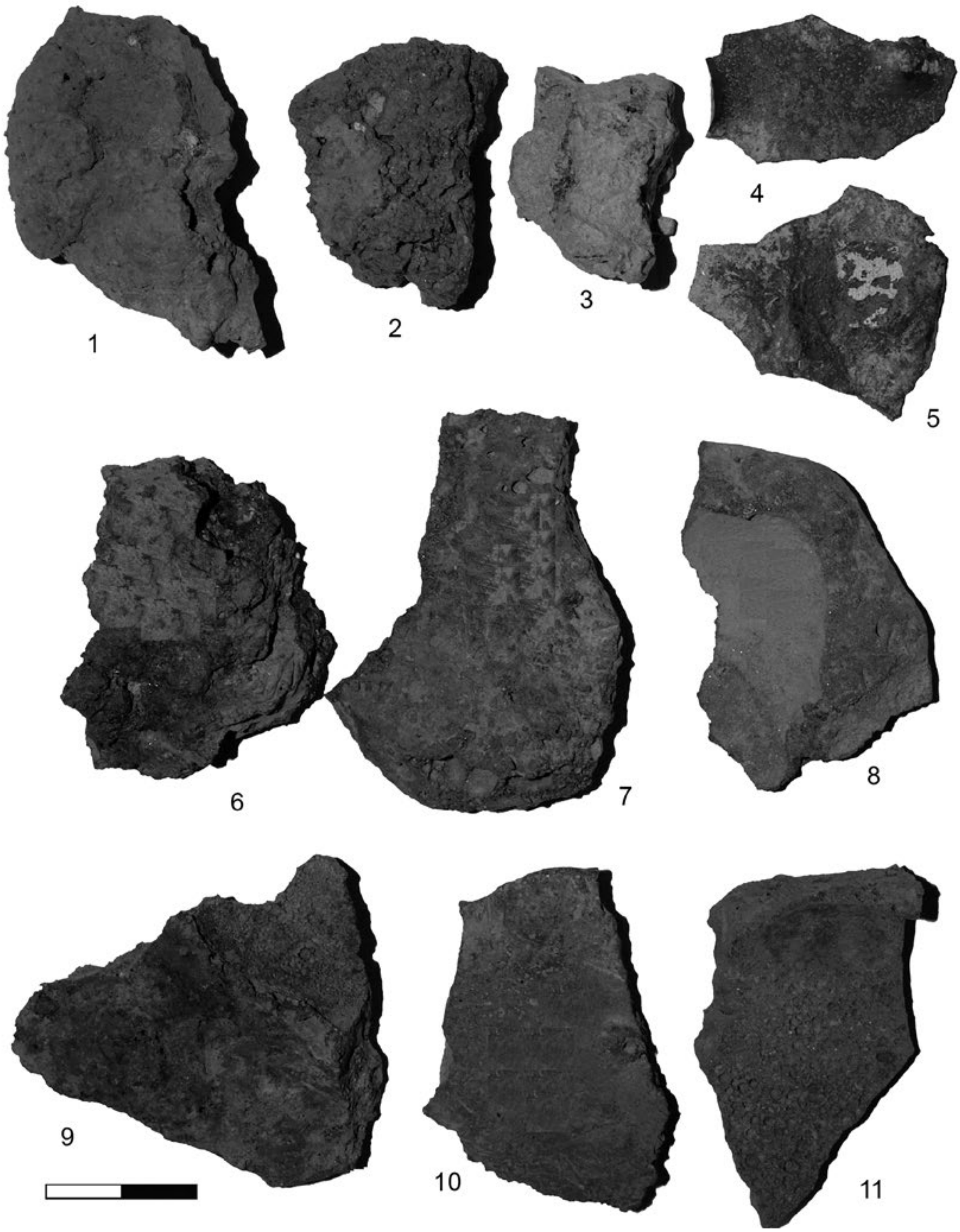


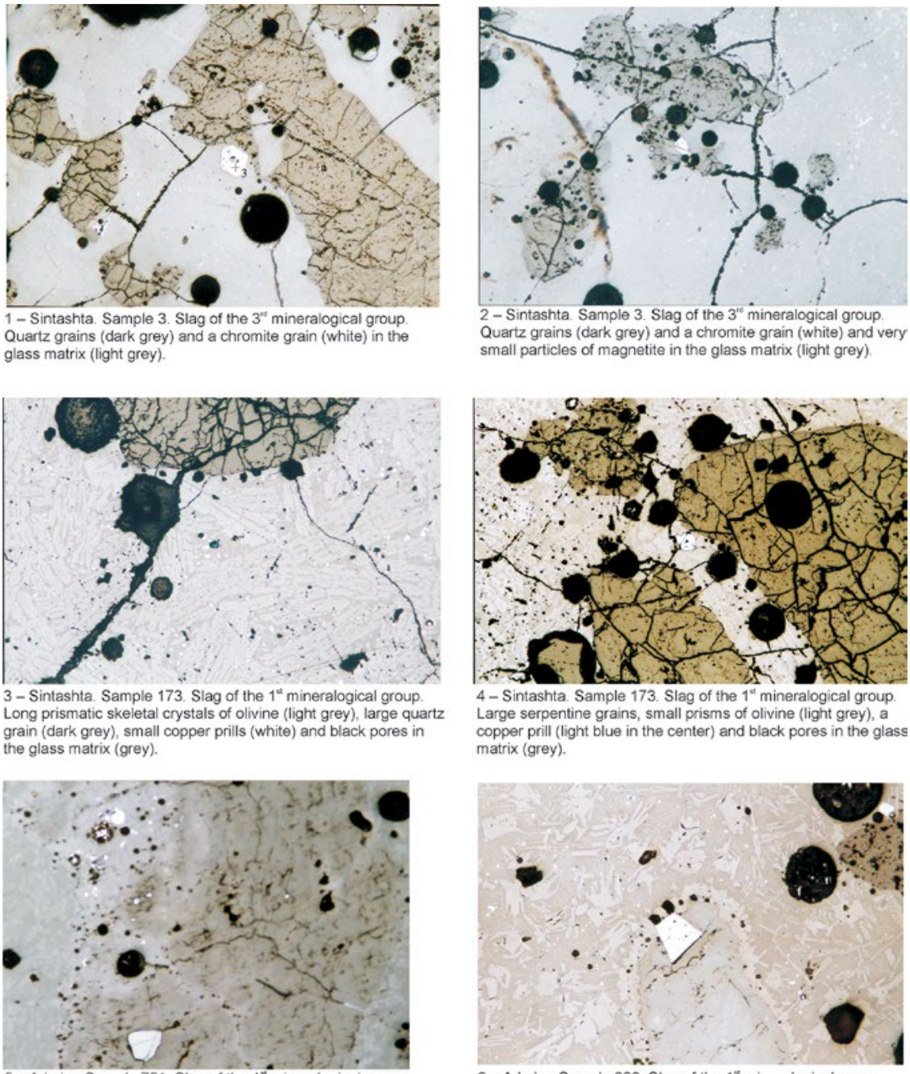
Fig. 5-1. Slag of the settlement of Sintashta: 1-3, 6 – shapeless slag; 4, 5 – thin slag cakes; 7-11 – flat slag cakes.

Tab. 5-2. Distribution of flat slag cakes and shapeless slag over settlements in the Transurals.

Sites	**Slags**	
	flat cakes	**shapeless**
Arkaim	44	18
Sintashta	29	15
Ustye	39	14
Krivoye Ozero	4	—
Vishnyovka	1	—
Petrovka	1	—
Novonikolskoye	1	—
Olgino	3	—
Burli	—	1
Semiozerki II	4	7
Konezavod	1	—
Sakryn-Sakla	1	—
Alandskoe	1	—
Sergeevka	—	2
Yagodniy Dol	1	—
Rodniki	2	—
Sintashta XIII	—	6
Tash-Kazgan	—	4
Malokizilskoye	—	2
Utyovka VI	2	—

Tab. 5-3. Distribution of flat slag cakes and shapeless slag over cultural groups.

Cultural groups	**Slags**	
	flat cakes	**shapeless**
Sintashta	54 73%	20 27%
Petrovka	8 38%	13 62%
Sintashta-Petrovka	70 70%	30 30%
Others	0 0%	7 100%
Total	**140** **62,5%**	**84** **37,5%**



1 – Sintashta. Sample 3. Slag of the 3rd mineralogical group. Quartz grains (dark grey) and a chromite grain (white) in the glass matrix (light grey).

2 – Sintashta. Sample 3. Slag of the 3rd mineralogical group. Quartz grains (dark grey) and a chromite grain (white) and very small particles of magnetite in the glass matrix (light grey).

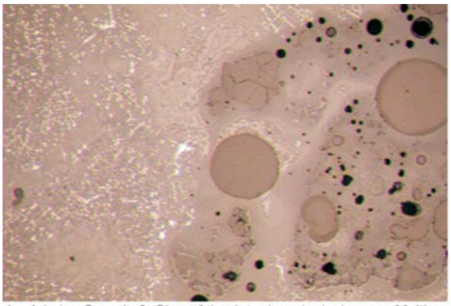
3 – Sintashta. Sample 173. Slag of the 1st mineralogical group. Long prismatic skeletal crystals of olivine (light grey), large quartz grain (dark grey), small copper prills (white) and black pores in the glass matrix (grey).

4 – Sintashta. Sample 173. Slag of the 1st mineralogical group. Large serpentine grains, small prisms of olivine (light grey), a copper prill (light blue in the center) and black pores in the glass matrix (grey).

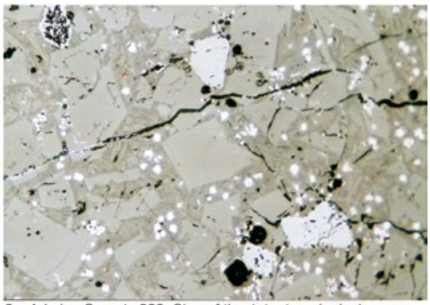
5 – Arkaim. Sample 751. Slag of the 1st mineralogical group. Melting grain of serpentine (dark grey on the left) with an inclusion of chromite grain (light blue) and black pores in the glass matrix (grey field on the left). Near the chromite there is an accumulation of small copper prills (white).

6 – Arkaim. Sample 680. Slag of the 1st mineralogical group. Large grain of serpentine (blue-grey below) with an inclusion of chromite grain (light) and black pores in the glass matrix (dark grey field). Crystals of olivine form along the edge of the chromite grain. Prismatic and needle-shaped olivine crystals are well presented in the glass.

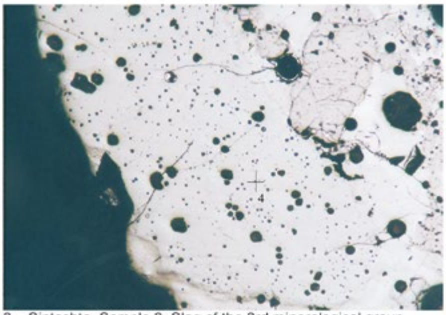
FIG. 5-I. MICROSTRUCTURES OF SLAG, REFLECTED LIGHT. 1 – SINTASHTA. SAMPLE 3. SLAG OF THE 3RD MINERALOGICAL GROUP. QUARTZ GRAINS (DARK GREY) AND A CHROMITE GRAIN (WHITE) IN THE GLASS MATRIX (LIGHT GREY). 2 – SINTASHTA. SAMPLE 3. SLAG OF THE 3RD MINERALOGICAL GROUP. QUARTZ GRAINS (DARK GREY) AND A CHROMITE GRAIN (WHITE) AND VERY SMALL PARTICLES OF MAGNETITE IN THE GLASS MATRIX (LIGHT GREY). 3 – SINTASHTA. SAMPLE 173. SLAG OF THE 1ST MINERALOGICAL GROUP. LONG PRISMATIC SKELETAL CRYSTALS OF OLIVINE (LIGHT GREY), LARGE QUARTZ GRAIN (DARK GREY), SMALL COPPER PRILLS (WHITE) AND BLACK PORES IN THE GLASS MATRIX (GREY). 4 – SINTASHTA. SAMPLE 173. SLAG OF THE 1ST MINERALOGICAL GROUP. LARGE SERPENTINE GRAINS, SMALL PRISMS OF OLIVINE (LIGHT GREY), A COPPER PRILL (LIGHT BLUE IN THE CENTER) AND BLACK PORES IN THE GLASS MATRIX (GREY). 5 – ARKAIM. SAMPLE 751. SLAG OF THE 1ST MINERALOGICAL GROUP. MELTING GRAIN OF SERPENTINE (DARK GREY ON THE LEFT) WITH AN INCLUSION OF CHROMITE GRAIN (LIGHT BLUE) AND BLACK PORES IN THE GLASS MATRIX (GREY FIELD ON THE LEFT). NEAR THE CHROMITE THERE IS AN ACCUMULATION OF SMALL COPPER PRILLS (WHITE). 6 – ARKAIM. SAMPLE 680. SLAG OF THE 1ST MINERALOGICAL GROUP. LARGE GRAIN OF SERPENTINE (BLUE-GREY BELOW) WITH AN INCLUSION OF CHROMITE GRAIN (LIGHT) AND BLACK PORES IN THE GLASS MATRIX (DARK GREY FIELD). CRYSTALS OF OLIVINE FORM ALONG THE EDGE OF THE CHROMITE GRAIN. PRISMATIC AND NEEDLE-SHAPED OLIVINE CRYSTALS ARE WELL PRESENTED IN THE GLASS.



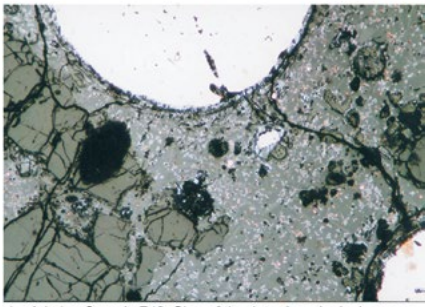
1 – Arkaim. Sample 2. Slag of the 1st mineralogical group. Melting grain of serpentine (dark grey on the right) with inclusions of particles and crystallizing skeletons of magnetite (light inclusions) and round pores in the glass matrix.



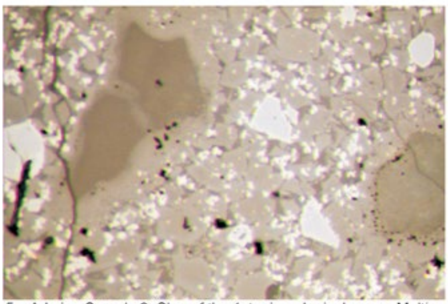
2 – Arkaim. Sample 822. Slag of the 1st mineralogical group. Polygonal crystals of olivine (grey), small grains of magnetite (light), grains of chromite (light blue) and small copper prills in the glass matrix (dark grey).



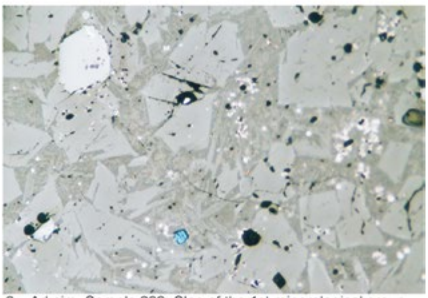
3 – Sintashta. Sample 3. Slag of the 3rd mineralogical group. Grains of quartz (grey) and round black pores in the glass matrix (light grey).



4 – Arkaim. Sample 740. Slag of the 1st mineralogical group. Large grains of serpentine (dark grey), small needle-shaped grains of olivine (grey), small grains of magnetite (light grey), grains of chromite (light blue) and large prills of copper in the glass matrix (grey).

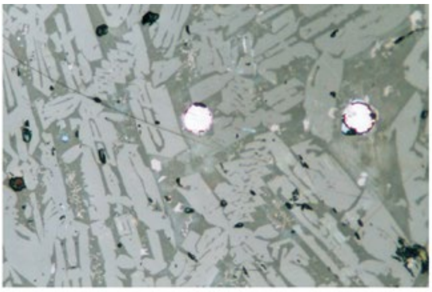


5 – Arkaim. Sample 2. Slag of the 1st mineralogical group. Melting grains of serpentine (dark grey), densely set crystals of olivine, grains of chromite (light blue) with white magnetite border and particles of magnetite (light inclusions) in the glass matrix.

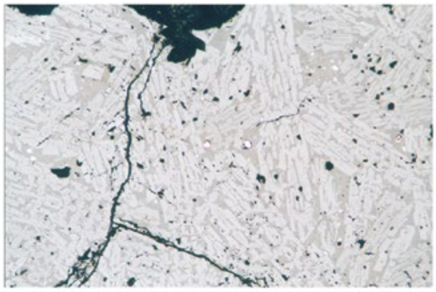


6 – Arkaim. Sample 822. Slag of the 1st mineralogical group. Polygonal crystals of olivine (grey), small grains of magnetite (light), grains of chromite (light blue) and small copper prills in the glass matrix (dark grey).

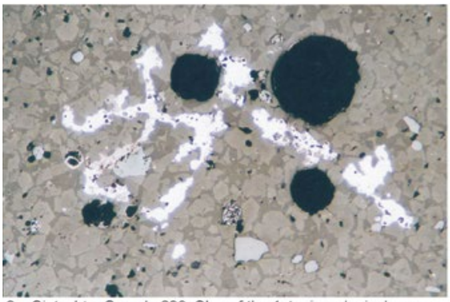
Fig. 5-II. Microstructures of slag, reflected light. 1 – Arkaim. Sample 2. Slag of the 1st mineralogical group. Melting grain of serpentine (dark grey on the right) with inclusions of particles and crystallizing skeletons of magnetite (light inclusions) and round pores in the glass matrix. 2 – Arkaim. Sample 822. Slag of the 1st mineralogical group. Polygonal crystals of olivine (grey), small grains of magnetite (light), grains of chromite (light blue) and small copper prills in the glass matrix (dark grey). 3 – Sintashta. Sample 3. Slag of the 3rd mineralogical group. Grains of quartz (grey) and round black pores in the glass matrix (light grey). 4 – Arkaim. Sample 740. Slag of the 1st mineralogical group. Large grains of serpentine (dark grey), small needle-shaped grains of olivine (grey), small grains of magnetite (light grey), grains of chromite (light blue) and large prills of copper in the glass matrix (grey). 5 – Arkaim. Sample 2. Slag of the 1st mineralogical group. Melting grains of serpentine (dark grey), densely set crystals of olivine, grains of chromite (light blue) with white magnetite border and particles of magnetite (light inclusions) in the glass matrix. 6 – Arkaim. Sample 822. Slag of the 1st mineralogical group. Polygonal crystals of olivine (grey), small grains of magnetite (light), grains of chromite (light blue) and small copper prills in the glass matrix (dark grey).



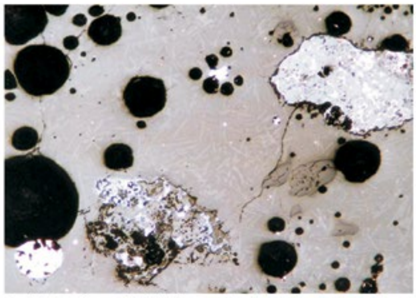
1 – Sintashta. Sample 173. Slag of the 1st mineralogical group. Crystallizing prisms and skeletons of olivine (grey), small octahedral of magnetite (light grey), copper prills with cuprite border, small prills and particles of cuprite (blue) and black pores in the glass matrix (dark grey).



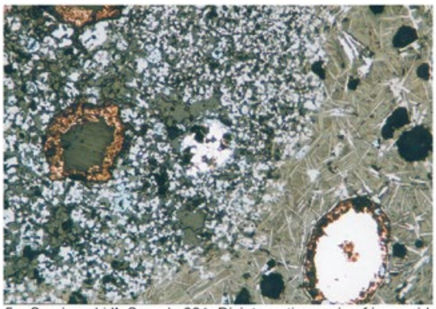
2 – Sintashta. Sample 173. Slag of the 1st mineralogical group. Crystallizing prisms of olivine (light grey), small copper prills and a large black pore in the glass matrix (grey).



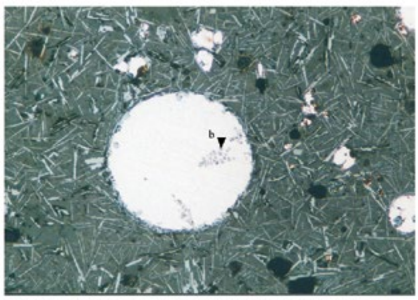
3 – Sintashta. Sample 839. Slag of the 1st mineralogical group. Polygonal and prismatic crystals of olivine (grey), grains of chromite (light grey), light molten metallic phase consisting of copper, iron and arsenic in the glass matrix (dark grey).



4 – Arkaim. Sample 751. Slag of the 1st mineralogical group. Small needle-shaped olivine crystals (grey), a copper prill (light below on the left), melting body of oxidized ore with inclusions of a metallic phases consisting of iron, copper and arsenic, round black pores in the glass matrix (dark grey field).

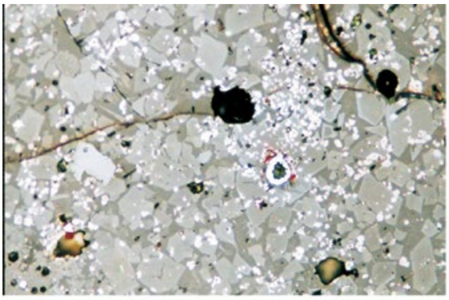


5 – Semiozerki II. Sample 221. Disintegrating grain of iron oxide and cuprite with copper inclusions (on the left). Thin needles of delafossite, a large copper globule and (on the right) in the glass matrix.



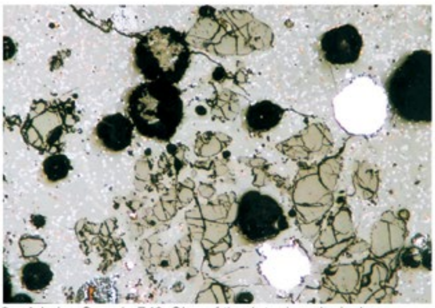
6 – Semiozerki II. Sample 221. Large copper globule with small inclusions of cuprite, small needles of delafossite and particles of cuprite in the glass matrix (dark grey).

Fig. 5-III. Microstructures of slag, reflected light. 1 – Sintashta. Sample 173. Slag of the 1st mineralogical group. Crystallizing prisms and skeletons of olivine (grey), small octahedral of magnetite (light grey), copper prills with cuprite border, small prills and particles of cuprite (blue) and black pores in the glass matrix (dark grey). 2 – Sintashta. Sample 173. Slag of the 1st mineralogical group. Crystallizing prisms of olivine (light grey), small copper prills and a large black pore in the glass matrix (grey). 3 – Sintashta. Sample 839. Slag of the 1st mineralogical group. Polygonal and prismatic crystals of olivine (grey), grains of chromite (light grey), light molten metallic phase consisting of copper, iron and arsenic in the glass matrix (dark grey). 4 – Arkaim. Sample 751. Slag of the 1st mineralogical group. Small needle-shaped olivine crystals (grey), a copper prill (light below on the left), melting body of oxidized ore with inclusions of a metallic phases consisting of iron, copper and arsenic, round black pores in the glass matrix (dark grey field). 5 – Semiozerki II. Sample 221. Disintegrating grain of iron oxide and cuprite with copper inclusions (on the left). Thin needles of delafossite, a large copper globule and pores (on the right) in the glass matrix. 6 – Semiozerki II. Sample 221. Large copper globule with small inclusions of cuprite, small needles of delafossite and particles of cuprite in the glass matrix (dark grey).

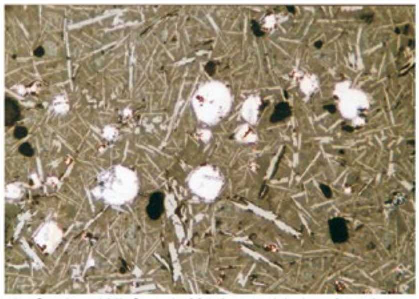


1 – Sintashta. Sample 846. Slag of the 1st mineralogical group. Polygonal and prismatic crystals of olivine (grey), grain of chromite (light blue on the left), prill of cuprite (blue and red in the center) and black pores in the glass matrix (dark grey).

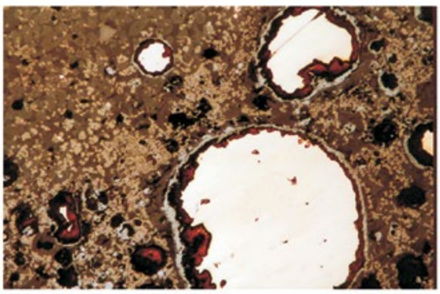
2 – Sintashta. Sample 873. Slag of the 1st mineralogical group. Large copper globule with inclusions of cuprite and cuprite border, particles of magnetite in the glass matrix.



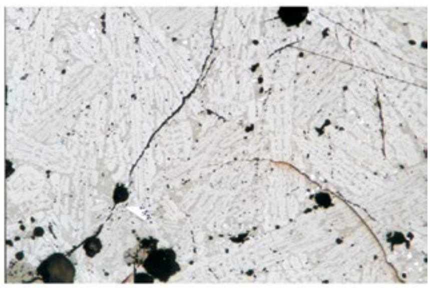
3 – Arkaim. Sample 740. Slag of the 1st mineralogical group. Large disintegrating grains of serpentine, copper prills (white), pores (black), small light magnetite rash, thin olivine needles (light grey) and small rare copper prills (yellow) in the glass matrix (grey field).



4 – Semiozerki II. Sample 221. Large globules of cuprite (white), small copper prills (yellow), small needles of delafossite and black pores in the glass matrix (dark field).



5 – Sintashta. Sample 846. Slag of the 1st mineralogical group. and prismatic crystals of olivine (green-brown), grain of chromite (grey above on the left), copper prills with cuprite border, particles of magnetite (brown) and black pores in the glass matrix (dark brown field).



6 – Sintashta. Sample 173. Slag of the 1st mineralogical group. Long skeletal prisms of olivine (light grey), small grain of chromite (light one below on the left), small copper prills and particles of magnetite (white) and black pores in the glass matrix (grey).

FIG. 5-IV. MICROSTRUCTURES OF SLAG, REFLECTED LIGHT. 1 – SINTASHTA. SAMPLE 846. SLAG OF THE 1ST MINERALOGICAL GROUP. POLYGONAL AND PRISMATIC CRYSTALS OF OLIVINE (GREY), GRAIN OF CHROMITE (LIGHT BLUE ON THE LEFT), PRILL OF CUPRITE (BLUE AND RED IN THE CENTER) AND BLACK PORES IN THE GLASS MATRIX (DARK GREY). 2 – SINTASHTA. SAMPLE 873. SLAG OF THE 1ST MINERALOGICAL GROUP. LARGE COPPER GLOBULE WITH INCLUSIONS OF CUPRITE AND CUPRITE BORDER, PARTICLES OF MAGNETITE IN THE GLASS MATRIX. 3 – ARKAIM. SAMPLE 740. SLAG OF THE 1ST MINERALOGICAL GROUP. LARGE DISINTEGRATING GRAINS OF SERPENTINE, COPPER PRILLS (WHITE), PORES (BLACK), SMALL LIGHT MAGNETITE RASH, THIN OLIVINE NEEDLES (LIGHT GREY) AND SMALL RARE COPPER PRILLS (YELLOW) IN THE GLASS MATRIX (GREY FIELD). 4 – SEMIOZERKI II. SAMPLE 221. LARGE GLOBULES OF CUPRITE (WHITE), SMALL COPPER PRILLS (YELLOW), SMALL NEEDLES OF DELAFOSSITE AND BLACK PORES IN THE GLASS MATRIX (DARK FIELD). 5 – SINTASHTA. SAMPLE 846. SLAG OF THE 1ST MINERALOGICAL GROUP. POLYGONAL AND PRISMATIC CRYSTALS OF OLIVINE (GREEN-BROWN), GRAIN OF CHROMITE (GREY ABOVE ON THE LEFT), COPPER PRILLS WITH CUPRITE BORDER, PARTICLES OF MAGNETITE (BROWN) AND BLACK PORES IN THE GLASS MATRIX (DARK BROWN FIELD). 6 – SINTASHTA. SAMPLE 173. SLAG OF THE 1ST MINERALOGICAL GROUP. LONG SKELETAL PRISMS OF OLIVINE (LIGHT GREY), SMALL GRAIN OF CHROMITE (LIGHT ONE BELOW ON THE LEFT), SMALL COPPER PRILLS AND PARTICLES OF MAGNETITE (WHITE) AND BLACK PORES IN THE GLASS MATRIX (GREY).

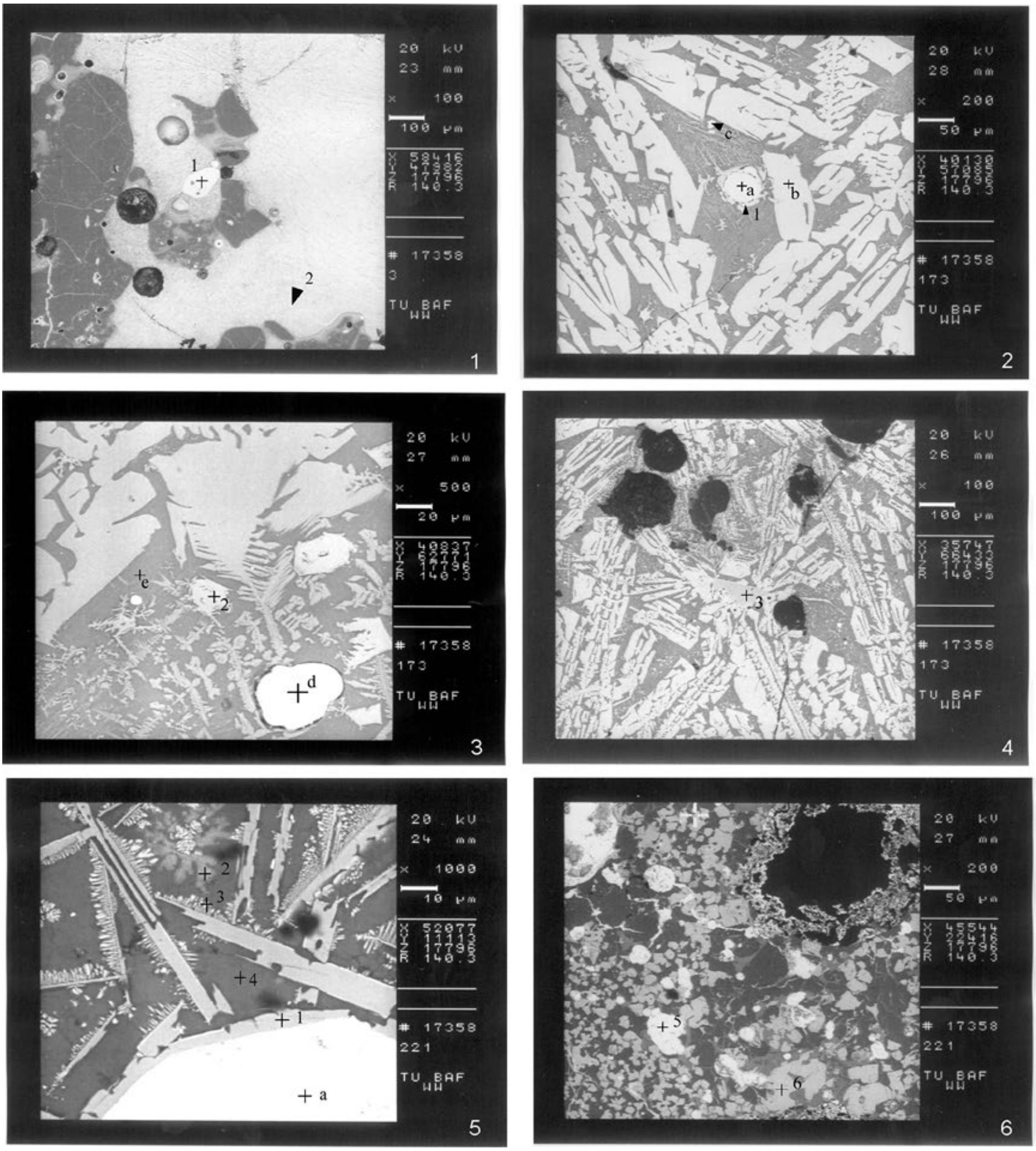


FIG. 5-V. MICROSTRUCTURES OF SLAG, SCANNING ELECTRON MICROSCOPE. 1 – SINTASHTA, SAMPLE 3; 2-4 – SINTASHTA, SAMPLE 173; 5, 6 – SEMIOZERKI II, SAMPLE 221.

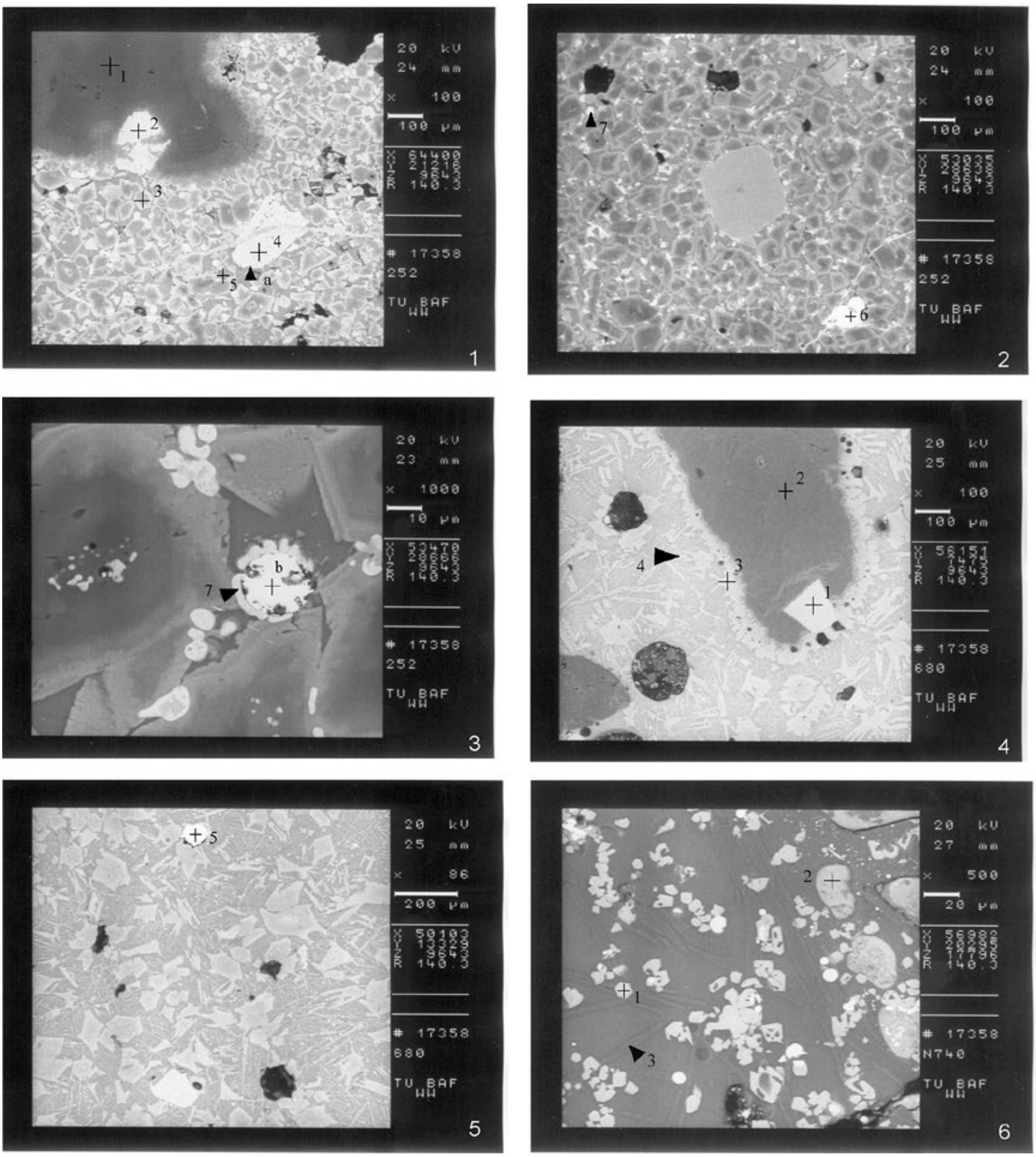


FIG. 5-VI. MICROSTRUCTURES OF SLAG, SCANNING ELECTRON MICROSCOPE. 1-3 – SEMIOZERKI II, SAMPLE 252; 4, 5 – ARKAIM, SAMPLE 680; 6 – ARKAIM, SAMPLE 740.

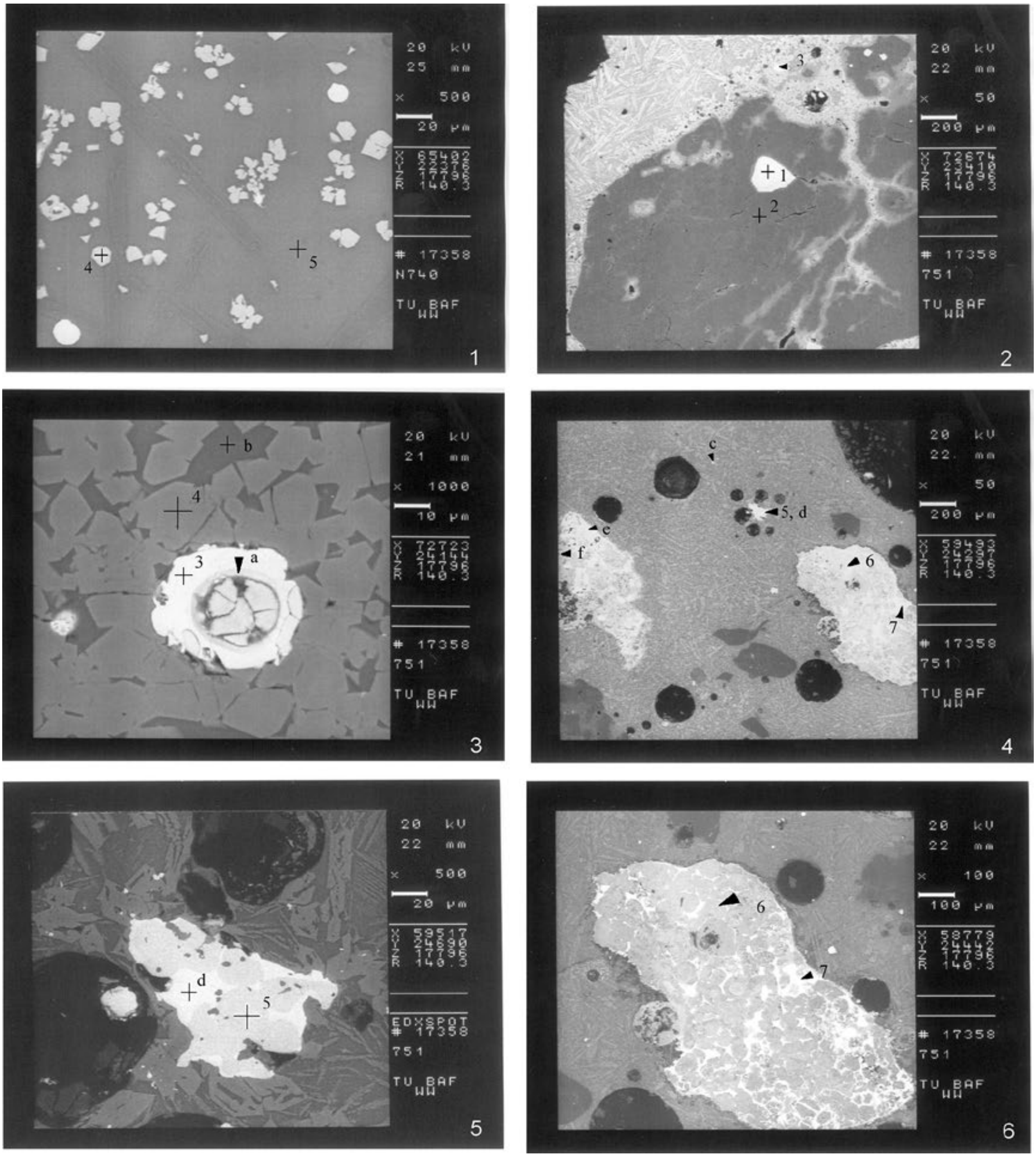


FIG. 5-VII. MICROSTRUCTURES OF SLAG, SCANNING ELECTRON MICROSCOPE. 1 – ARKAIM, SAMPLE 740; 2-6 – ARKAIM, SAMPLE 751.

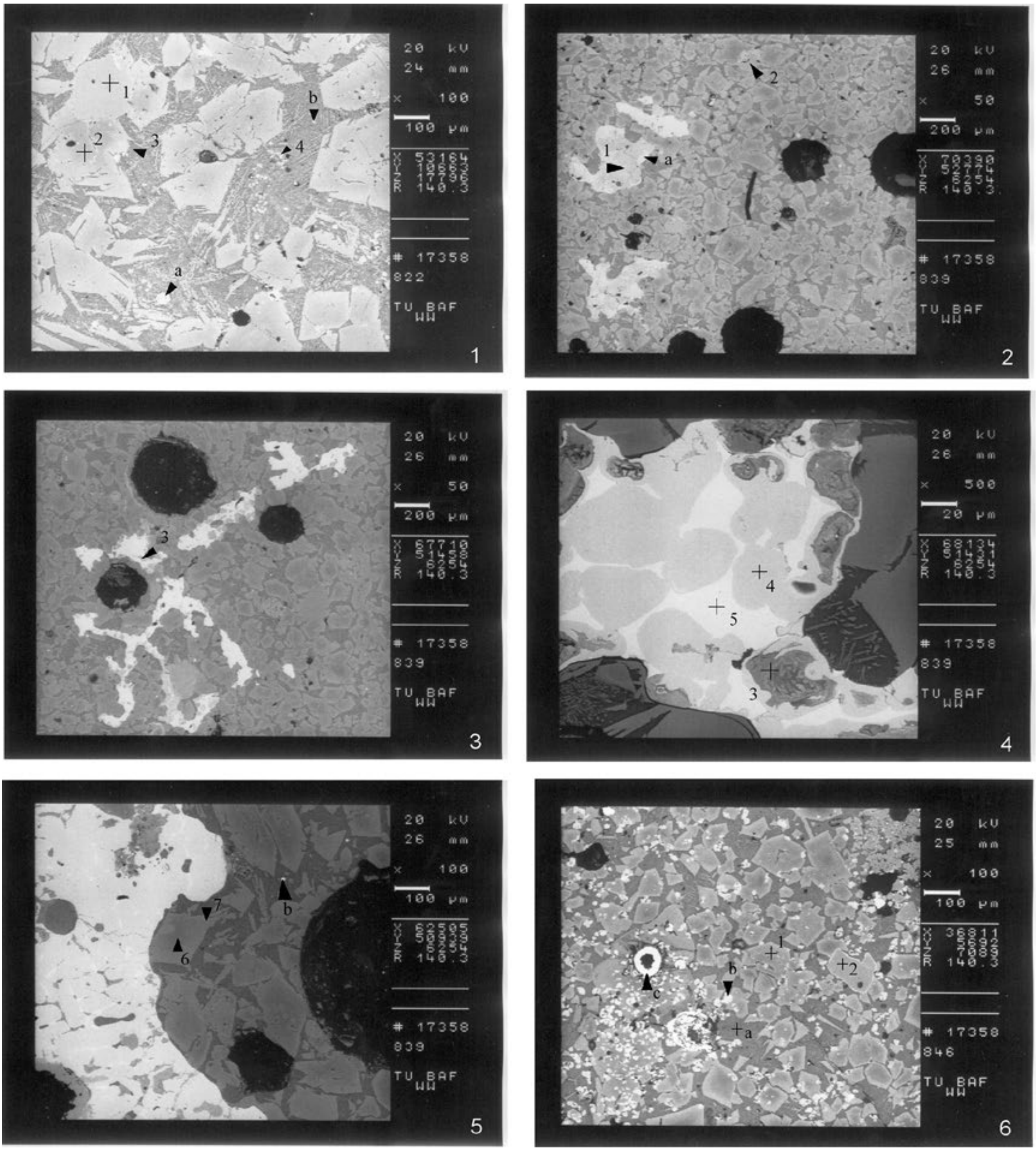


Fig. 5-VIII. Microstructures of slag, scanning electron microscope. 1 – Arkaim, sample 822; 2-5 – Sintashta, sample 839; 6 – Sintashta, sample 846.

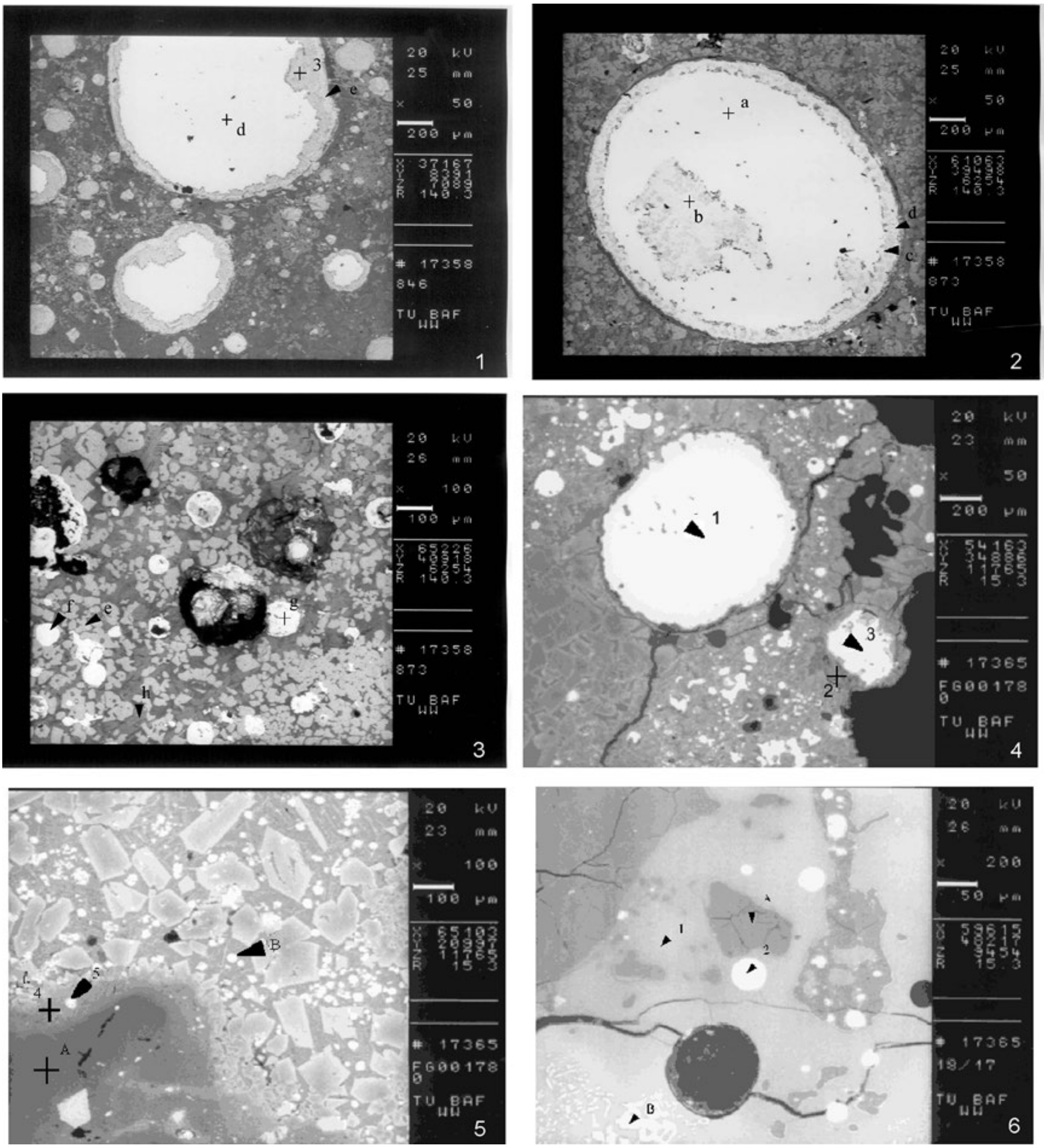
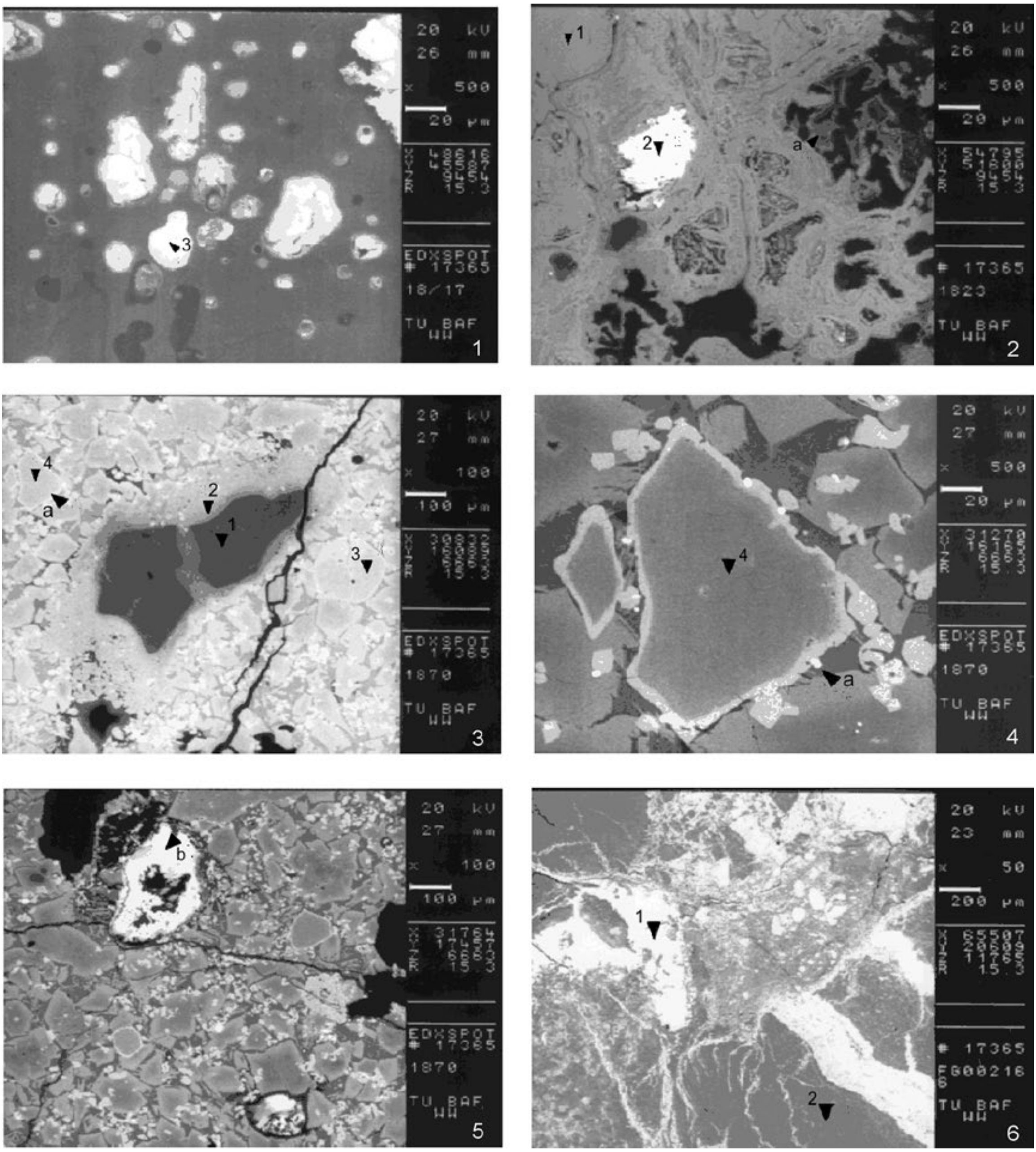
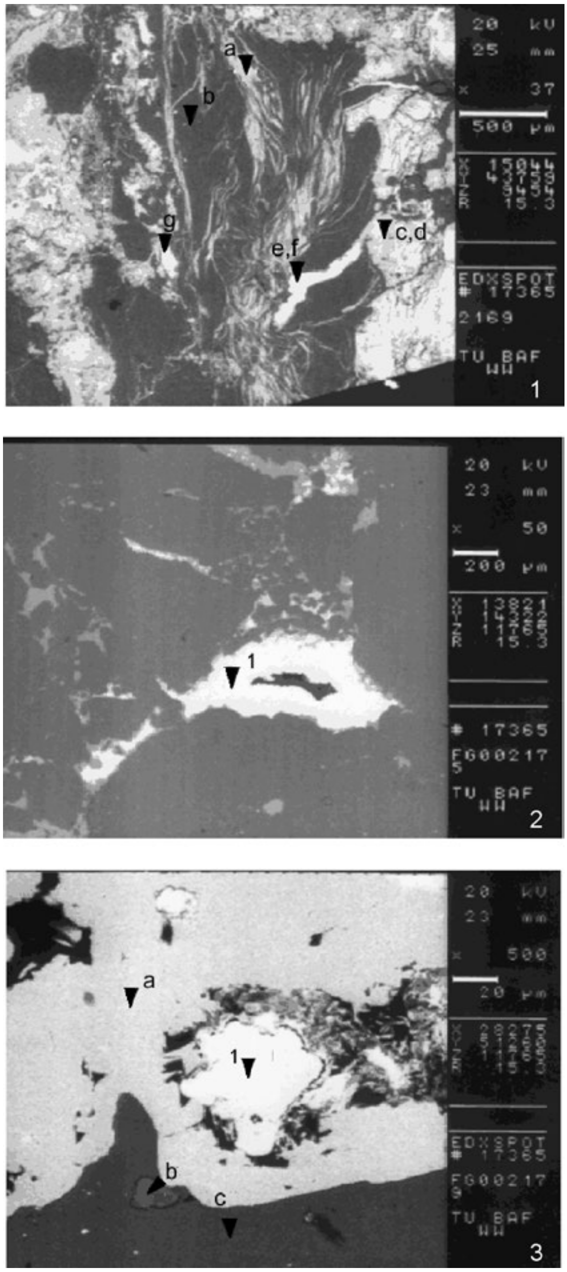


Fig. 5-IX. Microstructures of slag, scanning electron microscope. 1 – Sintashta, sample 846; 2, 3 – Sintashta, sample 873; 4, 5 – Arkaim, sample FG1780; 6 – Sintashta, sample FG1817.



Tab. 5-X. Microstructures of slag and ore, scanning electron microscope. 1 – Sintashta, sample FG1817; Sintashta, sample 1823; 3-5 – Solntse, sample 1870; 6 – Ivanovka, sample 2166.



Tab. 5-XI. Microstructures of slag and ore, scanning electron microscope. 1 – Ishkinino, sample 2169; 2 – Nikolskoe, sample 2175; 3 – Tash-Kazgan, sample 2179.

Tab. 5-4. EDX-analyses of slag and ore made in the Technical University of Freiberg by means of the Digital Scanning Microscope DSM 960 (weight %). Analyst B. Bleibe.

Site	Object	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Cr	Al
Sintashta	slag	3	1	chromite	27.28			21.85	4.93	34.01	9.17
Sintashta	slag	3	2	metal	0.53		83.04	3.91			
Sintashta	slag	3	3	chromite	27.49			18.87	5.80	34.68	9.78
Sintashta	slag	3	4	spar	53.10	35.90		0.96			5.64
Sintashta	slag	3	1 Wdh*	chromite	31.69			21.10	4.97	35.33	6.59
Sintashta	slag	3	5*	metal			83.24	4.17			
Sintashta	slag	3	6*	metal			76.24	4.01			
Sintashta	slag	173	1	sulfide			73.22	3.04			
Sintashta	slag	173	2	magnetite	21.55			69.07			5.73
Sintashta	slag	173	3	chromite	25.10			18.43	6.46	37.67	9.82
Semiozerki	slag	221	1	delafossite	25.57		42.04	30.81			1.58
Semiozerki	slag	221	2	cuprite	33.19	16.72	43.87	2.53			2.48
Semiozerki	slag	221	3	cuprite	25.35	10.19	59.20	2.56			2.05
Semiozerki	slag	221	4	glass	44.01	23.80	12.24	9.43			3.82
Semiozerki	slag	221	5	cuprite	15.14		83.11	1.75			
Semiozerki	slag	221	6	iron oxide	32.28			67.72			
Semiozerki	slag	221	3 Wdh*	cuprite	X		X	3.00			
Semiozerki	slag	252	1	serpentine	44.81	23.00		5.31	26.88		
Semiozerki	slag	252	2	chromite	25.49			24.79	3.44	34.97	9.33
Semiozerki	slag	252	3	olivine	38.30	16.39		33.75	11.56		
Semiozerki	slag	252	4	chromite	21.98	1.36		21.03	3.47	43.87	6.37
Semiozerki	slag	252	5	glass	41.71	21.77		18.37			5.11
Semiozerki	slag	252	6	cuprite	15.97		79.05	1.41			
Semiozerki	slag	252	7	copper edge	15.53	2.50		79.54		0.60	1.82
Arkaim	slag	680	1	chromite	25.59			15.16	9.10	41.30	8.85
Arkaim	slag	680	2	serpentine	46.12	29.94		6.98	16.96		
Arkaim	slag	680	3	olivine	35.80	16.64		36.72	10.83		
Arkaim	slag	680	4	magnetite	18.88	1.26		44.28	1.52	25.93	8.13
Arkaim	slag	680	5	metal			64.58				
Arkaim	slag	680	3 Wdh*	olivine	35.92	16.21		37.27	9.91	0.05	
Arkaim	slag	680	5 Wdh*	metal			64.02	0.79			

Site	Object	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Cr	Al
Arkaim	slag	740	1	magnetite	36.86			52.10			5.68
Arkaim	slag	740	2	cuprite	44.84		52.77	2.39			
Arkaim	slag	740	3	olivine	46.51	23.01		11.08	8.61		4.62
Arkaim	slag	740	4	magnetite	34.89			56.63	2.34		5.89
Arkaim	slag	740	5	glass	47.77	24.81	4.17	10.47	1.70		7.59
Arkaim	slag	751	1	chromite	27.60			15.46	7.59	37.51	8.82
Arkaim	slag	751	2	serpentine	48.12	28.78		3.12	12.75		
Arkaim	slag	751	3	metal	6.36		9.88	38.29			
Arkaim	slag	751	4	olivine	39.47	16.31		38.69	3.65		
Arkaim	slag	751	5	metal-dark phase			6.97	79.85			
Arkaim	slag	751	6	oxide-dark phase	35.43	1.82	16.10	40.64			
Arkaim	slag	751	7	metal			96.85	3.15			
Arkaim	slag	751	1 Wdh*	chromite	32.78			14.78	7.21	38.13	6.71
Arkaim	slag	751	2 Wdh*	serpentine	48.23	30.91		3.06	17.51	0.08	
Arkaim	slag	751	3 Wdh*	metal			10.65	44.86			
Arkaim	slag	751	4 Wdh*	olivine	36.31	16.64		36.26	10.29	0.09	
Arkaim	slag	751	6 Wdh*	oxide-dark phase	28.33	0.95	15.22	47.66			
Arkaim	slag	751	7 Wdh*	metal			87.68	7.98			
Arkaim	slag	822	1	chromite	22.38			20.79	6.62	38.97	9.24
Arkaim	slag	822	2	olivine	37.27	16.59		34.77	7.35		
Arkaim	slag	822	3	glass	45.10	24.94		16.18			5.92
Arkaim	slag	822	4	magnetite	20.88			71.30		4.77	3.05
Sintashta	slag	839	1	oxide	36.06		6.91	44.47			
Sintashta	slag	839	2	chromite	27.32			20.32	5.59	35.84	9.11
Sintashta	slag	839	3	oxide	33.48		6.40	40.58			
Sintashta	slag	839	4	metal	2.94		11.21	82.04			
Sintashta	slag	839	5	metal			89.35	4.60			
Sintashta	slag	839	6	olivine-dark phase	39.26	15.85		36.82	8.06		
Sintashta	slag	839	7	olivine	36.90	15.09		45.57	1.54		
Sintashta	slag	839	3 Wdh*	oxide	27.89		4.39	54.55			

Site	Object	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Cr	Al
Sintashta	slag	839	4 Wdh*	metal			9.55	82.70			
Sintashta	slag	839	5 Wdh*	metal			91.08	4.56			
Sintashta	slag	839	8*	olivine-dark phase	34.58	15.75		42.64	6.29	0.05	
Sintashta	slag	839	9*	olivine-light phase	32.42	14.80		50.73	0.89	0.07	
Sintashta	slag	846	1	olivine	41.06	15.81		34.52	8.62		
Sintashta	slag	846	2	chromite	28.50			18.59	6.27	33.55	10.17
Sintashta	slag	846	3	copper edge			64.04				
Sintashta	slag	846	1 Wdh*	olivine	34.40	15.41		43.26	6.50	0.04	
Arkaim	slag	FG1777	1	chromite	13.1			24.21	5.99	46.88	9.62
Arkaim	slag	FG1780	1	copper	4.18		76.6				
Arkaim	slag	FG1780	2	dark phase	33.46	0.55	36.65	10.38			
Arkaim	slag	FG1780	3	metal	2.05		66.88	2.4			
Arkaim	slag	FG1780	4	molten serpentine	33.47	20.81		26.05	19.81		
Arkaim	slag	FG1780	5	silicate	19.68	8.39		27.84			
Sintashta	slag	FG1803	1	chromite	11.13			26.45	7.9	42.47	12.04
Sintashta	slag	FG1817	1	smelt	38.2	42.42		5.5			6.83
Sintashta	slag	FG1817	2	silicate	21.77	10.22		5.02			
Sintashta	slag	FG1817	3	metal							
Sintashta	ore	FG1823	1	malachite	28.39		71.61				
Sintashta	ore	FG1823	2	metal							
Solntse	slag	FG1870	1	serpentine	38.88	28.27		6.79	26.25		2.03
Solntse	slag	FG1870	2	molten serpentine	27.67	19.26		45.27	7.36		
Solntse	slag	FG1870	3	chromite	8.96			26.11	8.36	46.75	9.82
Solntse	slag	FG1870	4	chromite	11.5			26.82	7.06	44.37	10.25
Solntse	slag	FG1870	5	olivine	25.45	17.5		51.1	5.59		
Kamenniy Ambar	ore	FG1878	1	rock	41.87	31.75			1.52		16.07
Kamenniy Ambar	ore	FG1878	2	serpentine	29.79	21.41		12.53	19.03	1.36	15.91
Tyubyak	ore	FG1921	1	mineral	26.65						
Tyubyak	ore	FG1926	1	copper oxide	21.48		67.18				

Site	Object	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Cr	Al
Tyubyak	slag	FG1928	1	copper			100				
Beregovskoye	slag	FG1934	1	covellite			66				
Beregovskoye	slag	FG1934	2	copper			100				
Beregovskoye	slag	FG1934	3	copper			100				
Sintashta	slag	FG1947	1	ore (chloride)	18.78		61.79	1.28			
Ivanovka	ore	FG2166	1	malachite	30.29		69.71				
Ivanovka	ore	FG2166	2	serpentine	38.58	18.33	1.76	18.85	11.35		13.14
Ishkinino	ore	FG2169	1	chromite	13.83			19.98	9.18	45.38	11.63
Ishkinino	ore	FG2171	1	malachite	30.01	0.35	69.65				
Nikoskoye	ore	FG2175	1	ore	26.52	0.98	61.27				
Tash-Kazgan	ore	FG2179	1	metal				4.03			
Ush-Katta	ore	FG2181	1	light crystal	33.76	16.53					
Ush-Katta	ore	FG2181	2	rock	41.33	38.35					12.26

Tab. 5-4. EDX-analyses of slag and ore made in the Technical University of Freiberg by means of the Digital Scanning Microscope DSM 960 (weight %). Analyst B. Bleibe. (contd.)

Site	Object	Sample	Analysis	Material	As	K	Ca	Cl	Ni	S	Mn	Ti	V
Sintashta	slag	3	1	chromite	2.75								
Sintashta	slag	3	2	metal	12.52								
Sintashta	slag	3	3	chromite	3.39								
Sintashta	slag	3	4	spar		4.39							
Sintashta	slag	3	1 Wdh*	chromite			0.06					0.26	
Sintashta	slag	3	5*	metal	11.43				1.15				
Sintashta	slag	3	6*	metal	4.93				0.66	11.40			
Sintashta	slag	173	1	sulfide						23.74			
Sintashta	slag	173	2	magnetite								1.35	2.30
Sintashta	slag	173	3	chromite	2.52								
Semiozerki	slag	221	1	delafossite									
Semiozerki	slag	221	2	cuprite		0.62	0.59						
Semiozerki	slag	221	3	cuprite		0.40	0.25						
Semiozerki	slag	221	4	glass	1.58	1.30	1.82				2.00		
Semiozerki	slag	221	5	cuprite									
Semiozerki	slag	221	6	iron oxide									
Semiozerki	slag	221	3 Wdh*	cuprite									
Semiozerki	slag	252	1	serpentine									
Semiozerki	slag	252	2	chromite	1.97								
Semiozerki	slag	252	3	olivine									
Semiozerki	slag	252	4	chromite	1.92								
Semiozerki	slag	252	5	glass		1.02	12.02						
Semiozerki	slag	252	6	cuprite				3.57					
Semiozerki	slag	252	7	copper edge									
Arkaim	slag	680	1	chromite									
Arkaim	slag	680	2	serpentine									
Arkaim	slag	680	3	olivine									
Arkaim	slag	680	4	magnetite									
Arkaim	slag	680	5	metal	31.56				3.86				
Arkaim	slag	680	3 Wdh*	olivine			0.30				0.34		

Site	Object	Sample	Analysis	Material	As	K	Ca	Cl	Ni	S	Mn	Ti	V
Arkaim	slag	680	5 Wdh*	metal	32.51				2.68				
Arkaim	slag	740	1	magnetite	5.36								
Arkaim	slag	740	2	cuprite									
Arkaim	slag	740	3	olivine	5.20						0.98		
Arkaim	slag	740	4	magnetite	0.25								
Arkaim	slag	740	5	glass	1.10	0.50	1.29				0.60		
Arkaim	slag	751	1	chromite	3.01								
Arkaim	slag	751	2	serpentine	7.24								
Arkaim	slag	751	3	metal	44.81					0.66			
Arkaim	slag	751	4	olivine	1.87								
Arkaim	slag	751	5	metal-dark phase	13.19								
Arkaim	slag	751	6	oxide-dark phase	6.00								
Arkaim	slag	751	7	metal									
Arkaim	slag	751	1 Wdh*	chromite			0.12					0.27	
Arkaim	slag	751	2 Wdh*	serpentine			0.01					0.14	
Arkaim	slag	751	3 Wdh*	metal	43.37				1.15				
Arkaim	slag	751	4 Wdh*	olivine			0.27				0.13		
Arkaim	slag	751	6 Wdh*	oxide-dark phase	7.48					0.36			
Arkaim	slag	751	7 Wdh*	metal	5.06				0.05				
Arkaim	slag	822	1	chromite	2.00								
Arkaim	slag	822	2	olivine	4.02								
Arkaim	slag	822	3	glass		0.99	6.86						
Arkaim	slag	822	4	magnetite									
Sintashta	slag	839	1	oxide	10.50				2.06				
Sintashta	slag	839	2	chromite	1.82								
Sintashta	slag	839	3	oxide	5.93			4.59	9.02				
Sintashta	slag	839	4	metal					3.80				
Sintashta	slag	839	5	metal	4.39				1.66				
Sintashta	slag	839	6	olivine-dark phase									
Sintashta	slag	839	7	olivine			0.90						
Sintashta	slag	839	3 Wdh*	oxide	4.44			1.70	7.03				

Site	Object	Sample	Analysis	Material	As	K	Ca	Cl	Ni	S	Mn	Ti	V
Sintashta	slag	839	4 Wdh*	metal	4.45				3.29				
Sintashta	slag	839	5 Wdh*	metal	3.01				1.35				
Sintashta	slag	839	8*	olivine-dark phase			0.48				0.22		
Sintashta	slag	839	9*	olivine-light phase			0.85				0.24		
Sintashta	slag	846	1	olivine									
Sintashta	slag	846	2	chromite	2.92								
Sintashta	slag	846	3	copper edge				35.96					
Sintashta	slag	846	1 Wdh*	olivine			0.30				0.09		
Arkaim	slag	FG1777	1	chromite									
Arkaim	slag	FG1780	1	copper					17.15				
Arkaim	slag	FG1780	2	dark phase					16.95	1.28			
Arkaim	slag	FG1780	3	metal					28.66				
Arkaim	slag	FG1780	4	molten serpentine									
Arkaim	slag	FG1780	5	silicate			1.48						
Sintashta	slag	FG1803	1	chromite									
Sintashta	slag	FG1817	1	smelt		4.68	1.77					0.6	
Sintashta	slag	FG1817	2	silicate			1.28						
Sintashta	slag	FG1817	3	metal									
Sintashta	ore	FG1823	1	malachite									
Sintashta	ore	FG1823	2	metal									
Solntse	slag	FG1870	1	serpentine									
Solntse	slag	FG1870	2	molten serpentine			0.44						
Solntse	slag	FG1870	3	chromite									
Solntse	slag	FG1870	4	chromite									
Solntse	slag	FG1870	5	olivine			0.36						
Kamenniy Ambar	ore	FG1878	1	rock		8.79							
Kamenniy Ambar	ore	FG1878	2	serpentine									
Tyubyak	ore	FG1921	1	mineral						6.25			

Site	Object	Sample	Analysis	Material	As	K	Ca	Cl	Ni	S	Mn	Ti	V
Tyubyak	ore	FG1926	1	copper oxide						3.72			
Tyubyak	slag	FG1928	1	copper									
Beregovskoye	slag	FG1934	1	covellite						12.55			
Beregovskoye	slag	FG1934	2	copper									
Beregovskoye	slag	FG1934	3	copper									
Sintashta	slag	FG1947	1	ore (chloride)				18.15					
Ivanovka	ore	FG2166	1	malachite									
Ivanovka	ore	FG2166	2	serpentine									
Ishkinino	ore	FG2169	1	chromite									
Ishkinino	ore	FG2171	1	malachite									
Nikoskoye	ore	FG2175	1	ore									
Tash-Kazgan	ore	FG2179	1	metal									
Ush-Katta	ore	FG2181	1	light crystal			23.27					26.44	
Ush-Katta	ore	FG2181	2	rock									

Tab. 5-4. EDX-analyses of slag and ore made in the Technical University of Freiberg by means of the Digital Scanning Microscope DSM 960 (weight %). Analyst B. Bleibe. (contd.)

Site	Object	Sample	Analysis	Material	Se	Pb	W	Zn	P	Ba	Mo	Na
Sintashta	slag	3	1	chromite								
Sintashta	slag	3	2	metal								
Sintashta	slag	3	3	chromite								
Sintashta	slag	3	4	spar								
Sintashta	slag	3	1 Wdh*	chromite								
Sintashta	slag	3	5*	metal								
Sintashta	slag	3	6*	metal	2.76							
Sintashta	slag	173	1	sulfide								
Sintashta	slag	173	2	magnetite								
Sintashta	slag	173	3	chromite								
Semiozerki	slag	221	1	delafossite								
Semiozerki	slag	221	2	cuprite								
Semiozerki	slag	221	3	cuprite								
Semiozerki	slag	221	4	glass								
Semiozerki	slag	221	5	cuprite								
Semiozerki	slag	221	6	iron oxide								
Semiozerki	slag	221	3 Wdh*	cuprite								
Semiozerki	slag	252	1	serpentine								
Semiozerki	slag	252	2	chromite								
Semiozerki	slag	252	3	olivine								
Semiozerki	slag	252	4	chromite								
Semiozerki	slag	252	5	glass								
Semiozerki	slag	252	6	cuprite								
Semiozerki	slag	252	7	copper edge								
Arkaim	slag	680	1	chromite								
Arkaim	slag	680	2	serpentine								
Arkaim	slag	680	3	olivine								
Arkaim	slag	680	4	magnetite								
Arkaim	slag	680	5	metal								
Arkaim	slag	680	3 Wdh*	olivine								

Site	Object	Sample	Analysis	Material	Se	Pb	W	Zn	P	Ba	Mo	Na
Arkaim	slag	680	5 Wdh*	metal								
Arkaim	slag	740	1	magnetite								
Arkaim	slag	740	2	cuprite								
Arkaim	slag	740	3	olivine								
Arkaim	slag	740	4	magnetite								
Arkaim	slag	740	5	glass								
Arkaim	slag	751	1	chromite								
Arkaim	slag	751	2	serpentine								
Arkaim	slag	751	3	metal								
Arkaim	slag	751	4	olivine								
Arkaim	slag	751	5	metal-dark phase								
Arkaim	slag	751	6	oxide-dark phase								
Arkaim	slag	751	7	metal								
Arkaim	slag	751	1 Wdh*	chromite								
Arkaim	slag	751	2 Wdh*	serpentine								
Arkaim	slag	751	3 Wdh*	metal								
Arkaim	slag	751	4 Wdh*	olivine								
Arkaim	slag	751	6 Wdh*	oxide-dark phase								
Arkaim	slag	751	7 Wdh*	metal								
Arkaim	slag	822	1	chromite								
Arkaim	slag	822	2	olivine								
Arkaim	slag	822	3	glass								
Arkaim	slag	822	4	magnetite								
Sintashta	slag	839	1	oxide								
Sintashta	slag	839	2	chromite								
Sintashta	slag	839	3	oxide								
Sintashta	slag	839	4	metal								
Sintashta	slag	839	5	metal								
Sintashta	slag	839	6	olivine-dark phase								
Sintashta	slag	839	7	olivine								
Sintashta	slag	839	3 Wdh*	oxide								

Site	Object	Sample	Analysis	Material	Se	Pb	W	Zn	P	Ba	Mo	Na
Sintashta	slag	839	4 Wdh*	metal								
Sintashta	slag	839	5 Wdh*	metal								
Sintashta	slag	839	8*	olivine-dark phase								
Sintashta	slag	839	9*	olivine-light phase								
Sintashta	slag	846	1	olivine								
Sintashta	slag	846	2	chromite								
Sintashta	slag	846	3	copper edge								
Sintashta	slag	846	1 Wdh*	olivine								
Arkaim	slag	FG1777	1	chromite								
Arkaim	slag	FG1780	1	copper								
Arkaim	slag	FG1780	2	dark phase					0.73			
Arkaim	slag	FG1780	3	metal								
Arkaim	slag	FG1780	4	molten serpentine								
Arkaim	slag	FG1780	5	silicate		44.4 (Mo?)						
Sintashta	slag	FG1803	1	chromite								
Sintashta	slag	FG1817	1	smelt								
Sintashta	slag	FG1817	2	silicate		61.71						
Sintashta	slag	FG1817	3	metal		100						
Sintashta	ore	FG1823	1	malachite								
Sintashta	ore	FG1823	2	metal		100						
Solntse	slag	FG1870	1	serpentine								
Solntse	slag	FG1870	2	molten serpentine								
Solntse	slag	FG1870	3	chromite								
Solntse	slag	FG1870	4	chromite								
Solntse	slag	FG1870	5	olivine								
Kamenniy Ambar	ore	FG1878	1	rock								
Kamenniy Ambar	ore	FG1878	2	serpentine								
Tyubyak	ore	FG1921	1	mineral		3.87				54.58	8.64	

Site	Object	Sample	Analysis	Material	Se	Pb	W	Zn	P	Ba	Mo	Na
Tyubyak	ore	FG1926	1	copper oxide							7.66	
Tyubyak	slag	FG1928	1	copper								
Beregovskoye	slag	FG1934	1	covellite		21.45?					21.45?	
Beregovskoye	slag	FG1934	2	copper								
Beregovskoye	slag	FG1934	3	copper								
Sintashta	slag	FG1947	1	ore (chloride)								
Ivanovka	ore	FG2166	1	malachite								
Ivanovka	ore	FG2166	2	serpentine								
Ishkinino	ore	FG2169	1	chromite								
Ishkinino	ore	FG2171	1	malachite								
Nikoskoye	ore	FG2175	1	ore					11.23			
Tash-Kazgan	ore	FG2179	1	metal		89.79	5.28					
Ush-Katta	ore	FG2181	1	light crystal								
Ush-Katta	ore	FG2181	2	rock								8.06

Tab. 5-5. EDX-analyses of slag and ore made in the Technical University of Freiberg by means of the Digital Scanning Microscope DSM 960 (atomic %). Analyst B. Bleibe.

Site	Object	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Cr	Al	As
Sintashta	slag	3	1	chromite	51.21			11.75	6.09	19.64	10.20	1.10
Sintashta	slag	3	2	metal	2.12		82.85	4.44				10.59
Sintashta	slag	3	3	chromite	51.00			10.03	7.08	19.80	10.75	1.34
Sintashta	slag	3	4	spar	67.24	25.90		0.35			4.24	
Sintashta	slag	3	1 Wdh*	chromite	56.69			10.81	5.85	19.45	6.99	
Sintashta	slag	3	5*	metal			84.14	4.80				9.80
Sintashta	slag	3	6*	metal			68.99	4.13				3.78
Sintashta	slag	173	1	sulfide			59.18	2.79				
Sintashta	slag	173	2	magnetite	46.95			43.10			7.40	
Sintashta	slag	173	3	chromite	47.74			10.04	8.08	22.04	11.07	1.02
Semiozerki	slag	221	1	delafossite	55.69		23.05	19.22			2.04	
Semiozerki	slag	221	2	cuprite	58.80	16.87	19.57	1.29			2.60	
Semiozerki	slag	221	3	cuprite	52.51	12.03	30.88	1.52			2.52	
Semiozerki	slag	221	4	glass	64.25	19.79	4.50	3.94			3.31	1.52
Semiozerki	slag	221	5	cuprite	41.39		57.23	1.37				
Semiozerki	slag	221	6	iron oxide	62.46			37.54				
Semiozerki	slag	221	3 Wdh*	cuprite	X		X	3.00				
Semiozerki	slag	252	1	serpentine	58.10	16.99		1.97	22.94			
Semiozerki	slag	252	2	chromite	49.43			13.77	4.39	20.86	10.73	0.82
Semiozerki	slag	252	3	olivine	59.00	14.38		14.89	11.72			
Semiozerki	slag	252	4	chromite	45.09	1.59		12.36	4.68	27.69	7.74	0.84
Semiozerki	slag	252	5	glass	61.69	18.34		7.78			4.48	
Semiozerki	slag	252	6	cuprite	42.14		52.54	1.07				
Semiozerki	slag	252	7	copper edge	37.87	3.48		55.57		0.45	2.63	
Arkaim	slag	680	1	chromite	47.50			8.06	11.12	23.59	9.74	
Arkaim	slag	680	2	serpentine	60.42	22.34		2.62	14.62			
Arkaim	slag	680	3	olivine	56.89	15.07		16.72	11.33			
Arkaim	slag	680	4	magnetite	40.97	1.55		27.53	2.17	17.31	10.47	
Arkaim	slag	680	5	metal			67.61					28.02
Arkaim	slag	680	3 Wdh*	olivine	57.38	14.76		17.06	10.42	0.02		
Arkaim	slag	680	5 Wdh*	metal			67.11	0.94				28.91

Site	Object	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Cr	Al	As
Arkaim	slag	740	1	magnetite	65.48			26.51			5.98	2.03
Arkaim	slag	740	2	cuprite	76.24		22.59	1.16				
Arkaim	slag	740	3	olivine	64.07	18.06		4.37	7.81		3.77	1.53
Arkaim	slag	740	4	magnetite	62.09			28.87	2.74		6.21	0.10
Arkaim	slag	740	5	glass	65.71	19.44	1.45	4.12	1.54		6.19	0.32
Arkaim	slag	751	1	chromite	50.70			8.13	9.18	21.20	9.61	1.18
Arkaim	slag	751	2	serpentine	63.87	21.76		1.19	11.13			2.05
Arkaim	slag	751	3	metal	21.41		8.37	36.91				32.20
Arkaim	slag	751	4	olivine	63.01	14.83		17.69	3.83			0.64
Arkaim	slag	751	5	metal-dark phase			6.39	83.35				10.26
Arkaim	slag	751	6	oxide-dark phase	66.29	1.94	7.59	21.79				2.40
Arkaim	slag	751	7	metal			96.43	3.57				
Arkaim	slag	751	1 Wdh*	chromite	56.90			7.35	8.24	20.37	6.91	
Arkaim	slag	751	2 Wdh*	serpentine	61.55	22.47		1.12	14.77	0.03		
Arkaim	slag	751	3 Wdh*	metal			10.65	51.20				36.90
Arkaim	slag	751	4 Wdh*	olivine	57.52	15.02		16.46	10.73	0.05		
Arkaim	slag	751	6 Wdh*	oxide-dark phase	58.86	1.12	7.96	28.37				3.32
Arkaim	slag	751	7 Wdh*	metal			87.68	7.98				4.28
Arkaim	slag	822	1	chromite	44.25			11.77	8.61	23.70	10.83	0.84
Arkaim	slag	822	2	olivine	59.75	15.16		15.97	7.75			1.38
Arkaim	slag	822	3	glass	63.88	20.12		6.57			4.98	
Arkaim	slag	822	4	magnetite	46.83			45.81		3.29	4.06	
Sintashta	slag	839	1	oxide	67.60		3.26	23.88				4.20
Sintashta	slag	839	2	chromite	50.93			10.85	6.86	20.56	10.07	0.72
Sintashta	slag	839	3	oxide	63.76		3.07	22.14				2.41
Sintashta	slag	839	4	metal	9.71		9.32	77.55				
Sintashta	slag	839	5	metal			89.26	5.23				3.72
Sintashta	slag	839	6	olivine-dark phase	61.21	14.08		16.44	8.27			
Sintashta	slag	839	7	olivine	61.58	14.35		21.78	1.70			
Sintashta	slag	839	3 Wdh*	oxide	57.80		2.29	32.39				1.97

Site	Object	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Cr	Al	As
Sintashta	slag	839	4 Wdh*	metal			8.61	84.78				3.40
Sintashta	slag	839	5 Wdh*	metal			90.82	5.17				2.55
Sintashta	slag	839	8*	olivine-dark phase	57.46	14.91		20.30	6.88	0.03		
Sintashta	slag	839	9*	olivine-light phase	57.48	14.95		25.77	1.03	0.04		
Sintashta	slag	846	1	olivine	62.56	13.72		15.07	8.64			
Sintashta	slag	846	2	chromite	51.88			9.70	7.51	18.79	10.98	1.13
Sintashta	slag	846	3	copper edge			49.84					
Sintashta	slag	846	1 Wdh*	olivine	57. 32	14.63		20.65	7.13	0.02		
Arkaim	slag	FG1777	1	chromite	29.81			15.68	8.92	32.61	13.17	
Arkaim	slag	FG1780	1	copper	14.52		69.16					
Arkaim	slag	FG1780	2	dark phase	64.83	0.61	17.88	5.76				
Arkaim	slag	FG1780	3	metal	7.50		61.47	2.51				
Arkaim	slag	FG1780	4	molten serpentine	50.91	17.91		11.35	19.83			
Arkaim	slag	FG1780	5	silicate	50.24	9.38		20.15				
Sintashta	slag	FG1803	1	chromite	25.22			17.16	11.79	29.62	16.19	
Sintashta	slag	FG1817	1	smelt	54.05	34.05		2.22			5.71	
Sintashta	slag	FG1817	2	silicate	63.46	16.97		4.19				
Sintashta	slag	FG1817	3	metal								
Sintashta	ore	FG1823	1	malachite	61.16		38.84					
Sintashta	ore	FG1823	2	metal								
Solntse	slag	FG1870	1	serpentine	30.07	33.01		2.66	23.60		1.65	
Solntse	slag	FG1870	2	molten serpentine	48.83	19.38		22.91	8.57			
Solntse	slag	FG1870	3	chromite	21.26			17.74	13.05	34.13	13.82	
Solntse	slag	FG1870	4	chromite	26.40			17.64	10.66	31.31	13.95	
Solntse	slag	FG1870	5	olivine	41.24	18.50		27.17	6.83			
Kamenniy Ambar	ore	FG1878	1	rock	56.52	24.41			1.35		12.86	
Kamenniy Ambar	ore	FG1878	2	serpentine	59.85	17.95		5.28	18.43	0.6	13.88	
Tyubyak	ore	FG1921	1	mineral	70.38							
Tyubyak	ore	FG1926	1	copper oxide	51.73		40.72					

Site	Object	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Cr	Al	As
Tyubyak	slag	FG1928	1	copper			100					
Beregovskoye	slag	FG1934	1	covellite			62.87					
Beregovskoye	slag	FG1934	2	copper			100					
Beregovskoye	slag	FG1934	3	copper			100					
Sintashta	slag	FG1947	1	ore (chloride)	45.78		36.27	0.85				
Ivanovka	ore	FG2166	1	malachite	63.31		36.69					
Ivanovka	ore	FG2166	2	serpentine	55.93	13.58	0.64	7.83	10.83		11.30	
Ishkinino	ore	FG2169	1	chromite	29.79			12.32	13	30.05	14.84	
Ishkinino	ore	FG2171	1	malachite	62.85	0.41	36.74					
Nikoskoye	ore	FG2175	1	ore	54.90	1.15	31.94					
Tash-Kazgan	ore	FG2179	1	metal				16.03				
Ush-Katta	ore	FG2181	1	light crystal	55.08	15.37						
Ush-Katta	ore	FG2181	2	rock	54.35	28.72					9.56	

Tab. 5-5. EDX-analyses of slag and ore made in the Technical University of Freiberg by means of the Digital Scanning Microscope DSM 960 (atomic %). Analyst B. Bleibe (contd.).

Site	Object	Sample	Analysis	Material	K	Ca	Cl	Ni	S	Mn	Ti	V	Se
Sintashta	slag	3	1	chromite									
Sintashta	slag	3	2	metal									
Sintashta	slag	3	3	chromite									
Sintashta	slag	3	4	spar	2.28								
Sintashta	slag	3	1 Wdh*	chromite		0.05					0.16		
Sintashta	slag	3	5*	metal				1.26					
Sintashta	slag	3	6*	metal				0.64	20.44				2.01
Sintashta	slag	173	1	sulfide					38.02				
Sintashta	slag	173	2	magnetite							0.98	1.57	
Sintashta	slag	173	3	chromite									
Semiozerki	slag	221	1	delafossite									
Semiozerki	slag	221	2	cuprite	0.45	0.42							
Semiozerki	slag	221	3	cuprite	0.33	0.21							
Semiozerki	slag	221	4	glass	0.78	1.06				0.85			
Semiozerki	slag	221	5	cuprite									
Semiozerki	slag	221	6	iron oxide									
Semiozerki	slag	221	3 Wdh*	cuprite									
Semiozerki	slag	252	1	serpentine									
Semiozerki	slag	252	2	chromite									
Semiozerki	slag	252	3	olivine									
Semiozerki	slag	252	4	chromite									
Semiozerki	slag	252	5	glass	0.62	7.09							
Semiozerki	slag	252	6	cuprite			4.25						
Semiozerki	slag	252	7	copper edge									
Arkaim	slag	680	1	chromite									
Arkaim	slag	680	2	serpentine									
Arkaim	slag	680	3	olivine									
Arkaim	slag	680	4	magnetite									
Arkaim	slag	680	5	metal				4.37					
Arkaim	slag	680	3 Wdh*	olivine		0.19				0.16			
Arkaim	slag	680	5 Wdh*	metal				3.04					

Site	Object	Sample	Analysis	Material	K	Ca	Cl	Ni	S	Mn	Ti	V	Se
Arkaim	slag	740	1	magnetite									
Arkaim	slag	740	2	cuprite									
Arkaim	slag	740	3	olivine						0.39			
Arkaim	slag	740	4	magnetite									
Arkaim	slag	740	5	glass	0.28	0.71				0.24			
Arkaim	slag	751	1	chromite									
Arkaim	slag	751	2	serpentine									
Arkaim	slag	751	3	metal					1.11				
Arkaim	slag	751	4	olivine									
Arkaim	slag	751	5	metal-dark phase									
Arkaim	slag	751	6	oxide-dark phase									
Arkaim	slag	751	7	metal									
Arkaim	slag	751	1 Wdh*	chromite		0.09					0.16		
Arkaim	slag	751	2 Wdh*	serpentine							0.06		
Arkaim	slag	751	3 Wdh*	metal				1.25					
Arkaim	slag	751	4 Wdh*	olivine		0.17				0.06			
Arkaim	slag	751	6 Wdh*	oxide-dark phase					0.38				
Arkaim	slag	751	7 Wdh*	metal				0.06					
Arkaim	slag	822	1	chromite									
Arkaim	slag	822	2	olivine									
Arkaim	slag	822	3	glass	0.58	3.88							
Arkaim	slag	822	4	magnetite									
Sintashta	slag	839	1	oxide				1.05					
Sintashta	slag	839	2	chromite									
Sintashta	slag	839	3	oxide			3.94	4.68					
Sintashta	slag	839	4	metal				3.42					
Sintashta	slag	839	5	metal				1.79					
Sintashta	slag	839	6	olivine-dark phase									
Sintashta	slag	839	7	olivine		0.60							
Sintashta	slag	839	3 Wdh*	oxide			1.59	3.97					

Site	Object	Sample	Analysis	Material	K	Ca	Cl	Ni	S	Mn	Ti	V	Se
Sintashta	slag	839	4 Wdh*	metal				3.21					
Sintashta	slag	839	5 Wdh*	metal				1.46					
Sintashta	slag	839	8*	olivine-dark phase		0.32				0.11			
Sintashta	slag	839	9*	olivine-light phase		0.60				0.12			
Sintashta	slag	846	1	olivine									
Sintashta	slag	846	2	chromite									
Sintashta	slag	846	3	copper edge			50.16						
Sintashta	slag	846	1 Wdh*	olivine		0.20				0.04			
Arkaim	slag	FG1777	1	chromite									
Arkaim	slag	FG1780	1	copper				16.32					
Arkaim	slag	FG1780	2	dark phase				8.95	1.28				
Arkaim	slag	FG1780	3	metal				28.52					
Arkaim	slag	FG1780	4	molten serpentine									
Arkaim	slag	FG1780	5	silicate		1.54							
Sintashta	slag	FG1803	1	chromite									
Sintashta	slag	FG1817	1	smelt	2.7	0.99					0.28		
Sintashta	slag	FG1817	2	silicate		1.49							
Sintashta	slag	FG1817	3	metal									
Sintashta	ore	FG1823	1	malachite									
Sintashta	ore	FG1823	2	metal									
Solntse	slag	FG1870	1	serpentine									
Solntse	slag	FG1870	2	molten serpentine		0.31							
Solntse	slag	FG1870	3	chromite									
Solntse	slag	FG1870	4	chromite									
Solntse	slag	FG1870	5	olivine		0.27							
Kamenniy Ambar	ore	FG1878	1	rock	4.85								
Kamenniy Ambar	ore	FG1878	2	serpentine									
Tyubyak	ore	FG1921	1	mineral					8.24				
Tyubyak	ore	FG1926	1	copper oxide					4.47				

Site	Object	Sample	Analysis	Material	K	Ca	Cl	Ni	S	Mn	Ti	V	Se
Tyubyak	slag	FG1928	1	copper									
Beregovskoye	slag	FG1934	1	covellite					23.66				
Beregovskoye	slag	FG1934	2	copper									
Beregovskoye	slag	FG1934	3	copper									
Sintashta	slag	FG1947	1	ore (chloride)			19.1						
Ivanovka	ore	FG2166	1	malachite									
Ivanovka	ore	FG2166	2	serpentine									
Ishkinino	ore	FG2169	1	chromite									
Ishkinino	ore	FG2171	1	malachite									
Nikoskoye	ore	FG2175	1	ore									
Tash-Kazgan	ore	FG2179	1	metal									
Ush-Katta	ore	FG2181	1	light crystal		15.15					14.14		
Ush-Katta	ore	FG2181	2	rock									

Tab. 5-5. EDX-analyses of slag and ore made in the Technical University of Freiberg by means of the Digital Scanning Microscope DSM 960 (atomic %). Analyst B. Bleibe (contd.).

Site	Object	Sample	Analysis	Material	Pb	W	Zn	P	Ba	Mo	Na
Sintashta	slag	3	1	chromite							
Sintashta	slag	3	2	metal							
Sintashta	slag	3	3	chromite							
Sintashta	slag	3	4	spar							
Sintashta	slag	3	1 Wdh*	chromite							
Sintashta	slag	3	5*	metal							
Sintashta	slag	3	6*	metal							
Sintashta	slag	173	1	sulfide							
Sintashta	slag	173	2	magnetite							
Sintashta	slag	173	3	chromite							
Semiozerki	slag	221	1	delafossite							
Semiozerki	slag	221	2	cuprite							
Semiozerki	slag	221	3	cuprite							
Semiozerki	slag	221	4	glass							
Semiozerki	slag	221	5	cuprite							
Semiozerki	slag	221	6	iron oxide							
Semiozerki	slag	221	3 Wdh*	cuprite							
Semiozerki	slag	252	1	serpentine							
Semiozerki	slag	252	2	chromite							
Semiozerki	slag	252	3	olivine							
Semiozerki	slag	252	4	chromite							
Semiozerki	slag	252	5	glass							
Semiozerki	slag	252	6	cuprite							
Semiozerki	slag	252	7	copper edge							
Arkaim	slag	680	1	chromite							
Arkaim	slag	680	2	serpentine							
Arkaim	slag	680	3	olivine							
Arkaim	slag	680	4	magnetite							
Arkaim	slag	680	5	metal							
Arkaim	slag	680	3 Wdh*	olivine							
Arkaim	slag	680	5 Wdh*	metal							

Site	Object	Sample	Analysis	Material	Pb	W	Zn	P	Ba	Mo	Na
Arkaim	slag	740	1	magnetite							
Arkaim	slag	740	2	cuprite							
Arkaim	slag	740	3	olivine							
Arkaim	slag	740	4	magnetite							
Arkaim	slag	740	5	glass							
Arkaim	slag	751	1	chromite							
Arkaim	slag	751	2	serpentine							
Arkaim	slag	751	3	metal							
Arkaim	slag	751	4	olivine							
Arkaim	slag	751	5	metal-dark phase							
Arkaim	slag	751	6	oxide-dark phase							
Arkaim	slag	751	7	metal							
Arkaim	slag	751	1 Wdh*	chromite							
Arkaim	slag	751	2 Wdh*	serpentine							
Arkaim	slag	751	3 Wdh*	metal							
Arkaim	slag	751	4 Wdh*	olivine							
Arkaim	slag	751	6 Wdh*	oxide-dark phase							
Arkaim	slag	751	7 Wdh*	metal							
Arkaim	slag	822	1	chromite							
Arkaim	slag	822	2	olivine							
Arkaim	slag	822	3	glass							
Arkaim	slag	822	4	magnetite							
Sintashta	slag	839	1	oxide							
Sintashta	slag	839	2	chromite							
Sintashta	slag	839	3	oxide							
Sintashta	slag	839	4	metal							
Sintashta	slag	839	5	metal							
Sintashta	slag	839	6	olivine-dark phase							
Sintashta	slag	839	7	olivine							
Sintashta	slag	839	3 Wdh*	oxide							

Site	Object	Sample	Analysis	Material	Pb	W	Zn	P	Ba	Mo	Na
Sintashta	slag	839	4 Wdh*	metal							
Sintashta	slag	839	5 Wdh*	metal							
Sintashta	slag	839	8*	olivine-dark phase							
Sintashta	slag	839	9*	olivine-light phase							
Sintashta	slag	846	1	olivine							
Sintashta	slag	846	2	chromite							
Sintashta	slag	846	3	copper edge							
Sintashta	slag	846	1 Wdh*	olivine							
Arkaim	slag	FG1777	1	chromite							
Arkaim	slag	FG1780	1	copper							
Arkaim	slag	FG1780	2	dark phase				0.73			
Arkaim	slag	FG1780	3	metal							
Arkaim	slag	FG1780	4	molten serpentine							
Arkaim	slag	FG1780	5	silicate	18.31 (Mo?)						
Sintashta	slag	FG1803	1	chromite							
Sintashta	slag	FG1817	1	smelt							
Sintashta	slag	FG1817	2	silicate	13.89						
Sintashta	slag	FG1817	3	metal	100						
Sintashta	ore	FG1823	1	malachite							
Sintashta	ore	FG1823	2	metal	100						
Solntse	slag	FG1870	1	serpentine							
Solntse	slag	FG1870	2	molten serpentine							
Solntse	slag	FG1870	3	chromite							
Solntse	slag	FG1870	4	chromite							
Solntse	slag	FG1870	5	olivine							
Kamenniy Ambar	ore	FG1878	1	rock							
Kamenniy Ambar	ore	FG1878	2	serpentine							
Tyubyak	ore	FG1921	1	mineral	0.79				16.79	3.81	
Tyubyak	ore	FG1926	1	copper oxide						3.08	

Site	Object	Sample	Analysis	Material	Pb	W	Zn	P	Ba	Mo	Na
Tyubyak	slag	FG1928	1	copper							
Beregovskoye	slag	FG1934	1	covellite	13.52?					13.52?	
Beregovskoye	slag	FG1934	2	copper							
Beregovskoye	slag	FG1934	3	copper							
Sintashta	slag	FG1947	1	ore (chloride)							
Ivanovka	ore	FG2166	1	malachite							
Ivanovka	ore	FG2166	2	serpentine							
Ishkinino	ore	FG2169	1	chromite							
Ishkinino	ore	FG2171	1	malachite							
Nikoskoye	ore	FG2175	1	ore				12.01			
Tash-Kazgan	ore	FG2179	1	metal	78.75	5.22					
Ush-Katta	ore	FG2181	1	light crystal							
Ush-Katta	ore	FG2181	2	rock							7.37

Tab. 5-6. EDX-analyses of slag and ore made in the Technical University of Freiberg by means of the Digital Scanning Microscope DSM 960 (qualitative analysis). Analyst B. Bleibe.

Site	Object	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Cr	Al	As	K	Ca	Cl
Sintashta	slag	3	a	quartz	X	X									
Sintashta	slag	173	a	copper			X	L							
Sintashta	slag	173	b	fayalite	X	X		X							
Sintashta	slag	173	c	magnetite	X			X	L		L				
Sintashta	slag	173	d	sulfide			X								
Sintashta	slag	173	e	glass	X	X		X			X		X	X	
Semiozerki	slag	221	a	copper			X								
Semiozerki	slag	221	b	cuprite	L		X								
Semiozerki	slag	252	a	chromite	X			X		L					
Semiozerki	slag	252	b	copper			X								
Arkaim	slag	751	a	metal		X	X	X				X			
Arkaim	slag	751	b	glass	X	X		L			L		L	L	
Arkaim	slag	751	c	copper			X	L							
Arkaim	slag	751	d	metal			X	L							
Arkaim	slag	751	e	malachite	L		X								
Arkaim	slag	751	f	cuprite	L		X								
Arkaim	slag	822	a	sulfide			X	L							
Arkaim	slag	822	b	copper			X	L							
Sintashta	slag	839	a	light phase	X		X	X				X			
Sintashta	slag	839	b	copper			X	L							
Sintashta	slag	846	a	glass	X	X		X			X		X	X	
Sintashta	slag	846	b	magnetite	X			X							
Sintashta	slag	846	c	cuprite	L		X								
Sintashta	slag	846	d	copper			X								
Sintashta	slag	846	e	cuprite	L		X								
Sintashta	slag	873	a	copper			X								
Sintashta	slag	873	b	cuprite	L		X								
Sintashta	slag	873	c	light phase	X		X								
Sintashta	slag	873	d	dark phase	L		X								X
Sintashta	slag	873	e	magnetite	X			X							
Sintashta	slag	873	f	cuprite	L		X								

Site	Object	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Cr	Al	As	K	Ca	Cl
Sintashta	slag	873	g	cuprite	L		X								
Sintashta	slag	873	h	olivine	X	X	L	X							
Arkaim	slag	FG1780	a	serpentine	X	X		L	X						
Arkaim	slag	FG1780	b	copper chloride			X								X
Arkaim	slag	FG1788	a	metal											
Arkaim	slag	FG1788	b	oxide	X	X									
Sintashta	slag	FG1802	a	copper			X					L			
Sintashta	slag	FG1802	b	wüstite	X			X							
Sintashta	slag	FG1803	a	malachite	X		X	L							X
Sintashta	slag	FG1803	b	copper			X					X			
Sintashta	slag	FG1817	a	quartz	X	X									
Sintashta	slag	FG1817	b	wüstite	X			X							
Sintashta	slag	FG1817	c	copper prill	X	X		L							
Sintashta	ore	FG1823	a	limonite	X		L	X							
Sintashta	ore	FG1826	a	malachite	X		X	L							
Sintashta	ore	FG1826	b	ore	X	X	X								
Sintashta	ore	FG1826	c	magnetite	X			X							
Solntse	slag	FG1870	a	copper			X								
Solntse	slag	FG1870	b	malachite	X		X								X
Kamenniy Ambar	ore	FG1878	a	malachite	X		X								
Tyubyak	ore	FG1921	a	malachite	X		X								
Tyubyak	ore	FG1921	b	mineral	X	X	X				L			L	
Tyubyak	ore	FG1921	c	rock	X	X					L				
Tyubyak	ore	FG1921	d	inclusion in rock										X	
Tyubyak	slag	FG1928	a	edge of copper	L		X								
Tyubyak	slag	FG1928	b	malachite	L	L	X	L							
Beregovskoye	slag	FG1934	a	quartz	X	X									
Beregovskoye	slag	FG1934	b	covellite			X								
Beregovskoye	slag	FG1934	c	dark phase	X		X								
Beregovskoye	slag	FG1934	d	light phase			X								

Site	Object	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Cr	Al	As	K	Ca	Cl
Dergamysh	ore	FG2165	a	malachite	X		X								
Dergamysh	ore	FG2165-2	a	malachite	X		X								
Dergamysh	ore	FG2165-2	b	mineral	X			X							
Dergamysh	ore	FG2165-2	c	mineral	X			X							
Ishkinino	ore	FG2169	a	malachite	X		X								
Ishkinino	ore	FG2169	b	serpentine	X	X			X						
Ishkinino	ore	FG2169	c	dark phase	X	L		X							
Ishkinino	ore	FG2169	d	light phase	X			X							
Ishkinino	ore	FG2169	e	dark phase	X		X	L							
Ishkinino	ore	FG2169	f	light phase	X			X							
Ishkinino	ore	FG2169	g	iron oxide	X			X							
Ishkinino	ore	FG2169	h	iron oxide	X	L		X							
Ishkinino	ore	FG2169	I	iron oxide	X			X							
Ishkinino	ore	FG2169	j	iron oxide	X	L	L	X							
Ishkinino	ore	FG2169	k	malachite	X		X								
Bakr-Uzyak	ore	FG2173	a	malachite	X		X								
Bakr-Uzyak	ore	FG2173	b	rock	X	X									
Bakr-Uzyak	ore	FG2173	c	rock	X	X	L	X	X		X				
Bakr-Uzyak	ore	FG2173	d	small octahedron	L	L		X			L				
Nikolskoe	ore	FG2175	a	quartz	X	X									
Vorovskaya Yama	ore	FG2177	a	malachite	X		X								
Vorovskaya Yama	ore	FG2177	b	rock	X	X		X						X	
Tash-Kazgan	ore	FG2179	a	malachite	X		X								
Tash-Kazgan	ore	FG2179	b	grey grain	X	X					L		L		
Tash-Kazgan	ore	FG2179	c	quartz	X	X									
Tash-Kazgan	ore	FG2180	a	malachite	X		X								
Tash-Kazgan	ore	FG2180	b	rock	X			L						X	
Tash-Kazgan	ore	FG2180	c	rock	X	X					X				
Tash-Kazgan	ore	FG2180	d	rock	X	X					X				

Site	Object	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Cr	Al	As	K	Ca	Cl
Ush-Katta	ore	FG2181	a	rock	X	X		L	X		X				
Ush-Katta	ore	FG2181	b	rock	X	X		L	X		X			L	
Ush-Katta	ore	FG2181	c	iron oxide	X	L		X							

L – low content

X – high content

Tab. 5-6. EDX-analyses of slag and ore made in the Technical University of Freiberg by means of the Digital Scanning Microscope DSM 960 (qualitative analysis). Analyst B. Bleibe (contd.).

Site	Object	Sample	Analysis	Material	Ni	S	Mn	Ti	V	Pb	W	Zn	P	Ba	Mo	Na
Sintashta	slag	3	a	quartz												
Sintashta	slag	173	a	copper												
Sintashta	slag	173	b	fayalite												
Sintashta	slag	173	c	magnetite												
Sintashta	slag	173	d	sulfide		X										
Sintashta	slag	173	e	glass												
Semiozerki	slag	221	a	copper												
Semiozerki	slag	221	b	cuprite												
Semiozerki	slag	252	a	chromite												
Semiozerki	slag	252	b	copper												
Arkaim	slag	751	a	metal												
Arkaim	slag	751	b	glass												
Arkaim	slag	751	c	copper												
Arkaim	slag	751	d	metal												
Arkaim	slag	751	e	malachite												
Arkaim	slag	751	f	cuprite												
Arkaim	slag	822	a	sulfide		X										
Arkaim	slag	822	b	copper												
Sintashta	slag	839	a	light phase	X											
Sintashta	slag	839	b	copper												
Sintashta	slag	846	a	glass												
Sintashta	slag	846	b	magnetite												
Sintashta	slag	846	c	cuprite												
Sintashta	slag	846	d	copper												
Sintashta	slag	846	e	cuprite												
Sintashta	slag	873	a	copper												
Sintashta	slag	873	b	cuprite												
Sintashta	slag	873	c	light phase												
Sintashta	slag	873	d	dark phase												
Sintashta	slag	873	e	magnetite												
Sintashta	slag	873	f	cuprite												

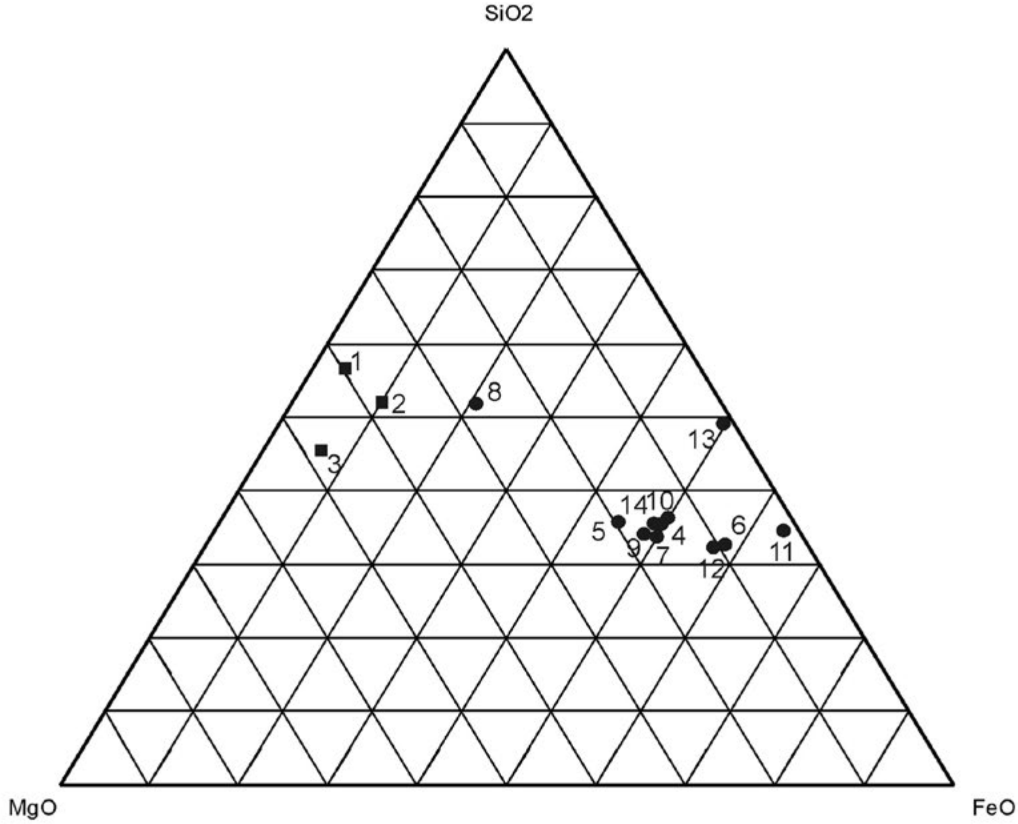
Site	Object	Sample	Analysis	Material	Ni	S	Mn	Ti	V	Pb	W	Zn	P	Ba	Mo	Na
Sintashta	slag	873	g	cuprite												
Sintashta	slag	873	h	olivine												
Arkaim	slag	FG1780	a	serpentine												
Arkaim	slag	FG1780	b	copper chloride												
Arkaim	slag	FG1788	a	metal						X						
Arkaim	slag	FG1788	b	oxide						X						
Sintashta	slag	FG1802	a	copper												
Sintashta	slag	FG1802	b	wüstite												
Sintashta	slag	FG1803	a	malachite												
Sintashta	slag	FG1803	b	copper												
Sintashta	slag	FG1817	a	quartz												
Sintashta	slag	FG1817	b	wüstite												
Sintashta	slag	FG1817	c	copper prill						X						
Sintashta	ore	FG1823	a	limonite												
Sintashta	ore	FG1826	a	malachite												
Sintashta	ore	FG1826	b	ore												
Sintashta	ore	FG1826	c	magnetite												
Solntse	slag	FG1870	a	copper												
Solntse	slag	FG1870	b	malachite												
Kamenniy Ambar	ore	FG1878	a	malachite												
Tyubyak	ore	FG1921	a	malachite												
Tyubyak	ore	FG1921	b	mineral												
Tyubyak	ore	FG1921	c	rock												L
Tyubyak	ore	FG1921	d	inclusion in rock									X			
Tyubyak	slag	FG1928	a	edge of copper												
Tyubyak	slag	FG1928	b	malachite												
Beregovskoye	slag	FG1934	a	quartz												
Beregovskoye	slag	FG1934	b	covellite		X										
Beregovskoye	slag	FG1934	c	dark phase												
Beregovskoye	slag	FG1934	d	light phase		X										

Site	Object	Sample	Analysis	Material	Ni	S	Mn	Ti	V	Pb	W	Zn	P	Ba	Mo	Na
Dergamysh	ore	FG2165	a	malachite												
Dergamysh	ore	FG2165-2	a	malachite												
Dergamysh	ore	FG2165-2	b	mineral												
Dergamysh	ore	FG2165-2	c	mineral												
Ishkinino	ore	FG2169	a	malachite												
Ishkinino	ore	FG2169	b	serpentine												
Ishkinino	ore	FG2169	c	dark phase												
Ishkinino	ore	FG2169	d	light phase												
Ishkinino	ore	FG2169	e	dark phase												
Ishkinino	ore	FG2169	f	light phase												
Ishkinino	ore	FG2169	g	iron oxide												
Ishkinino	ore	FG2169	h	iron oxide												
Ishkinino	ore	FG2169	I	iron oxide												
Ishkinino	ore	FG2169	j	iron oxide												
Ishkinino	ore	FG2169	k	malachite												
Bakr-Uzyak	ore	FG2173	a	malachite												
Bakr-Uzyak	ore	FG2173	b	rock												
Bakr-Uzyak	ore	FG2173	c	rock												
Bakr-Uzyak	ore	FG2173	d	small octahedron				X								
Nikolskoe	ore	FG2175	a	quartz												
Vorovskaya Yama	ore	FG2177	a	malachite												
Vorovskaya Yama	ore	FG2177	b	rock												
Tash-Kazgan	ore	FG2179	a	malachite												
Tash-Kazgan	ore	FG2179	b	grey grain												
Tash-Kazgan	ore	FG2179	c	quartz												
Tash-Kazgan	ore	FG2180	a	malachite												
Tash-Kazgan	ore	FG2180	b	rock												
Tash-Kazgan	ore	FG2180	c	rock												X
Tash-Kazgan	ore	FG2180	d	rock												X

Site	Object	Sample	Analysis	Material	Ni	S	Mn	Ti	V	Pb	W	Zn	P	Ba	Mo	Na
Ush-Katta	ore	FG2181	a	rock												
Ush-Katta	ore	FG2181	b	rock												
Ush-Katta	ore	FG2181	c	iron oxide												

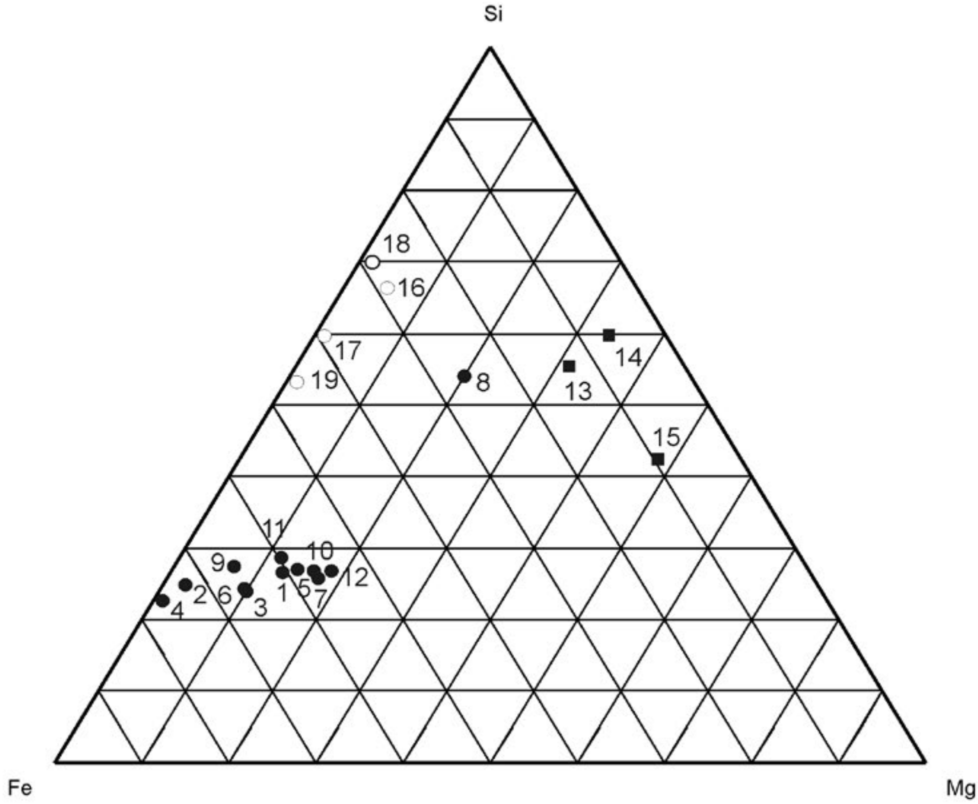
L – low content

X – high content



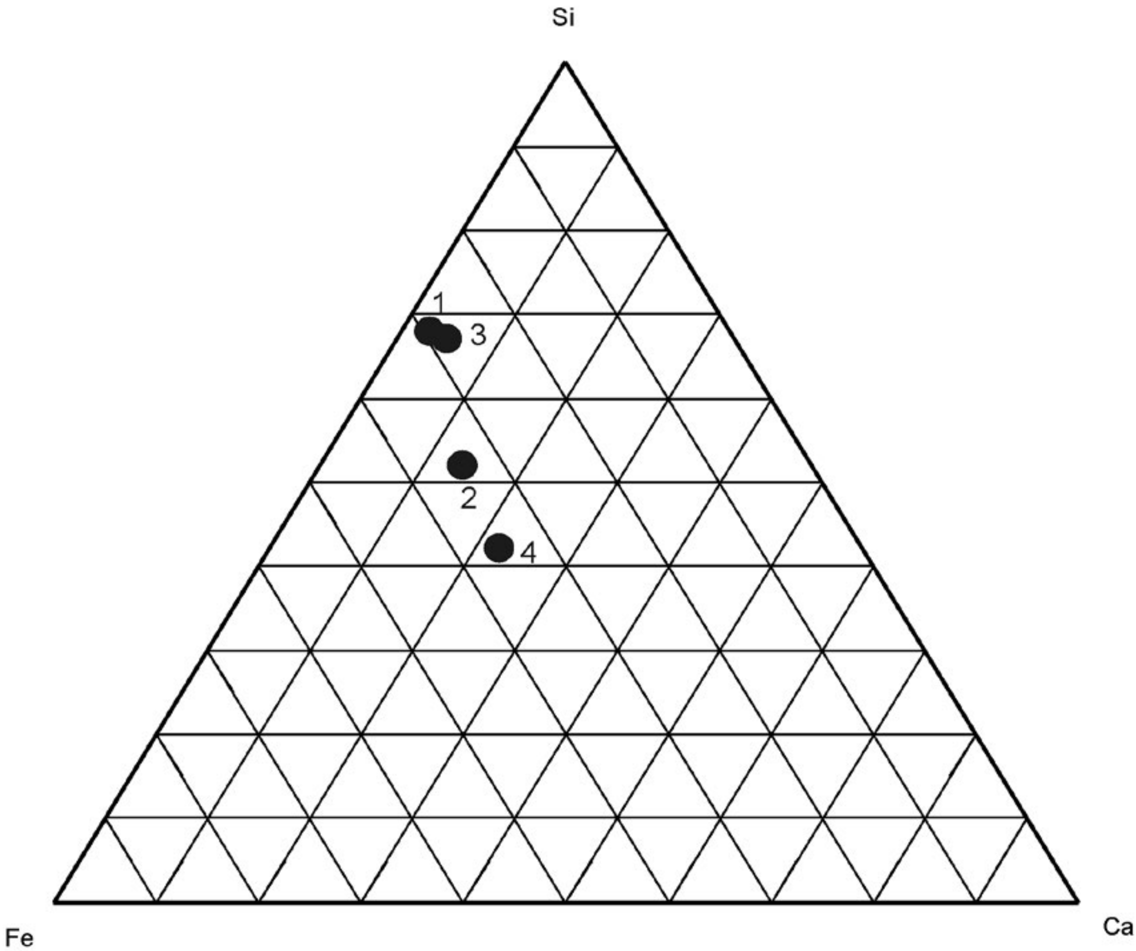
№	material	sample	SiO2	MgO	FeO
1	serpentine	680-2	53,00	36,52	10,48
2	serpentine	751-2W*	55,15	40,08	4,77
3	serpentine	252-1	45,41	47,52	7,07
4	olivine	822-2	36,71	14,00	49,29
5	olivine	252-3	35,55	20,00	44,45
6	olivine	846-1W*	32,76	10,97	56,27
7	olivine	680-3W*	34,42	16,84	48,75
8	olivine	740-3	51,87	26,37	21,76
9	olivine	751-4W*	34,98	17,54	47,48
10	olivine	839-6	35,50	14,64	49,86
11	olivine	839-7	33,86	2,91	63,23
12	olivine	839-8*	33,29	10,75	55,96
13	olivine	839-9*	31,38	1,52	31,38
14	olivine	846-1	36,34	16,10	47,56

Fig. 5-7. Phase plot of SiO2-MgO-FeO for serpentines (squares) and olivines (circles) (%).



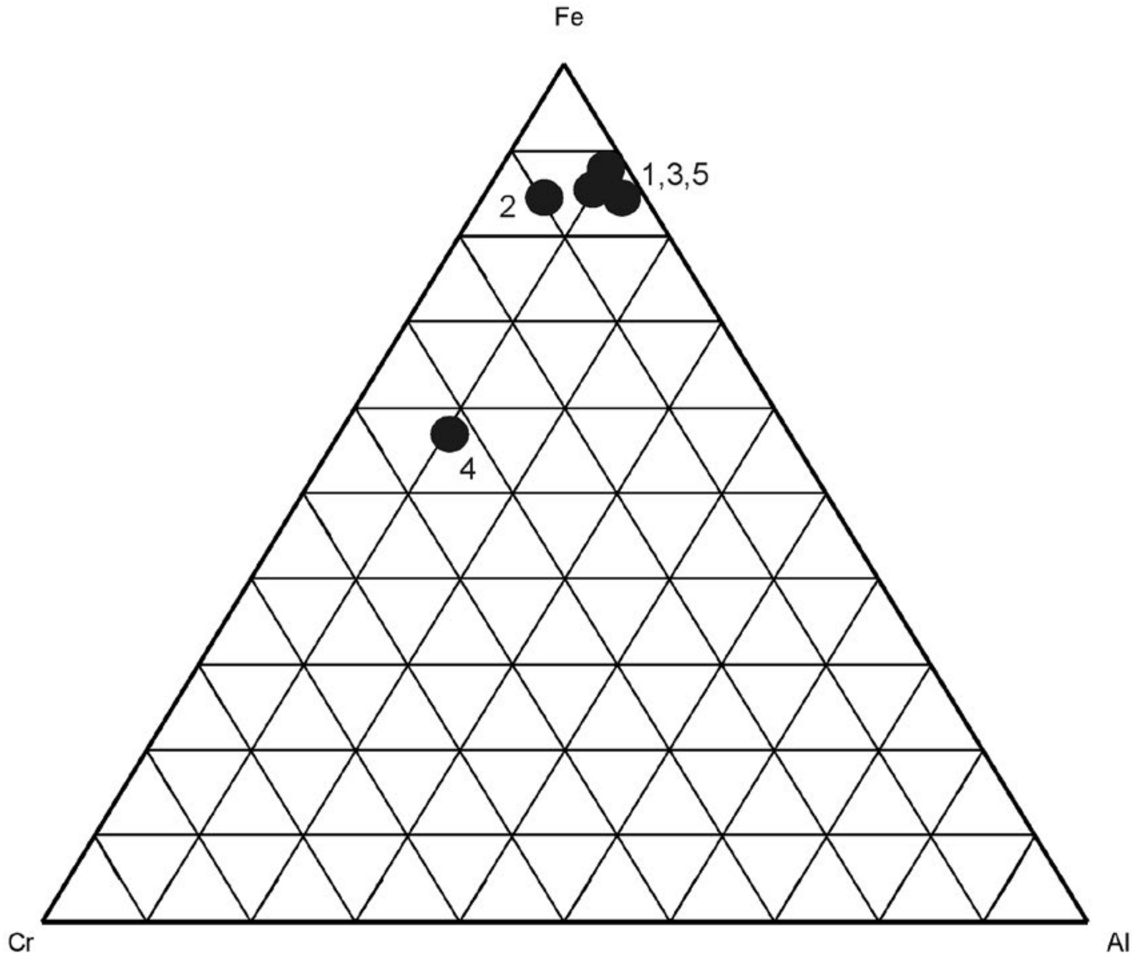
№	material	sample	Si	Fe	Mg	%Si	%Fe	%Mg
1	olivine-K	S-839-6	15,85	36,82	8,06	26,10	60,63	13,27
2	olivine-R	S-839-7	15,09	45,57	1,54	24,26	73,26	2,48
3	olivine-K	S-839-8*	15,75	42,64	6,29	24,35	65,92	9,72
4	olivine-R	S-839-9*	14,80	50,73	0,89	22,28	76,38	1,34
5	olivine-K	S-846-1	15,81	34,52	8,62	26,82	58,56	14,62
6	olivine-K	S-846-1W*	15,41	43,26	6,50	23,65	66,38	9,97
7	olivine-Ks	A-680-3	16,64	36,72	10,83	25,92	57,21	16,87
8	olivine-Ks	A-740-3	23,01	11,08	8,61	53,89	25,95	20,16
9	olivine-K	A-751-4	16,31	38,69	3,65	27,81	65,97	6,22
10	olivine-K	A-751-4W*	16,64	36,26	10,29	26,33	57,38	16,28
11	olivine-K	A-822-2	16,59	34,77	7,35	28,26	59,22	12,52
12	olivine-K	Se-252-3	16,39	33,75	11,56	26,56	54,70	18,74
13	serpentine	A-680-2	29,94	6,98	16,96	55,57	12,95	31,48
14	serpentine	A-751-2W*	30,91	3,06	17,51	60,04	5,94	34,01
15	serpentine	Se-252-1	23,00	5,31	26,88	41,67	9,62	48,70

Fig. 5-8. Phase plot (Si-Fe-Mg) for olivines (black circles), serpentines (squares) and glass (blank circles) (K – center, Ks – center of thin crystals, R – edge) (%).



№	sample	Si	Fe	Ca	%Si	%Fe	%Ca
1	A-740-5	24,81	10,47	1,29	67,84	28,63	3,53
2	A-822-3	24,94	16,18	6,86	51,98	33,72	14,30
3	Se-221-4	23,80	9,43	1,82	67,90	26,90	5,19
4	Se-252-5	21,77	18,37	12,02	41,74	35,22	23,04

FIG. 5-9. PHASE PLOT (SI-FE-CA) FOR GLASS (%).



№	sample	Fe	Cr	Al	%Fe	%Cr	%Al
1	A-740-4	56,63	0,00	5,89	90,58	0,00	9,42
2	A-822-4	71,30	4,77	3,05	90,12	6,03	3,85
3	S-173-2	69,07	0,00	5,73	92,34	0,00	7,66
4	A-680-4	44,28	25,93	8,13	56,52	33,10	10,38
5	A-740-1	52,10	0,00	5,68	90,17	0,00	9,83

FIG. 5-10. PHASE PLOT FE-CR-AL FOR MAGNETITE (%).

Tab. 5-11. Chemical analyses (XRF) of slag and ore made in the Activation Laboratories Ltd. Ancaster, Ontario, Canada (%).

№	Site	Material	SiO2 %	Al2O3 %	Fe2O3 %	MnO %	MgO %	CaO %	Na2O %	K2O %	TiO2 %	P2O5 %
1781	Arkaim	slag	31.60	4.73	57.48	0.124	5.21	2.44	0.17	0.54	0.391	0.29
1787	Arkaim	slag	51.06	6.55	35.62	0.191	3.37	2.55	0.07	1.78	0.289	0.33
1789	Arkaim	slag	32.61	3.75	58.93	0.083	5.50	1.70	0.24	0.77	0.172	0.20
1792	Arkaim	slag	25.53	3.63	66.42	0.111	5.00	1.78	0.30	0.81	0.225	0.17
1795	Sintashta	ore	58.42	3.37	6.90	0.193	0.68	5.84	0.34	0.38	0.072	0.13
1797	Sintashta	Chogray sandstone	54.41	1.63	39.90	0.014	0.21	1.02	0.44	0.12	0.081	0.79
1798	Sintashta	slag	38.72	8.52	45.06	0.089	2.97	2.14	0.35	2.23	0.341	0.61
1799	Sintashta	slag	36.36	3.22	41.33	0.349	11.63	4.89	0.47	1.18	0.150	0.39
1822	Sintashta	ore	35.83	1.60	14.51	0.038	26.11	0.23	0.41	0.10	0.065	0.05
1923	Tyubyak	slag	30.95	2.90	55.64	0.087	2.37	2.66	0.14	1.31	0.244	0.50
1925	Tyubyak	slag	46.25	3.30	31.75	0.077	9.75	5.52	0.14	0.70	0.157	0.33
1937	Beregovskoye	slag	17.21	2.84	19.19	0.043	0.98	5.12	0.37	1.05	0.145	1.58
1941	Beregovskoye	slag	36.35	5.39	11.90	0.052	1.01	3.73	1.11	0.88	0.266	1.10
1942	Birsk I	slag	35.71	5.11	10.32	0.063	1.07	4.32	1.04	0.92	0.250	1.32
1946	Sintashta	slag	36.31	8.40	46.29	0.107	3.41	2.05	0.46	2.11	0.484	0.24
2027	Kargaly	ore	15.99	2.81	1.66	0.013	0.51	0.54	0.57	0.44	0.124	0.04
2165	Dergamysh	ore	36.46	10.46	9.34	0.077	15.80	0.75	0.01	0.04	0.192	0.01
2167	Ishkinino	ore	29.59	0.34	15.20	0.056	26.70	0.15	-0.01	0.06	0.008	0.01
2172	Ishkinino	ore	27.74	9.61	18.47	0.014	5.47	0.64	0.05	0.06	0.050	0.04
2176	Vorovskaya Yama	ore	21.09	1.08	20.43	0.798	0.13	17.47	-0.01	0.10	0.014	0.18

Tab. 5-11. Chemical analyses (XRF) of slag and ore made in the Activation Laboratories Ltd. Ancaster, Ontario, Canada (%) (contd.).

№	Site	Material	LOI %	TOTAL %	Ba ppm	Sr ppm	Y ppm	Sc ppm	Zr ppm	Be ppm	V ppm
1781	Arkaim	slag	-3.88	99.10	385	165	11	14	71	-1	118
1787	Arkaim	slag	-2.70	99.11	1255	227	30	15	105	-1	202
1789	Arkaim	slag	-4.94	99.02	366	119	13	15	41	-1	124
1792	Arkaim	slag	-4.46	99.51	401	154	11	21	35	-1	133
1795	Sintashta	ore	13.71	90.04	494	112	97	62	42	1	542
1797	Sintashta	Chogray sandstone	1.84	100.46	53	89	11	37	59	7	16
1798	Sintashta	slag	-3.11	97.91	692	163	41	25	74	-1	445
1799	Sintashta	slag	-2.44	97.53	463	492	7	11	21	-1	54
1822	Sintashta	ore	15.89	94.82	10	35	3	20	2	-1	77
1923	Tyubyak	slag	-3.44	93.36	212	111	19	8	36	2	124
1925	Tyubyak	slag	-2.39	95.59	329	121	4	13	37	-1	90
1937	Beregovskoye	slag	3.32	51.85	115200	3740	11	3	59	-1	128
1941	Beregovskoye	slag	5.48	67.25	42930	2554	12	7	143	-1	260
1942	Birsk I	slag	7.36	67.48	43020	2645	12	8	130	1	231
1946	Sintashta	slag	-2.73	97.13	1037	196	39	38	100	2	318
2027	Kargaly	ore	22.48	45.18	52580	3399	9	6	35	-1	32
2165	Dergamysh	ore	17.88	91.03	9	39	2	21	19	-1	77
2167	Ishkinino	ore	15.66	87.79	4	3	-1	4	7	-1	9
2172	Ishkinino	ore	21.67	83.82	12	44	1	76	14	-1	124
2176	Vorovskaya Yama	ore	12.48	73.78	282	13	6	4	12	-1	60

Tab. 5-12. Bulk (wet) chemical analyses of slag and ore made in the Chemical laboratory of the Chelyabinsk geological expedition (%).

№	Site	Material	SiO2	Al2O3	Fe3O4	MnO	FeO	Fe2O3	CaO	SO3	TiO2	MgO	K2O	Cu
13	Petrovka II	slag	53.50	0	9.76	0	20.4	0	1.51	0	0			
46	Novonikolskoye	slag	29.6	0	2.85	0	39.4	0	10.4	0	0			
54	Visnyovka	slag	23.6	0	2.52	0	46.9	0	7.36	0	0			
61	Sintashta	slag	43.6	0	1.65	0	29.3	0	1.2	0	0			
63	Sintashta	slag	34.5	0	2.2	0	39.6	0	2.77	0	0			
83	Sintashta	slag	10.8	0	0.4	0	0.21	0	0.42	0	0			
677	Arkaim	slag	40.9	4.83	0	0.11	32.8	10.26	1.98	0.07	0.31			
678	Arkaim	slag	31.1	4.35	0	0.19	43.7	7.53	2.66	0.09	0.28			
682	Arkaim	slag	29.9	3.57	0	0.13	50.2	3.66	2.34	0.15	0.32			
686	Arkaim	slag	30.8	3.57	0	0.12	47.8	4.85	2.39	0.15	0.32			
690	Arkaim	slag	21.9	4.63	0	0.11	49.6	5.68	1.67	0.12	0.24			
2106	Nikolskoye	ore	49.48	5.19		0.11		5.68	1.43	1.56		1.38	0.21	21.53
2126	Nikolskoye	ore	30.64	5.94		0.07		17.67	1.43	0.13		9.5	0.07	17

Tab. 5-13. Coefficients of basicity of ore and slag.

№	Site	Material	Coefficient of basicity	Group
2176	Vorovskaya Yama	ore	1.74	basic
1792	Arkaim	slag	2.52	ultra-basic
1923	Tyubyak	slag	1.80	basic
1781	Arkaim	slag	1.78	basic
1789	Arkaim	slag	1.83	basic
1946	Sintashta	slag	1.70	basic
690	Arkaim	slag	2.13	basic
54	Vishnyovka	slag	2.41	basic
46	Novonikoskoye	Slag	1.78	basic
682	Arkaim	slag	1.67	basic
686	Arkaim	slag	1.59	basic
678	Arkaim	slag	1.51	basic
1799	Sintashta	slag	1.71	basic
1798	Sintashta	slag	1.55	basic
2167	Ishkinino	ore	1.41	average
1822	Sintashta	ore	1.10	average
1937	Beregovskoye	slag	1.23	average
63	Sintashta	slag	1.29	average
1925	Tyubyak	slag	1.10	average
2172	Ishkinino	ore	0.66	acid
2165	Dergamysh	ore	0.99	acid
1797	Sintashta	chogray sandstone	0.78	acid
1942	Birsk I	slag	0.61	acid
1941	Beregovskoye	slag	0.64	acid
1787	Arkaim	slag	0.97	acid
677	Arkaim	slag	0.98	acid
61	Sintashta	slag	0.74	acid
2126	Dergamysh	ore	0.79	acid
2161	Ishkinino	ore	0.68	acid
13	Petrobka II	slag	0.59	acid
1795	Sintashta	ore	0.30	ultra-acid
2106	Nikolskoye	ore	0.16	ultra-acid
83	Sintashta	slag	0.10	ultra-acid

Tab. 5-14. Coefficients of ratio of iron and magnesian components.

Sample	Site	Material	FeO/MgO
1822	Sintashta	ore	0.56
2167	Ishkinino	ore	0.57
2165	Dergamysh	ore	0.59
2161	Nikolskoye	ore	0.82
2126	Nikolskoye	ore	1.86
2027	Kargaly	ore	3.25
1925	Tyubyak	slag	3.26
2172	Ishkinino	ore	3.38
1799	Sintashta	slag	3.55
2106	Nikolskoye	ore	4.12
1942	Birsk I	slag	9.64
1795	Sintashta	ore	10.15
1787	Arkaim	slag	10.57
1789	Arkaim	slag	10.71
1781	Arkaim	slag	11.03
1941	Beregovskoye	slag	11.78
1792	Arkaim	slag	13.28
1946	Sintashta	slag	13.57
1798	Sintashta	slag	15.17
1937	Beregovskoye	slag	19.58
1923	Tyubyak	slag	23.48
2176	Vorovskaya Yama	ore	157.15
1797	Sintashta	chogray sandstone	190

Tab. 5-15. Average contents of oxides of aluminum, calcium, potassium and phosphorus (%) in ore and slag of the Sintashta time.

	Al_2O_3	CaO	K_2O	P_2O_5
Ore	4.79	1.25	0.15	0.07
Slag	3.78	2.72	1.19	0.59

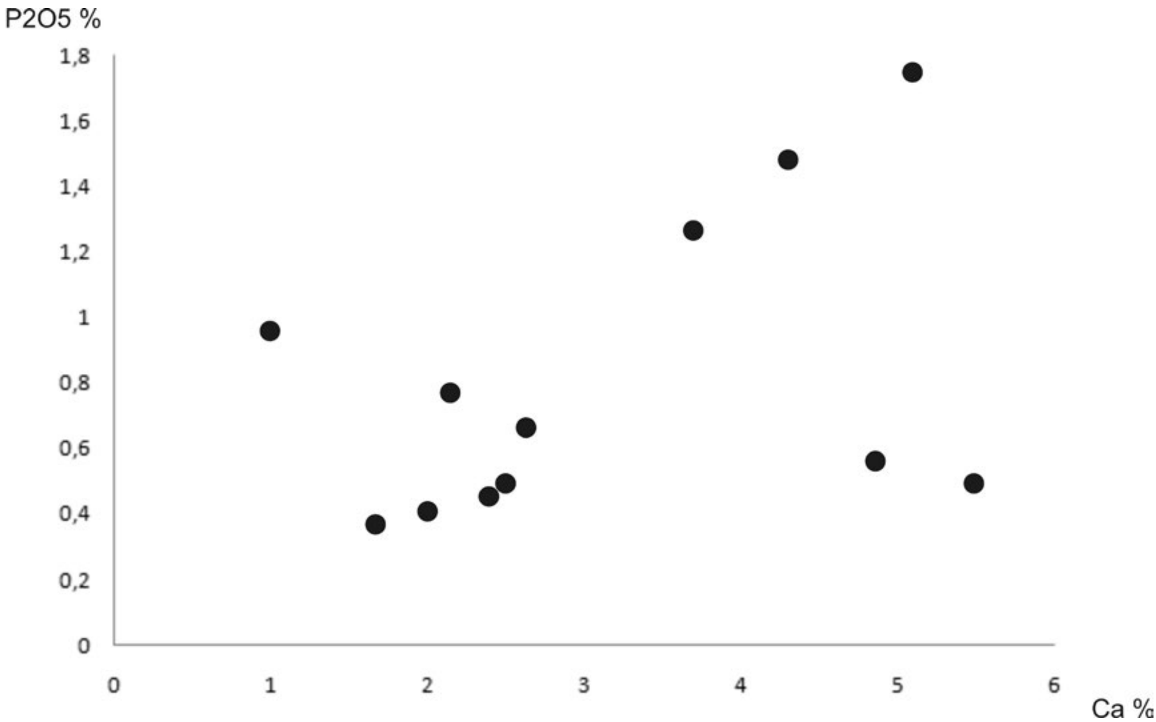


FIG. 5-16. CORRELATION OF CONTENTS OF CALCIUM AND PHOSPHORUS IN THE SINTASHTA SLAG BASED ON THE CHEMICAL ANALYSES.

Tab. 5-17. X-ray diffraction analyses of slag (Department of Physics-1, South-Ural State University).

Sample	Site	quartz	tridymite	cristobalite	wüstite	hematite	magnetite	copper
1	Sintashta	X	X	?	?	?	X	X
5	Sintashta	X				?	?	
7	Sintashta	X	X			X	X	X
43	Sintashta	X	X		X		X	X
83	Sintashta	X		?	X	X	?	
87	Sintashta		X			?	X	?
98	Tash-Kazgan	X						
99	Tash-Kazgan	X						
100	Tash-Kazgan	X						
101	Tash-Kazgan	X						
12	Petrovka II	X	X	X	X	?		?
46	Novonikolskoye	X		X	X		X	
54	Vishnyovka		?	X	X	X		
44	Sargari	X	?	X		?		X
49	Telmana XVI	X	X	X	X	?	X	?
27	Myrzhik	X	X	X	X	X	?	X
19	Atasu				X			
53	Ak-Moustapha							
90	Shandasha	X	?	?	X			
91	Shandasha	?	?	X	X			
76	Ubagan			X				
32	Kipel	X	X		X	?	X	?
81	Yazyovo III				X			
92	Bakr-Uzyak	X						
93	Bakr-Uzyak	?		X				
94	Bakr-Uzyak	?		X	X	X		
95	Bakr-Uzyak	X	X	X			?	
96	Bakr-Uzyak	X		?			X	
67	Korshunovo I	X				X	X	
68	Vorobyovo	X		X				
69	Vorobyovo	X		X	X		X	
34	Itkul I	X	X	X			X	X
35	Itkul I			X	X	X		X
36	Itkul I		?	X	X		X	X
37	Itkul I							
38	Itkul II	X	?					
39	Itkul II	X		X		X	X	X
33	Bakal	X			X	X	?	
97	Gumyoshki	X				?		
102	Ai-Bunar	X	X	X	?	X	X	

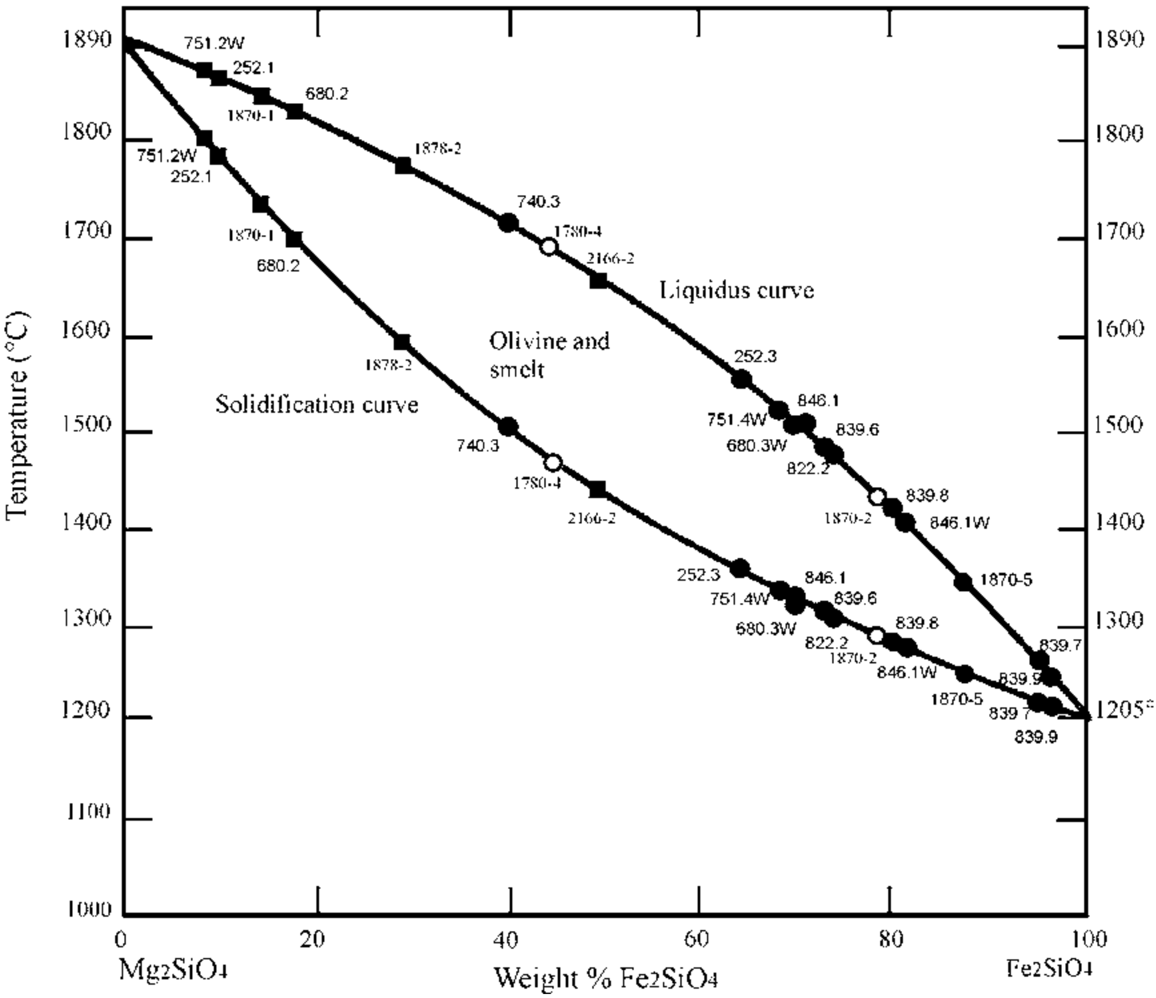


FIG. 5-18. THE BINARY SYSTEM FORSTERITE-FAYALITE (MG2SIO4-FE2SIO4) FOR OLIVINES OF THE SINTASHTA SITES. BLACK CIRCLES – OLIVINE CRYSTALS, BLANK CIRCLES – MOLTEN SERPENTINE, SQUARES – GRAINS OF SERPENTINE.

Tab. 5-19. Ratio of oxides decreasing viscosity (TiO_2, MgO, Fe_2O_3, MnO, K_2O, CaO, Na_2O) to those increasing it (SiO_2, Al_2O_3,) – coefficient Kz and coefficient of viscosity (Pa•s) at the temperature of 1400°C calculated according to Bachmann et al. 1987.

№	Site	Material	Kz	η 1400 (Pa·s)
1781	Arkaim	slag	1.83	0.00
1792	Arkaim	slag	2.57	1.46
1789	Arkaim	slag	1.86	2.19
1799	Sintashta	slag	1.53	2.76
1946	Sintashta	slag	1.23	3.52
1798	Sintashta	slag	1.14	3.85
1787	Arkaim	slag	0.77	5.94
1923	Tyubyak	slag	1.86	2.18
1937	Beregovskoye	slag	1.42	3.00
1925	Tyubyak	slag	0.98	4.56
1941	Beregovskoye	slag	0.48	9.75
1942	Birsk I	slag	0.47	9.91
2126	Dergamysh	ore	1.25	3.46
2161	Ishkinino	ore	0.99	4.50
2106	Nikolskoye	ore	0.58	7.95

Tab. 5-20. Distribution of mineralogical groups of slag over sites.

Site	Mineralogical groups				
	I	II	III	IV	others
Arkaim	_35__ 58.3%	_10__ 16.7%	_15__ 25%		
Sintashta	_17__ 38.6%	_3__ 6.8%	_13 29.6%	_10_ 22.7%	_1_ 2.3%
Ustye	_19__ 35.8%	_11__ 20.8%	_16__ 30.2%	_7__ 13.2%	
Krivoye Ozero	_4__ 100%				
Olgino	_2__ 66.6%		_1__ 33.3%		
Sakrim-Sakla	_1__ 100%				
Alandskoye	_1__ 100%				
Yagodniy Dol			_1__ 100%		
Malokizilskoye		_2__ 100%			
Utyovka VI	_2__ 100%				
Tash-Kazgan		_4__ 100%			
Rodniki			_2__ 66.6%	_1__ 33.3%	
Sintashta XIII				_6__ 100%	
Semiozerki	_3__ 27.3%			_8__ 72.7%	
Konezavod		_1__ 100%			
Petrovka					_1__ 100%
Novonikolskoye					_1__ 100%
Urgun	_6__ 100%				
Total	**_90__ 44.1%**	**_31__ 15.2%**	**_48__ 23.3%**	**_32__ 15.9%**	**_3__ 1.5%**

Tab. 5-21. Distribution of mineralogical groups of slag over cultural groups.

Cultural groups	Mineralogical groups					
	I	II	III	IV	others	total
Sintashta	45 59.2%	12 15.8%	17 22.4%		2 2.6%	76 100%
Sintashta-Petrovka	36 37.1%	14 14.4%	29 29.9%	17 17.6%	1 1%	97 100%
Petrovka	3 13%	1 4.4%	2 8.7%	15 65.2%	2 8.7%	23 100%
Others	6 60%	4 40%				10 100%
Total	90 43.7%	31 15.1%	48 23.3%	32 15.5%	5 2.4%	206 100%

Tab. 5-22. Distribution of technological types of slag over cultural groups.

Technological types / Cultural groups	I	II	III	Others	Total
Sintashta	74 97.3%			2 2.7%	**76 100%**
Sintashta -Petrovka	79 81.5%	17 17.5%	1 1%		**97 100%**
Petrovka	6 24%	17 68%	2 8%		**25 100%**
Total	**159 80.3%**	**34 17.2%**	**3 1.5%**	**2 1%**	**198 100%**

Tab. 5-23. Emission spectral analyses of slag (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).

Site	Sample	Cluster	Group	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Sintashta	1	6	2	0.0015	0.015	<0.001	0.005	<0.001	0.02	<0.0005	<0.0003	0.015
Sintashta	42	6		0.0015	0.0015	0.05	0.2	0.007	0.2	<0.0005	<0.0003	1
Petrovka	58	6		0.1	0.01	0.002	0.05	0.005	0.2	<0.0005	<0.0003	0.7
Sintashta	62	6		0.003	0.0015	0.015	0.15	0.015	0.3	0.002	0.0003	1
Sintashta	83	6	4	0.02	0.003	0.001	0.05	0.0015	0.005	<0.0005	0.0003	0.1
Sintashta	86	6		0.005	0.002	0.01	0.1	0.01	0.5	0.0015	<0.0003	0.15
Sintashta	87	5b		0.01	0.003	0.07	0.07	0.007	0.2	0.0015	<0.0003	0.3
Sintashta	88	5a	4	0.005	0.002	0.2	0.03	0.01	0.3	0.0015	<0.0003	0.05
Tash-Kazgan	100	5b	2	0.07	0.002	0.015	0.15	0.01	0.5	0.001	0.00015	0.2
Tash-Kazgan	101	6	2	0.003	0.002	0.007	0.15	0.0015	0.3	<0.0005	<0.0003	0.2
Konezavod	220	6	2	0.015	0.005	0.02	0.05	0.007	0.2	0.0005	0.00015	0.5
Semiozerki	221	4b	2	0.03	0.02	0.03	0.5	0.007	0.2	<0.0005	0.00015	1
Semiozerki	252	5a	1	0.02	0.007	0.1	0.07	0.0015	0.1	<0.0005	0.00015	0.2
Semiozerki	260	4b	2	0.007	0.01	nd	1	0.007	0.3	0.001	<0.0003	1
Sintashta	279	6	1	0.005	0.0015	0.01	0.05	0.01	0.5	0.0015	<0.0003	0.1
Sintashta	280	5b	3	0.02	0.007	0.15	0.03	0.01	0.3	0.002	0.00015	0.5
Sintashta	285	5b	1	0.03	0.007	0.15	0.05	0.005	0.1	<0.0005	0.00015	1
Sintashta	286	5a	1	0.005	0.001	0.1	0.15	0.01	0.3	0.0015	<0.0003	0.2
Sintashta	298	6	4	0.001	<0.0005	0.0015	0.1	0.0015	0.2	<0.0005	<0.0003	0.07
Sintashta	299	6	1	0.001	<0.0005	0.001	0.03	0.001	0.1	<0.0005	<0.0003	0.03
Sintashta	300	4c		0.03	0.005	0.01	0.03	0.003	0.15	<0.0005	0.0007	1
Sintashta	301	5a		0.01	0.007	0.07	0.1	0.007	0.2	0.001	0.00015	1
Sintashta	302	5b		0.03	0.01	0.07	0.05	0.01	0.3	0.0005	0.00015	1
Arkaim	305	5a	1	0.005	0.001	0.15	0.1	0.01	0.2	0.001	<0.0003	0.15
Arkaim	308	4a	2	0.007	0.005	0.005	0.15	0.007	0.2	0.0005	<0.0003	1
Arkaim	311	5a	1	0.015	0.01	0.1	0.2	0.003	0.15	<0.0005	0.00015	0.7
Arkaim	312	5a	1	0.01	0.015	0.1	0.03	0.01	0.3	0.0015	0.00015	0.7
Arkaim	313	5a	1	0.01	0.005	0.2	0.2	0.002	0.1	<0.0005	<0.0003	0.2
Rodniki	322	5b	3	0.01	0.003	0.1	0.05	0.007	0.3	0.001	<0.0003	0.7
Tyubyak	426	3	2	0.0015	0.0003	0.005	0.05	0.003	0.1	<0.0005	0.00015	1
Tyubyak	427	2	3	0.01	0.002	0.07	0.005	0.001	0.07	<0.0005	0.0003	1

Site	Sample	Cluster	Group	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Tyubyak	428	2	1	0.003	0.001	0.07	0.02	0.0015	0.07	<0.0005	0.00015	1
Tyubyak	429	2	1	0.007	0.0015	0.07	0.01	0.003	0.03	<0.0005	0.0003	1
Tyubyak	431	2	3	0.015	0.002	0.15	0.03	0.0015	0.1	<0.0005	0.0002	1
Tyubyak	445	1	1	0.007	0.002	0.03	0.05	0.015	0.3	0.001	0.003	1
Tyubyak	446	1	2	0.005	0.001	0.015	0.05	0.015	0.2	0.001	0.0015	1
Tyubyak	447	1	2	0.005	0.002	0.015	0.03	0.015	0.2	0.0005	0.007	1
Tyubyak	448	1	2	0.005	0.003	0.02	0.05	0.015	0.2	0.0015	0.007	1
Tyubyak	449	1	4	0.01	0.0015	0.03	0.03	0.01	0.3	0.001	0.0015	1
Tyubyak	450	2	3	0.015	0.0015	0.1	0.07	0.007	0.1	0.0005	<0.0003	1
Tyubyak	451	1	4	0.005	0.003	0.01	0.07	0.02	0.3	0.001	0.007	1
Tyubyak	452	2	1	0.015	0.003	0.003	0.02	0.005	0.07	<0.0005	0.0003	1
Tyubyak	454	2	1	0.007	0.0015	0.15	0.03	0.003	0.15	0.001	0.0002	1
Tyubyak	455	3	4	0.002	<0.0005	0.007	0.05	<0.001	0.05	<0.0005	0.00015	1
Tyubyak	459	2	1	0.007	0.0015	0.15	0.07	0.0015	0.1	0.0005	0.0003	1
Arkaim	679	5b	1	0.015	0.003	0.15	0.5	0.005	0.15	0.0005	0.0003	1
Arkaim	680	5a	3	0.007	0.003	0.1	0.1	0.007	0.2	0.001	0.0003	0.5
Arkaim	681	5b	1	0.07	0.005	0.1	0.1	0.005	0.15	0.0005	0.00015	1
Arkaim	683	5b	1	0.015	0.007	0.1	0.1	0.007	0.15	<0.0005	0.0003	0.7
Arkaim	684	5a	1	0.007	0.003	0.15	0.1	0.007	0.2	0.001	0.0003	0.5
Arkaim	685	5b	1	0.1	0.007	0.15	0.1	0.005	0.15	<0.0005	0.0003	1
Arkaim	687	5b	1	0.07	0.015	0.15	0.1	0.005	0.15	<0.0005	0.0005	1
Arkaim	688	5b	1	0.2	0.015	0.15	0.1	0.005	0.15	<0.0005	0.0003	1
Arkaim	689	5a	3	0.007	0.007	0.1	0.1	0.005	0.2	0.0005	<0.0003	0.1
Arkaim	691	5a	3	0.005	0.003	0.1	0.05	0.007	0.2	0.0015	0.00015	0.5
Arkaim	692	4a	2	0.005	0.003	0.003	0.3	0.007	0.2	0.0005	0.00015	1
Arkaim	693	5b	1	0.015	0.005	0.07	0.1	0.01	0.15	0.0005	0.0003	0.7
Arkaim	695	6		0.007	0.0015	0.02	0.15	0.015	0.5	0.0015	<0.0003	0.05
Arkaim	725	4a	2	0.005	0.003	0.003	0.2	0.005	0.15	<0.0005	0.00015	1
Arkaim	726	5b	1	0.015	0.002	0.07	0.15	0.003	0.07	0.0005	0.00015	0.7
Arkaim	727	5a	1	0.003	0.0015	0.07	0.1	0.007	0.15	0.001	<0.0003	0.2
Arkaim	728	6	2	0.003	0.003	0.02	0.2	0.005	0.15	0.0005	<0.0003	0.5
Arkaim	729	4a	2	0.01	0.01	0.007	0.3	0.007	0.2	0.0005	<0.0003	1
Arkaim	730	5a	3	0.007	0.002	0.05	0.15	0.007	0.5	0.0015	<0.0003	0.1

Site	Sample	Cluster	Group	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Arkaim	731	5b	1	0.01	0.005	0.03	0.15	0.003	0.1	0.0005	0.00015	1
Arkaim	732	5b		0.007	0.003	0.05	0.07	0.007	0.1	0.0005	<0.0003	0.5
Arkaim	733	5a	3	0.005	0.002	0.3	0.1	0.007	0.1	0.0005	<0.0003	0.7
Arkaim	734	5b	3	0.015	0.003	0.3	0.07	0.007	0.1	0.0005	<0.0003	0.3
Arkaim	735	5a	1	0.007	0.002	0.03	0.02	0.001	0.07	<0.0005	0.00015	0.5
Arkaim	736	5a	3	0.005	0.003	0.07	0.1	0.0015	0.1	<0.0005	<0.0003	0.7
Arkaim	737	5a	1	0.01	0.003	0.07	0.1	0.005	0.1	0.0005	0.00015	0.5
Arkaim	738	4a	2	0.007	0.007	0.007	0.3	0.007	0.2	0.0005	<0.0003	1
Arkaim	739	4a	2	0.007	0.003	0.005	0.2	0.007	0.2	<0.0005	0.00015	1
Arkaim	740	4a	3	0.005	0.003	0.007	0.5	0.007	0.2	0.0005	<0.0003	1
Arkaim	741	6	1	0.0015	0.002	0.01	0.15	0.015	0.3	0.0015	<0.0003	0.5
Arkaim	742	5b	3	0.15	0.003	0.15	0.07	0.007	0.15	<0.0005	0.0003	0.7
Arkaim	743	5b	3	0.07	0.007	0.2	0.1	0.007	0.15	0.0005	0.0003	1
Arkaim	744	5b	1	0.005	0.003	0.02	0.05	0.01	0.3	0.0015	<0.0003	0.3
Arkaim	745	6	1	0.1	0.015	0.01	0.07	0.0015	0.07	<0.0005	0.015	0.5
Arkaim	746	5b	1	0.007	0.003	0.1	0.05	0.007	0.3	0.0015	<0.0003	0.3
Arkaim	747	5b	3	0.03	0.007	0.1	0.1	0.005	0.1	0.0005	0.00015	0.7
Arkaim	748	5a	3	0.007	0.003	0.2	0.07	0.003	0.15	0.0005	<0.0003	0.15
Arkaim	749	5a	3	0.005	0.003	0.1	0.07	0.01	0.15	0.0005	<0.0003	0.3
Arkaim	750	5a	1	0.005	0.01	0.05	0.07	0.007	0.1	<0.0005	<0.0003	0.5
Arkaim	751	5a	3	0.007	0.01	0.03	0.1	0.007	0.2	0.0005	<0.0003	0.5
Arkaim	752	5b	1	0.03	0.01	0.02	0.07	0.0015	0.07	<0.0005	0.00015	1
Arkaim	753	4a	1	0.003	0.007	0.01	0.05	0.007	0.2	0.0005	0.00015	1
Arkaim	754	5a	1	0.007	0.005	0.05	0.07	0.001	0.07	<0.0005	0.00015	1
Arkaim	755	6	2	0.005	0.003	0.007	0.1	0.007	0.2	0.0005	0.00015	0.5
Arkaim	756	6	1	0.003	0.005	0.015	0.05	0.01	0.2	0.0005	0.0003	1
Sintashta-XIII	796	6		0.001	0.0005	<0.001	0.03	0.003	0.2	0.0005	0.0005	1
Sintashta-XIII	797	6		0.001	0.0003	<0.001	0.03	0.015	0.1	<0.0005	0.0003	0.3
Sintashta-XIII	798	6		0.001	0.0003	<0.001	0.03	0.0015	0.1	<0.0005	0.0003	0.15
Utyovka	813	5b	1	0.3	0.02	0.05	0.1	0.0015	0.1	<0.0005	0.0003	1
Utyovka	814	5a	1	0.03	0.003	0.15	0.15	0.003	0.15	0.0005	0.00015	1
Arkaim	822	5b	1	0.03	0.015	0.07	0.1	0.0015	0.1	0.0005	0.0003	1
Arkaim	823	5b	1	0.3	0.02	0.03	0.07	0.005	0.2	<0.0005	0.0003	1

Site	Sample	Cluster	Group	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Arkaim	824	6		0.005	0.001	0.015	0.05	0.01	0.7	0.002	<0.0003	0.02
Arkaim	825	5a	3	0.007	0.003	0.1	0.05	0.015	0.2	0.002	<0.0003	0.3
Arkaim	826	5a	2	0.01	0.003	0.15	0.1	0.01	0.15	0.0015	<0.0003	0.2
Olgino	828	5a	1	0.007	0.002	0.1	0.03	0.007	0.15	0.0015	0.0003	0.3
Olgino	829	5b	1	0.15	0.015	0.015	0.02	0.003	0.1	<0.0005	0.0003	1
Krivoye Ozero	830	5a	1	0.005	0.005	0.2	0.05	0.003	0.1	<0.0005	0.0003	0.5
Krivoye Ozero	831	5b	1	0.015	0.005	0.05	0.2	0.0015	0.07	0.0005	0.0003	0.7
Krivoye Ozero	832		1	0.01	0.007	0.1	0.1	0.007	0.07	<0.0005	0.00015	0.7
Krivoye Ozero	833	5a	1	0.003	0.002	0.5	0.02	0.007	0.15	0.0005	<0.0003	1
Yagodniy Dol	836	5b	3	0.03	0.015	0.15	0.1	0.003	0.2	0.001	<0.0003	0.5
Rodniki	837	4b	2	0.015	0.015	0.01	1	0.015	0.5	0.002	<0.0003	1
Rodniki	838	5a	3	0.005	0.003	0.1	0.15	0.01	0.2	0.0015	<0.0003	0.3
Ustye	839	5b	1	0.07	0.002	0.1	0.07	0.005	0.15	<0.0005	0.0003	0.5
Ustye	840	4c	1	0.005	0.0015	0.001	0.1	0.001	0.1	<0.0005	0.0003	0.7
Ustye	841	5a	2	0.005	0.003	0.007	0.1	0.003	0.2	0.0005	<0.0003	0.2
Ustye	842	5b	3	0.005	0.002	0.03	0.1	0.007	0.3	0.001	<0.0003	0.7
Ustye	843	5a	3	0.005	0.002	0.15	0.07	0.005	0.2	0.0005	<0.0003	0.2
Ustye	844	5a	3	0.005	0.003	0.07	0.1	0.007	0.3	0.0005	<0.0003	0.7
Ustye	845	5b	3	0.07	0.015	0.1	0.05	0.007	0.3	0.001	0.0003	0.7
Ustye	846	6	1	0.03	0.015	0.07	0.15	0.005	0.2	0.0005	0.015	1
Ustye	847	5b	1	0.015	0.007	0.1	0.03	0.0015	0.05	<0.0005	0.00015	1
Ustye	848	4c	1	0.007	0.0015	0.002	0.15	0.0015	0.15	<0.0005	0.0003	0.7
Ustye	849	6	1	0.005	0.0015	0.01	0.3	0.0015	0.1	<0.0005	0.00015	0.5
Ustye	850	4c	1	0.007	0.0015	0.002	0.2	0.0015	0.05	<0.0005	0.00015	1
Ustye	851	5a		0.005	0.007	0.2	0.1	0.01	0.2	0.001	<0.0003	0.7
Ustye	852	6		0.003	0.0015	0.005	0.5	0.005	0.2	0.0005	<0.0003	0.07
Ustye	853	5a	3	0.005	0.002	0.015	0.15	0.007	0.5	0.0015	<0.0003	0.7
Ustye	854	5a	3	0.003	0.002	0.02	0.3	0.01	0.3	0.0015	<0.0003	0.15
Ustye	855	5a	3	0.005	0.001	0.05	0.15	0.01	0.3	0.001	<0.0003	0.1
Ustye	856	5a	3	0.01	0.005	0.03	0.15	0.007	0.3	0.001	<0.0003	0.5
Ustye	857	6	1	0.005	0.0015	0.015	0.3	0.003	0.15	<0.0005	0.0003	0.7
Ustye	858	2	1	0.007	0.0015	0.02	0.1	0.005	0.15	0.001	0.00015	1
Ustye	859	5a	1	0.003	0.0007	0.07	0.1	0.01	0.2	<0.0005	<0.0003	0.5

Site	Sample	Cluster	Group	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Ustye	860	6	2	0.005	0.003	0.03	0.1	0.01	0.3	0.001	<0.0003	0.7
Ustye	861	4b	2	0.015	0.015	0.007	1	0.007	0.5	0.002	0.00015	1
Ustye	862	6	1	0.003	0.002	0.01	0.15	0.015	0.2	0.0015	<0.0003	0.5
Ustye	863	5a	1	0.003	0.0003	0.2	0.2	0.007	0.15	0.001	<0.0003	0.07
Ustye	864	6	2	0.003	0.001	0.002	0.07	0.0015	0.1	<0.0005	<0.0003	1
Ustye	865	3	2	0.003	0.002	0.0015	0.3	0.003	0.1	<0.0005	<0.0003	1
Ustye	866	3	2	0.002	0.001	0.002	0.15	0.0015	0.07	<0.0005	<0.0003	1
Ustye	867	4b	2	0.015	0.015	0.007	1	0.003	0.5	0.0015	0.00015	1
Ustye	868	3	3	0.015	0.003	0.01	0.1	0.007	0.3	0.001	0.00015	1
Ustye	869	4b	2	0.02	0.02	0.005	1	0.01	0.5	0.0015	0.00015	1
Ustye	870	4b	2	0.07	0.05	0.007	1	0.01	0.5	0.002	<0.0003	1
Ustye	871	5b	2	0.05	0.003	0.03	0.1	0.007	0.3	0.0015	0.00015	1
Ustye	872	3	2	0.003	0.0015	0.007	0.3	0.005	0.1	<0.0005	<0.0003	1
Ustye	873	6	1	0.005	0.0015	0.002	0.07	0.0015	0.07	<0.0005	0.00015	1
Ustye	874	4b	2	0.015	0.015	0.007	1	0.01	0.05	0.0015	<0.0003	1
Ustye	875	3	1	0.003	0.0007	0.0015	0.2	0.001	0.07	<0.0005	0.0005	1
Ustye	876	5b	3	0.015	0.007	0.1	0.05	0.007	0.3	0.0015	<0.0003	0.3
Ustye	877	5a	1	0.005	0.002	0.15	0.2	0.005	0.2	0.0005	0.00015	0.2
Ustye	878	5a	3	0.005	0.003	0.2	0.07	0.01	0.3	0.002	<0.0003	0.3
Ustye	879	5a	3	0.005	0.005	0.03	0.05	0.01	0.3	0.0015	<0.0003	0.15
Burli	889	4c		0.002	0.002	0.002	0.03	0.001	0.05	<0.0005	0.001	1
Sergeevka	1109	4c		0.007	0.002	0.007	0.15	0.01	0.3	<0.0005	0.001	1
Sergeevka	1111	4c		0.015	0.002	0.007	0.15	0.0015	0.2	<0.0005	0.0007	1
Sensitivity of the analysis				Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
				0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.0003	0.001

Tab. 5-23. Emission spectral analyses of slag (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30) (contd.).

Site	Sample	Cluster	Group	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
Sintashta	1	6	2	0.005	0.0005	0.00003	<0.01	<0.003	<0.001	0.002	0.0007	<0.01
Sintashta	42	6		0.05	0.003	0.002	0.005	0.7	<0.001	0.001	0.0005	0.15
Petrovka	58	6		0.01	0.015	0.001	0.005	0.003	<0.001	<0.001	0.001	0.05
Sintashta	62	6		0.05	0.007	0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.1
Sintashta	83	6	4	0.2	0.0007	0.00005	0.005	<0.003	<0.001	<0.001	0.0005	0.01
Sintashta	86	6		0.02	0.03	0.00015	0.01	<0.003	<0.001	<0.001	0.0003	0.07
Sintashta	87	5b		0.01	0.0015	0.0001	0.05	0.0015	<0.001	<0.001	0.0015	0.1
Sintashta	88	5a	4	nd	0.0003	0.00003	0.005	<0.003	<0.001	<0.001	0.0015	0.1
Tash-Kazgan	100	5b	2	0.1	0.003	0.00003	0.01	<0.003	<0.001	<0.001	0.0003	0.1
Tash-Kazgan	101	6	2	0.005	0.0007	0.0001	0.005	<0.003	<0.001	<0.001	0.00015	0.2
Konezavod	220	6	2	0.015	0.003	0.0002	0.005	<0.003	<0.001	<0.001	0.0007	0.05
Semiozerki	221	4b	2	0.3	0.07	0.0001	0.02	0.003	<0.001	<0.001	0.002	0.07
Semiozerki	252	5a	1	0.007	0.0007	0.00005	0.02	<0.003	<0.001	<0.001	0.00015	0.05
Semiozerki	260	4b	2	1	1	0.0002	0.03	0.005	0.002	<0.001	0.0015	0.5
Sintashta	279	6	1	0.007	0.001	0.00007	0.005	<0.003	<0.001	<0.001	0.0005	0.1
Sintashta	280	5b	3	0.007	0.0015	0.00005	0.1	<0.003	<0.001	<0.001	0.001	0.15
Sintashta	285	5b	1	0.01	0.002	0.0001	0.1	<0.003	<0.001	<0.001	0.00015	0.03
Sintashta	286	5a	1	0.01	0.0015	0.00007	0.01	<0.003	<0.001	<0.001	0.0002	0.07
Sintashta	298	6	4	0.015	0.001	0.00003	<0.01	<0.003	<0.001	<0.001	0.0002	0.03
Sintashta	299	6	1	0.01	0.001	0.00003	<0.01	<0.003	<0.001	<0.001	0.00015	<0.01
Sintashta	300	4c		0.2	0.15	0.003	0.1	0.003	<0.001	0.001	0.0003	0.015
Sintashta	301	5a		0.01	0.0005	0.00015	0.02	<0.003	<0.001	<0.001	0.00015	0.07
Sintashta	302	5b		0.05	0.005	0.0005	0.07	<0.003	<0.001	<0.001	0.001	0.07
Arkaim	305	5a	1	0.007	0.0005	0.00003	0.015	<0.003	<0.001	<0.001	<0.0001	0.07
Arkaim	308	4a	2	0.15	0.0015	0.0005	0.005	<0.003	<0.001	<0.001	0.0003	0.03
Arkaim	311	5a	1	0.015	0.002	0.0002	0.007	<0.003	<0.001	<0.001	0.0002	0.03
Arkaim	312	5a	1	0.007	0.002	0.0003	0.15	<0.003	<0.001	<0.001	0.0015	0.2
Arkaim	313	5a	1	0.01	0.001	0.00003	0.01	<0.003	<0.001	<0.001	0.0002	0.03
Rodniki	322	5b	3	0.007	0.005	0.0002	0.07	<0.003	<0.001	<0.001	0.001	0.1
Tyubyak	426	3	2	0.01	0.002	0.003	0.03	<0.003	<0.001	<0.001	<0.0001	0.03
Tyubyak	427	2	3	0.02	0.003	0.0015	0.3	<0.003	<0.001	<0.001	0.0003	0.01

Site	Sample	Cluster	Group	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
Tyubyak	428	2	1	0.01	0.0015	0.001	0.05	<0.003	<0.001	<0.001	0.0001	0.02
Tyubyak	429	2	1	0.03	0.003	0.003	0.15	<0.003	<0.001	<0.001	0.0003	0.01
Tyubyak	431	2	3	0.03	0.002	0.0015	0.2	<0.003	<0.001	<0.001	0.00015	0.02
Tyubyak	445	1	1	nd	0.05	0.003	0.005	<0.003	<0.001	<0.001	0.01	3
Tyubyak	446	1	2	0.007	0.02	0.003	0.005	<0.003	<0.001	<0.001	0.001	3
Tyubyak	447	1	2	nd	0.03	0.003	0.005	<0.003	<0.001	<0.001	0.01	3
Tyubyak	448	1	2	nd	0.03	0.003	0.003	<0.003	<0.001	<0.001	0.02	3
Tyubyak	449	1	4	0.007	0.015	0.002	0.005	<0.003	<0.001	<0.001	0.0005	0.7
Tyubyak	450	2	3	0.02	0.007	0.002	0.1	<0.003	<0.001	<0.001	0.00015	0.02
Tyubyak	451	1	4	0.007	0.03	0.003	0.005	<0.003	<0.001	<0.001	0.015	3
Tyubyak	452	2	1	0.015	0.005	0.003	0.15	<0.003	<0.001	<0.001	0.0001	0.1
Tyubyak	454	2	1	0.015	0.0015	0.003	0.5	<0.003	<0.001	<0.001	0.00015	0.2
Tyubyak	455	3	4	0.03	0.015	0.003	0.02	<0.003	<0.001	<0.001	<0.0001	0.05
Tyubyak	459	2	1	0.015	0.0015	0.003	0.5	<0.003	<0.001	<0.001	0.0003	0.1
Arkaim	679	5b	1	0.01	0.0003	0.0003	0.1	<0.003	<0.001	<0.001	0.00015	0.05
Arkaim	680	5a	3	0.007	0.0003	0.00005	0.03	<0.003	<0.001	<0.001	0.0003	0.05
Arkaim	681	5b	1	0.02	0.0007	0.00003	0.02	<0.003	<0.001	<0.001	0.0003	0.02
Arkaim	683	5b	1	0.01	0.0005	0.00007	0.07	<0.003	<0.001	<0.001	0.0005	0.05
Arkaim	684	5a	1	0.007	0.0005	0.0002	0.015	<0.003	<0.001	<0.001	0.0003	0.15
Arkaim	685	5b	1	0.015	0.0015	0.0005	0.15	<0.003	<0.001	<0.001	0.0002	0.05
Arkaim	687	5b	1	0.03	0.003	0.0007	0.15	<0.003	<0.001	<0.001	0.0002	0.03
Arkaim	688	5b	1	0.02	0.0015	0.00015	0.03	<0.003	<0.001	<0.001	0.0003	0.02
Arkaim	689	5a	3	0.007	0.0005	0.00005	0.015	<0.003	<0.001	<0.001	0.0003	0.07
Arkaim	691	5a	3	0.007	0.0003	0.0003	0.03	<0.003	<0.001	<0.001	0.0003	0.05
Arkaim	692	4a	2	0.2	0.005	0.0002	0.005	<0.003	<0.001	<0.001	0.0007	0.03
Arkaim	693	5b	1	0.02	0.002	0.0005	0.15	<0.003	<0.001	<0.001	0.0003	0.02
Arkaim	695	6		0.007	0.003	0.00005	0.005	<0.003	<0.001	<0.001	0.00015	0.1
Arkaim	725	4a	2	0.15	0.005	0.002	0.005	<0.003	<0.001	<0.001	0.0005	0.015
Arkaim	726	5b	1	0.02	0.0015	0.0003	0.1	<0.003	<0.001	<0.001	0.00015	0.02
Arkaim	727	5a	1	0.01	0.0007	0.00003	0.01	<0.003	<0.001	<0.001	0.0003	0.03
Arkaim	728	6	2	0.03	0.001	0.0002	0.005	<0.003	<0.001	<0.001	0.0003	0.03
Arkaim	729	4a	2	0.15	0.005	0.0015	0.005	<0.003	<0.001	<0.001	0.0007	0.03
Arkaim	730	5a	3	0.01	0.0007	0.00003	0.1	<0.003	<0.001	<0.001	0.0007	0.1

Site	Sample	Cluster	Group	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
Arkaim	731	5b	1	0.03	0.001	0.0002	0.15	<0.003	<0.001	<0.001	0.001	0.03
Arkaim	732	5b		0.015	0.002	0.0001	0.03	<0.003	<0.001	<0.001	0.0015	0.03
Arkaim	733	5a	3	nd	0.0003	0.0001	0.02	<0.003	<0.001	<0.001	0.00015	0.02
Arkaim	734	5b	3	nd	<0.0003	0.00005	0.1	<0.003	<0.001	<0.001	0.00015	0.07
Arkaim	735	5a	1	0.007	0.001	0.0001	<0.01	<0.003	<0.001	<0.001	0.0002	0.01
Arkaim	736	5a	3	0.01	0.007	0.0003	<0.01	<0.003	<0.001	<0.001	0.00015	0.015
Arkaim	737	5a	1	0.01	0.001	0.00007	0.015	<0.003	<0.001	<0.001	0.0002	0.02
Arkaim	738	4a	2	0.15	0.007	0.002	0.005	<0.003	<0.001	0.002	0.0015	0.05
Arkaim	739	4a	2	0.15	0.005	0.001	0.005	<0.003	<0.001	<0.001	0.001	0.05
Arkaim	740	4a	3	0.15	0.005	0.0005	0.005	<0.003	<0.001	0.001	0.0005	0.03
Arkaim	741	6	1	0.2	0.0005	0.0002	0.005	<0.003	<0.001	<0.001	0.0003	0.03
Arkaim	742	5b	3	0.03	0.0007	0.0001	0.15	<0.003	<0.001	<0.001	0.0003	0.015
Arkaim	743	5b	3	nd	0.0005	0.0001	0.3	<0.003	<0.001	<0.001	0.0002	0.03
Arkaim	744	5b	1	0.007	0.0007	0.00015	0.03	<0.003	<0.001	<0.001	0.0015	0.05
Arkaim	745	6	1	0.01	0.001	0.0001	0.01	<0.003	<0.001	<0.001	0.0015	0.01
Arkaim	746	5b	1	nd	0.003	0.00007	0.07	<0.003	<0.001	<0.001	0.003	0.1
Arkaim	747	5b	3	0.007	0.0007	0.0001	0.1	<0.003	<0.001	<0.001	0.0015	0.05
Arkaim	748	5a	3	nd	0.0003	0.00003	0.1	<0.003	<0.001	<0.001	0.0003	0.1
Arkaim	749	5a	3	nd	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.0007	0.03
Arkaim	750	5a	1	0.015	0.0007	0.00003	0.01	<0.003	<0.001	<0.001	0.001	0.02
Arkaim	751	5a	3	0.05	0.0015	0.00005	0.03	<0.003	<0.001	<0.001	0.003	0.1
Arkaim	752	5b	1	0.03	0.003	0.0002	0.02	<0.003	<0.001	<0.001	0.00015	0.01
Arkaim	753	4a	1	1	0.02	0.0002	0.015	<0.003	<0.001	<0.001	0.002	0.015
Arkaim	754	5a	1	0.015	0.007	0.0002	0.005	<0.003	<0.001	<0.001	0.00015	0.01
Arkaim	755	6	2	0.15	0.003	0.00007	0.015	0.015	<0.001	<0.001	0.0007	0.015
Arkaim	756	6	1	0.007	0.0015	0.001	0.005	<0.003	<0.001	<0.001	0.0007	0.15
Sintashta-XIII	796	6		0.07	0.03	0.00007	0.01	<0.003	<0.001	<0.001	0.0007	0.01
Sintashta-XIII	797	6		0.07	0.03	0.00005	0.05	<0.003	<0.001	<0.001	0.002	<0.01
Sintashta-XIII	798	6		0.07	0.03	0.0001	0.05	<0.003	<0.001	<0.001	0.002	<0.01
Utyovka	813	5b	1	0.02	0.002	0.003	0.1	<0.003	<0.001	<0.001	0.0001	0.015
Utyovka	814	5a	1	0.007	0.001	0.0003	0.03	<0.003	<0.001	<0.001	0.0001	0.015
Arkaim	822	5b	1	0.1	0.003	0.00015	0.1	<0.003	<0.001	<0.001	0.0002	0.03
Arkaim	823	5b	1	0.1	0.005	0.0003	0.05	<0.003	<0.001	<0.001	0.0001	0.015

Site	Sample	Cluster	Group	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
Arkaim	824	6		0.007	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.07
Arkaim	825	5a	3	nd	0.0003	0.00005	0.05	<0.003	<0.001	<0.001	0.0007	0.07
Arkaim	826	5a	2	nd	0.0003	0.0001	0.03	<0.003	<0.001	<0.001	0.0003	0.07
Olgino	828	5a	1	nd	0.0007	0.00007	0.02	<0.003	<0.001	<0.001	0.0003	0.05
Olgino	829	5b	1	0.03	0.0015	0.0001	0.005	<0.003	<0.001	<0.001	0.002	0.01
Krivoye Ozero	830	5a	1	0.02	0.0007	0.0002	0.015	<0.003	<0.001	<0.001	0.0002	0.01
Krivoye Ozero	831	5b	1	0.03	0.0015	0.0003	0.02	<0.003	<0.001	<0.001	0.0002	0.01
Krivoye Ozero	832		1	0.7	0.0015	0.0005	0.03	<0.003	<0.001	<0.001	0.0002	0.01
Krivoye Ozero	833	5a	1	nd	0.0005	0.0005	0.015	<0.003	<0.001	<0.001	0.00015	0.015
Yagodniy Dol	836	5b	3	nd	0.0007	0.00005	0.05	<0.003	<0.001	<0.001	0.0003	0.1
Rodniki	837	4b	2	0.2	1	0.00007	0.0005	<0.003	0.001	<0.001	0.0005	1
Rodniki	838	5a	3	nd	0.0007	0.00007	0.03	<0.003	<0.001	<0.001	0.0015	0.1
Ustye	839	5b	1	0.015	0.0007	0.00007	0.02	<0.003	<0.001	0.0015	0.0002	0.01
Ustye	840	4c	1	0.2	0.02	0.0015	0.005	<0.003	<0.001	<0.001	0.00015	0.015
Ustye	841	5a	2	0.01	0.0005	0.00003	0.015	<0.003	<0.001	<0.001	0.001	0.15
Ustye	842	5b	3	0.007	0.0007	0.001	0.07	<0.003	<0.001	<0.001	0.001	0.15
Ustye	843	5a	3	nd	0.0003	0.0003	0.015	<0.003	<0.001	<0.001	0.00015	0.07
Ustye	844	5a	3	0.007	0.001	0.00005	0.07	<0.003	<0.001	<0.001	0.0007	0.1
Ustye	845	5b	3	0.01	0.001	0.0001	0.1	<0.003	<0.001	<0.001	0.0007	0.07
Ustye	846	6	1	0.03	0.005	0.001	0.07	<0.003	<0.001	<0.001	0.0005	0.03
Ustye	847	5b	1	0.05	0.005	0.00007	0.03	<0.003	<0.001	<0.001	0.0002	0.01
Ustye	848	4c	1	0.2	0.015	0.001	0.01	<0.003	<0.001	<0.001	0.0003	0.02
Ustye	849	6	1	0.01	0.005	0.00005	0.005	<0.003	<0.001	<0.001	0.0002	0.1
Ustye	850	4c	1	0.07	0.015	0.0003	0.01	<0.003	<0.001	<0.001	0.00015	0.02
Ustye	851	5a		nd	0.0005	0.00007	0.07	<0.003	<0.001	<0.001	0.001	0.15
Ustye	852	6		0.015	0.001	0.0001	0.005	<0.003	<0.001	<0.001	0.002	0.1
Ustye	853	5a	3	0.015	0.002	0.00005	0.02	<0.003	<0.001	<0.001	0.0015	0.07
Ustye	854	5a	3	0.01	0.001	0.00003	0.01	<0.003	<0.001	<0.001	0.0003	0.15
Ustye	855	5a	3	0.015	0.002	0.00003	0.005	<0.003	<0.001	<0.001	0.0007	0.07
Ustye	856	5a	3	0.01	0.0015	0.00003	0.02	<0.003	<0.001	<0.001	0.0007	0.1
Ustye	857	6	1	0.01	0.002	0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.07
Ustye	858	2	1	0.05	0.007	0.003	0.05	0.0015	<0.001	<0.001	0.0005	0.02
Ustye	859	5a	1	0.0015	0.0003	0.00015	0.03	<0.003	<0.001	<0.001	0.0007	0.03

Site	Sample	Cluster	Group	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
Ustye	860	6	2	0.02	0.007	0.0002	0.02	<0.003	<0.001	<0.001	0.0007	0.1
Ustye	861	4b	2	0.15	0.03	<0.00003	0.01	<0.003	<0.001	<0.001	0.0001	0.3
Ustye	862	6	1	0.07	0.005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0007	0.03
Ustye	863	5a	1	nd	0.0003	<0.00003	0.005	<0.003	<0.001	<0.001	0.0001	0.15
Ustye	864	6	2	0.01	0.002	0.00005	0.01	0.001	<0.001	<0.001	0.0003	0.05
Ustye	865	3	2	0.015	0.015	0.002	0.01	<0.003	<0.001	0.003	0.03	0.15
Ustye	866	3	2	0.01	0.005	0.003	0.01	<0.003	<0.001	0.002	0.015	0.1
Ustye	867	4b	2	0.1	0.02	<0.00003	0.015	<0.003	<0.001	<0.001	0.001	0.5
Ustye	868	3	3	0.1	0.1	0.0015	0.2	0.03	<0.001	<0.001	0.02	0.05
Ustye	869	4b	2	0.1	0.02	<0.00003	0.015	<0.003	<0.001	<0.001	0.0003	0.3
Ustye	870	4b	2	0.5	0.007	<0.00003	0.03	<0.003	<0.001	<0.001	0.0005	0.15
Ustye	871	5b	2	0.015	0.015	0.00005	0.01	<0.003	<0.001	<0.001	0.0003	0.07
Ustye	872	3	2	nd	0.01	0.001	0.01	<0.003	<0.001	0.0015	0.05	0.2
Ustye	873	6	1	0.15	0.01	0.00005	0.015	<0.003	<0.001	<0.001	0.00015	0.01
Ustye	874	4b	2	0.2	0.02	<0.00003	0.01	<0.003	<0.001	<0.001	0.00015	0.3
Ustye	875	3	1	0.3	0.05	0.0015	0.02	0.0015	<0.001	<0.001	0.07	0.03
Ustye	876	5b	3	0.007	0.001	0.00005	0.07	<0.003	<0.001	<0.001	0.0005	0.07
Ustye	877	5a	1	0.01	0.005	0.00003	0.01	<0.003	<0.001	<0.001	0.00015	0.15
Ustye	878	5a	3	nd	0.0015	0.00003	0.03	<0.003	<0.001	<0.001	0.0007	0.07
Ustye	879	5a	3	0.01	0.0003	0.00005	0.015	<0.003	<0.001	<0.001	0.0003	0.1
Burli	889	4c		1	0.15	0.0005	0.2	0.03	0.002	<0.001	0.0003	0.01
Sergeevka	1109	4c		0.3	0.02	0.0015	0.07	<0.003	0.001	0.003	0.0001	0.02
Sergeevka	1111	4c		0.2	0.03	0.002	1	<0.003	<0.001	0.01	0.0001	0.1
Sensitivity of the analysis				Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
				0.003	0.0003	0.00003	0.01	0.003	0.001	0.001	0.0001	0.01

Tab. 5-23. Emission spectral analyses of slag (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30) (contd.).

Site	Sample	Cluster	Group	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Sintashta	1	6	2	<0.01	<0.001	0.0015	0.03	<0.001	0.0005	<0.001	0.0002
Sintashta	42	6		0.01	<0.001	<0.0005	0.0015	nd	0.001	0.003	0.00015
Petrovka	58	6		0.01	<0.001	0.02	0.0001	nd	0.0005	0.001	0.00015
Sintashta	62	6		0.02	<0.001	0.0005	0.00015	0.01	0.001	0.01	0.0007
Sintashta	83	6	4	0.01	<0.001	0.0007	0.00007	0.0015	<0.0005	<0.001	<0.0001
Sintashta	86	6		0.02	<0.001	0.0003	0.0002	0.015	0.0015	0.003	0.0002
Sintashta	87	5b		0.01	<0.001	0.001	0.0002	0.01	0.001	0.003	0.0003
Sintashta	88	5a	4	0.01	<0.001	0.0005	0.00015	0.007	<0.0005	0.002	0.0002
Tash-Kazgan	100	5b	2	0.05	<0.001	0.0003	0.0002	0.015	0.0015	0.002	0.0002
Tash-Kazgan	101	6	2	0.07	<0.001	<0.0005	0.0002	0.01	0.001	<0.001	0.0001
Konezavod	220	6	2	0.01	<0.001	0.003	0.00015	0.01	0.0015	0.001	0.00015
Semiozerki	221	4b	2	0.05	<0.001	0.01	0.0005	0.007	0.0015	0.03	0.003
Semiozerki	252	5a	1	0.01	<0.001	0.0003	0.00003	0.001	<0.0005	0.002	0.0002
Semiozerki	260	4b	2	0.015	<0.001	0.001	0.002	0.01	0.001	0.015	0.001
Sintashta	279	6	1	0.07	0.001	0.0003	0.0002	0.015	0.001	0.005	0.0002
Sintashta	280	5b	3	0.015	<0.001	0.0007	0.00015	0.01	0.001	0.005	0.0003
Sintashta	285	5b	1	0.01	<0.001	0.0005	0.00007	nd	0.001	<0.001	0.00015
Sintashta	286	5a	1	0.015	<0.001	0.0005	0.0005	0.007	0.001	0.003	0.0003
Sintashta	298	6	4	0.01	<0.001	<0.0005	0.00015	0.001	0.0015	<0.001	0.0001
Sintashta	299	6	1	0.01	<0.001	<0.0005	0.00005	0.0015	0.0015	<0.001	<0.0001
Sintashta	300	4c		0.01	<0.001	0.005	0.0002	nd	0.0015	0.001	0.0001
Sintashta	301	5a		0.01	<0.001	<0.0005	0.0002	0.007	<0.0005	0.0015	0.00015
Sintashta	302	5b		0.01	<0.001	0.0015	0.0002	0.007	0.001	0.003	0.0002
Arkaim	305	5a	1	0.02	<0.001	0.0007	0.00005	0.007	<0.0005	0.001	0.0001
Arkaim	308	4a	2	0.01	<0.001	0.0015	0.00003	nd	0.0005	0.001	0.0001
Arkaim	311	5a	1	0.01	<0.001	0.0003	0.00003	0.001	0.0005	<0.001	0.0001
Arkaim	312	5a	1	0.01	<0.001	0.0005	0.00015	0.007	0.001	0.0015	0.00015
Arkaim	313	5a	1	0.01	<0.001	0.0005	0.0003	0.003	0.0005	0.001	0.00015
Rodniki	322	5b	3	0.015	<0.001	0.0005	0.00015	0.007	0.001	0.002	0.0002
Tyubyak	426	3	2	<0.01	<0.001	<0.0005	0.00003	nd	0.0005	<0.001	<0.0001
Tyubyak	427	2	3	0.01	<0.001	0.0003	<0.00003	0.001	0.0005	<0.001	0.0001

Site	Sample	Cluster	Group	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Tyubyak	428	2	1	0.015	<0.001	<0.0005	<0.00003	0.001	0.0005	<0.001	0.0001
Tyubyak	429	2	1	0.01	<0.001	<0.0005	<0.00003	0.001	0.0015	<0.001	0.0001
Tyubyak	431	2	3	0.01	<0.001	0.0005	<0.00003	0.001	0.001	<0.001	<0.0001
Tyubyak	445	1	1	0.5	<0.001	0.0003	0.0002	0.02	0.0015	0.002	0.0001
Tyubyak	446	1	2	0.3	<0.001	0.0003	0.00015	0.01	0.001	0.0015	<0.0001
Tyubyak	447	1	2	0.3	<0.001	0.0003	0.00015	0.01	0.0015	0.0015	0.00015
Tyubyak	448	1	2	0.5	<0.001	0.0003	0.0002	0.015	0.0015	0.003	0.00015
Tyubyak	449	1	4	0.15	0.001	0.0003	0.0002	0.015	0.00015	0.002	<0.0001
Tyubyak	450	2	3	0.015	<0.001	0.0007	<0.00003	nd	0.0015	0.001	0.0001
Tyubyak	451	1	4	0.2	<0.001	<0.0005	0.0002	0.03	0.0015	0.003	0.00015
Tyubyak	452	2	1	0.01	<0.001	<0.0005	<0.00003	nd	0.0005	<0.001	<0.0001
Tyubyak	454	2	1	0.02	<0.001	0.001	0.00005	nd	0.001	0.001	0.0001
Tyubyak	455	3	4	<0.01	<0.001	<0.0005	<0.00003	nd	<0.0005	<0.001	<0.0001
Tyubyak	459	2	1	0.03	<0.001	0.0007	0.00007	nd	0.001	<0.001	0.0001
Arkaim	679	5b	1	0.01	<0.001	<0.0005	0.00015	0.002	0.0005	0.0015	0.0002
Arkaim	680	5a	3	0.01	<0.001	<0.0005	0.00015	0.007	0.001	0.0015	0.0002
Arkaim	681	5b	1	0.01	<0.001	<0.0005	0.00005	nd	0.0005	0.001	0.0001
Arkaim	683	5b	1	0.01	<0.001	<0.0005	0.00003	nd	0.0005	0.001	0.0001
Arkaim	684	5a	1	0.01	<0.001	<0.0005	0.00005	0.01	0.0005	0.001	0.0001
Arkaim	685	5b	1	0.01	<0.001	0.0003	0.00003	0.003	0.0005	<0.001	0.0001
Arkaim	687	5b	1	0.01	<0.001	0.0005	0.00003	nd	0.0005	<0.001	0.0001
Arkaim	688	5b	1	0.01	<0.001	0.0015	0.00005	nd	<0.0005	<0.001	0.0001
Arkaim	689	5a	3	0.015	<0.001	0.0003	0.00007	0.007	0.0005	0.002	0.00015
Arkaim	691	5a	3	0.01	<0.001	0.0003	0.0002	0.007	0.0005	0.003	0.00015
Arkaim	692	4a	2	0.01	<0.001	0.0003	0.00005	nd	0.001	<0.001	0.0001
Arkaim	693	5b	1	0.01	<0.001	0.0003	0.0002	nd	0.0015	0.001	0.0001
Arkaim	695	6		0.05	<0.001	<0.0005	0.0002	0.01	0.0015	0.003	0.0002
Arkaim	725	4a	2	0.01	<0.001	<0.0005	0.00003	nd	0.0005	<0.001	0.0001
Arkaim	726	5b	1	0.01	<0.001	0.005	<0.00003	0.003	0.0005	<0.001	0.0001
Arkaim	727	5a	1	0.01	<0.001	0.0003	0.00003	0.007	0.0005	0.001	0.00015
Arkaim	728	6	2	0.01	<0.001	0.0003	0.00005	nd	0.0005	0.001	0.0002
Arkaim	729	4a	2	0.01	<0.001	0.0003	0.00015	0.005	0.0005	0.001	0.00015
Arkaim	730	5a	3	0.01	<0.001	0.0003	0.0002	0.01	0.0005	0.005	0.0003

Site	Sample	Cluster	Group	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Arkaim	731	5b	1	0.01	<0.001	0.0003	0.00003	0.0015	0.001	<0.001	0.0001
Arkaim	732	5b		0.01	<0.001	0.0003	0.00003	0.005	0.001	<0.001	0.0001
Arkaim	733	5a	3	0.01	<0.001	0.001	0.00003	0.003	0.0005	<0.001	0.0001
Arkaim	734	5b	3	0.015	<0.001	0.001	0.0007	0.005	<0.0005	0.001	0.0001
Arkaim	735	5a	1	0.015	<0.001	0.0003	<0.00003	0.0015	0.001	<0.001	<0.0001
Arkaim	736	5a	3	0.015	<0.001	0.0005	0.00003	0.001	0.0015	<0.001	0.00015
Arkaim	737	5a	1	0.01	<0.001	0.0003	0.00003	0.001	0.0015	<0.001	0.00015
Arkaim	738	4a	2	0.01	<0.001	0.0005	0.0001	nd	0.0015	0.001	0.00015
Arkaim	739	4a	2	0.01	<0.001	0.0003	0.00005	0.007	0.0015	0.001	0.00015
Arkaim	740	4a	3	0.01	<0.001	0.0003	0.00007	0.005	0.001	0.001	0.0001
Arkaim	741	6	1	0.015	<0.001	0.0003	0.00007	0.005	0.0005	0.002	0.00015
Arkaim	742	5b	3	0.01	<0.001	0.0003	0.00003	0.0015	0.001	<0.001	0.0001
Arkaim	743	5b	3	0.01	<0.001	0.0003	0.00005	0.01	0.001	<0.001	0.0001
Arkaim	744	5b	1	0.01	<0.001	0.0003	0.0005	0.005	0.001	0.007	0.0007
Arkaim	745	6	1	0.01	<0.001	0.0003	<0.00003	nd	<0.0005	<0.001	0.0001
Arkaim	746	5b	1	0.01	<0.001	0.0003	0.0002	0.01	0.001	0.005	0.00015
Arkaim	747	5b	3	0.01	<0.001	0.0003	0.00003	0.005	0.0005	<0.001	0.0001
Arkaim	748	5a	3	0.01	<0.001	0.0003	0.00005	0.005	<0.0005	<0.001	0.0001
Arkaim	749	5a	3	0.01	<0.001	0.0003	0.00003	0.005	0.0005	0.001	0.0001
Arkaim	750	5a	1	0.01	<0.001	0.0003	0.00003	0.005	0.001	<0.001	0.0001
Arkaim	751	5a	3	0.015	<0.001	0.0003	0.00005	0.007	0.001	0.002	0.00015
Arkaim	752	5b	1	0.01	<0.001	0.0003	0.00007	0.0015	0.001	0.001	0.0001
Arkaim	753	4a	1	0.01	<0.001	0.001	0.00005	nd	0.0015	0.001	0.00015
Arkaim	754	5a	1	0.01	<0.001	0.0003	<0.00003	nd	0.001	<0.001	0.0001
Arkaim	755	6	2	0.01	<0.001	<0.0005	0.0001	0.0015	0.0005	0.001	0.0001
Arkaim	756	6	1	0.01	<0.001	<0.0005	0.0001	0.01	0.0005	0.001	0.00015
Sintashta-XIII	796	6		0.01	<0.001	0.0003	<0.00003	0.007	0.001	<0.001	<0.0001
Sintashta-XIII	797	6		0.01	<0.001	0.0003	0.00003	0.007	0.001	<0.001	<0.0001
Sintashta-XIII	798	6		0.01	<0.001	0.0005	<0.00003	0.007	0.001	<0.001	<0.0001
Utyovka	813	5b	1	0.01	<0.001	0.007	<0.00003	nd	0.001	<0.001	0.0001
Utyovka	814	5a	1	0.01	<0.001	0.0005	0.00003	0.003	0.0005	<0.001	0.0001
Arkaim	822	5b	1	0.01	<0.001	0.0003	0.00015	0.002	0.001	<0.001	0.0001
Arkaim	823	5b	1	0.01	<0.001	0.0003	<0.00003	nd	<0.0005	<0.001	0.0001

Site	Sample	Cluster	Group	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Arkaim	824	6		0.03	<0.001	<0.0005	0.002	0.015	0.0015	0.002	0.0001
Arkaim	825	5a	3	0.01	<0.001	0.0003	0.00015	0.007	0.001	0.002	0.0002
Arkaim	826	5a	2	0.01	<0.001	0.0003	0.0001	0.007	0.0005	0.002	0.0002
Olgino	828	5a	1	0.01	<0.001	0.0003	0.0002	0.005	0.0005	0.0015	0.00015
Olgino	829	5b	1	0.01	<0.001	0.0003	<0.00003	nd	0.001	<0.001	0.0001
Krivoye Ozero	830	5a	1	0.01	<0.001	<0.0005	<0.00003	0.001	0.001	<0.001	0.0001
Krivoye Ozero	831	5b	1	0.01	<0.001	0.002	0.0007	0.001	0.001	<0.001	0.0001
Krivoye Ozero	832		1	0.01	<0.001	<0.0005	0.0001	0.001	0.001	<0.001	0.0001
Krivoye Ozero	833	5a	1	0.01	<0.001	<0.0005	0.00003	0.001	0.0005	<0.001	0.00015
Yagodniy Dol	836	5b	3	0.015	<0.001	<0.0005	0.0002	0.003	0.0005	0.001	0.0002
Rodniki	837	4b	2	0.05	<0.001	<0.0005	0.003	nd	0.0005	0.03	0.003
Rodniki	838	5a	3	0.015	<0.001	0.0003	0.0001	0.007	0.001	0.003	0.0003
Ustye	839	5b	1	0.01	<0.001	0.0003	<0.00003	0.0015	0.001	<0.001	0.00015
Ustye	840	4c	1	0.01	<0.001	0.03	0.0001	0.015	0.0005	0.001	0.0001
Ustye	841	5a	2	0.01	<0.001	<0.0005	0.0002	0.007	0.001	0.003	0.0003
Ustye	842	5b	3	0.01	<0.001	<0.0005	0.0002	0.007	0.001	0.005	0.0005
Ustye	843	5a	3	0.01	<0.001	0.0003	0.0001	0.003	0.0005	0.001	0.00015
Ustye	844	5a	3	0.01	<0.001	0.0003	0.0002	0.005	0.001	0.003	0.0002
Ustye	845	5b	3	0.01	<0.001	0.0003	0.0002	0.003	0.001	0.003	0.0002
Ustye	846	6	1	0.01	<0.001	0.002	0.0001	0.001	0.001	0.001	0.00015
Ustye	847	5b	1	0.01	<0.001	0.0005	<0.00003	0.002	0.001	<	<0.0001
Ustye	848	4c	1	0.01	<0.001	0.02	0.0002	0.001	0.001	0.0015	0.0001
Ustye	849	6	1	0.01	<0.001	0.002	0.0002	0.001	0.001	0.0015	0.00015
Ustye	850	4c	1	0.01	<0.001	0.1	0.00015	0.001	0.0005	<0.001	<0.0001
Ustye	851	5a		0.015	<0.001	0.0003	0.0002	0.005	0.001	0.003	0.0003
Ustye	852	6		0.03	0.001	<0.0005	0.00007	0.007	0.001	0.001	<0.0001
Ustye	853	5a	3	0.01	<0.001	0.0003	0.00015	0.007	0.001	0.005	0.0003
Ustye	854	5a	3	0.015	<0.001	0.0003	0.0002	0.007	0.0005	0.01	0.0005
Ustye	855	5a	3	0.015	<0.001	0.0003	0.0003	0.007	0.0005	0.01	0.0005
Ustye	856	5a	3	0.01	<0.001	0.0003	0.0002	0.007	0.001	0.007	0.0005
Ustye	857	6	1	0.01	<0.001	0.0015	0.0002	0.002	0.0005	0.002	0.0003
Ustye	858	2	1	0.01	<0.001	0.0003	0.0001	0.0015	0.001	0.0015	0.0001
Ustye	859	5a	1	0.01	<0.001	0.0003	0.00015	0.003	0.0005	0.003	0.0002

Site	Sample	Cluster	Group	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Ustye	860	6	2	0.02	<0.001	0.0003	0.0003	0.005	0.001	0.007	0.0005
Ustye	861	4b	2	0.015	<0.001	<0.0005	0.0007	0.015	0.001	0.005	0.0002
Ustye	862	6	1	0.015	<0.001	0.0003	0.0002	0.003	0.0005	0.015	0.0015
Ustye	863	5a	1	0.02	<0.001	0.0003	0.00007	0.003	<0.0005	0.001	0.00015
Ustye	864	6	2	0.01	<0.001	<0.0005	0.00007	0.001	<0.0005	0.001	<0.0001
Ustye	865	3	2	0.015	<0.001	0.0003	0.0003	0.0015	0.001	0.01	0.0007
Ustye	866	3	2	0.015	<0.001	<0.0005	0.0002	0.0015	0.001	0.001	0.00015
Ustye	867	4b	2	0.015	<0.001	<0.0005	0.0007	0.01	0.0015	0.003	0.0002
Ustye	868	3	3	0.01	<0.001	0.0003	0.0002	0.01	0.0015	0.003	0.0002
Ustye	869	4b	2	0.015	<0.001	0.0015	0.0007	0.015	0.0015	0.0005	0.0003
Ustye	870	4b	2	0.01	0.001	<0.0005	0.0007	0.01	0.001	0.007	0.0003
Ustye	871	5b	2	0.01	<0.001	<0.0005	0.0003	0.01	0.001	0.005	0.0007
Ustye	872	3	2	0.03	<0.001	0.0003	0.0003	0.0015	0.001	0.005	0.0005
Ustye	873	6	1	0.01	<0.001	0.001	0.00007	nd	0.0005	<0.001	<0.0001
Ustye	874	4b	2	0.02	<0.001	0.001	0.0007	0.007	0.0015	0.005	0.00015
Ustye	875	3	1	0.01	<0.001	0.0003	0.00007	nd	0.0005	0.002	0.00015
Ustye	876	5b	3	0.01	<0.001	0.0003	0.00015	0.005	0.001	0.002	0.0002
Ustye	877	5a	1	0.02	<0.001	0.0003	0.00003	0.003	0.0005	0.001	0.00015
Ustye	878	5a	3	0.01	<0.001	<0.0005	0.00015	0.007	0.001	0.005	0.0003
Ustye	879	5a	3	0.015	<0.001	<0.0005	0.0002	0.005	0.001	0.003	0.0002
Burli	889	4c		0.01	<0.001	<0.0005	0.00015	nd	<0.0005	0.005	0.0002
Sergeevka	1109	4c		0.01	<0.001	0.05	0.00003	0.007	0.001	<0.001	<0.0001
Sergeevka	1111	4c		0.01	<0.001	0.07	<0.00003	<0.001	0.0005	0.001	<0.0001
Sensitivity of the analysis				Sr	W	Sn	Be	Zr	Ga	Y	Yb
				0.01	0.001	0.0005	0.00003	0.001	0.0005	0.001	0.0001

Tab. 5-24. Distribution of chemical clusters of slag over sites.

Clusters Sites	1	2	3	4a	4b	4c	5a	5b	6
Tyubyak	6	8	2						
Ustye		1	5		5	3	13	6	8
Arkaim				8			21	19	7
Sintashta						1	3	2	8
Krivoye Ozero							2	1	
Yagodniy Dol								1	
Olgino							1	1	
Utyovka							1	1	
Burli						1			
Sergeevka						2			
Semiozerki					2		1		
Rodniki					1		1	1	
Tash-Kazgan								1	1
Petrovka									1
Sintashta XIII									3
Konezavod									1
Total	**6**	**9**	**7**	**8**	**8**	**7**	**43**	**33**	**29**

Tab. 5-25. Correlation between clusters I (ti, mn, zn, as, ba, sr, ni, co, cr, v, pb, sn, ga, ge, ag, mo) and clusters II (ti, zn, sr, ni, v, sc, sn, ga, y, ge, ag, mo, be).

Clusters	1	2	3	4a	4b	4c	5a	5b	6
1	6								
2		7	1				1		
3			6						
4		1		8			2		3
5					8		1		
6						7			
7							16	2	
8							1	6	3
9							4	8	7
10							7	5	2
11							11	1	9
12								11	
13									5

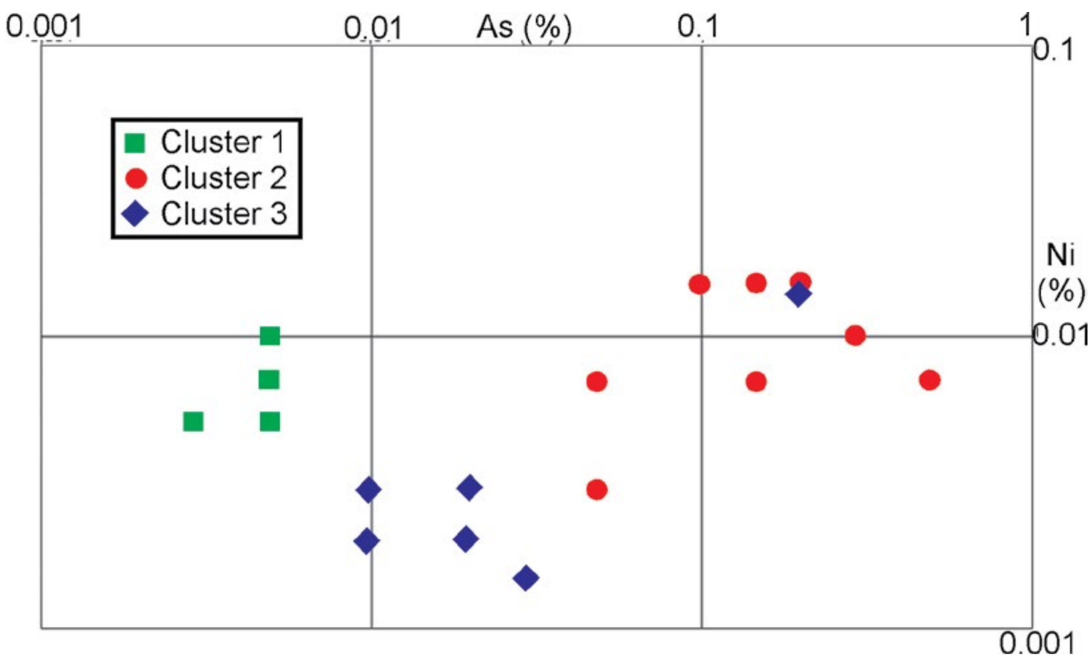


FIG. 5-26. CORRELATION OF CONCENTRATIONS OF AS-NI IN SLAG OF THE CHEMICAL CLUSTERS 1-3.

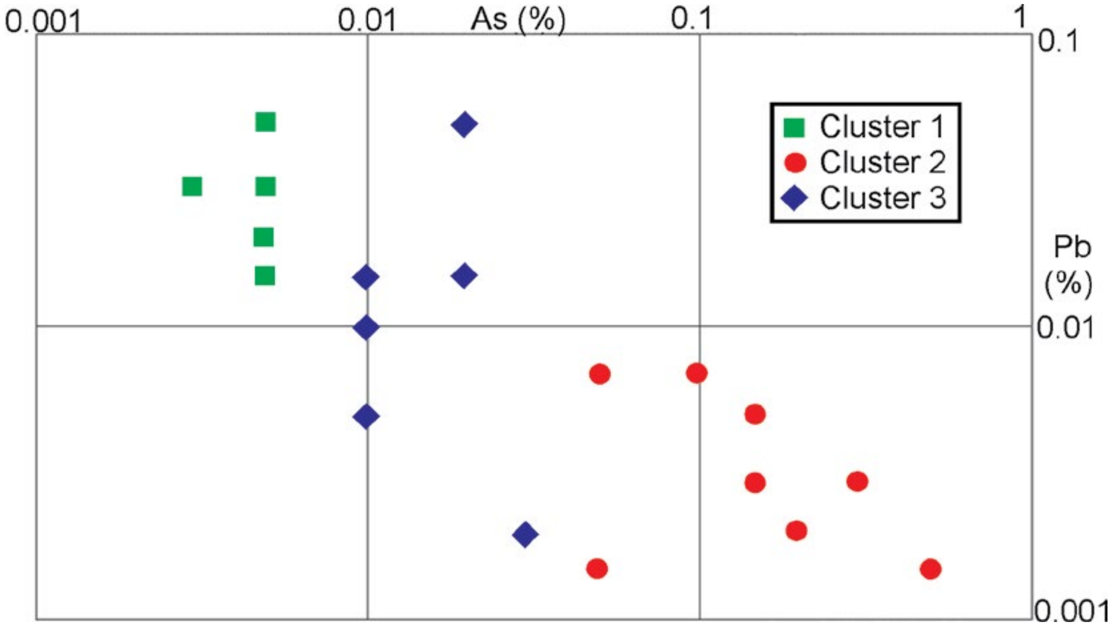


FIG. 5-27. CORRELATION OF CONCENTRATIONS OF AS-PB IN SLAG OF THE CHEMICAL CLUSTERS 1-3.

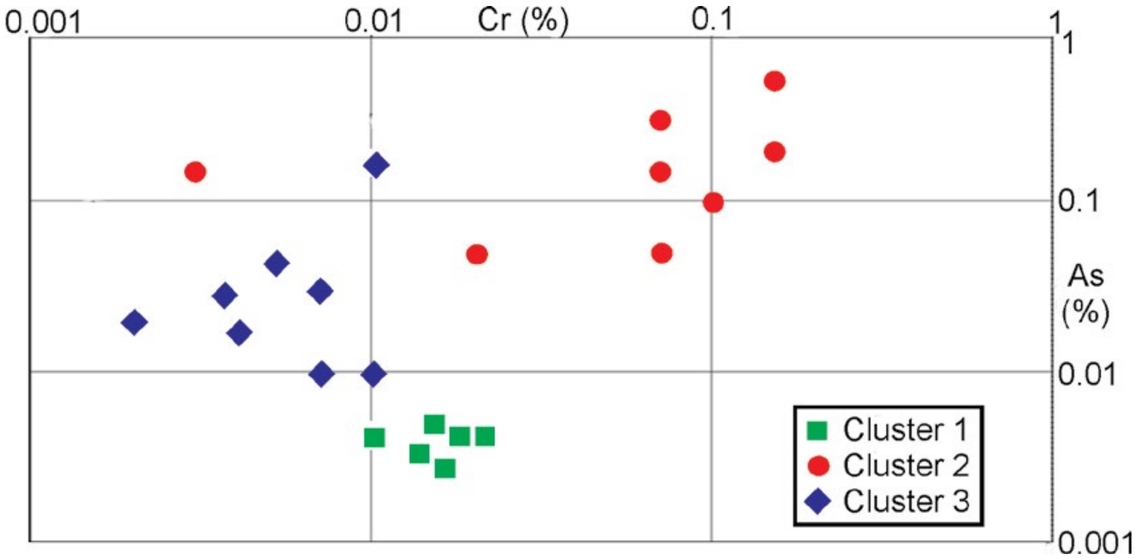


FIG. 5-28. CORRELATION OF CONCENTRATIONS OF CR-AS IN SLAG OF THE CHEMICAL CLUSTERS 1-3.

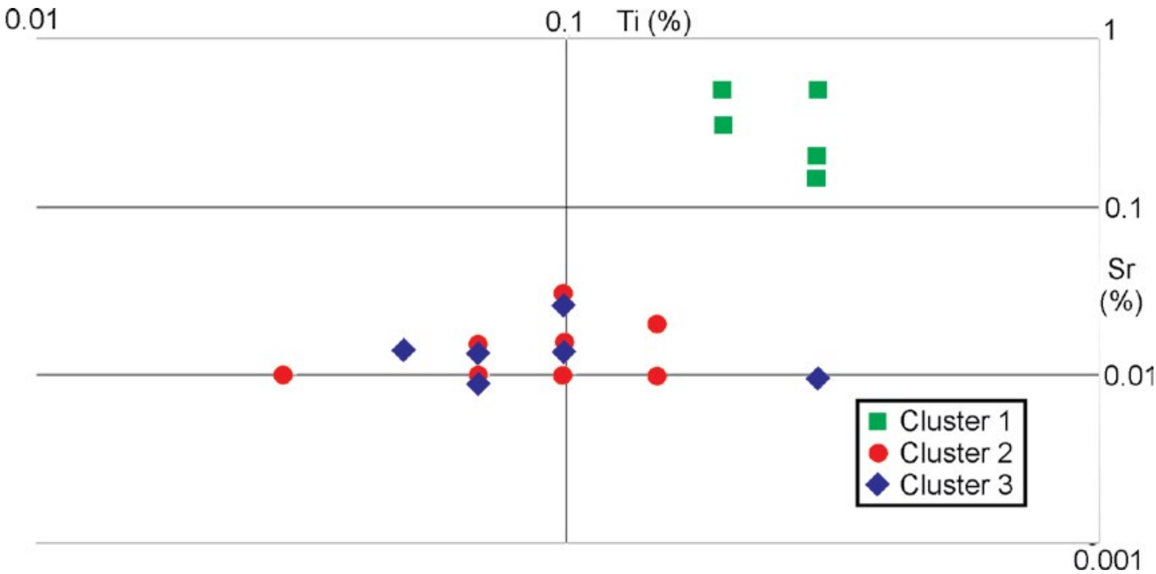


FIG. 5-29. CORRELATION OF CONCENTRATIONS OF TI-SR IN SLAG OF THE CHEMICAL CLUSTERS 1-3.

Tab. 5-30. Correlation between chemical clusters and mineralogical groups of slag.

Clusters / Mineral groups	1	2	3	4a	4b	4c	5a	5b	6
1	1	6	1	1		3	19	20	10
2	3		4	6	8		2	2	7
3		3	1	1			19	10	
4	2		1				1		2
nd						4	2	3	10

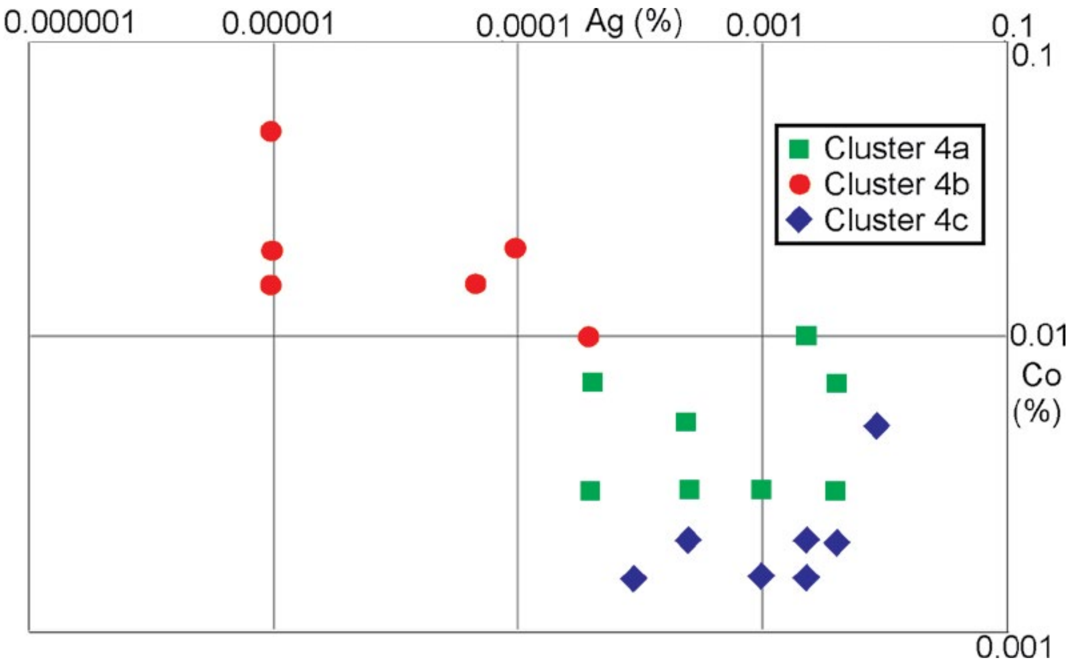


FIG. 5-31. CORRELATION OF CONCENTRATIONS OF AG-CO IN SLAG OF THE CHEMICAL CLUSTERS 4.

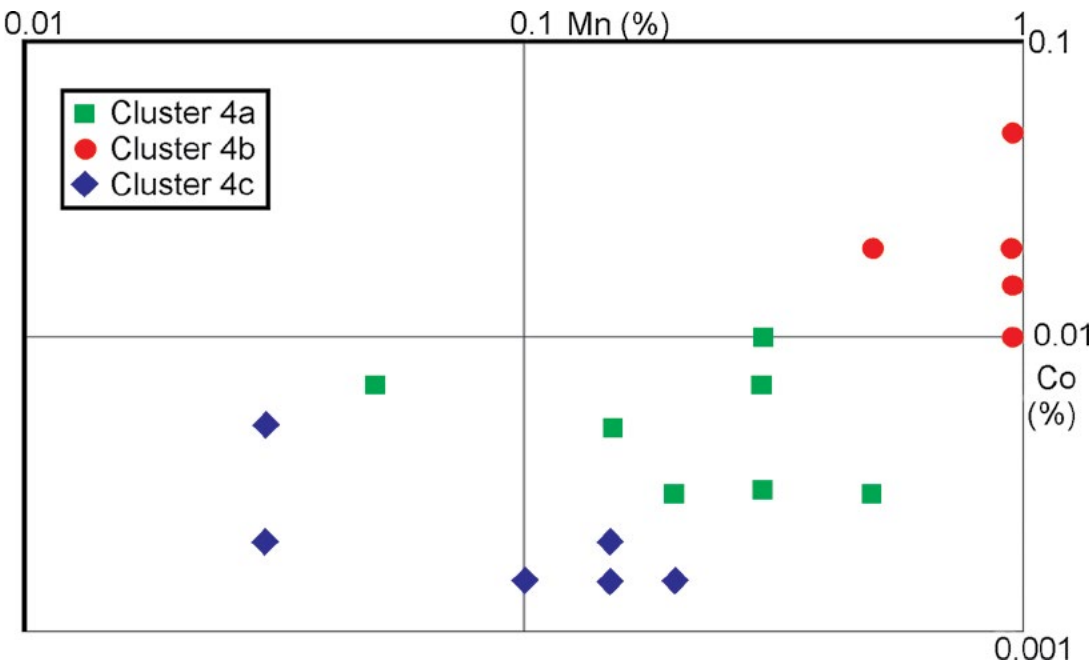


FIG. 5-32. CORRELATION OF CONCENTRATIONS OF MN-CO IN SLAG OF THE CHEMICAL CLUSTERS 4.

Tab. 5-33. Distribution of chemical clusters of slag and their proportion in different cultural groups.

Clusters / Cultural groups	1	2	3	4a	4b	4c	5a	5b	6	Total
Sintashta				8 (11.9%)		4 (6%)	25 (37.3%)	23 (34.3%)	7 (10.5%)	67 (100%)
Sintashta-Petrovka		1 (2.2%)	5 (10.8%)				16 (34.8%)	8 (17.4%)	16 (34.8%)	46 (100%)
Petrovka					8 (50%)		2 (12.5%)	1 (6.2%)	5 (31.3%)	16 (100%)
Abashevo	6 (37.5%)	8 (50%)	2 (12.5%)							16 (100%)
Others						3 (60%)		1 (20%)	1 (20%)	5 (100%)
Total	6 (4%)	9 (6%)	7 (4.7%)	8 (5.3%)	8 (5.3%)	7 (4.7%)	43 (28.7%)	33 (22%)	29 (19.3%)	150 (100%)

Tab. 5-34. Distribution of chemical clusters of slag over cultural groups.

Clusters / Cultural groups	1	2	3	4a	4b	4c	5a	5b	6
Sintashta				8 (100%)		4 (57.1%)	25 (58.1%)	23 (70%)	7 (24.1%)
Sintashta-Petrovka		1 (11.1%)	5 (71.4%)				16 (37.2%)	8 (24%)	16 (55.2%)
Petrovka					8 (100%)		2 (4.7%)	1 (3%)	5 (17.2%)
Abashevo	6 (100%)	8 (88.9%)	2 (28.6%)						
Others						3 (42.9%)		1 (3%)	1 (3.5%)
Total	6 (100%)	9 (100%)	7 (100%)	8 (100%)	8 (100%)	7 (100%)	43 (100%)	33 (100%)	29 (100%)

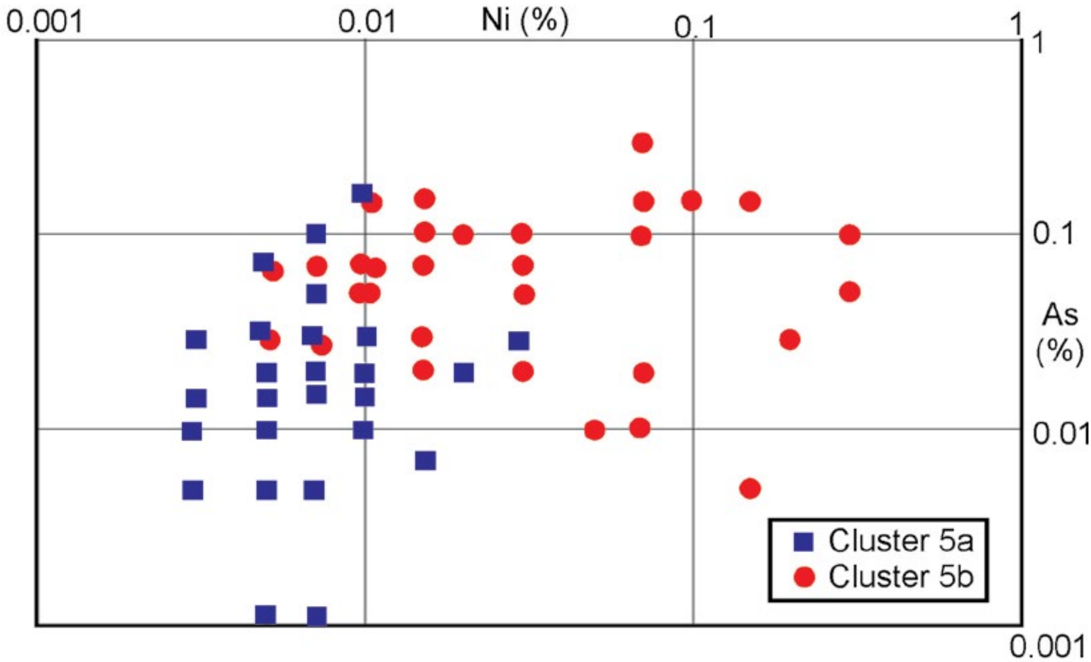


FIG. 5-35. CORRELATION OF CONCENTRATIONS OF NI-AS IN SLAG OF THE CHEMICAL CLUSTERS 5.

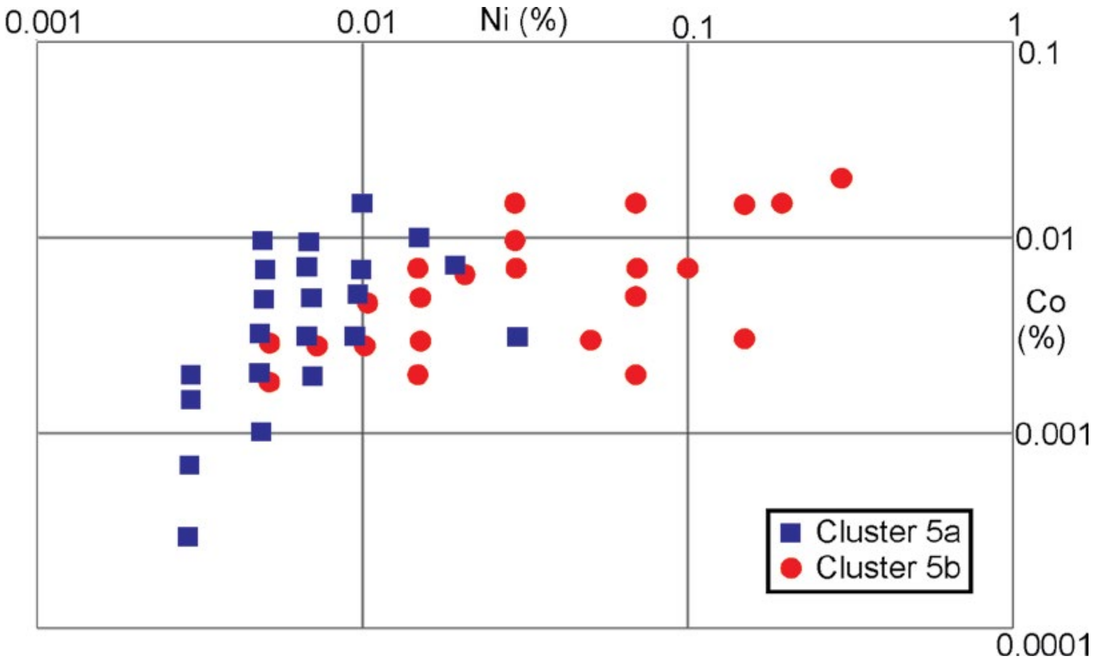


FIG. 5-36. CORRELATION OF CONCENTRATIONS OF NI-CO IN SLAG OF THE CHEMICAL CLUSTERS 5.

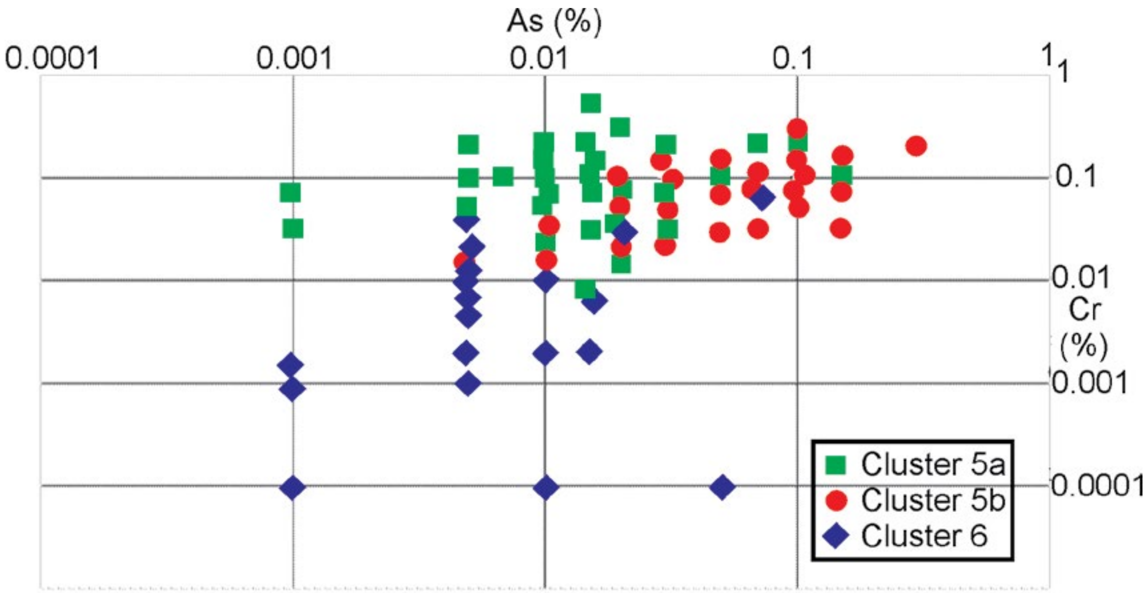


FIG. 5-37. CORRELATION OF CONCENTRATIONS OF AS-CR IN SLAG OF THE CHEMICAL CLUSTERS 5, 6.

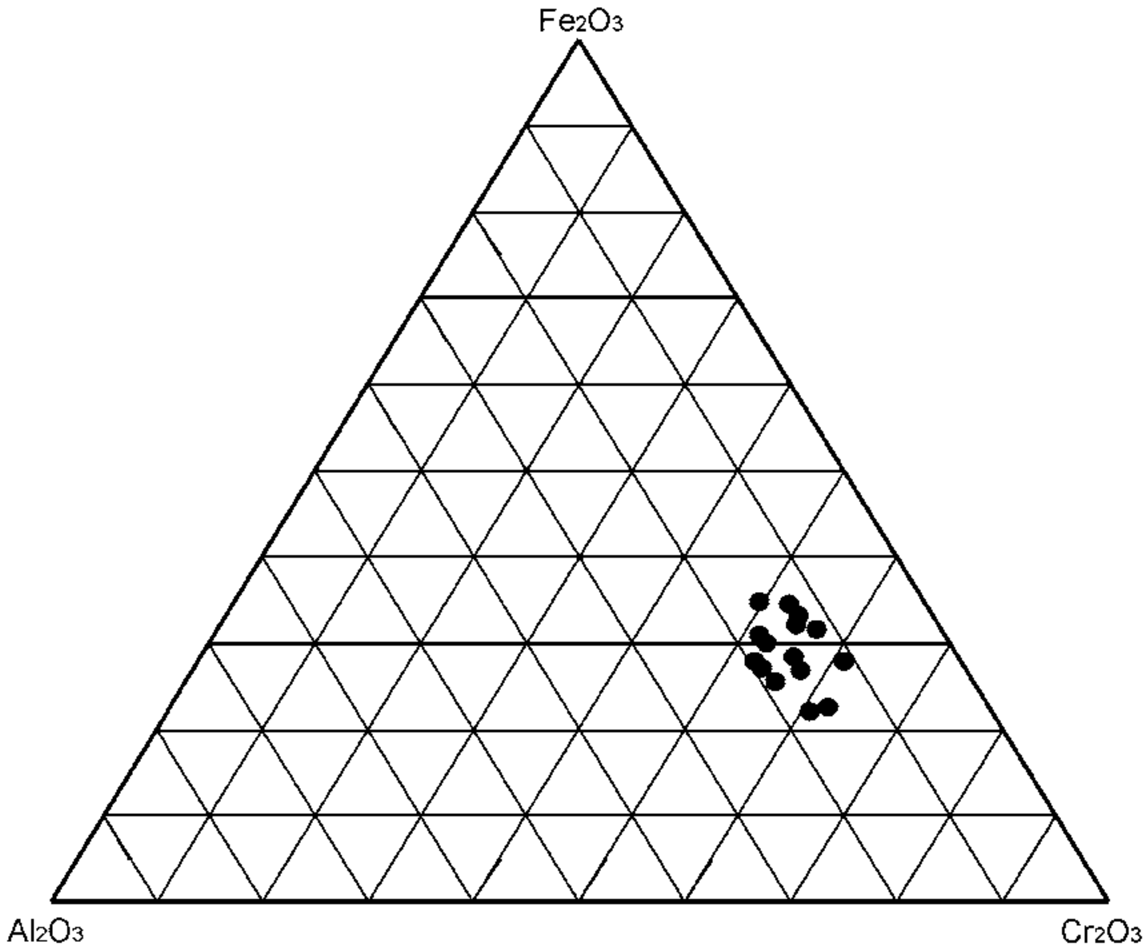


FIG. 5-38. PHASE PLOT FE2O3 – AL2O3 – CR2O3 FOR CHROMITES IN SLAG OF THE SINTASHTA CULTURE (%).

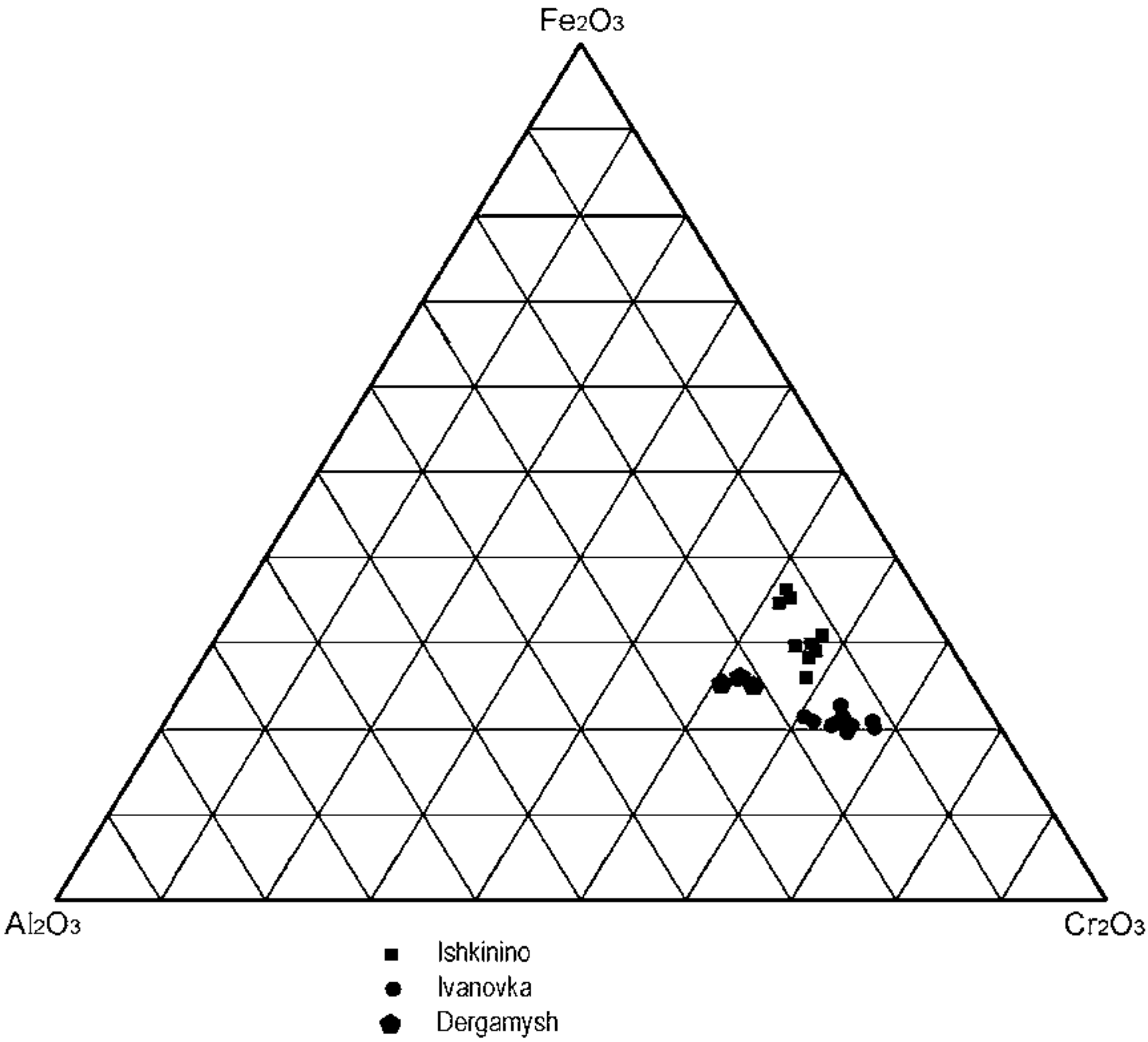


FIG. 5-39. PHASE PLOT FE2O3 – AL2O3 – CR2O3 FOR CHROMITES IN ORES FROM THE DEPOSITS OF ISHKININO, IVANOVKA AND DERGAMYSH (%).

Tab. 5-40. X-ray spectroscopic analyses of chromites in oxidized ore from the mines of Ishkinino and Vorovskaya Yama, and in slags from the Sintashta (Sintashta, Arkaim, Alandskoe, Ustye) and Petrovka (Rodniki, Kuysak) settlements.

№ of polished section		№ analysis	contents, weight %													parameters		
			SiO2	MnO	TiO2	Al2O3	Cr2O3	MgO	SFeO	V2O5	NiO	CoO	ZnO	CaO	total	Cr#	Mg#	Z Fe3+
T3[1]	Ishkinino	2a	-	0.38	0.25	15.01	50.60	10.66	23.10	0.23	0.07	-	-	-	100.29	69.35	51.30	6.85
		2b	-	0.32	0.26	15.46	50.65	10.70	23.37	0.26	0.07	-	0.11	-	101.21	68.72	51.00	6.75
		2c	-	0.40	0.29	15.46	50.21	10.53	23.73	0.26	0.08	-	-	-	100.95	68.53	50.40	7.05
		3a	-	0.41	0.33	15.44	49.87	10.14	24.40	0.26	0.08	-	0.09	-	101.03	68.43	48.70	7.20
		3b	-	0.44	0.30	15.87	48.72	9.93	25.26	0.25	0.08	-	-	-	100.84	67.34	47.70	7.85
		3c	-	0.42	0.35	14.63	44.85	7.99	32.68	0.21	0.09	-	0.14	-	101.35	67.27	38.90	14.00
		4a	-	0.44	0.32	17.70	46.71	9.23	25.97	0.23	0.07	-	-	-	100.67	63.91	44.30	7.05
		4b	-	0.48	0.31	17.86	45.28	9.01	26.50	0.22	0.07	-	0.14	-	99.86	62.98	43.60	7.75
		4c	-	0.37	0.31	17.23	47.48	9.38	26.03	0.25	0.08	-	-	-	101.13	64.89	44.80	7.30
		5a	-	0.41	0.30	16.27	48.83	9.93	24.67	0.24	0.08	-	-	-	100.72	66.83	47.60	7.00
		5b	-	0.40	0.28	15.98	47.40	9.33	25.63	0.24	0.07	-	0.09	-	99.43	66.54	45.50	7.85
		5c	-	0.40	0.28	15.50	48.94	10.22	23.65	0.21	0.08	0.07	0.13	-	99.48	67.92	49.70	7.10
		6a	-	0.43	0.29	14.78	50.61	10.66	22.41	0.26	0.07	-	-	-	99.49	69.70	51.80	6.45
		6b	-	0.38	0.30	13.71	50.72	10.14	23.22	0.27	0.05	-	0.11	-	98.91	71.27	50.00	7.05
		6c	-	0.43	0.29	14.32	49.34	8.87	26.28	0.23	0.09	-	0.10	-	99.95	69.80	43.50	7.95
T3a[1]	Ishkinino	2	-	-	-	14.61	53.24	10.79	21.61	-	-	-	-	-	100.25	70.96	51.60	4.80
		3	-	-	-	14.76	53.41	10.00	23.31	-	-	-	-	-	101.48	70.82	47.60	4.90
		4	-	-	-	14.19	54.33	12.07	20.40	-	-	-	-	-	100.99	71.96	57.00	5.50
		5	-	-	-	13.38	50.49	8.73	25.60	-	-	-	-	-	98.20	71.68	43.30	7.30
		6	-	-	-	14.67	51.62	8.19	26.93	-	-	-	-	-	101.41	70.23	39.50	6.10
		7	-	-	-	14.58	50.62	8.63	26.34	-	-	-	-	-	100.17	69.96	41.90	6.85
		8	-	-	-	14.01	51.08	9.26	25.86	-	-	-	-	-	100.21	70.96	44.90	7.55
		9	-	-	-	12.15	52.95	8.30	25.81	-	-	-	-	-	99.21	74.49	41.20	6.50
		10	-	-	-	12.72	51.72	8.54	25.38	-	-	-	-	-	98.36	73.15	42.50	6.70
		11	-	-	-	12.79	52.78	8.64	25.05	-	-	-	-	-	99.26	73.46	42.60	6.00
		13	-	-	-	12.13	53.94	8.35	25.36	-	-	-	-	-	99.78	74.91	41.20	5.70

№ of polished section		№ analysis	contents, weight %													parameters		
			SiO2	MnO	TiO2	Al2O3	Cr2O3	MgO	SFeO	V2O5	NiO	CoO	ZnO	CaO	total	Cr#	Mg#	Z Fe3+
		14	-	-	-	12.56	53.32	9.06	25.19	-	-	-	-	-	100.13	74.02	44.30	6.65
		15	-	-	-	12.21	52.14	8.53	26.18	-	-	-	-	-	99.06	74.15	42.30	7.55
802[2]	Vorovskaya Yama	12318a	-	0.53	-	19.22	50.43	11.49	16.95	-	-	-	1.28	-	99.90	63.78	54.80	0.05
		12318b	-	0.55	-	17.98	53.01	9.94	18.02	-	-	-	0.43	-	99.93	65.80	47.80	0.00
		12318c	0.52	1.98	-	17.69	49.38	6.11	22.76	-	-	-	1.47	-	99.91	64.50	31.00	0.00
		12318d	1.21	0.37	-	19.07	50.67	12.14	16.26	-	-	-	0.20	-	99.92	64.04	57.60	0.45
		12318e	0.94	1.33	-	18.24	49.97	8.76	20.21	-	-	-	0.48	-	99.93	65.00	43.10	0.00
		12318f	1.44	1.27	-	19.38	48.01	9.66	19.26	-	-	-	0.82	-	99.84	62.44	47.30	0.10
		12318h	0.91	0.85	-	18.77	51.52	10.81	16.70	-	-	-	0.40	-	99.96	64.30	52.00	0.00
		12318i	0.68	0.56	-	18.49	50.25	11.96	16.83	-	-	-	1.14	-	99.91	64.57	57.30	1.20
		12318j	0.64	1.94	-	17.67	48.68	3.92	25.48	-	-	-	1.60	-	99.93	65.00	20.30	0.00
		12318k	0.52	0.70	-	19.29	50.34	11.87	16.43	-	-	-	0.77	-	99.92	63.65	56.50	0.20
		12318l	1.02	1.88	-	19.16	48.11	8.47	21.03	-	-	-	0.28	-	99.95	62.70	41.70	0.00
		12318m	1.03	0.33	-	20.07	50.65	11.59	15.58	-	-	-	0.69	-	99.94	62.25	55.10	0.00
		12318n	1.08	2.47	-	17.48	47.81	2.77	26.90	-	-	-	1.41	-	99.92	63.65	14.60	0.00
		12318o	1.09	3.24	-	11.93	43.46	1.14	37.51	-	-	-	1.56	-	99.93	70.95	6.30	10.85
		12319c	0.64	1.10	-	17.07	51.59	9.88	19.38	-	-	-	0.24	-	99.90	66.97	48.10	0.55
		12319a	0.49	0.75	-	18.12	50.57	12.33	17.34	-	-	-	0.21	-	99.81	65.18	58.50	2.35
		12319d	0.79	0.84	-	18.66	50.52	13.29	15.71	-	-	-	0.09	-	99.90	64.50	62.60	2.10
		12319e	0.45	2.43	-	18.93	47.16	4.71	25.14	-	-	-	1.14	-	99.96	61.80	24.00	0.00
		12319f	0.58	0.89	-	18.46	51.01	11.95	16.30	-	-	-	0.76	-	99.95	64.96	57.10	0.45
		12319g	0.74	0.30	-	19.36	50.12	12.88	15.60	-	-	-	0.91	-	99.91	63.45	60.80	1.10
		12319h	0.74	0.10	-	18.59	50.68	12.15	16.77	-	-	-	0.90	-	99.93	64.66	57.70	1.20
		12319j	0.56	0.69	-	19.15	50.50	12.47	15.81	-	-	-	0.73	-	99.91	63.88	59.10	0.60
		12319k	0.99	1.10	-	19.10	48.62	12.23	17.14	-	-	-	0.73	-	99.91	63.07	58.50	2.25
		12319l	1.06	1.50	-	19.30	49.20	8.67	19.68	-	-	-	0.51	-	99.92	62.50	42.60	0.00
		2319m	1.23	2.50	-	17.69	46.76	3.36	26.53	-	-	-	1.86	-	99.93	63.20	17.70	0.00

№ of polished section		№ analysis	contents, weight %													parameters		
			SiO2	MnO	TiO2	Al2O3	Cr2O3	MgO	SFeO	V2O5	NiO	CoO	ZnO	CaO	total	Cr#	Mg#	Z Fe3+
		12319n	0.68	0.55	-	19.37	50.69	11.97	16.00	-	-	-	0.64	-	99.90	63.60	56.90	0.00
		12319o	1.36	1.34	-	18.88	48.76	8.95	19.80	-	-	-	0.81	-	99.90	63.20	44.10	0.00
		12319p	0.69	1.20	-	18.17	50.53	8.21	20.65	-	-	-	0.48	-	99.93	64.65	40.40	0.00
		12319q	1.37	0.32	-	19.97	50.33	12.04	15.40	-	-	-	0.49	-	99.92	62.50	57.20	0.00
		12319r	1.28	2.26	-	19.45	46.76	4.07	25.42	-	-	-	0.70	-	99.94	60.60	20.90	0.00
		12319s	0.71	0.60	-	18.48	52.22	11.54	16.24	-	-	-	0.13	-	99.92	65.20	55.00	0.00
		12319t	0.84	0.75	-	17.94	52.25	11.34	16.63	-	-	-	0.18	-	99.93	66.00	54.40	0.00
		12319u	1.16	1.75	-	19.82	48.33	9.34	18.23	-	-	-	1.28	-	99.91	61.40	46.00	0.00
		12319v	1.24	2.04	-	19.10	47.21	7.28	22.52	-	-	-	0.55	-	99.94	62.30	36.40	0.00
		12319w	0.25	2.44	-	18.35	48.30	6.86	23.08	-	-	-	0.67	-	99.95	63.70	34.30	0.00
		12317l	-	0.09	-	44.31	25.06	20.38	9.47	-	-	-	0.66	-	99.97	27.51	82.60	2.05
		12317m	-	-	-	44.09	23.94	20.79	9.90	-	-	-	1.20	-	99.92	26.68	84.40	3.45
Гр-4[1]	Sintashta	2	-	0.54	0.33	11.26	50.44	7.87	30.96	0.40	-	-	-	-	101.80	75.01	38.80	12.15
		5	-	0.49	-	8.25	54.87	8.27	28.79	-	-	-	-	-	100.67	81.59	43.10	9.85
		6	-	0.51	-	8.41	55.48	8.63	27.31	-	-	-	-	-	100.34	81.44	39.20	10.30
		8	-	-	-	8.56	55.98	7.97	29.49	-	-	-	-	-	102.00	66.89	33.30	10.15
		9	-	-	-	15.59	46.90	6.90	32.08	-	-	-	-	-	101.47	66.76	33.40	8.95
		10	-	-	-	15.63	46.80	6.82	30.78	-	-	-	-	-	100.03	72.78	21.50	26.15
		11	-	0.73	0.69	9.81	39.10	4.15	44.97	-	-	-	-	-	99.45	83.54	14.80	25.95
		14	-	-	1.06	5.78	43.76	2.77	45.82	0.59	-	-	-	-	99.78	79.57	43.40	6.00
		16	-	0.45	-	9.88	57.30	8.81	24.84	-	-	-	-	-	101.28	78.96	43.80	5.60
		20	-	0.45	0.24	10.27	57.41	8.94	24.56	-	-	-	-	-	101.87	78.49	44.00	5.85
		21	-	-	0.37	10.40	56.63	8.93	24.53	0.46	-	-	-	-	101.32	78.49	44.00	5.85
Гр-286[1]	Sintashta	3	-	-	-	11.75	52.21	9.16	27.97	-	-	-	-	-	101.09	74.87	44.40	10.30
		4	-	-	0.41	11.33	52.61	9.33	28.14	-	-	-	-	-	101.82	75.69	45.20	10.80
		5	-	-	0.37	11.95	52.22	9.13	28.16	-	-	-	-	-	101.83	74.55	44.10	10.25
		6	-	-	-	12.89	50.75	6.79	30.10	-	-	-	-	-	100.53	72.53	33.50	8.45
		7	-	0.67	0.37	10.90	52.64	6.46	27.32	-	-	-	-	-	98.36	76.42	33.20	6.05

№ of polished section		№ analysis	contents, weight %													parameters		
			SiO2	MnO	TiO2	Al2O3	Cr2O3	MgO	SFeO	V2O5	NiO	CoO	ZnO	CaO	total	Cr#	Mg#	Z Fe3+
		8	-	-	-	11.24	54.09	6.20	27.96	0.51	-	-	-	-	100.00	76.36	31.30	5.20
		12	-	-	-	13.37	54.33	8.33	23.25	-	-	-	-	-	99.28	73.16	41.10	2.75
		13	-	0.78	-	14.66	53.35	9.06	23.28	-	-	-	-	-	101.13	70.93	43.80	3.50
656[1]	Arkaim	1	0.59	-	-	10.94	56.75	8.88	20.97	-	-	-	-	-	98.13	77.67	44.90	2.15
		2	0.77	0.67	-	10.78	54.50	9.00	22.46	-	-	-	-	-	98.18	77.23	45.70	4.90
		3	-	-	-	11.34	55.15	9.24	26.07	-	-	-	-	-	101.79	76.54	44.70	7.65
		4	-	0.96	-	10.15	55.23	10.62	21.47	-	-	-	-	-	98.42	78.51	53.10	6.70
		6	-	0.68	-	13.90	52.89	8.41	23.19	-	-	-	-	-	99.07	71.86	41.70	3.15
		7	-	-	-	14.73	51.21	7.47	25.96	-	-	-	-	-	99.37	69.99	36.80	4.30
		8	-	-	-	16.63	47.49	10.99	25.15	-	-	-	-	-	100.26	65.69	52.00	9.35
		9	-	-	0.47	16.48	46.68	10.57	24.92	-	-	-	-	-	99.12	65.51	50.90	9.05
		10	-	0.62	0.35	17.04	45.64	11.11	25.02	-	-	-	-	-	99.78	63.90	53.10	10.05
		11	-	-	-	12.64	50.44	4.14	32.67	-	-	-	-	-	99.90	72.81	21.00	6.90
		12	-	0.85	-	12.29	50.32	4.85	32.76	-	-	-	-	-	101.07	73.31	24.40	8.45
		13	-	-	-	12.36	49.75	4.39	35.29	-	-	-	-	-	101.80	72.97	21.80	10.10
726[1]	Arkaim	1	-	-	-	13.39	53.79	9.28	22.81	-	-	-	-	-	100.97	72.94	45.50	4.10
		2	-	-	-	13.77	55.15	10.26	21.89	-	-	-	-	-	101.07	72.88	49.10	3.95
		4	-	-	-	14.20	50.33	7.86	26.14	-	-	-	-	-	100.46	70.40	39.00	5.90
		5	-	-	-	14.62	49.57	8.33	26.76	-	-	-	-	-	101.10	69.45	40.80	7.20
		6	-	-	-	13.89	48.93	8.03	27.41	-	-	-	-	-	99.08	70.26	39.90	8.20
		7	-	-	-	11.82	53.56	5.95	28.35	-	-	-	-	-	99.67	75.26	29.90	5.00
		8	-	-	-	11.91	53.10	5.76	29.25	-	-	-	-	-	100.02	74.93	28.90	5.65
		9	-	-	-	12.95	52.04	5.80	29.29	-	-	-	-	-	100.08	72.95	29.00	5.50
Гр-750[1]	Arkaim	2	-	-	0.41	13.16	55.21	11.89	20.48	-	-	-	-	-	101.15	73.78	56.60	5.60
		3	-	-	-	12.84	55.00	12.08	20.56	-	-	-	-	-	100.48	74.17	57.60	6.30
B11-51[1]	Alandskoye	1	-	-	0.43	11.52	52.99	25.69	9.91	-	-	-	-	-	100.54	75.52	48.30	9.30
		3	-	-	-	11.66	53.46	26.62	9.65	-	-	-	-	-	101.39	75.47	46.60	9.35
		4	-	-	0.40	13.37	53.40	20.22	11.61	-	-	-	-	-	99.00	72.81	56.30	5.65

№ of polished section		№ analysis	contents, weight %													parameters		
			SiO2	MnO	TiO2	Al2O3	Cr2O3	MgO	SFeO	V2O5	NiO	CoO	ZnO	CaO	total	Cr#	Mg#	Z Fe3+
		5	-	0.63	0.30	13.08	53.82	20.06	12.56	-	-	-	-	-	100.45	73.40	60.10	6.95
		6	-	0.99	-	13.69	53.83	20.73	12.40	-	-	-	-	-	101.64	72.52	58.70	6.85
		7	-	0.67	-	13.61	52.32	21.13	12.58	-	-	-	-	-	100.31	72.06	60.00	8.25
		8	-	0.78	0.33	13.44	53.11	20.75	12.22	-	-	-	-	-	100.63	72.60	58.50	7.15
		9	-	-	-	13.41	53.43	21.17	11.62	-	-	-	-	-	99.63	72.80	55.80	6.45
		10	-	-	-	14.09	52.78	20.30	13.20	-	-	-	-	-	100.38	71.55	62.10	7.90
		11	-	0.55	0.38	13.56	50.91	20.17	12.71	-	-	-	-	-	98.28	71.58	61.80	8.35
		13	-	-	-	12.48	52.40	22.31	11.96	-	-	-	-	-	99.15	73.82	57.70	9.10
		14	-	-	-	11.66	54.45	22.72	11.17	-	-	-	-	-	100.00	75.80	54.00	7.85
842[1]	Ustye	1	0.84	-	0.10	16.97	49.66	8.79	23.66	-	-	-	-	-	100.02	66.25	42.70	3.55
		2	1.25	-	0.14	13.11	49.72	5.77	30.12	-	-	-	-	-	100.09	71.81	29.10	7.25
		2a	3.21	0.10	0.12	13.14	48.63	5.20	29.56	-	-	-	-	-	99.97	71.28	26.90	6.35
		3	0.24	-	0.10	15.82	51.84	10.57	21.04	-	-	-	-	-	99.62	68.71	50.80	3.80
		3a	0.21	-	0.10	16.54	51.48	10.87	21.40	-	-	-	-	-	100.59	67.62	51.50	4.25
		3b	0.25	-	0.10	16.15	51.87	10.57	21.99	-	-	-	-	-	100.92	68.31	50.20	4.40
		4	0.33	-	0.16	13.93	46.29	6.43	33.61	-	-	-	-	-	100.74	69.02	31.70	12.35
		4a	0.37	0.12	0.16	14.17	46.46	6.10	33.49	-	-	-	-	-	100.88	68.76	30.10	11.45
		4b	1.44	0.10	0.13	13.69	46.05	5.68	33.70	-	-	-	-	-	100.80	69.29	28.50	11.65
		4c	0.40	0.11	0.15	13.82	48.26	6.28	31.66	-	-	-	-	-	100.68	70.39	31.10	9.55
		5	0.28	0.13	0.34	20.40	40.39	8.35	29.68	-	-	-	-	-	99.57	57.08	40.00	9.95
		5a	0.22	0.11	0.36	20.47	40.85	8.47	29.31	-	-	-	-	-	99.78	57.27	40.50	9.55
		5b	0.25	0.10	0.36	20.15	40.35	8.23	29.34	-	-	-	-	-	98.77	57.31	39.80	9.70
		6	0.42	0.15	-	11.58	52.51	6.34	29.00	-	-	-	-	-	100.01	75.25	31.90	6.90
		6a	1.26	0.10	0.11	11.67	55.06	7.37	25.56	-	-	-	-	-	101.14	76.00	36.80	4.15
		6b	0.31	-	0.08	12.22	56.08	7.28	24.25	-	-	-	-	-	100.22	75.47	36.20	1.95
		7a	0.31	0.10	0.09	13.41	51.73	9.76	24.28	-	-	-	-	-	98.67	72.12	47.70	7.10
		7b	0.29	0.11	0.14	13.60	52.65	9.72	24.62	-	-	-	-	-	101.12	72.19	46.90	6.75
		7c	0.29	0.11	0.07	13.68	51.80	9.94	24.23	-	-	-	-	-	100.11	71.74	48.20	7.10

№ of polished section		№ analysis	contents, weight %													parameters		
			SiO2	MnO	TiO2	Al2O3	Cr2O3	MgO	SFeO	V2O5	NiO	CoO	ZnO	CaO	total	Cr#	Mg#	Z Fe3+
		8	0.35	0.19	0.11	13.61	45.52	5.51	34.71	-	-	-	-	-	99.99	69.18	27.60	12.55
		8a	0.29	0.20	0.13	12.88	47.54	6.89	31.78	-	-	-	-	-	99.71	71.23	34.40	11.65
		8b	0.51	0.15	0.11	12.18	47.18	4.10	35.53	-	-	-	-	-	99.76	72.22	21.00	11.45
		9	0.30	0.13	0.07	13.86	49.41	9.10	26.34	-	-	-	-	-	99.20	70.54	44.70	8.65
		9a	0.24	0.20	-	13.75	51.44	11.26	23.47	-	-	-	-	-	100.35	71.51	54.00	8.55
		9b	0.24	0.20	-	14.07	53.11	11.75	21.01	-	-	-	-	-	100.37	71.70	56.10	6.20
877-1[1]	Ustye	6a*	2.17	0.16	-	10.05	55.96	7.47	23.19	0.23	0.21	-	-	-	99.44	78.89	38.60	2.85
		3	0.15	0.15	1.33	17.57	39.54	7.77	33.91	0.46	0.20	-	-	-	101.07	60.14	37.80	15.20
		3a	0.23	0.20	1.33	17.77	38.39	7.65	33.20	0.48	0.17	-	-	-	99.41	59.17	37.80	14.95
		3b	0.14	0.17	1.35	17.98	39.01	7.40	32.94	0.50	0.19	-	-	-	99.68	59.26	36.50	13.85
		7a	1.95	0.15	0.15	11.03	53.23	5.53	27.78	0.27	0.09	-	-	-	100.17	76.39	28.60	4.55
		7b*	1.80	0.14	0.19	10.91	52.11	5.42	29.57	0.32	0.18	-	-	-	100.61	76.22	27.90	6.65
		8b	0.66	0.11	0.08	14.12	53.02	8.62	23.38	0.08	-	-	-	-	100.07	71.58	42.40	3.45
		11a	0.22	0.09	0.08	12.46	51.98	11.49	22.58	-	-	-	-	-	98.90	73.67	56.00	8.85
		2	0.16	0.13	0.08	11.73	55.99	6.00	26.53	0.25	0.12	-	-	-	100.98	76.19	30.10	2.35
		2a	0.10	0.12	0.11	11.10	55.75	9.62	23.36	0.24	0.12	-	-	-	100.52	77.12	47.30	5.80
		2c*	0.15	0.13	0.20	10.84	56.35	9.33	23.48	0.27	0.13	-	-	-	100.87	77.71	45.90	5.35
		4	0.10	0.17	0.34	13.14	49.60	9.29	25.93	0.27	0.14	-	-	-	98.97	71.69	46.00	9.05
		4a	0.12	0.24	0.32	14.33	49.35	9.19	26.97	0.30	0.13	-	-	-	100.93	69.78	44.60	9.00
		4b	0.16	0.12	0.32	13.49	49.20	9.42	26.37	0.28	0.14	-	-	-	99.49	70.98	46.30	9.55
		12	0.18	0.13	0.12	15.35	49.19	9.91	25.02	0.11	-	-	-	-	100.01	68.24	47.80	7.80
		12a	0.19	0.13	0.13	14.54	49.60	9.97	25.17	0.07	-	-	-	-	99.78	69.60	48.30	8.40
		12b	0.16	0.15	0.12	14.65	47.58	9.15	26.98	0.10	-	-	-	-	98.87	68.53	44.90	9.60
		9	0.17	0.10	0.25	16.50	41.00	8.12	33.32	0.17	-	-	-	-	99.64	62.51	39.50	15.30
		9b*	0.18	0.11	0.24	16.05	40.70	8.29	33.25	0.12	-	-	-	-	98.94	62.98	40.60	16.00
		1	0.12	-	0.09	14.38	54.02	12.30	19.49	0.20	0.11	-	-	-	100.70	71.60	58.30	5.10
		1a	0.13	-	0.13	14.53	53.33	12.15	19.27	0.20	0.13	-	-	-	99.86	71.14	58.10	4.90
		1b	0.14	-	0.09	14.75	52.65	12.31	18.96	0.21	0.10	-	-	-	99.20	70.56	59.10	5.05

№ of polished section		№ analysis	contents, weight %													parameters		
			SiO2	MnO	TiO2	Al2O3	Cr2O3	MgO	SFeO	V2O5	NiO	CoO	ZnO	CaO	total	Cr#	Mg#	Z Fe3+
		16	0.34	0.10	0.09	11.88	52.93	7.21	26.73	0.08	-	-	-	-	99.35	74.93	36.30	5.80
		16a	0.30	0.13	0.07	11.46	52.24	8.04	26.31	0.09	-	-	-	-	98.63	75.36	40.50	7.40
		5	0.30	0.12	0.07	10.48	53.42	8.60	25.77	0.23	0.14	-	-	-	99.13	77.35	43.20	7.95
		5a	0.31	0.12	0.07	9.51	55.47	7.47	26.16	0.21	0.13	-	-	-	99.44	79.64	37.90	6.20
		5b*	0.59	-	0.09	9.12	55.93	7.15	26.16	0.26	0.09	-	-	-	99.39	80.42	36.50	5.75
		10b	0.27	0.15	0.10	10.24	52.76	8.96	25.44	0.11	0.18	-	-	-	98.21	77.58	45.30	8.75
		15b	0.25	0.14	0.19	13.15	46.69	5.94	33.64	0.08	-	-	-	-	100.08	70.44	29.70	12.05
Gr-879[1]	Ustye	1	-	0.11	0.11	14.95	52.68	12.58	19.28	-	-	-	-	-	99.69	70.29	59.80	5.55
		2	-	0.09	0.09	15.37	52.25	12.50	19.12	-	-	-	-	-	99.42	69.51	59.40	5.20
		3	-	0.10	0.11	17.62	49.47	11.39	20.21	-	-	-	-	-	98.89	65.34	54.30	4.20
		4	-	0.10	0.10	17.38	51.24	12.52	19.77	-	-	-	-	-	101.10	66.42	58.20	4.90
		5	-	0.12	0.07	13.12	53.63	11.19	20.83	-	-	-	-	-	98.96	73.29	54.40	5.65
		6	-	0.11	0.08	13.77	54.26	10.91	21.78	-	-	-	-	-	100.91	72.56	52.10	5.25
		8	-	0.10	0.08	13.79	52.62	11.56	21.30	-	-	-	-	-	99.46	71.90	55.70	6.60
835[2]	Ustye	12300	-	0.17	0.16	12.20	57.14	8.36	21.67	-	-	-	-	0.20	99.90	75.84	41.50	0.90
		12300a	-	-	0.20	11.59	58.41	7.23	22.40	-	-	-	-	0.11	99.94	77.55	36.20	0.00
		12300b	-	0.32	0.36	12.22	54.84	8.09	23.75	-	-	-	-	0.32	99.90	75.05	40.30	3.40
		12300c	-	-	-	10.11	58.94	6.99	23.57	-	-	-	-	0.28	99.89	79.65	35.30	1.00
		12300e	-	-	0.22	9.21	58.42	7.96	23.80	-	-	-	-	0.29	99.90	81.12	40.10	3.65
		12301w	-	-	0.02	10.02	59.88	10.32	19.59	-	-	-	-	0.06	99.89	80.02	50.80	2.40
		12301x	-	-	0.12	10.31	59.35	11.13	18.92	-	-	-	-	0.10	99.93	79.45	54.40	3.15
		12301y	-	-	0.22	9.82	60.09	10.34	19.30	-	-	-	-	0.16	99.93	80.41	51.00	2.20
		12301	-	0.04	0.29	11.67	55.84	8.00	23.80	-	-	-	-	0.29	99.93	76.24	39.90	3.20
		12301a	-	-	0.38	11.11	56.17	8.31	23.84	-	-	-	-	0.08	99.89	77.24	41.40	4.00
		12301b	-	-	0.28	11.46	56.00	8.77	23.40	-	-	-	-	-	99.91	76.63	43.40	4.15
		12300u	-	-	0.44	5.46	54.94	1.53	37.37	-	-	-	-	0.16	99.90	87.12	8.20	10.30
		12300v	-	-	0.20	12.13	56.24	8.84	22.12	-	-	-	-	0.39	99.92	75.68	43.70	2.55
		12300w	-	-	0.07	11.84	55.89	10.03	21.94	-	-	-	-	0.19	99.96	76.00	49.10	4.60

№ of polished section		№ analysis	contents, weight %													parameters		
			SiO2	MnO	TiO2	Al2O3	Cr2O3	MgO	SFeO	V2O5	NiO	CoO	ZnO	CaO	total	Cr#	Mg#	Z Fe3+
		12301t	-	-	0.49	19.15	46.55	7.25	26.18	-	-	-	-	0.36	99.98	62.00	35.20	3.25
		12301u	-	-	0.41	19.76	46.88	7.47	25.43	-	-	-	-	-	99.95	61.42	36.00	2.40
		12301v	-	-	0.43	16.67	46.79	5.31	30.39	-	-	-	-	0.36	99.95	65.33	26.40	5.55
		12301k	-	-	0.10	12.98	54.37	9.78	22.40	-	-	-	-	0.27	99.90	73.76	47.80	4.55
		12301l	-	-	0.27	12.77	54.05	8.94	23.53	-	-	-	-	0.35	99.91	73.97	44.00	4.55
		12301m	-	-	-	12.98	54.04	9.75	23.14	-	-	-	-	-	99.91	73.65	47.40	5.30
		12300f	-	-	0.22	11.62	56.85	9.14	21.76	-	-	-	-	0.38	99.97	76.66	45.20	2.75
		12300h	0.08	0.08	0.11	11.98	55.63	8.48	23.47	-	-	-	-	0.19	100.02	75.69	42.00	3.55
		12300i	-	-	0.49	10.78	56.77	4.43	27.11	-	-	-	-	0.33	99.91	77.93	22.80	0.55
		12300j	-	-	0.28	10.47	57.34	3.93	27.50	-	-	-	-	0.38	99.90	78.60	20.30	0.00
		12300k	-	-	0.03	10.99	56.14	5.65	27.02	-	-	-	-	0.10	99.93	77.40	28.60	2.65
		12300l	-	-	0.41	11.85	58.82	11.26	17.47	-	-	-	-	0.11	99.92	76.91	54.80	1.25
		12300m	-	0.01	0.41	11.67	60.04	8.91	18.68	-	-	-	-	0.13	99.85	79.00	37.23	0.00
		12300n	-	-	0.27	11.86	60.15	9.73	17.53	-	-	-	-	0.34	99.88	76.90	48.00	0.00
		12300o	0.08	-	0.34	12.08	56.59	10.59	20.04	-	-	-	-	0.29	100.01	75.85	51.70	3.35
		12300p	-	0.08	0.16	12.44	56.72	11.01	19.41	-	-	-	-	0.23	100.05	75.37	53.40	3.15
		12300q	-	-	0.01	12.48	60.23	8.22	19.00	-	-	-	-	-	99.94	78.95	40.60	0.00
		12301e	-	-	0.58	13.28	54.70	8.76	22.37	-	-	-	-	0.22	99.91	73.42	43.20	2.55
		12301f	-	-	0.36	14.81	52.26	10.51	21.99	-	-	-	-	0.01	99.94	70.30	50.60	5.05
		12301g	-	-	0.28	14.02	54.52	8.87	22.16	-	-	-	-	0.07	99.92	72.30	43.40	2.10
		12301n	-	-	0.22	12.75	58.55	7.68	20.46	-	-	-	-	0.28	99.94	74.90	38.20	0.00
		12301o	-	-	0.23	12.13	58.65	6.37	22.35	-	-	-	-	0.24	99.97	75.85	32.10	0.00
		12301p	-	-	0.52	12.32	57.47	9.84	19.64	-	-	-	-	0.16	99.95	75.80	48.30	1.20
		12301q	-	-	0.22	12.62	54.53	7.82	24.60	-	-	-	-	0.12	99.91	74.34	38.80	3.60
		12301r	-	-	0.11	11.49	54.04	6.23	27.73	-	-	-	-	0.34	99.94	75.92	31.40	4.90
		12301s	-	-	0.11	12.68	54.19	8.59	24.07	-	-	-	-	0.28	99.92	74.15	42.30	4.45
		12301h	-	-	0.33	13.35	56.14	10.86	19.24	-	-	-	-	0.03	99.95	73.82	52.60	2.40
		12301i	-	-	0.29	13.81	54.82	9.76	20.93	-	-	-	-	0.29	99.90	72.68	47.60	2.45

№ of polished section		№ analysis	contents, weight %													parameters		
			SiO2	MnO	TiO2	Al2O3	Cr2O3	MgO	SFeO	V2O5	NiO	CoO	ZnO	CaO	total	Cr#	Mg#	Z Fe3+
		12301j	-	-	0.07	12.70	55.56	10.51	20.96	-	-	-	-	0.13	99.93	74.57	51.00	4.05
306/ k681[2]	Kuysak	12304c	-	-	0.18	13.47	54.07	7.93	24.00	-	-	-	-	0.27	99.92	72.93	39.20	2.85
		12304d	-	0.04	0.21	13.90	54.76	7.35	23.47	-	-	-	-	0.17	99.90	72.57	36.40	0.85
		12304v	-	-	0.42	9.69	62.01	7.44	20.13	-	-	-	-	0.21	99.90	80.60	37.70	0.00
		12304w	-	0.03	0.36	10.62	61.23	7.48	19.95	-	-	-	-	0.24	99.91	78.85	37.70	0.00
		12304x	-	0.07	0.51	9.55	61.89	6.99	20.58	-	-	-	-	0.34	99.93	80.80	35.60	0.00
		12304e	-	-	0.27	13.89	54.62	7.35	23.40	-	-	-	-	0.33	99.86	72.52	36.50	0.85
		12304f	-	0.02	0.11	9.83	60.95	6.23	22.65	-	-	-	-	0.18	99.97	80.25	31.70	0.00
		12304g	-	-	-	8.43	62.42	5.43	23.52	-	-	-	-	0.10	99.90	82.90	27.90	0.00
		12304h	-	-	0.35	9.22	61.37	6.30	22.31	-	-	-	-	0.37	99.92	81.35	32.20	0.00
		12304j	-	-	0.37	12.02	55.30	6.10	25.90	-	-	-	-	0.24	99.93	75.55	30.80	2.05
		12304k	-	-	0.41	10.54	57.13	4.86	26.55	-	-	-	-	0.30	99.79	78.44	25.00	0.75
		12304l	-	-	-	12.95	54.37	7.13	25.21	-	-	-	-	0.19	99.85	73.80	35.40	2.90
		12304o	-	0.38	1.84	18.23	39.07	5.98	33.88	-	-	-	-	0.58	99.96	58.98	29.80	12.35
		12304p	-	-	1.30	17.78	40.21	5.97	34.55	-	-	-	-	0.14	99.95	60.27	29.50	12.60
		12304q	-	0.03	1.49	18.53	39.31	6.67	33.68	-	-	-	-	0.24	99.95	58.72	32.80	12.80
		12304r	-	0.06	0.62	13.43	53.09	8.30	24.15	-	-	-	-	0.28	99.93	72.63	41.10	4.05
		12304s	-	0.15	0.52	13.99	53.13	7.54	24.63	-	-	-	-	0.02	99.98	71.80	37.30	2.85
		12304t	-	0.20	0.68	15.35	51.39	9.50	22.54	-	-	-	-	0.29	99.95	69.18	46.30	4.00
		12304x	-	0.02	0.38	13.59	54.80	7.43	23.67	-	-	-	-	-	99.89	73.00	36.80	1.35
		12304y	-	0.10	0.18	13.85	54.18	7.67	23.74	-	-	-	-	0.20	99.92	72.43	37.90	1.90
		12304z	-	-	0.22	13.90	54.21	7.94	23.55	-	-	-	-	0.09	99.91	72.36	39.10	2.10
G3-sh[2]	Kuysak	139	0.64	0.15	-	12.49	54.13	10.68	21.82	-	-	-	-	-	99.91	74.39	52.10	5.90
		139a	0.84	0.23	-	12.55	53.69	11.09	21.51	-	-	-	-	-	99.91	74.15	54.10	6.45
		139b	0.52	0.25	-	12.06	55.08	10.14	21.88	-	-	-	-	-	99.93	75.38	49.70	4.95
		139o	0.92	0.11	-	17.92	52.86	9.39	18.71	-	-	-	-	-	99.91	65.75	45.40	0.00
		139p	1.33	0.18	-	18.52	51.72	9.58	18.59	-	-	-	-	-	99.92	64.60	46.30	0.00
		139q	1.12	0.50	-	18.04	51.69	9.22	19.32	-	-	-	-	-	99.89	65.35	44.80	0.00

№ of polished section		№ analysis	contents, weight %													parameters		
			SiO2	MnO	TiO2	Al2O3	Cr2O3	MgO	SFeO	V2O5	NiO	CoO	ZnO	CaO	total	Cr#	Mg#	Z Fe3+
		1310a	0.65	0.55	-	10.01	57.00	6.47	25.22	-	-	-	-	-	99.90	79.25	33.00	2.65
		1310b	1.49	0.42	-	9.96	57.56	5.98	24.50	-	-	-	-	-	99.91	79.52	30.90	0.90
		1310c	0.74	0.29	-	9.44	57.69	6.34	25.39	-	-	-	-	-	99.89	80.38	32.40	2.65
		139y	0.85	0.13	-	9.50	58.23	9.23	21.97	-	-	-	-	-	99.91	80.43	46.20	3.95
		139z	0.92	0.30	-	9.58	57.97	7.68	23.47	-	-	-	-	-	99.92	80.24	38.90	2.85
		139r	0.80	0.39	-	12.85	52.58	10.90	22.44	-	-	-	-	-	99.96	73.32	53.10	7.25
		139s	1.02	0.39	-	12.92	52.34	10.24	23.02	-	-	-	-	-	99.93	73.11	50.30	6.80
		139t	1.09	0.11	-	13.35	53.19	10.19	22.02	-	-	-	-	-	99.95	72.78	49.90	5.15
		1310d	0.98	0.06	-	12.06	54.97	8.96	22.89	-	-	-	-	-	99.92	75.35	44.40	4.05
		1310e	0.92	0.62	-	12.61	53.89	9.30	22.59	-	-	-	-	-	99.93	74.15	46.10	4.45
		1310f	1.17	0.27	-	13.01	53.17	10.52	21.77	-	-	-	-	-	99.91	73.28	51.60	5.70
		139i	0.91	0.37	-	12.04	58.37	10.73	17.51	-	-	-	-	-	99.93	76.48	52.70	0.50
		139j	0.56	0.30	-	11.38	60.04	8.84	18.81	-	-	-	-	-	99.93	77.60	44.00	0.00
		139k	0.60	0.11	-	12.49	57.63	9.35	19.75	-	-	-	-	-	99.93	75.56	46.10	0.35
		1310o	1.07	0.48	-	13.92	51.58	8.91	23.99	-	-	-	-	-	99.95	71.29	44.00	5.25
		1310p	0.79	0.32	-	13.90	51.81	8.64	24.44	-	-	-	-	-	99.90	71.43	42.60	5.15
		1310q	1.03	0.30	-	13.74	51.98	9.10	23.78	-	-	-	-	-	99.93	71.75	44.80	5.30
		139u	0.76	0.43	-	12.26	57.64	8.48	20.40	-	-	-	-	-	99.97	75.85	42.30	0.00
		139v	0.92	0.56	-	11.40	58.24	8.66	20.16	-	-	-	-	-	99.94	77.40	43.40	0.05
		139w	2.01	0.50	-	12.00	56.96	8.60	19.88	-	-	-	-	-	99.95	76.05	43.40	0.00

Notes: ΣFeO – FeO+Fe2O3. Blank – a component isn't found. Key calculated parameters: Cr#=100Cr/(Cr+Al), Mg#=100Mg/(Mg+Fe2+), Z Fe3+ – a part of trivalent iron in R3+, %.
In the column with analysis number: 1 Analyses are made on the microprobe analyzer JEOL JCXA-733 (Institute of Mineralogy, Miass, analyst E.I. Churin). 2 Analyses are made on the raster electronic microscope REMMA-202MV (Institute of Mineralogy, Miass, analyst V.A. Kotlyarov).

Tab. 5-41. Chemical compositions of chromites in slag.

Site	Contents, weight %						Parameters			N
	MnO	TiO2	Al2O3	Cr2O3	MgO	ΣFeO	Cr#	Mg#	Z Fe3+	
Ishkinino	0.32-0.48	0.25-0.35	12,13-17-86	44.85-54.33	7.99-12.07	20.40-32.68	62.98-74.91	38.90-57.00	4.80-14.00	28
	(0.41)	(0.30)	(14.64)	(50.42)	(9.49)	(24.71)	(69.79)	(46.03)	(7.05)	
Vorovskaya Yama	0.00-3.24	-	11.93-44.31	23.94-53.01	1.14-20.79	9.47-37.51	26.68-70.95	6.30-84.40	0.00-10.85	37
	(1.18)	-	(19.91)	(48.20)	(9.93)	(19.15)	(62.00)	(47.15)	(0.78)	
Sintashta	0.00-0.78	0.00-1.06	5.78-15.63	39.10-57.41	2.77-9.33	23.25-45.82	66.76-83.54	14.80-45.20	2.75-12.15	19
	(0.24)	(0.20)	(11.15)	(51.94)	(7.61)	(29.49)	(75.69)	(37.68)	(9.68)	
Arkaim	0.00-0.98	0.00-0.47	10.15-17.04	45.64-56.75	4.14-12.08	20.48-35.29	63.90-78.51	21.00-57.60	2.15-10.10	22
	(0.17)	(0.06)	(13.27)	(51.94)	(8.41)	(25.86)	(72.41)	(41.20)	(6.37)	
Alandskoye	0.00-0.99	0.00-0.43	11.52-14.09	50.91-54.45	9.65-13.20	20.06-26.62	71.55-75.80	46.60-62.10	5.65-9.35	12
	(0.33)	(0.15)	(12.96)	(53.08)	(11.80)	(21.82)	(73.33)	(56.66)	(7.76)	
Kuysak	0.00-0.62	0.00-1.84	8.43-18.53	39.07-62.42	2.19-13.52	16.69-34.55	58.72-82.90	11.50-64.10	0.05-12.80	79
	(0.18)	(0.28)	(12.80)	(54.55)	(8.35)	(23.02)	(73.98)	(41.36)	(3.18)	
Rodniki	0.00-0.32	0.00-0.58	5.46-19.76	46.55-60.23	1.53-11.26	17.47-37.37	61.42-87.12	8.20-54.80	0.55-10.30	43
	(0.02)	(0.24)	(12.22)	(56.03)	(8.36)	(22.85)	(75.58)	(41.10)	(2.75)	
Ustye	0.00-0.24	0.00-1.33	8.45-27.86	38.39-59.50	4.10-14.37	15.24-35.53	48.92-82.35	21.00-63.20	0.05-16.00	121
	(0.10)	(0.13)	(13.57)	(51.86)	(8.75)	(25.75)	(71.72)	(42.78)	(6.99)	

Notes: ΣFeO – $FeO+Fe_2O_3$. 0.00 – below a detection limit. In brackets average values are shown. N – number of analyses. Calculated parameters: Cr#=100Cr/(Cr+Al), Mg#=100Mg/(Mg+Fe^{2+}), Z Fe^{3+} - a part of trivalent iron in R^{3+}, %.
Analyses are made on the microprobe analyzer JEOL JCXA-733 (Institute of Mineralogy, Miass, analyst E.I. Churin) and the raster electronic microscope REMMA-202MV (Institute of Mineralogy, Miass, analyst V.A. Kotlyarov).

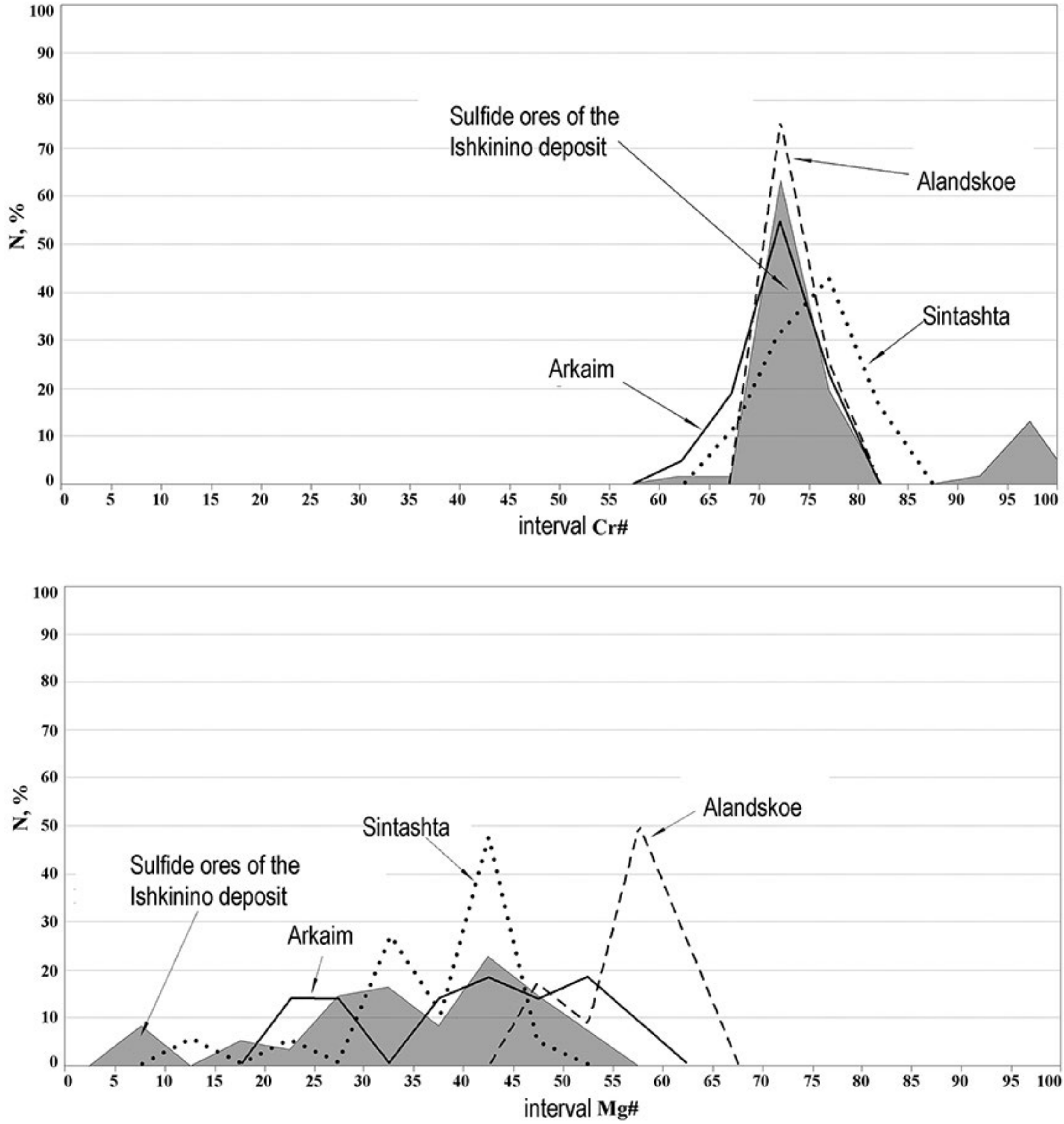


FIG. 5-42. DIAGRAMS OF DISTRIBUTION CR# AND MG# IN THE CHROMITES FROM THE SETTLEMENTS OF SINTASHTA (19 ANALYSES), ARKAIM (22 ANALYSES), ALANDSKOE (12 ANALYSES) AND SULFIDE ORES FROM THE ISHKININO DEPOSIT (62 ANALYSES). N – OCCURRENCE FREQUENCY (AFTER GRIGORIEV ET AL. 2005).

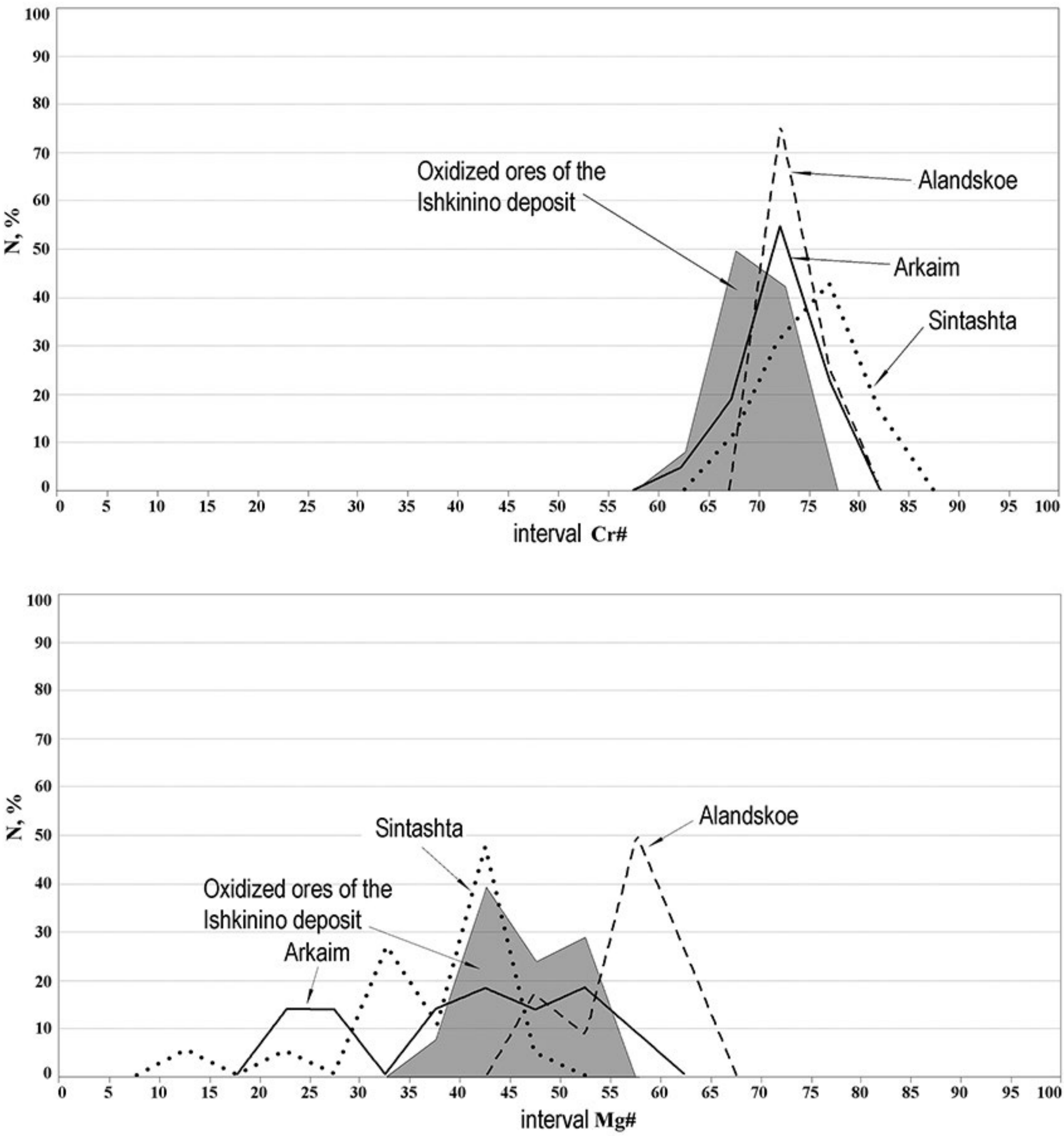


FIG. 5-43. DIAGRAMS OF DISTRIBUTION CR# AND MG# IN THE CHROMITES FROM THE SETTLEMENTS OF SINTASHTA (19 ANALYSES), ARKAIM (22 ANALYSES), ALANDSKOE (12 ANALYSES) AND OXIDIZED ORES FROM THE ISHKININO DEPOSIT (39 ANALYSES). N – OCCURRENCE FREQUENCY (AFTER GRIGORIEV ET AL. 2005).

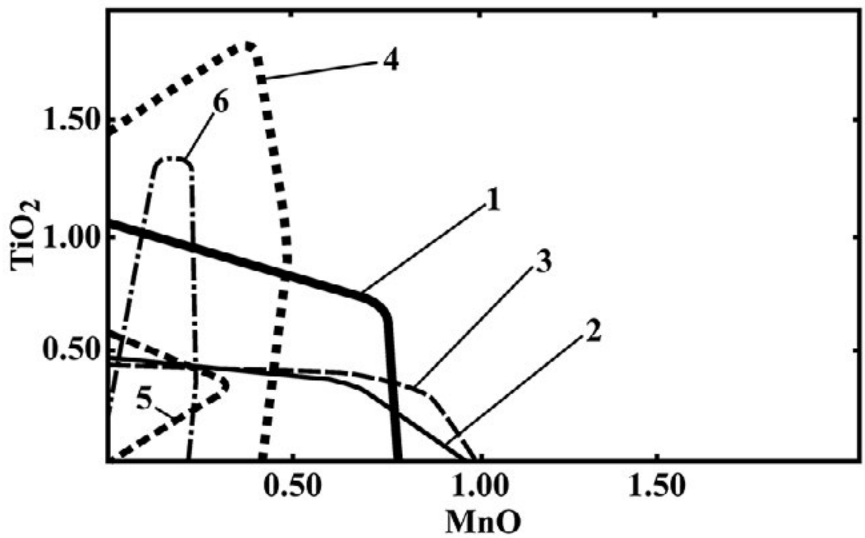


Fig. 5-44. Ratio of MnO to TiO2 (weight %) in the chromites of slag from settlements. Fields of compositions of chromites in slag: 1 – Sintashta, 2 – Arkaim, 3 – Alandskoe, 4 – Kuysak, 5 – Rodniki, 6 – Ustye (after Dunaev et al. 2006).

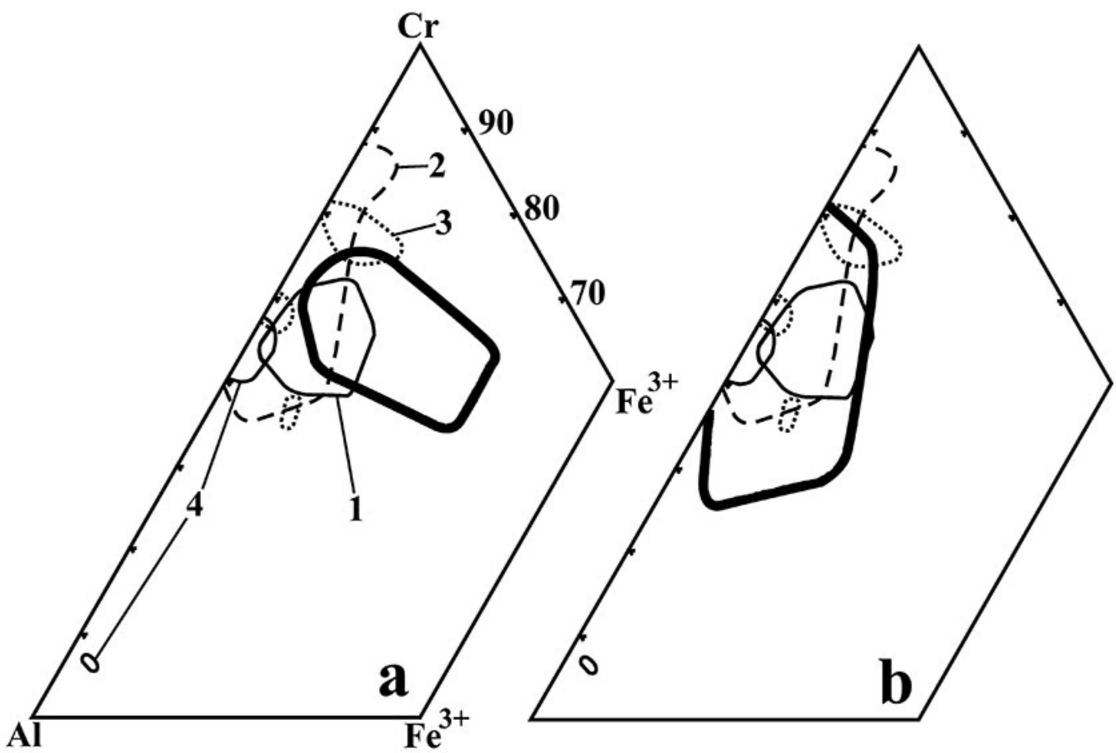


Fig. 5-45. Compositions of chromites (%) in slag from settlements in coordinates Al–Cr–Fe3+ (bold line: a – Sintashta, b – Ustye). Fields of compositions of chromites in ores from the deposits of: 1 – Ishkinino, 2 – Ivanovka, 3 – Dergamysh, 4 – Vorovskaya Yama (after Dunaev et al. 2006).

Tab. 5-46. Chemical analyses of ores extracted in the antiquity from the Ishkinino mine (Zaykov et al. 2005a).

Type of ore	Contents %									
	Assay analysis					XRF analyses				
	Cu	Zn	S	Au	Ag	Fe	As	Cr	Pb	Ni
Azurite-malachite (store № 1)	7.95	0.03	0.06	–	–	14.17	1.01	1.95	–	0.06
Oxidized ore (store № 2)	2.57	0.05	0.09	–	–	16.77	0.58	1.20	0.21	0.20
Iron oxide	0.46	0.07	0.06	–	–	57.59	0.60	2.30	0.21	0.18

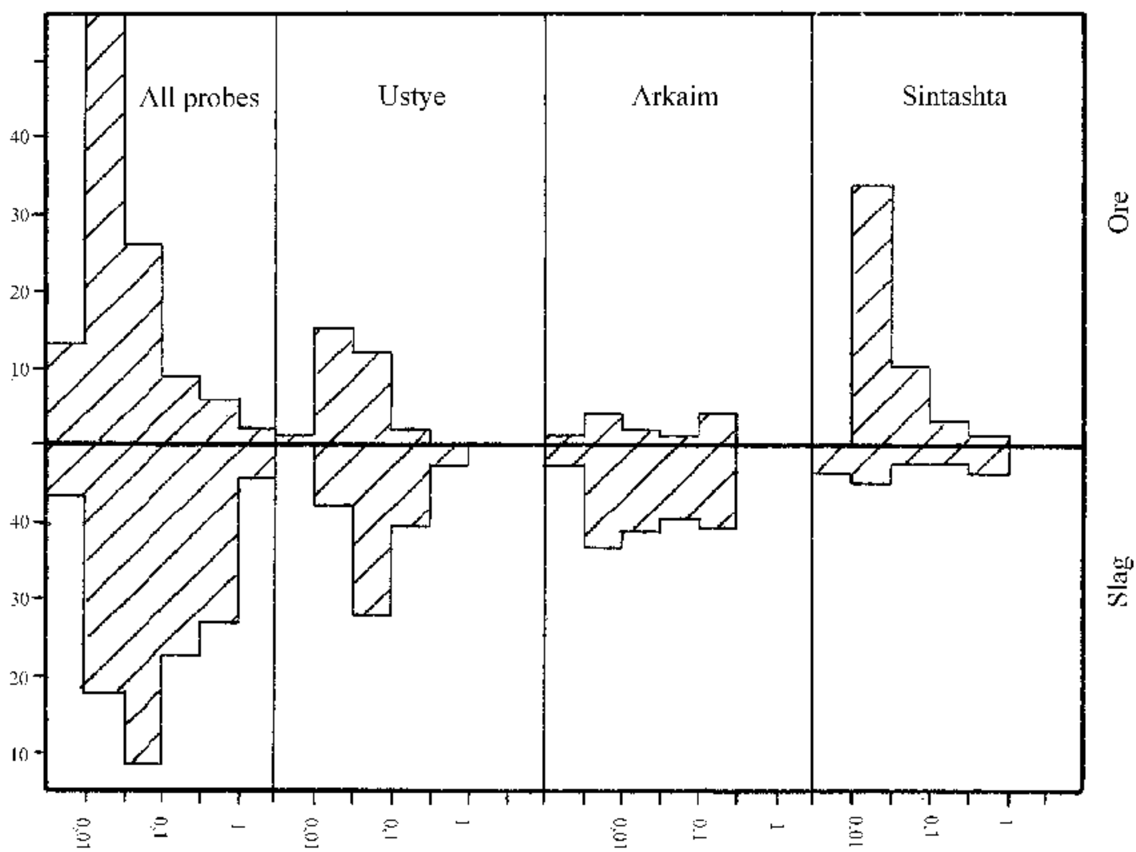


FIG. 5-47. DIAGRAM OF DISTRIBUTION OF ARSENIC (%) IN ORE AND SLAG OF THE SINTASHTA SETTLEMENTS IN THE TRANSURALS.

Tab. 5-48. XRF analyses of metal objects (%) of the Sintashta-Abashevo time (Institute of Archaeometallurgy, Technical University of Freiberg).

Lab.-Nr.	Site	Type	FE	CO	NI	CU	ZN	AS	SE
FG-001808	Bolshekaraganskiy	adz	0.25	< 0.005	0.34	95.7	< 0.01	3.4	0.009
FG-001809	Bolshekaraganskiy	adz	0.29	< 0.005	0.3	96.5	< 0.01	2.81	0.038
FG-001810	Bolshekaraganskiy	adz	0.14	< 0.005	0.4	94.5	< 0.01	4.9	< 0.005
FG-001857	Bolshekaraganskiy	adz	0.12	0.016	0.39	95.2	< 0.1	4.1	0.018
FG-001858	Bolshekaraganskiy	adz	0.24	0.041	0.228	97.2	< 0.01	2.17	0.034
FG-001882	Kamenniy Ambar	adz	0.32	0.037	0.34	96.3	< 0.01	2.27	0.01
FG-001883	Kamenniy Ambar	adz	0.08	0.012	0.221	96.9	< 0.01	2.65	0.005
FG-001884	Kamenniy Ambar	adz	0.59	0.014	0.03	98.9	< 0.01	0.34	0.063
FG-001886	Kamenniy Ambar	adz	0.16	0.007	0.1	98.5	< 0.01	1.14	0.007
FG-001892	Kamenniy Ambar	adz	0.16	0.005	0.104	99.1	< 0.1	0.43	0.033
FG-001832	Arkaim	awl	0.05	< 0.005	0.14	93.8	< 0.01	3.6	0.012
FG-001864	Arkaim	awl	0.09	< 0.005	< 0.010	93.7	< 0.1	0.099	0.017
FG-001845	Bolshekaraganskiy	awl	0.22	0.007	0.168	96.9	< 0.1	2.26	0.013
FG-001846	Bolshekaraganskiy	awl	0.08	0.018	0.35	98.6	< 0.1	0.66	0.015
FG-001856	Bolshekaraganskiy	awl	0.25	0.029	0.281	96.5	< 0.1	2.67	0.011
FG-001889	Kamenniy Ambar	awl	0.28	< 0.005	0.232	97.4	< 0.1	2.01	0.036
FG-001834	Sintashta	awl	1.9	< 0.005	< 0.010	97.5	< 0.01	0.063	< 0.005
FG-001836	Sintashta	awl	0.66	< 0.005	< 0.010	98.9	< 0.01	0.164	< 0.005
FG-001852	Sintashta	awl	3.1	0.44	0.83	94.7	< 0.01	0.85	< 0.005
FG-001854	Sintashta	awl	1.37	0.187	0.45	91.9	< 0.01	6	< 0.005
FG-001829	Bolshekaraganskiy	bracelet	4.3	< 0.005	0.054	40.7	< 0.01	1.11	0.089
FG-001853	Sintashta	bracelet	0.42	0.044	0.145	98.6	< 0.01	0.67	< 0.005
FG-001804	Bolshekaraganskiy	chisel	0.28	0.005	0.064	98.8	< 0.01	0.74	< 0.005
FG-001838	Bolshekaraganskiy	chisel	0.19	0.005	0.23	95.9	< 0.1	2.9	0.01
FG-001841	Bolshekaraganskiy	chisel	0.23	0.013	0.023	99.3	< 0.01	0.214	0.045
FG-001843	Bolshekaraganskiy	chisel	0.47	0.015	0.077	98.7	< 0.01	0.51	0.023
FG-001890	Kamenniy Ambar	chisel	0.19	0.011	0.49	95.6	< 0.01	3.6	0.039
FG-001912	Tyubyak	chisel	< 0.05	< 0.005	0.022	99.8	< 0.01	0.005	< 0.005
FG-001842	Bolshekaraganskiy	clip	0.67	< 0.005	< 0.010	98.7	< 0.01	0.42	0.029

Lab.-Nr.	Site	Type	FE	CO	NI	CU	ZN	AS	SE
FG-001872	Kamenniy Ambar	clip	0.76	0.072	0.213	98.3	< 0.01	0.114	0.128
FG-001877	Kamenniy Ambar	clip	1.75	0.24	0.47	97.3	< 0.01	0.082	0.026
FG-001835	Sintashta	clip	1.58	0.005	0.017	97.6	< 0.01	0.72	< 0.005
FG-001831	Arkaim	drift	0.19	< 0.005	0.052	99	< 0.01	0.59	0.031
FG-001896	Birsk	drift	0.12	< 0.005	0.014	98.9	< 0.01	0.82	0.008
FG-001840	Bolshekaraganskiy	drift	0.33	< 0.005	1.13	97.4	< 0.1	1.01	0.034
FG-001855	Bolshekaraganskiy	drift	0.56	0.056	0.222	96.9	< 0.01	2.2	< 0.005
FG-001876	Kamenniy Ambar	drift	0.46	0.05	0.153	98.6	< 0.01	0.56	0.025
FG-001837	Sintashta	drift	0.32	0.016	0.118	94.5	< 0.01	4.9	0.005
FG-001851	Sintashta	drift	< 0.05	0.017	0.054	97.9	< 0.01	0.108	< 0.005
FG-001904	Tyubyak	drift	0.43	< 0.005	0.082	91.7	< 0.01	0.081	< 0.005
FG-001908	Tyubyak	drift	0.11	< 0.005	0.054	99.7	< 0.01	0.011	0.005
FG-001913	Yumakovo I	drift	0.06	< 0.005	< 0.010	99.6	< 0.01	0.148	0.013
FG-001828	Bolshekaraganskiy	facing of vessel	0.19	< 0.005	0.063	98.5	< 0.01	0.81	0.007
FG-001862	Arkaim	fishing hook	0.22	0.034	0.143	98.7	< 0.01	0.202	0.01
FG-001806	Bolshekaraganskiy	harpoon	0.13	0.007	0.112	97.7	< 0.1	1.94	0.019
FG-001893	Shibaevo	hook	0.42	< 0.005	0.028	98.9	< 0.1	0.32	0.041
FG-001909	Tyubyak	hook	0.1	0.006	< 0.010	99.6	< 0.01	0.005	< 0.005
FG-001894	Birsk	ingot	0.07	< 0.005	< 0.010	99.6	< 0.01	0.193	0.007
FG-001830	Bolshekaraganskiy	ingot	2.11	0.013	< 0.010	97.6	< 0.01	0.005	0.235
FG-001839	Bolshekaraganskiy	ingot	0.16	0.012	1.16	98.1	< 0.1	0.36	0.063
FG-001879	Kamenniy Ambar	ingot	0.94	0.103	0.118	98.6	< 0.01	0.016	0.056
FG-001868	Solntse	ingot	0.71	0.084	0.175	98.6	< 0.01	0.296	< 0.005
FG-001871	Solntse	ingot	3.7	0.58	0.88	94.3	< 0.01	0.39	0.019
FG-001895	Birsk	knife	< 0.05	< 0.005	0.042	96.8	< 0.1	0.14	< 0.005
FG-001897	Birsk	knife	0.11	< 0.005	< 0.010	97.2	< 0.1	2.49	0.012
FG-001898	Birsk	knife	< 0.05	< 0.005	< 0.010	99.8	< 0.1	0.015	0.013
FG-001807	Bolshekaraganskiy	knife	0.26	0.005	0.286	96	< 0.1	3.2	0.009
FG-001811	Bolshekaraganskiy	knife	0.15	< 0.005	0.204	94.1	< 0.1	5.4	0.013

Lab.-Nr.	Site	Type	FE	CO	NI	CU	ZN	AS	SE
FG-001812	Bolshekaraganskiy	knife	0.12	< 0.005	0.223	97.1	< 0.01	2.12	< 0.005
FG-001813	Bolshekaraganskiy	knife	0.27	< 0.005	0.3	97.4	< 0.1	1.83	0.016
FG-001814	Bolshekaraganskiy	knife	0.13	< 0.005	0.046	99.1	< 0.01	0.46	0.067
FG-001844	Bolshekaraganskiy	knife	3.8	0.036	0.02	94.7	< 0.01	1.1	0.039
FG-001848	Bolshekaraganskiy	knife	0.12	0.028	0.192	96.8	< 0.1	2.65	0.018
FG-001849	Bolshekaraganskiy	knife	0.26	0.03	0.204	97.8	< 0.1	1.56	0.042
FG-001850	Bolshekaraganskiy	knife	0.3	0.043	0.277	97.4	< 0.1	1.87	0.007
FG-001859	Bolshekaraganskiy	knife	< 0.05	0.006	0.033	99.7	< 0.1	0.096	0.029
FG-001860	Bolshekaraganskiy	knife	0.39	0.056	0.199	98.8	< 0.01	0.46	0.039
FG-001861	Bolshekaraganskiy	knife	0.23	0.04	0.42	96.5	< 0.1	2.6	0.018
FG-001863	Bolshekaraganskiy	knife	0.29	0.028	0.25	97.8	< 0.1	1.31	0.011
FG-001881	Kamenniy Ambar	knife	0.12	0.008	0.274	96.7	< 0.1	2.12	< 0.005
FG-001885	Kamenniy Ambar	knife	0.15	< 0.005	0.07	99.1	< 0.01	0.52	0.035
FG-001887	Kamenniy Ambar	knife	1.25	0.011	0.276	94.8	< 0.1	3.5	0.01
FG-001888	Kamenniy Ambar	knife	0.44	0.015	0.6	97.7	< 0.01	1.08	0.037
FG-001891	Kamenniy Ambar	knife	0.23	< 0.005	0.278	96.7	< 0.1	2.55	0.033
FG-001902	Naberezhniy	knife	0.26	< 0.005	< 0.010	99.1	< 0.01	0.49	< 0.005
FG-001833	Sintashta	knife	0.08	< 0.005	< 0.010	99.8	< 0.01	0.01	0.014
FG-001911	Tyubyak	rod	0.08	< 0.005	< 0.010	99.8	< 0.01	0.009	0.006
FG-001901	Birsk	sickle	0.08	0.006	< 0.010	99.8	< 0.01	0.005	< 0.005
FG-001880	Kamenniy Ambar	sickle	0.19	0.023	0.151	98.8	< 0.1	0.67	0.023
FG-001899	Naberezhniy	sickle	0.26	< 0.005	< 0.010	98.4	< 0.01	1.2	0.006
FG-001900	Naberezhniy	sickle	0.25	0.005	0.021	98.8	< 0.01	0.74	< 0.005
FG-001910	Tyubyak	sickle	1.18	0.017	< 0.010	95.3	< 0.01	3.2	0.008
FG-001906	Yumakovo I	sickle	0.13	< 0.005	0.015	99.2	< 0.01	0.53	0.007
FG-001907	Yumakovo III	sickle	0.5	0.006	0.022	98.6	< 0.01	0.7	0.009
FG-001903	Yumakovo IV	sickle	0.33	< 0.005	< 0.010	99.2	< 0.01	0.33	0.006
FG-001905	Yumakovo IV	sickle	0.13	0.006	< 0.010	99.4	< 0.01	0.15	0.007
FG-001805	Bolshekaraganskiy	spearhead	0.15	0.009	0.197	96.7	< 0.01	2.85	0.012
FG-001867	Kamenniy Ambar	wedge	0.23	< 0.005	0.047	99.3	< 0.1	0.046	0.143

Tab. 5-48. XRF analyses of metal objects (%) of the Sintashta-Abashevo time (Institute of Archaeometallurgy, Technical University of Freiberg)(contd.).

Lab.-Nr.	Site	Type	AU	PB	BI	AG	SN	SB	TE
FG-001808	Bolshekaraganskiy	adz	< 0.01	< 0.01	< 0.005	0.013	< 0.005	0.33	< 0.008
FG-001809	Bolshekaraganskiy	adz	< 0.01	< 0.01	< 0.005	0.023	< 0.005	0.01	< 0.008
FG-001810	Bolshekaraganskiy	adz	< 0.01	< 0.01	< 0.005	0.025	< 0.005	0.02	< 0.008
FG-001857	Bolshekaraganskiy	adz	0.02	< 0.01	< 0.005	0.047	< 0.005	0.022	< 0.008
FG-001858	Bolshekaraganskiy	adz	0.01	< 0.01	< 0.005	0.021	0.006	0.012	< 0.008
FG-001882	Kamenniy Ambar	adz	0.01	< 0.01	< 0.005	0.65	0.015	0.011	< 0.008
FG-001883	Kamenniy Ambar	adz	< 0.01	0.02	< 0.005	0.04	< 0.005	< 0.005	< 0.008
FG-001884	Kamenniy Ambar	adz	< 0.01	< 0.01	< 0.005	0.008	< 0.005	< 0.005	< 0.008
FG-001886	Kamenniy Ambar	adz	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	0.008
FG-001892	Kamenniy Ambar	adz	< 0.01	< 0.01	< 0.005	0.029	< 0.005	< 0.005	< 0.008
FG-001832	Arkaim	awl	< 0.01	< 0.01	< 0.005	0.009	3.7	< 0.005	< 0.008
FG-001864	Arkaim	awl	0.03	0.11	< 0.005	0.027	10.1	0.032	< 0.008
FG-001845	Bolshekaraganskiy	awl	< 0.01	< 0.01	< 0.005	0.071	< 0.005	0.32	0.016
FG-001846	Bolshekaraganskiy	awl	0.02	< 0.01	< 0.005	0.104	< 0.005	0.048	< 0.008
FG-001856	Bolshekaraganskiy	awl	0.01	< 0.01	< 0.005	0.021	< 0.005	0.148	< 0.008
FG-001889	Kamenniy Ambar	awl	< 0.01	< 0.01	< 0.005	< 0.005	0.01	< 0.005	< 0.008
FG-001834	Sintashta	awl	< 0.01	0.36	< 0.005	< 0.005	0.054	0.024	< 0.008
FG-001836	Sintashta	awl	< 0.01	0.14	< 0.005	< 0.005	0.019	0.012	0.009
FG-001852	Sintashta	awl	< 0.01	< 0.01	< 0.005	0.008	< 0.005	0.02	< 0.008
FG-001854	Sintashta	awl	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	0.037	< 0.008
FG-001829	Bolshekaraganskiy	bracelet	< 0.01	0.65	0.128	0.265	51	1.2	0.022
FG-001853	Sintashta	bracelet	< 0.01	0.01	< 0.005	0.005	< 0.005	< 0.005	< 0.008
FG-001804	Bolshekaraganskiy	chisel	< 0.01	< 0.01	< 0.005	0.032	< 0.005	0.011	< 0.008
FG-001838	Bolshekaraganskiy	chisel	0.02	0.02	< 0.005	0.012	0.013	1.04	< 0.008
FG-001841	Bolshekaraganskiy	chisel	0.01	< 0.01	< 0.005	0.043	0.006	< 0.005	< 0.008
FG-001843	Bolshekaraganskiy	chisel	< 0.01	< 0.01	< 0.005	0.072	0.005	< 0.005	< 0.008
FG-001890	Kamenniy Ambar	chisel	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	< 0.008
FG-001912	Tyubyak	chisel	< 0.01	< 0.01	< 0.005	0.068	< 0.005	< 0.005	< 0.008
FG-001842	Bolshekaraganskiy	clip	0.01	0.02	< 0.005	0.046	< 0.005	< 0.005	< 0.008
FG-001872	Kamenniy Ambar	clip	< 0.01	< 0.01	< 0.005	0.292	< 0.005	0.009	< 0.008

Lab.-Nr.	Site	Type	AU	PB	BI	AG	SN	SB	TE
FG-001877	Kamenniy Ambar	clip	0.03	< 0.01	< 0.005	< 0.005	0.008	< 0.005	< 0.008
FG-001835	Sintashta	clip	< 0.01	0.02	< 0.005	< 0.005	0.007	< 0.005	< 0.008
FG-001831	Arkaim	drift	< 0.01	< 0.01	< 0.005	0.014	< 0.005	< 0.005	0.008
FG-001896	Birsk	drift	< 0.01	< 0.01	< 0.005	0.047	< 0.005	0.005	< 0.008
FG-001840	Bolshekaraganskiy	drift	< 0.01	< 0.01	< 0.005	0.006	< 0.005	0.012	< 0.008
FG-001855	Bolshekaraganskiy	drift	< 0.01	< 0.01	< 0.005	0.019	< 0.005	0.016	< 0.008
FG-001876	Kamenniy Ambar	drift	< 0.01	< 0.01	0.007	0.037	< 0.005	0.009	< 0.008
FG-001837	Sintashta	drift	< 0.01	< 0.01	< 0.005	0.023	0.021	0.019	< 0.008
FG-001851	Sintashta	drift	< 0.01	0.7	< 0.005	0.024	0.52	0.058	< 0.008
FG-001904	Tyubyak	drift	< 0.01	0.29	< 0.005	0.054	6.6	0.192	< 0.008
FG-001908	Tyubyak	drift	< 0.01	0.04	< 0.005	0.009	< 0.005	0.006	< 0.008
FG-001913	Yumakovo I	drift	< 0.01	< 0.01	< 0.005	0.05	< 0.005	< 0.005	< 0.008
FG-001828	Bolshekaraganskiy	facing of vessel	< 0.01	0.17	< 0.005	0.14	< 0.005	0.043	< 0.008
FG-001862	Arkaim	fishing hook	< 0.01	0.31	0.007	0.025	< 0.005	0.018	< 0.008
FG-001806	Bolshekaraganskiy	harpoon	< 0.01	< 0.01	0.005	0.036	< 0.005	0.005	< 0.008
FG-001893	Shibaevo	hook	0.01	0.01	< 0.005	0.041	0.01	0.079	< 0.008
FG-001909	Tyubyak	hook	0.02	0.06	0.005	0.01	0.033	0.006	< 0.008
FG-001894	Birsk	ingot	< 0.01	< 0.01	0.012	0.025	< 0.005	< 0.005	< 0.008
FG-001830	Bolshekaraganskiy	ingot	< 0.01	0.01	< 0.005	< 0.005	< 0.005	< 0.005	< 0.008
FG-001839	Bolshekaraganskiy	ingot	< 0.01	< 0.01	< 0.005	0.011	< 0.005	< 0.005	< 0.008
FG-001879	Kamenniy Ambar	ingot	0.01	< 0.01	0.012	0.097	0.014	< 0.005	< 0.008
FG-001868	Solntse	ingot	0.01	< 0.01	< 0.005	0.068	< 0.005	0.018	< 0.008
FG-001871	Solntse	ingot	< 0.01	< 0.01	< 0.005	0.107	< 0.005	< 0.005	< 0.008
FG-001895	Birsk	knife	0.01	0.04	0.008	0.024	3.1	0.124	< 0.008
FG-001897	Birsk	knife	0.02	< 0.01	< 0.005	0.037	< 0.005	< 0.005	< 0.008
FG-001898	Birsk	knife	< 0.01	< 0.01	< 0.005	0.054	0.009	< 0.005	< 0.008
FG-001807	Bolshekaraganskiy	knife	0.02	< 0.01	< 0.005	0.017	< 0.005	0.037	< 0.008
FG-001811	Bolshekaraganskiy	knife	0.02	< 0.01	< 0.005	0.02	< 0.005	0.028	0.008
FG-001812	Bolshekaraganskiy	knife	< 0.01	0.01	< 0.005	0.047	0.012	0.34	< 0.008
FG-001813	Bolshekaraganskiy	knife	0.03	< 0.01	< 0.005	0.029	< 0.005	0.023	< 0.008

Lab.-Nr.	Site	Type	AU	PB	BI	AG	SN	SB	TE
FG-001814	Bolshekaraganskiy	knife	< 0.01	0.02	< 0.005	0.059	< 0.005	< 0.005	< 0.008
FG-001844	Bolshekaraganskiy	knife	0.03	0.02	< 0.005	0.096	0.039	< 0.005	0.031
FG-001848	Bolshekaraganskiy	knife	< 0.01	< 0.01	< 0.005	0.028	< 0.005	0.102	< 0.008
FG-001849	Bolshekaraganskiy	knife	0.01	< 0.01	< 0.005	0.021	< 0.005	0.011	< 0.008
FG-001850	Bolshekaraganskiy	knife	< 0.01	< 0.01	< 0.005	0.022	< 0.005	< 0.005	< 0.008
FG-001859	Bolshekaraganskiy	knife	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	< 0.008
FG-001860	Bolshekaraganskiy	knife	0.01	< 0.01	< 0.005	0.007	< 0.005	0.009	< 0.008
FG-001861	Bolshekaraganskiy	knife	< 0.01	< 0.01	< 0.005	0.023	0.103	0.016	0.008
FG-001863	Bolshekaraganskiy	knife	0.1	< 0.01	< 0.005	0.021	< 0.005	0.018	0.011
FG-001881	Kamenniy Ambar	knife	< 0.01	0.02	< 0.005	0.65	< 0.005	< 0.005	0.015
FG-001885	Kamenniy Ambar	knife	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	0.005	< 0.008
FG-001887	Kamenniy Ambar	knife	< 0.01	< 0.01	< 0.005	0.011	< 0.005	0.005	< 0.008
FG-001888	Kamenniy Ambar	knife	< 0.01	< 0.01	< 0.005	0.016	< 0.005	0.013	< 0.008
FG-001891	Kamenniy Ambar	knife	< 0.01	< 0.01	< 0.005	0.014	0.038	< 0.005	< 0.008
FG-001902	Naberezhniy	knife	< 0.01	< 0.01	< 0.005	0.072	0.005	0.005	< 0.008
FG-001833	Sintashta	knife	< 0.01	< 0.01	< 0.005	0.031	< 0.005	< 0.005	< 0.008
FG-001911	Tyubyak	rod	< 0.01	< 0.01	< 0.005	0.082	< 0.005	< 0.005	< 0.008
FG-001901	Birsk	sickle	< 0.01	< 0.01	< 0.005	0.039	< 0.005	< 0.005	< 0.008
FG-001880	Kamenniy Ambar	sickle	< 0.01	0.02	< 0.005	0.011	0.005	0.009	< 0.008
FG-001899	Naberezhniy	sickle	< 0.01	< 0.01	< 0.005	0.081	0.006	0.006	< 0.008
FG-001900	Naberezhniy	sickle	< 0.01	< 0.01	< 0.005	0.085	< 0.005	< 0.005	< 0.008
FG-001910	Tyubyak	sickle	< 0.01	0.01	< 0.005	0.112	< 0.005	< 0.005	< 0.008
FG-001906	Yumakovo I	sickle	< 0.01	< 0.01	< 0.005	0.086	< 0.005	< 0.005	< 0.008
FG-001907	Yumakovo III	sickle	< 0.01	< 0.01	< 0.005	0.074	< 0.005	< 0.005	< 0.008
FG-001903	Yumakovo IV	sickle	< 0.01	< 0.01	< 0.005	0.072	0.008	< 0.005	< 0.008
FG-001905	Yumakovo IV	sickle	< 0.01	< 0.01	< 0.005	0.225	< 0.005	< 0.005	< 0.008
FG-001805	Bolshekaraganskiy	spearhead	< 0.01	< 0.01	< 0.005	0.017	< 0.005	0.018	< 0.008
FG-001867	Kamenniy Ambar	wedge	0.07	< 0.01	0.005	< 0.005	< 0.005	0.031	< 0.008

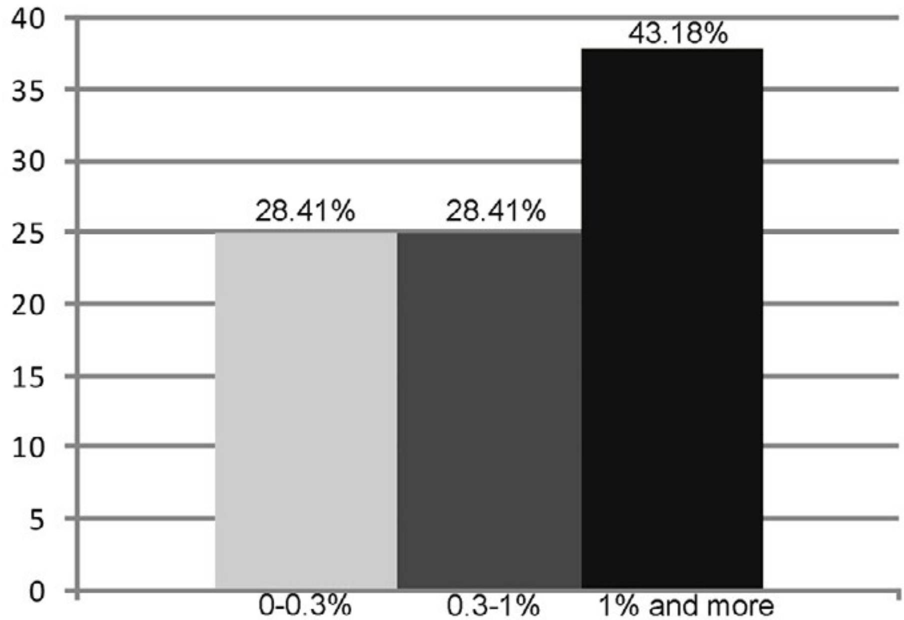


FIG. 5-49. DISTRIBUTION LOW-ARSENICAL, MIDDLE-ARSENICAL AND HIGH-ARSENICAL METAL OF THE SINTASHTA-ABASHEVO TIME (BASED ON THE XRF ANALYSES).

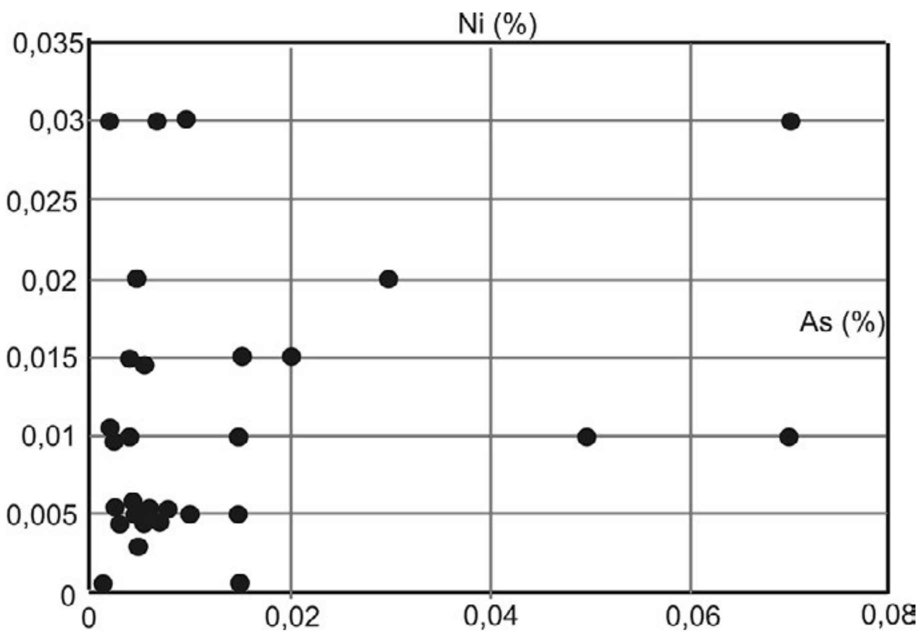


FIG. 5-50. CORRELATION OF CONCENTRATIONS OF NI – AS IN SLAG OF THE 2ND MINERALOGICAL GROUP.

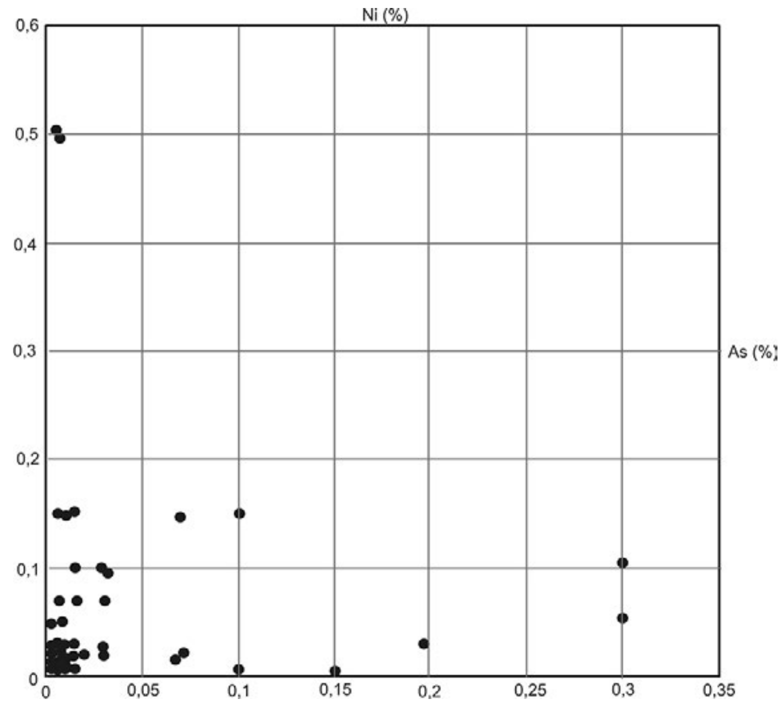


FIG. 5-51. CORRELATION OF CONCENTRATIONS OF NI – AS IN SLAG OF THE 1ST MINERALOGICAL GROUP.

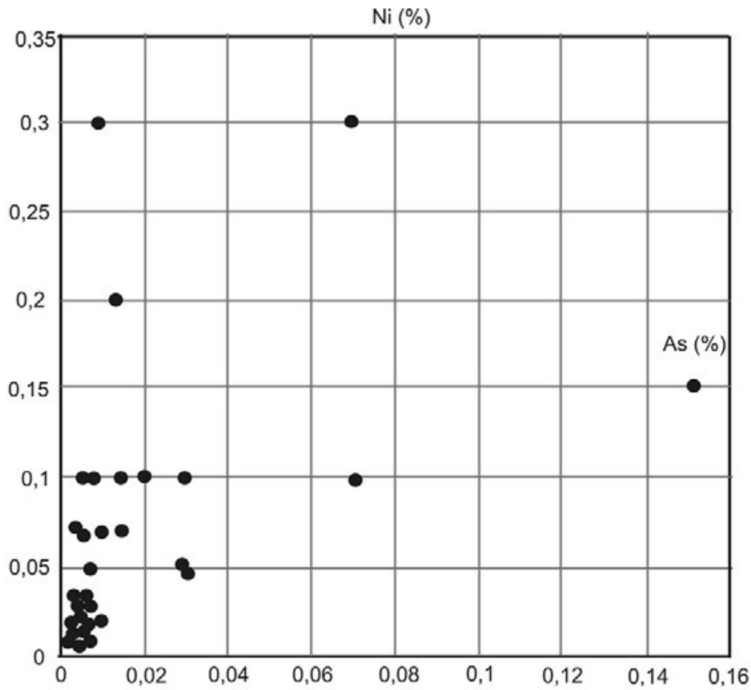


FIG. 5-52. CORRELATION OF CONCENTRATIONS OF NI – AS IN SLAG OF THE 3RD MINERALOGICAL GROUP.

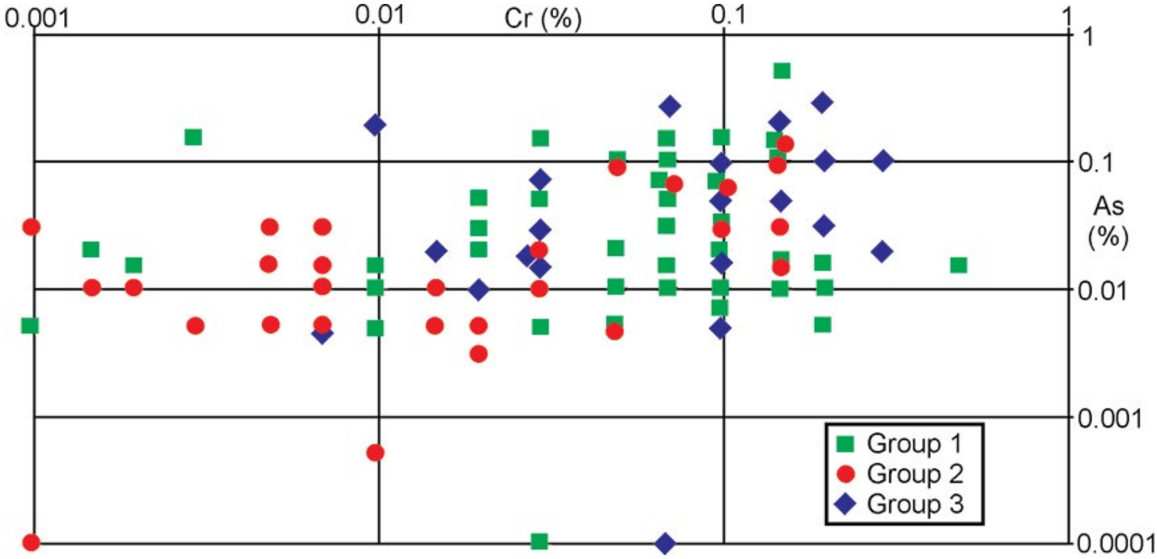


FIG. 5-53. CORRELATION OF CONCENTRATIONS OF CR – AS IN SLAG OF THE 1ST – 3RD MINERALOGICAL GROUPS.

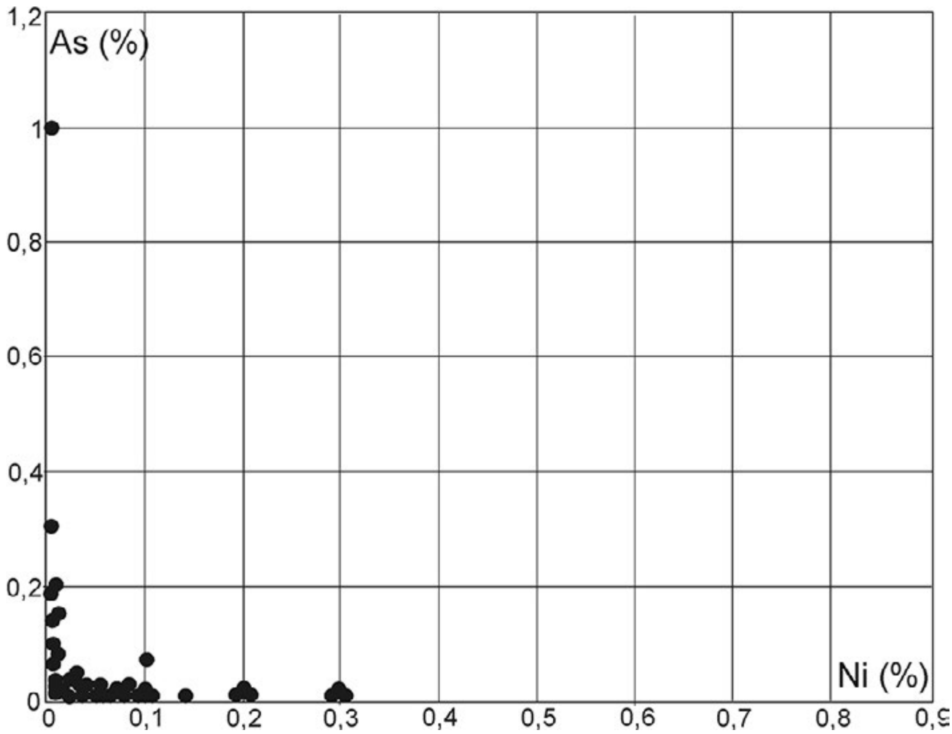


FIG. 5-54. CORRELATION OF CONCENTRATIONS OF NI – AS IN ORE OF THE SINTASHTA-ABASHEVO TIME.

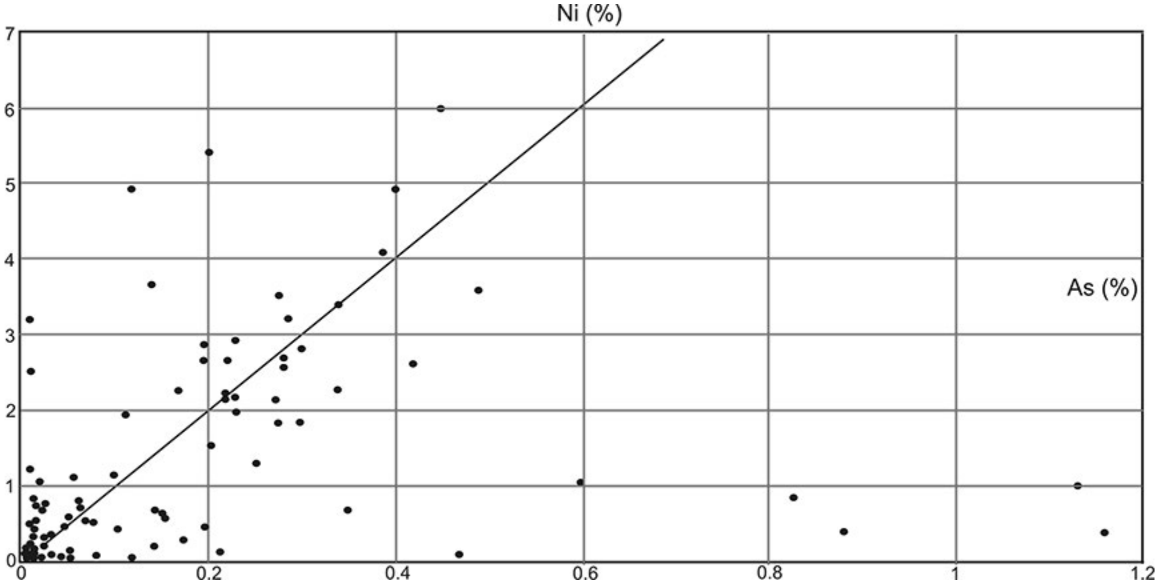


FIG. 5-55. CORRELATION OF CONCENTRATIONS OF NI – AS IN METAL OF THE SINTASHTA-ABASHEVO TIME.

Tab. 5-56. Diapason of arsenic contents and its average value in different types of artifacts of the Sintashta-Abashevo time.

Type	Diapason As (%)	Average value (%)
rod	0.009	0.009
wedge	0.046	0.046
hook	0.005-0.32	0.163
fishing hook	0.202	0.202
ingot	0.005-0.39	0.21
clip	0.082-0.72	0.334
facing of vessel	0.81	0.81
sickle	0.005-3.2	0.836
bracelet	0.67-1.11	0.89
drift	0.011-4.9	1.042
chisel	0.005-3.6	1.328
awl	0.063-6	1.838
harpoon	1.94	1.94
adz	0.34-4.9	2.421
knife	0.01-5.4	2.85
spearhead	2.85	2.85

Chapter 6.
Sintashta metalworking

Technology of metalworking

For understanding the nature of Sintashta metallurgy the carried-out metallographic study is important. This analysis allowed a number of conclusions to be made. Sintashta people selected furnace charge purposefully for producing the low-alloyed copper-arsenic objects as in technology of their metalworking post-casting forging operations dominated, and alloys with the high arsenic content, more than 3-5%, are unsuitable for forging as it is difficult to achieve the homogenization in them (Degtyareva 2010, p. 17, 87).

Casting with limited forging rework is identified seldom, for manufacturing of arrows and nails. And, the complicated casting was not mastered. Large tools (adzes, sickles, and knives) were cast into open casting moulds with the following forging. Axes and a part of knives were casted in rare instances into bi-fold moulds and forged too. All other tools (chisels, awls, hooks, and needles) were made of semi-finished products by forging. For production of spearheads a triangular billet was cast, from which then the spearhead was formed by forging. Ornaments are made in some instances by casting, but usually by form-building forging on figured anvils (Degtyareva 2010, p. 121, 123, 134, 138). Sometimes, if tin was present in metal, discrepancy of the forging technology to the composition of metal took place that caused a fast peening and red brittleness of the metal. Respectively, tin was obviously not very familiar ligature for the Sintashta masters (Degtyareva 2010, p. 133).

At forging there were two temperature operating modes – low-temperature (400-500 °C) and for one third of products – high-temperature (600-700 °C); cold forging, sometimes with intermediate annealing, was used less often. It is supposed that low temperatures of forging were caused by aspiration to avoid sublimation of arsenic (Degtyareva 2010, p. 121, 138). However, in daggers of the Anatolian settlement of Ikiztepe in edges the average arsenic content is 4.27%, and in handles which had not been forged – 4.21%, this means that at forging an absolutely insignificant part of arsenic is sublimated (Gülçur 2002, p. 45). Therefore, the reason was probably another. Judging from one category of products (knives), a choice of this or that temperature mode did not depend on concentration of arsenic or nickel (see Degtyareva 2010, tab. 10). Besides, discussing the analysis of the Maikop arsenic-nickel bronzes, we pointed that at higher temperatures the fissuring of products raises (Ryndina *et al.* 2008). Therefore in this case the chosen temperature modes of forging and the preference of forging operations were quite adequate to raw materials (arsenic bronzes with nickel impurity) that is visible in lack of forge defects.

Contrary to it, earlier Pit-Grave metallurgy of the Southern Urals was based on working of pure copper from oxidized ores at high temperatures (Degtyareva 2010, p. 58). The Maikop tradition of the EBA which we have discussed above, is even closer to that of Sintashta, although it is separated by a long period. Possibly, it may be explained by the presence in both cases of nickel impurity in the arsenic bronzes that compelled to choose similar temperature modes. Unfortunately, we cannot compare the Sintashta technology with the south of the Circumpontic Metallurgical Province as there are no detailed metallographic studies.

Only basing on general archaeological reasons it is possible to tell that the similar principles of metalworking existed in the Middle Bronze Age in the Northern Caucasus and the south of Eastern Europe (Korenevskii 1983, p. 99, 100). But on the Anatolian settlements close casting technologies were applied. As a rule, simple products (bars, knives, adzes, simple spearheads) were cast into open moulds. Axes and some ornaments were cast into the closed bi-fold moulds (Müller-Karpe A. 1994, S. 140, 143-146). This means, it is possible to speak about the roots of Sintashta metalworking in the Middle Bronze Age complexes of the Circumpontic

Metallurgical Province, and within the Early Bronze Age the lines of similarity can be traced to the Maikop metalworking.

Types of metal objects of Sintashta culture

As it was already noted, Sintashta culture differs by the abundance of metal, first of all, in its funeral monuments. The amount of this metal grows every year, not all artifacts are published, therefore by no means a complete sampling of available artifacts is given here, but it is sufficient to give an idea about the nature of Sintashta metalworking. In provided tables the drawings of these artifacts are given from publications reflected in the text below. Besides the Sintashta objects some Abashevo objects are present in the tables. This analysis is necessary for us, above all, to show the general character of Sintashta metallurgy, connections of ore smelting technology with types of objects and raw materials. Therefore this analysis pretends to be considered neither as a total characteristic of the Sintashta metal nor as an attempt to give its full and correct typology. For the last characteristics it is necessary to address to other works in which these questions are solved in more detail. In particular, A.D. Degtyareva's monograph has been recently published (2010) in which it is considered 599 Sintashta copper artifacts, and together with the complex of the Ustye settlement (there is also metal of Petrovka culture) – 750 artifacts[1].

Shaft-bushed axes are represented by two examples with a massive back, short tube, rectangular ridge and narrow elongated wedge. Both axes have been found in the Sintashta cemetery (Gening *et al.* 1992, p. 122, 232; Pryakhin 1976, p. 131). The bush of axes is well developed, the hole on the bush is round with a visible ovality, and the cross-section of the wedge is lenticular (Fig. 6-1.). E.N. Chernykh, in his classification of the North Eurasian axes distinguished those with a narrow back and a massive one (Chernykh 1970, p. 58). The axes with the narrow back are characteristic of the Abashevo culture. It is more likely that they reflect a further development of metalworking traditions of the Catacomb period (Korenevskii 1983, p. 99). The axes with the massive back originated only from the Sintashta sites and were not connected with the Abashevo ones genetically.

Similar axes, but without a ridge, are known in the Multi-Cordoned Ware culture (KMK) (Archaeology of Ukrainian SSR 1985, p. 456; Kovaleva I. 1981, p. 27). Some KMK objects fall into the 'Kostromskaya' type of axes of the Catacomb period (Korenevskii 1983, pp. 97, 98), which indicates the Caucasian influence and is dated to the second quarter of the 2nd millennium BC in the system of traditional chronology (Kovalyova 1981, p. 27). This corresponds to the Sintashta dates. These axes differ in the prominent bush and curvature of the wedge. Because of the contemporary position of these objects, we have no possibility to connect origins of the Sintashta axes with the metalworking of KMK. I have suggested their Caucasian-Near-Eastern origins (Grigoriev 1999). In this connection the opinion of S.S. Berezanskaya merits attention, that the KMK axes have morphological parallels in the Caucasus (Berezanskaya *et al.* 1986, p. 38). Therefore, it is possible that the southern impulses, in general, had put into effect the formation of metalworking of the North Eurasian Middle Bronze Age II. Artifacts of such well-known hoards of Eastern Europe, as Kolontaevka, Ribakovka, Berislav (Leskov 1967, fig. 14), have parallels among axes with a massive back and knee-shaped wedge in Transcaucasia (Svanetia) and Anatolia. In Eastern Georgia axes similar to those in Eastern Europe are known too (Picchelauri 1997, Taf. 8, 85-87). The close parallels to the Sintashta axes were found in the Caucasus. One of the Caucasian axes has a spherical knob on the back, which is very similar to the rectangular ridges of the Sintashta axes (Krupnov 1951, p. 45).

[1] Today it is more preferable to use this typology, although it has some defects. But it is made on a rather large massif of material, and coordinated with metallographic studies. Unfortunately, more often we see another situation when with the description of any artifact related by one researcher to type 1B or 2.2 according to classification of another researcher. This situation seems to me senseless, creating only visibility of the research procedure. As it was already spoken, classifications have to be carried out on the large massif of material covering not only a complex of one or two sites, but, at least, that of several cultures, i.e. within specialized studies in this field. And they have to be based on accurately developed criteria and be verified by statistical procedures as it is present, for example, in Chernykh's works.

In the framework of the Sintashta problem, axes with the massive back are most important for us. Above all, it is necessary to pay attention to the presence of axes with a massive back in Anatolia. However, their bush is round. They appeared at the end of the Early Bronze Age, but existed also at a later time (Stronach, 1957, p. 120, fig. 11.3). A mould for casting an axe with massive back has been found on the settlement of Kültepe in Anatolia (Müller-Karpe A, 1994, Taf. 41). Axes with massive backs are known also in Egypt. They differ from the Sintashta examples, but only in the form of the back (Müller-Karpe, 1974, Taf. 161.4).

Bronze arrowheads were found only in the Sintashta cemetery and in the Aktyubinsk area in the cemetery of Tanabergen II (Fig. 6-2.1-6). (Gening *et al.* 1994, p. 302, 321; Tkachev 2007, fig. 9.8). They have a short rectangular tang and an elongated leaf-shaped blade. The 'herring-bone' pattern had been placed along the rod. These arrowheads have no parallels in Eastern Europe. It is necessary to note that there were no metal arrowheads in Northern Eurasia in the previous period. In addition to those from Sintashta, three arrowheads are known only. The first was found in a mound near the Liventsovka fortress on the Lower Don (Rogudeev 1997, fig. 1.5), dated, apparently, to the time of Sintashta culture. Two others have a rather simple two-winged form, a triangular or sub-rhombic blade, and have been found among materials of Abashevo culture (Pryakhin 1976, p. 152). However, these objects were contemporary to Sintashta. It is necessary to note that Sintashta arrowheads differ in a complete and standard form that indicates a long evolution of the type. Therefore, it seems more logical to look for roots of this type in the Near East, where two-winged metal arrowheads are known since the Early Bronze Age and are widely distributed in the 2nd millennium BC. From the very beginning these were only tanged two-winged arrowheads (Archaeology of Asia fig. 17; Medvedskaya 1980; Gorelik 1993, tab. XLIII, 29-33, 43-45, 56-105; Müller-Karpe 1974, Taf. 167). In literature the attention was paid that these arrowheads, unlike those in Sintashta are not ornamented and their connection with Seima-Turbino metallurgy has been suggested, which was based on ornamentation of Seima-Turbino spearheads (in general, different ornamentation), a shank and forged blade (Tkachev 2007, p. 287). However these Seima parallels cannot be considered as typological correspondences. The question of possible influence of Seima metalworking on the formation of Sintashta complex of metal is also doubtful.

There are three **javelin-heads** in the collection of the Sintashta cemetery (Gening *et al.* 1992, fig. 105, 175). They have a rhombic blade and an elongated pointed tang (Fig. 6-2.7-9).

Three finds of bronze **harpoons** are known on the Sintashta sites (Fig. 6-2.10,11): two in the cemetery of Sintashta and one in the Bolshekaraganskiy cemetery (Gening *et al.* 1992, fig. 79; Botalov *et al.* 1996). There are no other similar finds in Northern Eurasia. The analogies to them are in the south. The bronze harpoon, for example, was found in Egypt (Tell ed Dab'a) (Müller-Karpe 1974, Taf. 161.9), although this parallel is not irreproachable from typological point of view.

Spearheads with a rather short disconnected open socket and elongated leaf-shaped blade were found only on some sites of Sintashta culture and related Potapovka sites (Sintashta, Kamenniy Ambar, Bolshekaraganskiy, Tanabergen II, Zhaman-Kargala I) (Gening *et al.* 1994, p. 176, 212, 320; Kostyukov *et al.* 1995, p. 197; Botalov *et al.* 1996, fig. 17.2; Tkachev, 2007, fig. 9.1, 23.3) (Fig. 6-3.1-4,7). Besides, spearheads of this type were found in the Seima-Turbino cemeteries of Rostovka, Seima, Ust-Gayva, and the Pokrovsk cemetery of the Early Srubnaya (Timber-Grave) culture. All of them were made of arsenic copper, and this reflects not the Seima, but the Sintashta tradition of metalworking (Chernikh, Kuzminikh 1989, p. 65, 66). Abashevo spearheads, contrary to them, have the elongated open socket and short blade, although there are spearheads with a short socket too (Pryakhin 1976, p. 135-137). Objects comparable with those of Abashevo are known from sites of Yamnaya (Pit-Grave) and Balanovo cultures (Morgunova, Kravtsov 1994, p. 79; Orlovskaya 1994, p. 112). Therefore, it is most likely that as well as in the case with axes, Abashevo spearheads prolonged traditions of the local metalworking. Nevertheless, the idea of a genetic line of spearheads from those of Balanovo culture of the Middle Volga to Abashevo, Verkhnekizilsky hoard and Sintashta (Tkachev 2007, p. 281, 282) is doubtful. The only uniting feature is the opened socket that reflects a general technological level of metalworking in the huge territory. If not to focus attention on this detail, it would be impossible to compare Balanovo spearheads with those from Verkhnekizilsky and the latter with Sintashta. Perfectly understanding it, V.V. Tkachev puts into operation a 'Seima' factor thanks to which a specific form of blade of the Sintashta spearheads appeared.

The analogies to the Sintashta type of spearheads may be revealed in the Caucasus and in Anatolia, though the construction of blades of spearheads in these regions does not correspond always precisely to the Sintashta blades. More often they are narrower, however, some artifacts differ in a similar construction of blades (Avilova, Chernykh 1989, p. 504; Chernykh 1966, p. 104; Dzhaparidze 1994, tab. 25; Tekhov 1977, p. 34; Erkanal 1977, Taf. 15, 16; Picchelauri 1997, p. 24, Taf. 70-73; Müller-Karpe 1974, Taf. 297.43,45).

Very peculiar finds are two b**ayonet-shaped points** found in the Potapovka cemetery, in mound 3 (Fig. 6-3.5,6). In Northern Eurasia similar objects are unknown. There were knives, typical of the metalworking of Poltavka culture, in the same grave with them. All these objects had been not alloyed with arsenic, which blends with parameters of the Poltavka metallurgy too (Agapov, Kuzminikh 1994). However, the complex containing typical Sintashta artifacts has been found under this mound too. It is necessary to note that, in the opinion of excavators, the Poltavka and Sintashta complexes of the cemetery were synchronous and reflect a contact of these populations (Vasiliev *et al*. 1994). Basically, it is necessary to agree with a partial synchronization of the Poltavka and Sintashta cultures, however, it is necessary to note that the Poltavka materials of the cemetery give a poor basis for this assumption. Moreover, they can contain non-simultaneous complexes, what has been already indicated in the literature (Otroshenko 1996; Grigoriev 1999). Therefore, a problem of the chronological position of two above-mentioned bayonet-shaped points is open. The bent ends of spearhead tangs were typical in the Near East (Avilova 2008, fig. 23, 28, 31), these objects have in some instances a narrow massive blade, but I do not know more exact analogs.

Axe-adzes found on the Sintashta sites have, as a rule, straight lines, in the most cases with a slightly enlarged cutting edge (Fig. 6-4., Fig. 6-5.). The sides of instruments are often slightly narrowed towards the heel. Many adzes have a semicircular heel (Gening *et al.* 1992, p. 61, 232, 255, 265, 268, 272, 307, 320; Kostyukov *et al.* 1995, p. 196, 197; Botalov *et al.* 1996, fig. 2, 17, 18, Tkachev 2007, p. 186; Degtyareva, Kuzminykh 2003, fig. 1.1). These adzes could have been used for chopping wood. Some of them have remains of the belting braid of the handle. However, a part of these adzes could have been used as battle-axes, under a condition of the attachment to them of a perpendicular handle. There are also three adzes of the elongated trapezoidal form constricted towards the heel and extending to the edge (Kamenniy Ambar, Potapovka). They differ in the considerably smaller sizes. It is necessary to note that in the cemetery of Kamenniy Ambar adzes of the standard type have smaller sizes too. Especially it should be noted an original object with the forged socket from the cemetery of Tanabergen II (Tkachev 2007, fig. 9.2).

Axe-adzes are quite representative artifacts in Northern Eurasia. They are present often on the Abashevo sites. As a rule, a heel of Abashevo adzes is slightly expanded, although there are sometimes examples with a narrowed heel. In the Seima-Turbino sites adzes have been found in the western zone (Eastern Europe) only. Typologically they are identical to the first described group of the Sintashta adzes, were made of arsenic bronze, which has allowed them to be linked with the Abashevo metallurgical production (Chernikh, Kuzminikh 1989, p. 134).

In the Multi-Cordoned Ware culture adzes have elongated proportions, a very narrow heel and a wide arched forged edge (Archeologia of Ukrainian SSR 1985, p. 456, 459). The analogies to them are present in materials of the North Caucasian culture (Chernikh 1966, p. 104).

In opinion of some scholars, Sintashta and Abashevo adzes can be traced back to the extended towards the edge adzes of the Privolnaya type of the Catacomb time (Korenevskii 1983, p. 97, 103; Degtyareva 2010,

p. 94). Adzes of this type were found in the Northern Caucasus. Besides, all listed adzes, including those of KMK, are present in Anatolia (Avilova, Chernikh 1989, p. 54). These objects were extremely widespread in the Circumpontic zone, up to Palestine and Egypt (Miron 1992; Müller-Karpe 1974, Taf. 167). As for the socketed adze from Tanabergen II, a similar artifact is known in Northern Syria in the layer Hama J (Müller-Karpe 1974, Taf. 247D).

Chisels with a forged open socket are rather rare finds on Sintashta and Abashevo sites (Fig. 6-6.). Two of them were found in the Bolshekaraganskiy cemetery, and one more in the settlement of Tyubyak. A fragment of chisel was found in the Sintashta cemetery (Botalov *et al.* 1996; Gening *et al.* 1992, fig. 148.5). The chisels go back, probably, to the production of the Catacomb time (Korenevskii 1983, p. 105), but they were widespread in more southerly areas of the CMP too (Avilova, Chernikh 1989, p. 54). Typical for the MBA of Northern Eurasia stemmed chisels are not presented on the Sintashta sites. Only one object is known from the Abashevo barrow (Korenevskii 1983, p. 105) that reflects closer connections of Abashevo metalworking with former Eastern European traditions, in comparison with the Sintashta metalworking.

Socketed chisels of the Sintashta sites have many parallels in Anatolia and North-western Syria. They are dated to the late 3rd – early 2nd millennium BC (Müller-Karpe A. 1994, p. 170-173, Taf. 74, 75).

Stemmed chisels, drifts and wedges (Botalov *et al.* 1996; Gening *et al.* 1992; Kostyukov *et al.* 1995**)** are presented by a large series; they have usually a rectangular cross-section and different length (Fig. 6-7.). The chisels have a forged working edge. There are analogies to these instruments in Anatolia (Müller-Karpe A. 1994, pp. 159-174, Taf. 65-72). But it should be noted that these are quite simple objects which have been poorly typologically expressed. Therefore, a conclusion that they, in general, reflect the Circumpontic traditions seems to be correct (Degtyareva 2010, p. 95).

Knives are the most mass category of metal artifacts of Sintashta culture (see. Gening *et al.* 1992; Vasiliev *et al.* 1994; Kostyukov *et al.* 1995; Botalov *et al.* 1996; Tkachev 2007, p. 182-184; Degtyareva, Kuzminykh 2003, fig. 1.2-10). The most widespread type is a double-edged knife with a waist, small stop and a rhombic or pointed heel to the tang (Fig. 6-8.…Fig. 6-11.). Its forms are very variable. It allowed to V.V. Tkachev to divide them into three separate types, differing by the heel of the tang: rhombic, pointed and roundish (Tkachev 2007, p. 182-183). It is really possible to do, but actually this classification has an artificial character as in each of these three types it is possible to choose the objects which are very similar to objects of other type. A slightly uncompleted heel to the tang (two or three differently made blow by a hammer) and it is already another type. This part of the tool was hidden in a bone or wooden handle, and at any end of the tang it could be made. Therefore often this factor had a casual character. The general narrowness of the tang, presence of stops and waists is functional for these objects. Thus, similar classification might exist, but it has lost contact with reality and therefore does not bear the main function of any classification – to be a tool for receiving a new knowledge. Certainly, in case the suggested types appear statistically connected with some territorial or chronological complexes, it improves the thing. But while it has not happen, we will consider these objects within one type.

Knives of this type occur in all Sintashta and Potapovka complexes. In contemporary cultures knives of this type are known in the Petrovka sites on the Ishim and Tobol (Zdanovich 1988, p. 75; Potyomkina 1985, p. 264, 265), and are rather characteristic of the Abashevo culture (Pryakhin 1976, p. 146; Chernykh 1970, p. 66). They are detected also in the Seima-Turbino cemeteries, where they are interpreted as typical Abashevo artifacts (Chernykh, Kuzminykh 1989, pp. 101, 102).

Some scholars connect the appearance of this type of knives with a further development of Catacomb-type objects by Abashevo metallurgists (Korenevskii 1983, p. 102). Origins of knives with the waist from the Catacomb knives with a pentagonal blade may be illustrated by an example from the cemetery of Kamenniy

Ambar (Kostyukov *et al.* 1995, p. 201). Nevertheless, except for them, other transitional examples are, practically, unknown. Therefore, it is impossible to exclude a stranger character of this type in the Transurals. A similar hypothesis can be indicated by discoveries of knives with the waist in Karabakh. They are dated to the late 3rd – early 2nd millennium BC (Gorelik 1993, p. 222, tab. III, 54, 55). A dagger with a rhombic tang and a waist has been found in the grave at Bayindirköy (Yortan culture) in North-Western Anatolia. However, the tang of the dagger is broader, and has also a rivet arrangement (Stronach 1957, p. 92, fig. 1.17). A knife with a rhombic heel to the tang has been found at Tell el Ajjul, on the border of Egypt and Palestine. However, a construction of its blade is another than those of the Sintashta knives (Müller-Karpe 1974, Taf. 167. 20). The example from Ur (18-17th centuries BC), having a pointed heel to the tang, is very similar to Sintashta knives, as well as one Catacomb knife from Novokamenskoye, dated to the same time (Gorelik 1993, p. 224, tab. IV, 13, 46). A knife from the burial of the Bakhmutino type of the Catacomb culture, which has been found at Verkhne-Yanchenko, relates to the same type. As against of the Sintashta knives, it has a blunted top of the tang (Bratchenko 1976, fig. 46.5). The knives of the Multi-Cordoned Ware culture differ, although some similar features (slightly sharpen edges at the transition from the blade to the tang) in these knives are visible (Archaeology of Ukrainian SSR 1985, p. 456). In complexes of this culture single finds of the Sintashta-Abashevo type of knives are known only (Pryakhin 1976, p. 147).

In addition to those described above, there are in the Sintashta complexes knives of Eastern European types, but very rarely (Fig. 6-12., Fig. 6-13.). These knives have a straight tang (in some instances without tang), and a leaf-shaped, semi-triangular or pentagonal blade (Gening *et al.* 1992, p. 122, 124, 302, 307; Tkachev 2007, p. 182-184). Due to this variability they allow to do more detailed classification based on the form of tang and blade. It is necessary to note that on the Abashevo sites such types are more widespread (Pryakhin 1976, p. 141-144). In the Potapovka complexes one knife with a tang and a leaf-shaped blade is known (Vasiliev *et al.* 1994, p. 142).

The time span for the existence of similar artifacts is rather wide, but predominantly they occur in Pit-Grave, Poltavka, Catacomb and North Caucasian cultures, less often in KMK (Korenevskii 1978).

Finally, rather district **knife/sickles** (Fig. 6-14.) occur in some cases in materials of the Don Abashevo culture, Potapovka type and Sintashta culture (Pryakhin 1976, p. 144; Kostyukov *et al.* 1995, p. 199; Vasiliev *et al.* 1994, p. 134). These knives have a long straight metal handle, arranged in one line with an edge. I do not know of analogies to this type. It is much more likely to be a stage in the development of the slightly bent sickle, appropriate to Abashevo and Sintashta.

Some knives have amorphous shape and do not yield to typological classification.

Sickles are rather widespread, but most of them have been found in the settlement and the cemetery of Sintashta, where the broadest excavations were carried out. One sickle originated from the cemetery of Kamenniy Ambar. Sickles are more characteristic of the Abashevo sites. Several such artifacts have been found on the Tyubyak settlement. These are plate-type, slightly bent instruments. The degree of their curvature hardly varies (Gening *et al.* 1992, p. 109, 158, 268, 285; Pryakhin 1976, p. 139, fig. 25, 1-9; Kostyukov *et al.* 1995) (Fig. 6-15.). In Catacomb sites sickles are unknown (Korenevskii 1983, p. 105). They cannot go back to Transcaucasian prototypes too, as more developed forms of objects were used there (Avilova, Chernykh 1989, p. 53). The sickles of the North Caucasian culture had much greater curvature (Chernykh 1966, p. 104), which eliminates a possibility of the borrowing of instruments of this type by the Abashevo tribes from the Northern Caucasus. Slightly bent sickles are known in Mesopotamia, in Kish (Müller-Karpe 1974, Tab. 199). They have very similar forms. However, they are dated to a very early time, which does not allow them to be connected directly with those in Sintashta. Therefore the connection of these tools with the CMP is preferable, but it is difficult to suggest the concrete analogies.

On different Sintashta sites many **fishhooks** have been revealed (Gening *et al.* 1992, fig. 79.14, 122.4, 126.16,17, 140.6, 148.2,3, 153.19; Kostyukov *et al.* 1995, fig. 21.8; Zdanovich 1997; Vasiliev *et al.* 1994; Tkachev 2007, fig. 55.10-12). They have different sizes and rather standard forms (Fig. 6-16.). Their top is usually curled, forming a closed loop for the attachment of the fishing-line. Only one fishhook, having a forget end, is somewhat different. In other cultures of Northern Eurasia such or similar finds are unknown in the previous time. In the south, fishhooks of similar types were found in Syria (Tell Asmar) (Müller-Karpe 1974, Taf. 206). Bronze fishing hooks are well presented also in Suse. Their top can be as bent as forget (Talion 1987, p. 196).

Socketed hooks are very infrequent for Sintashta culture (Fig. 6-17.1,3,4). One such object was found in the Bolshekaraganskiy cemetery. In addition, one socketed hook has been found on the Tyubyak settlement, relating to the Ural Abashevo culture. There is a find of the socketed hook on the settlement of Shibaevo in the Chelyabinsk area, however, this is a multi-phase settlement, and the socketed hook was out of the cultural layer. Therefore, its dating is not sure determined (Zdanovich D. 2002, fig. 21.7; Gorbunov 1992, fig. 16.2; Nelin 2004, fig. 8.12). Similar socketed hooks were widespread in different zones of the Circumpontic area; however, they were never characteristic of the Urals. For the Late Bronze Age similar socketed hooks are known on the settlement of Pavlovka in Kazakhstan, relating to the Fyodorovo culture, and in the Loboykovskiy hoard in the Ukraine (Zdanovich 1988, tab. 10,15; Chernykh 1976, tab. XXXII). The latter was, probably, connected with the Fyodorovo impulses to the west. In outcome, the hook from Shibaevo may be dated to both Sintashta and Fyodorovo periods. The problem can be solved by means of the analysis of metal, because the Fyodorovo metallurgy based on tin-ligatures. Because this hook was made of arsenic copper (Tab. 5-48.), its Sintashta origin is most likely. It corresponds also to its rather graceful shape that is characteristic of the MBA hooks more than for those of the LBA. The origin of these hooks was connected with the Catacomb metalworking of Eastern Europe (Korenevskii 1983). In the Near East (Suse) similar hooks and knives of the Catacomb types are known (Avilova 2008, fig. 29) but it is connected more likely with the problem of the Catacomb culture origins, and hardly is related to Sintashta. In Anatolia these hooks are also known.

Conditionally the bent rod with rhombic section from the settlement Tyubyak is related to hooks, but premeditation of this form is not obvious (Fig. 6-17.2).

Awls are the commonest type of artifact on Sintashta and Abashevo sites (Fig. 6-18.). They have different sizes and a square cross-section. It is necessary to indicate the absence on sites of the Sintashta and Abashevo cultures of awls with a stop, which were typical of different areas of the Circumpontic zone in the Middle Bronze Age. A.D. Degtyareva (2010, p. 117) wrote about several awls with a stop. But this is not that expressed stop that was the CMP standard, but rather a small deliberate widening. But also in the CMP not all objects have an ideal stop. Therefore the roots of this type were Circumpontic.

Needles, distinguished by usually round cross-section, are less often (Fig. 6-18.3,27,32,39,48).

Very often finds are the bronze **clips** (Fig. 6-19.3-9,11-15,18-20,23,24,26,35-38,41,43,44) and **staples** (Fig. 6-19.1,22,29,30-32,45-49,54). The formers served, above all, for binding cracks in the potteries. Some bronze **rivets** (Fig. 6-19.50-53,56-58), **nails** (Fig. 6-19.55,59-62) and pieces of **wire** (Fig. 6-19.2,21) have been found too. Bronze **flat plates** on the rim of wooden vessels are infrequent, but very typical of the Sintashta sites (Fig. 6-19.1,4-6,9). Alongside them there are also **thin bronze plates** (Fig. 6-19.2,3,7,8,10,11), **strips** (Fig. 6-20.12,13) and fragments of unclear objects (Fig. 6-20.14-16).

Ornaments on the Sintashta sites occur not so often as on the Abashevo ones, and their set, is rather poor (Fig. 6-21., Fig. 6-22.): grooved bracelets, beads (some with 4 knobs), tubes and one cone-shaped bead, grooved pendants in 1.5 revolutions, temporal ring-shaped pendants and rings (in 1,5 or 2 revolutions or with spiral-shaped ends), grooved bracelets with spiral-shaped ends, a fragment of the so-called glasses-shaped pendant.

A specific type is pendant set of silver and paste beads from the cemetery of Sintashta (Fig. 6-23.) which, are interpreted as a breast-ornament (Gening *et al.* 1992, photo 52, fig. 99, p. 192, 318), but A.D. Degtyareva fairly consider it as the set covering plaits and fastened to any headdress (Degtyareva 2010, p. 128). Probably, there were more similar sets, and they were made not only of silver. The bronze pendant of this type is known in the Potapovka cemetery (Fig. 6-22.18), one more in Zhaman-Kargala I (Degtyareva 2010, p. 128).

In Abashevo culture a similar situation is observed only in the Don-Volga area. In the Volga-Ural area, and especially on the Middle Volga, alongside the ornaments listed above there are bracelets with various cross-sections and pointed ends, platelet-rosettes, tubes, so-called glass-shaped pendants, and hemispherical platelets (Bolshov, Kuzmina 1995, p. 110, 111; Kuzmina O. 1992, p. 49-58; Efimenko, Tretyakov 1961, p. 56-67; Khalikov 1961, p. 215-218; Chernykh 1970, p. 71, 72; Kusnetsov 1983, p. 113).

Some part of these ornaments (especially those which are typical of Abashevo culture), probably, was developed in the forest zone of Eastern Europe (Gorbunov 1990, p. 9, 10; Kuzmina O. 1992, p. 58). At the same time, some objects, such as glass-shaped pendants, are known early enough in the Caucasus and the Near East (Gadzhiev 1987, p. 7; Avilova, Chernykh 1989, p. 64; Archaeology of Asia, 1986, p. 116; Avilova 2008, fig. 4.18), and their penetration into Eastern Europe from there is not excluded (Egoreichenko 1991). But it could occur earlier and have no relation to the formation of Sintashta ornaments, but could also have. Strict data here are absent. The same concerns some other types: temporal pendants in 1.5 revolutions widespread in the Caucasus and in Catacomb culture (Tekhov 1977, p. 56; Avilova, Chernykh 1989, p. 67; Gadzhiev 1987, p. 10, 11) and tubes (Avilova, Chernykh 1989, p. 65; Gadzhiev 1987, p. 10).

Sintashta plait-ornament has no analogies in Eastern Europe. Golden pendants made by the same principle are known in Troy (Avilova 2008, fig. 1.3,4, 2.2,3), but they are not identical typologically.

Problem of genesis of the Sintashta complex of metal

The problem of genesis of Sintashta metalworking was already considered (Grigoriev 1999, p. 111-113). A new of Tkachev (2007, p. 279-287) compels me to return to this question. In his opinion, the roots of Sintashta metalworking should be looked for in Catacomb culture, but as direct link between Sintashta and Catacomb metalworking cannot be traced, a long evolution of the Catacomb principles in Abashevo culture is supposed, the perception by Abashevo and Sintashta metallurgists of some Seima-Turbino principles of metalworking that, finally, resulted in the formation of Sintashta complex of metal. However this point of view strikes on a series of contradictions, both specifically typological, and system character. The Abashevo complex of metal also has no direct connections with that of Sintashta. We do not see there this declared evolution. Similarity with the Ural Abashevo metalworking can be certainly traced, but with Middle Volga Abashevo the Sintashta metal is incomparable neither on morphological, nor on the technological bases (Degtyareva 2010, p. 134, 145). We pay attention also that all given parallels in Catacomb culture (as after V.V. Tkachev as above in this text) belong to the Late Catacomb time.

As both the Late Catacomb and Abashevo cultures in Eastern Europe were replaced by the Late Bronze Age Timber-grave culture, the role of the Seima factor (and it is also the transition to LBA) in the formation of Sintashta metalworking may be explained. But in this case do we have to relate Sintashta culture to the beginning of the LBA and synchronize it with the early Timber-grave culture? And it even without discussion of a doubtful and unproven problem of the long evolution of the Catacomb metalworking in Abashevo culture! And how to be with the well demonstrated (Vasiliev *et al.* 1994) formation of the early Timber-grave culture of the Pokrovsk type on the Potapovka base? And Potapovka type was formed on the Sintashta base

(Otroshenko 2000, Grigoriev 1999). Perhaps, it is worth trying to change this relation and to try to show the formation of Sintashta from Potapovka type? An obviously unpromising attempt! Here only some of paradoxes are shown.

Basing on the above-stated analysis of individual categories of objects, it is possible to make the following conclusions. The Sintashta complex of metal did not origin from the Abashevo one. There are individual objects on whose example it can be still discussed. But it is possible to discuss with the same success also a question of simultaneous introduction of these types into the both Sintashta and Abashevo environments, although some proper Abashevo inclusions are quite possible.

Connections with the Catacomb metalworking that is shown both in metal and types of alloy are more significant; and researchers (Degtyareva 2010, p. 88, 147) have already written about it. And this approach of Tkachev is lawful. But, if to address to concrete parallels, these connections are mostly visible at the late stage of Catacomb culture. Therefore, a conclusion seems to be also possible that at the beginning of the MBA II some new categories of objects penetrated the both Late Catacomb and Sintashta complex of metal. As we have seen, a number of objects has parallels in the southern zone of the CMP. Some of these objects had a long genesis in the south. But we can assume their earlier, pre-Sintashta penetration into Eastern Europe and introduction into Sintashta metallurgy already from Eastern Europe with the same success, as well as a direct introduction from the south. At any variant the absolutely exact typological correspondences are known not so often. For individual categories of artifacts the East European roots are more preferable, for others – the Near Eastern roots. But it is obvious also that at the beginning of the MBA II some transformation of the complex of metal took place in Eastern Europe, and southern connections are the most obvious reasons of this transformation.

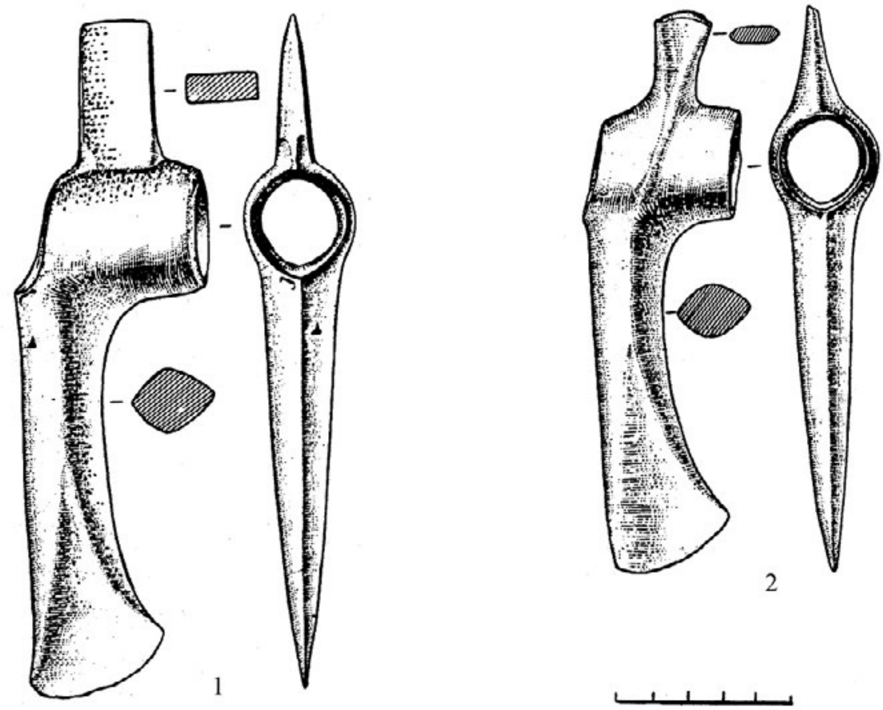


Fig. 6-1. Axes. Sintashta, SM, 1 – grave 39; 2 – grave 3.

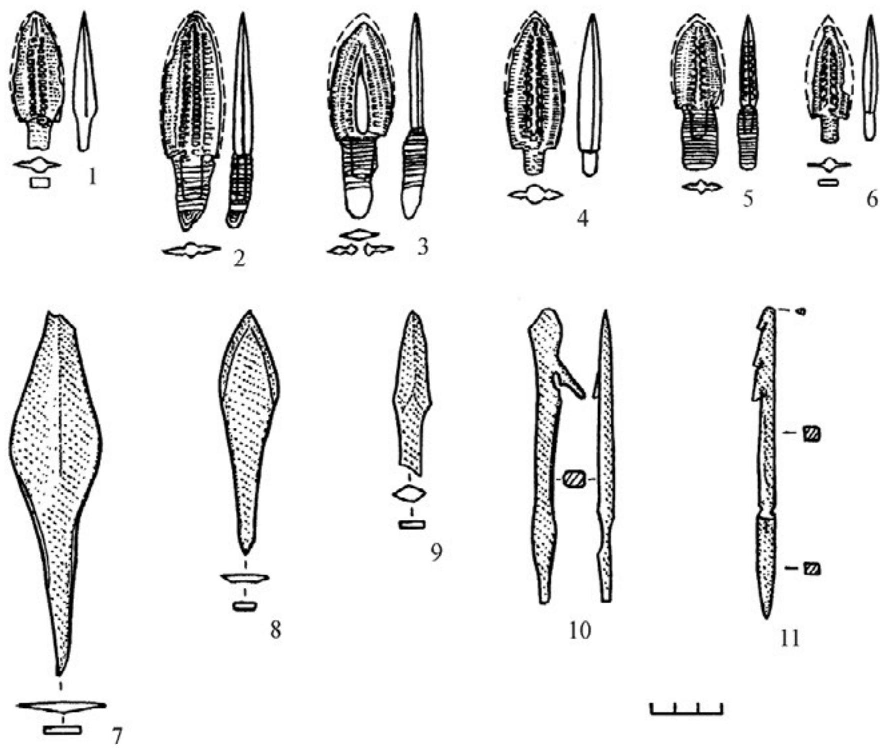


Fig. 6-2. Arrowheads and javelins. 1 – 5 – Sintashta, SII, g. 7; 6 – Sintashta, SII, g. 1; 7 – Sintashta, SM, g. 31; 8 – Sintashta, SII; 9 – Sintashta, SM, g. 16; 10 – Sintashta, SM, g. 12; 11 – Bolshekaraganskiy, k. 24, g. 1 (sample 32).

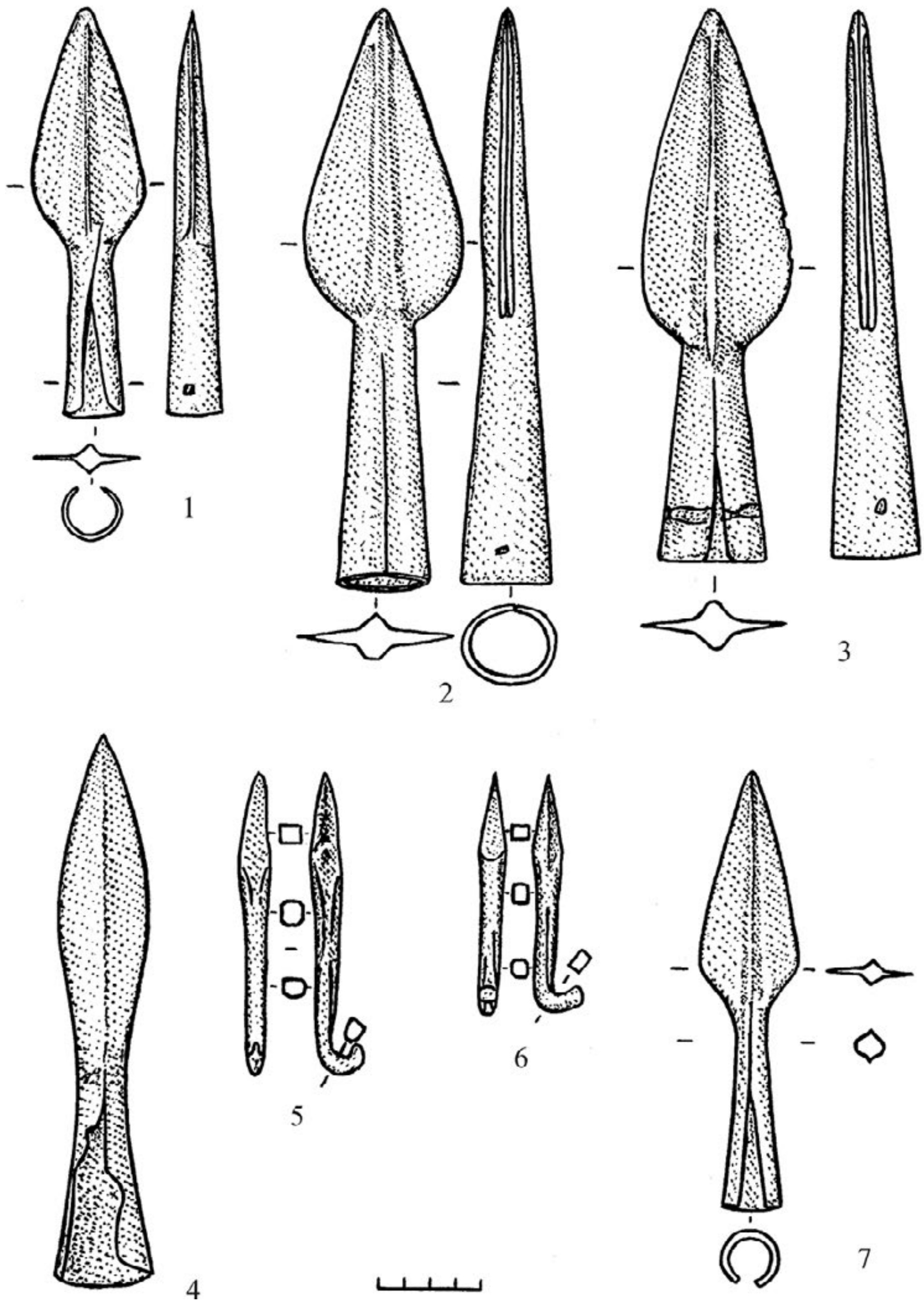


Fig. 6-3. Spearheads. 1 – Kameniy Ambar, k. 2, g. 5; 2 – Sintashta, SM, g. 18; 3 – Sintashta, SM, g. 30; 4 – Sintashta, SII, g. 7; 5, 6 – Potapovka, k. 3, g. 5; 7 – Bolshekaraganskiy, k. 24, g. 1 (sample 31).

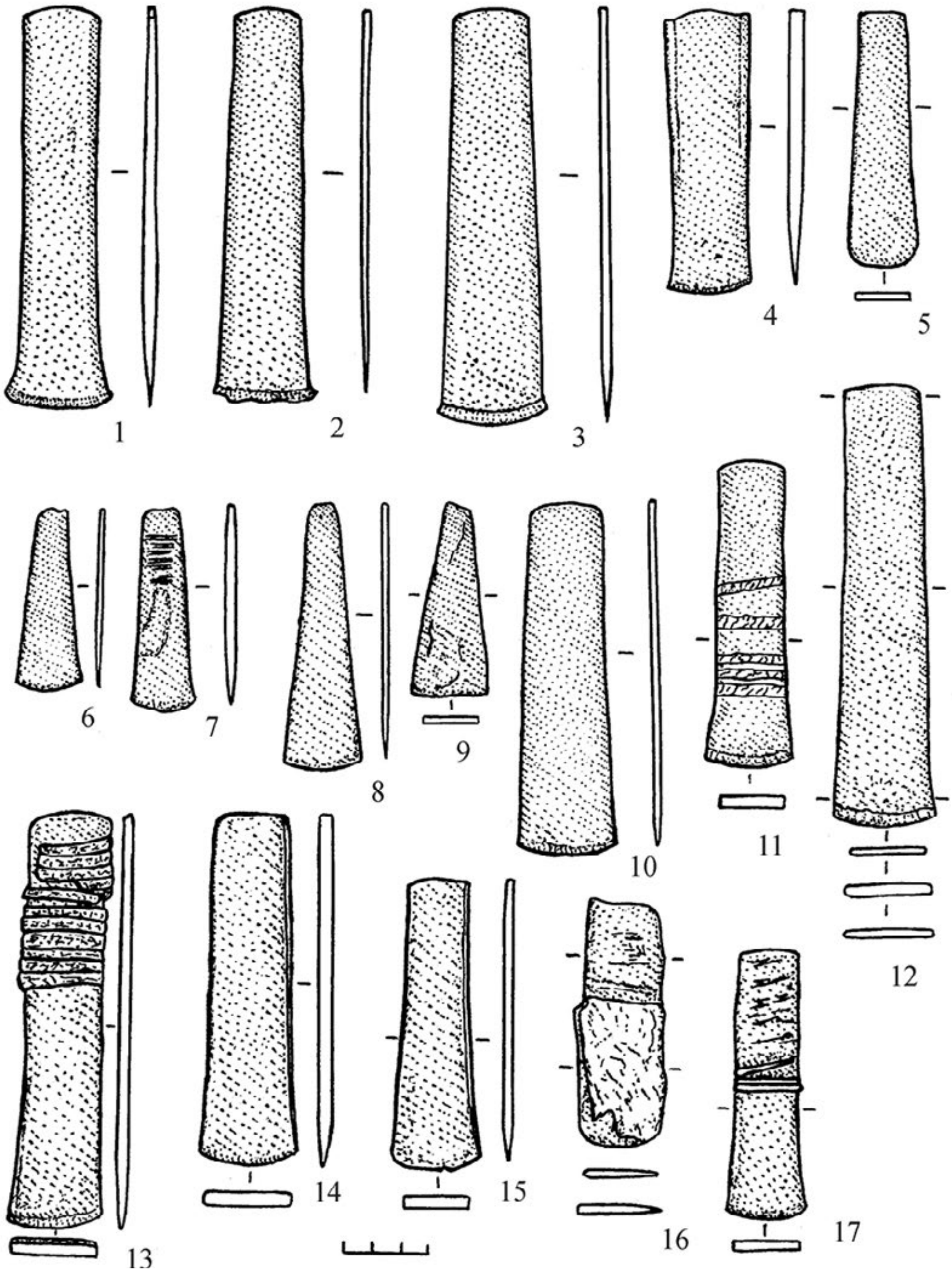


FIG. 6-4. ADZES. 1 – BOLSHEKARAGANSKIY, K. 24, G. 1, SAMPLE 83; 2 – BOLSHEKARAGANSKIY, K. 24, G. 1, SAMPLE 34; 3 – BOLSHEKARAGANSKIY, K. 24, G. 2, SAMPLE 35; 4 – BOLSHEKARAGANSKIY, K. 11, MOUND, SAMPLE 84; 5 – KAMENNIY AMBAR, K. 4, SAMPLE 110; 6 – KAMENNIY AMBAR, K. 2, G. 12; 7 – KAMENNIY AMBAR, K.2, G. 6, SAMPLE 112; 8 – KAMENNIY AMBAR, K. 2, G. 4; 9 – POTAPOVKA, K. 5, G. 4; 10 – KAMENNIY AMBAR, K. 2, G. 5, SAMPLE 118; 11 – SINTASHTA, SI, G. 1; 12 – SINTASHTA, SI, G. 14; 13 – SINTASHTA, SII, G. 2; 14 – SINTASHTA, SII, G. 2; 15 – SINTASHTA, SM, G. 39; 16 – SINTASHTA, SI, G. 4; 17 – SINTASHTA, SI, G. 3.

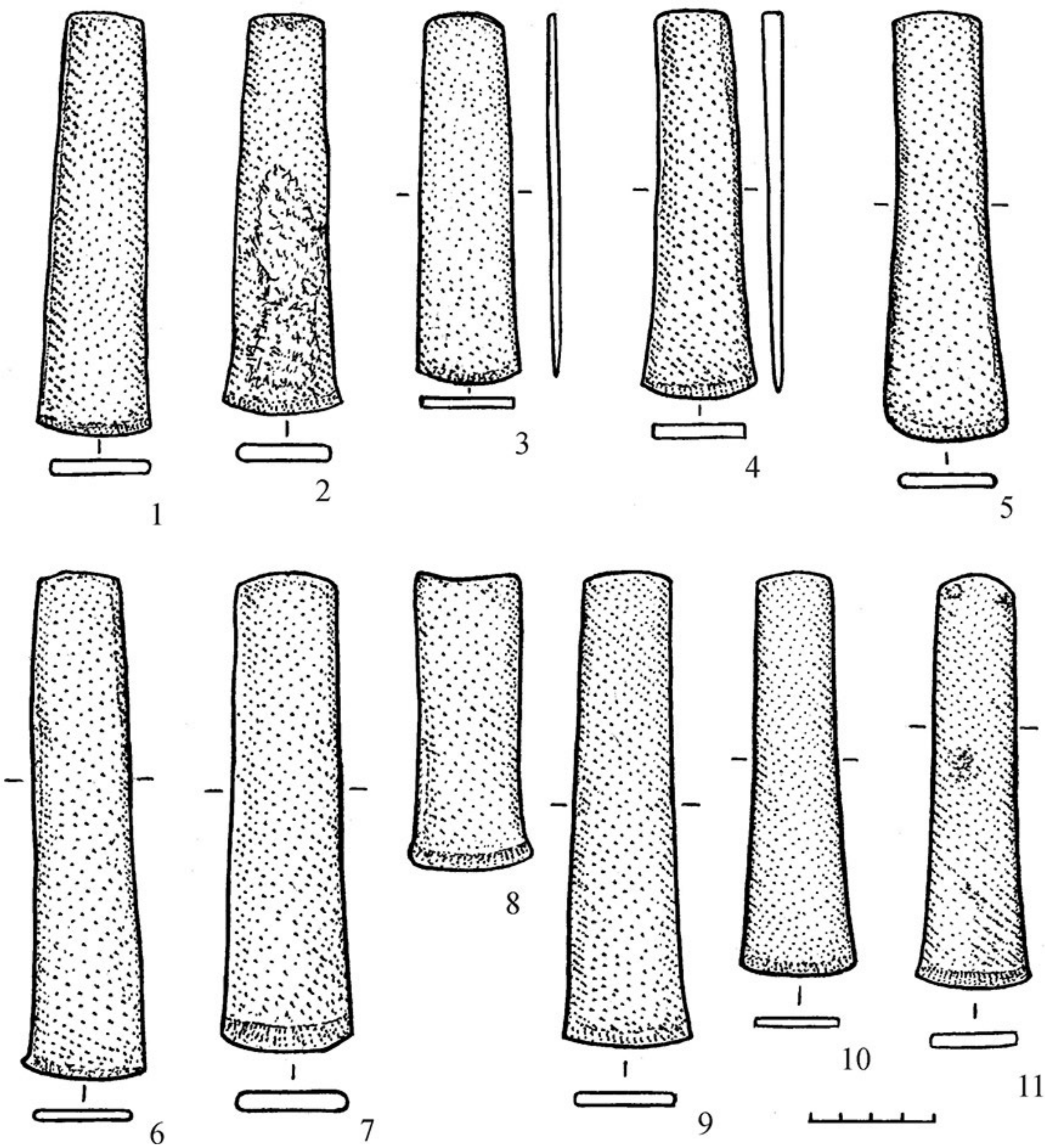


Fig. 6-5. Adzes. 1 – Sintashta, SI, g. 15; 2 – Sintashta, SI, g. 15; 3 – Sintashta, SM, g. 6; 4 – Sintashta, SII, g. 7; 5 – Bolshekaraganskiy, k. 25, g. 9, sample 69; 6 – Bolshekaraganskiy, k. 25, sample 64; 7, 11 – Sintashta, SI, g. 14; 8 – Bolshekaraganskiy, sample 36; 9 – Kamenniy Ambar, k. 4, g. 14, sample 108; 10 – Kamenniy Ambar, k. 4, sample 109.

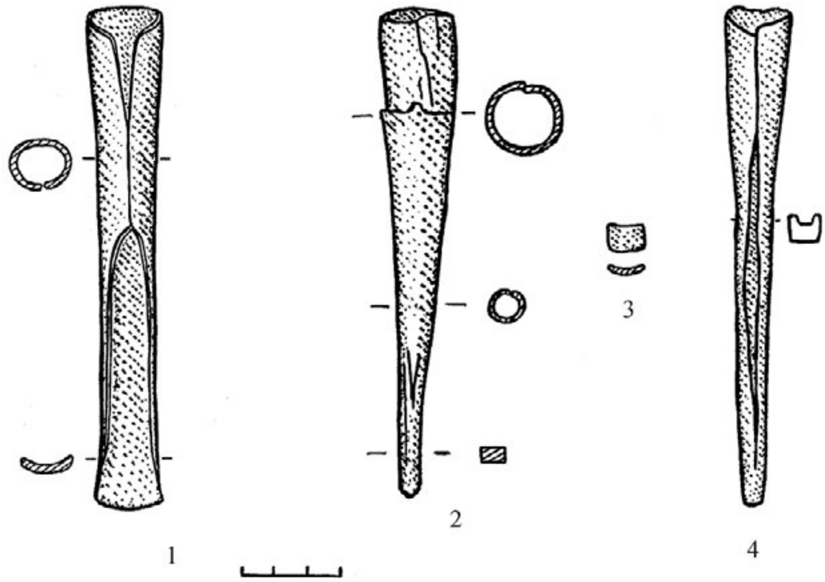


Fig. 6-6. Fig. 12. Socketed chisels. 1 – Bolshekaraganskiy, k. 25, g. 12, sample 67; 2 – Bolshekaraganskiy, k. 24, g. 1, sample 30; 3 – Sintashta, S I, g. 14; 4 – Tyubyak, 1990, R-3, section 3, 63/10, sample 134.

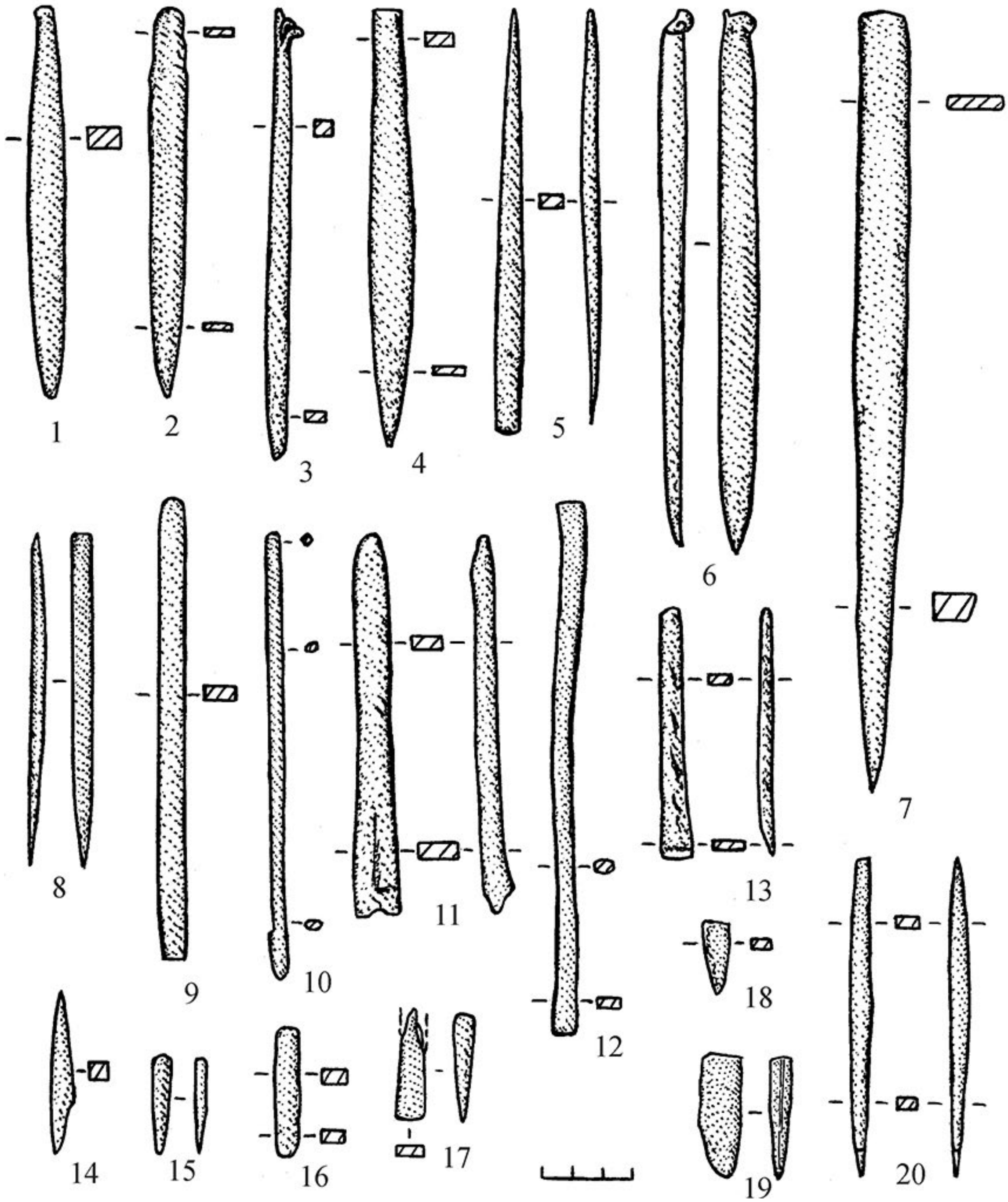


Fig. 6-7. Stemmed chisels, drifts, rods and wedges. 1 – Sintashta. SI, g.14; 2 – Tyubyak, 1990, R-3, 26/4, sample 130; 3 (sample 57), 9 (sample 81) – Arkaim; 4 – Birskoe I, R-VIII, 32/3, sample 122; 5 – Kamenniy Ambar, sample 116; 6 – Kamenniy Ambar, k.4, g. 8, sample 102; 7 – Kamenniy Ambar, k. 2, g. 8; 8 (sample 77), 11, 13, 16 (sample 63), 20 (sample 60) – Sintashta, settlement; 10 – Yumakovo, 1988, sample 139; 12 – Tyubyak, 1990, R-III, section 3, surface, sample 138; 14 – Sintashta. SI, mound; 15 – Kamenniy Ambar, sample 93; 17 – Sintashta, SM, g. 16; 18 – Bolshekaraganskiy, sample 66; 19 – Sintashta, SI, g. 1.

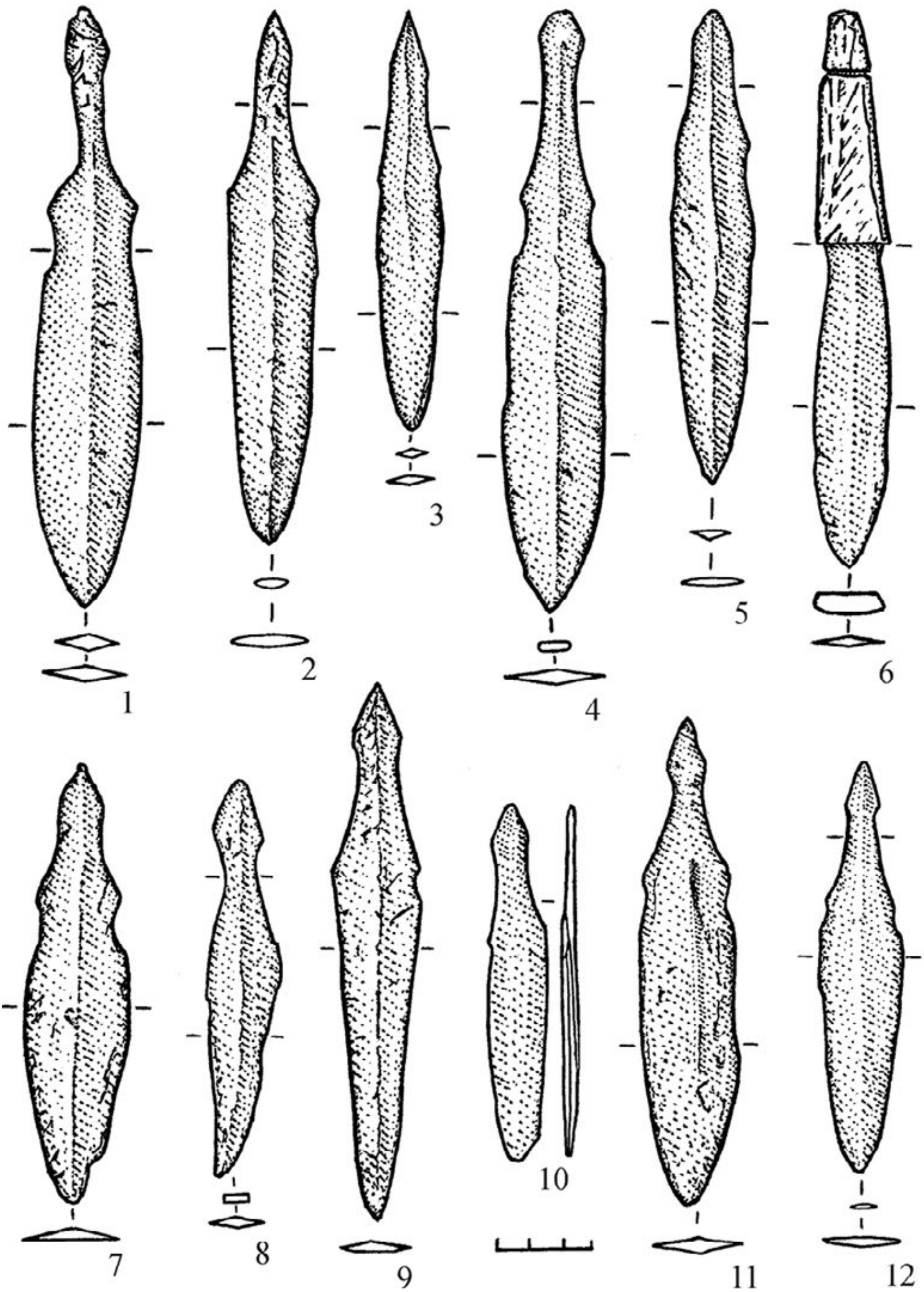


Fig. 6-8. Double-edged knives with waist and stop. 1 (sample 37), 2 (sample 38) – Bolshekaraganskiy, k. 24, g. 1; 3 – Bolshekaraganskiy, k. 24, g. 8, sample 40; 4 (sample 39), 5 (sample 87) – Bolshekaraganskiy, k. 11, g. 1; 6 – Bolshekaraganskiy, k. 11, g. 3, sample 33; 7 – Potapovka, k. 5, g. 14; 8 – Potapovka, k. 1, g. 5; 9 – Potapovka, k. 3, g. 8; 10 – Sintashta, SII, g. 7; 11 – Sintashta, SI, g. 14; 12 – Sintashta, SM, g. 5.

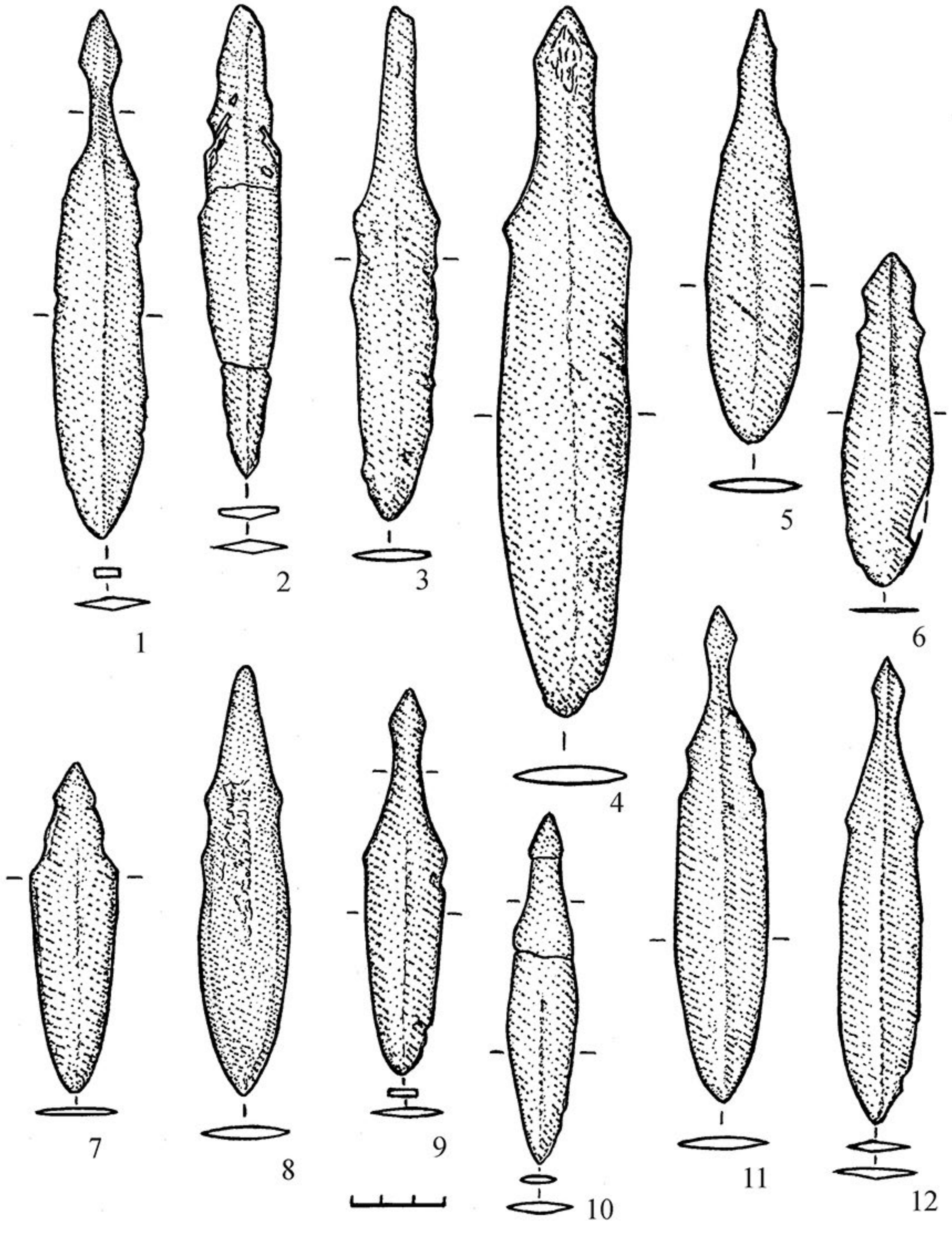


Fig. 6-9. Double-edged knives with waist and stop. 1 – Sintashta, SM, g. 39; 2 – Sintashta, SM, g. 27; 3, 4 – Sintashta, SI, g. 3; 5 – Sintashta, SI, g. 5; 6 – Sintashta, SM, g. 2; 7 – Sintashta, SM, g. 30; 8 – Sintashta, SI, g. 15; 9 – Sintashta, SM, g. 5; 10 – Sintashta, SM, g. 11; 11 – Sintashta, SI, g. 14; 12 – Sintashta, SM, g. 16.

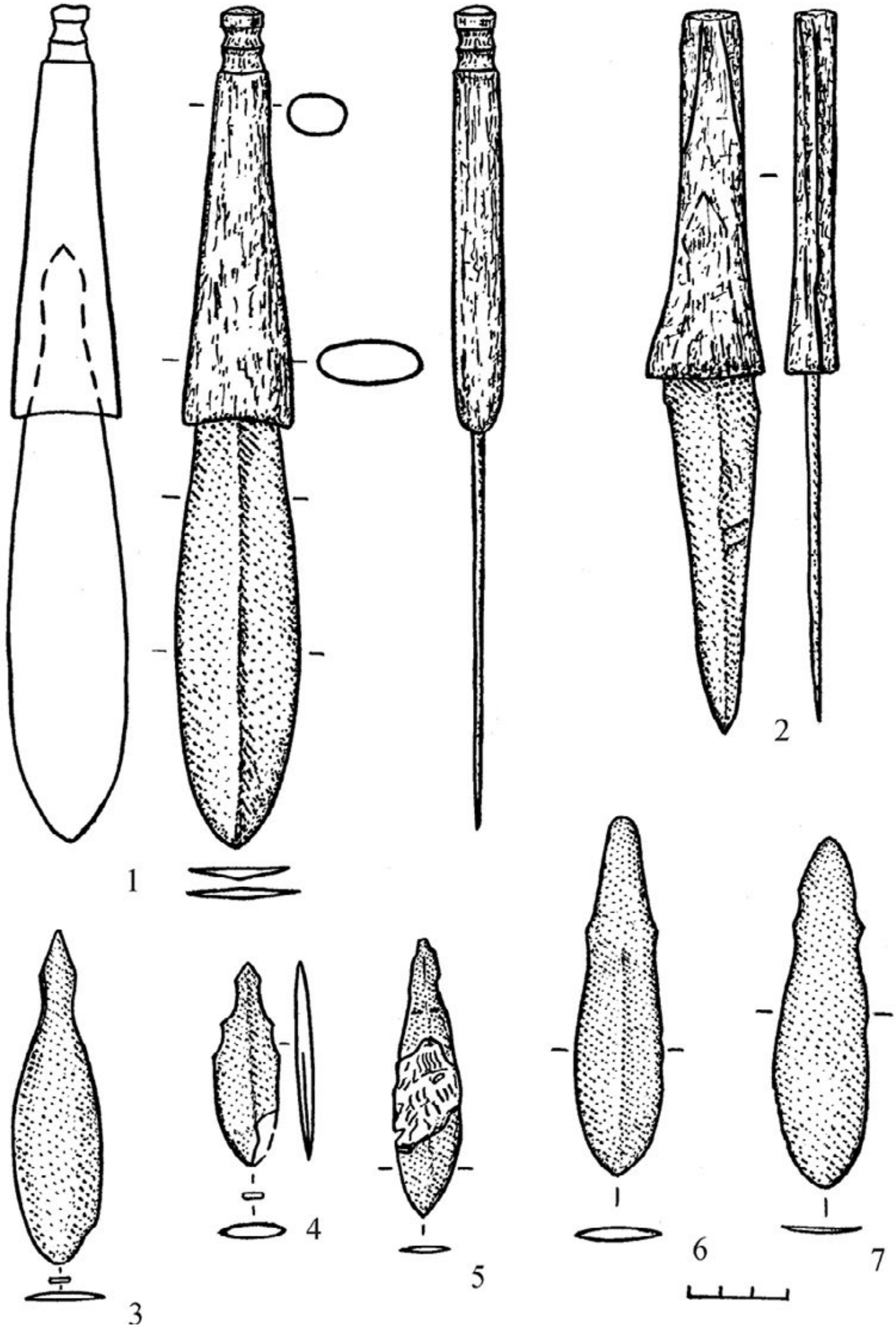


FIG. 6-10. DOUBLE-EDGED KNIVES WITH WAIST AND STOP. 1 – POTAPOVKA, K. 5, G. 8; 2 – POTAPOVKA, K. 3, G. 8; 3 – SINTASHTA, SM, G. 15; 4 – SINTASHTA, SII, G. 7; 5 – SINTASHTA, SI, G. 1; 6 – SINTASHTA, SI, G. 14; 7 – SINTASHTA, SM, G. 2.

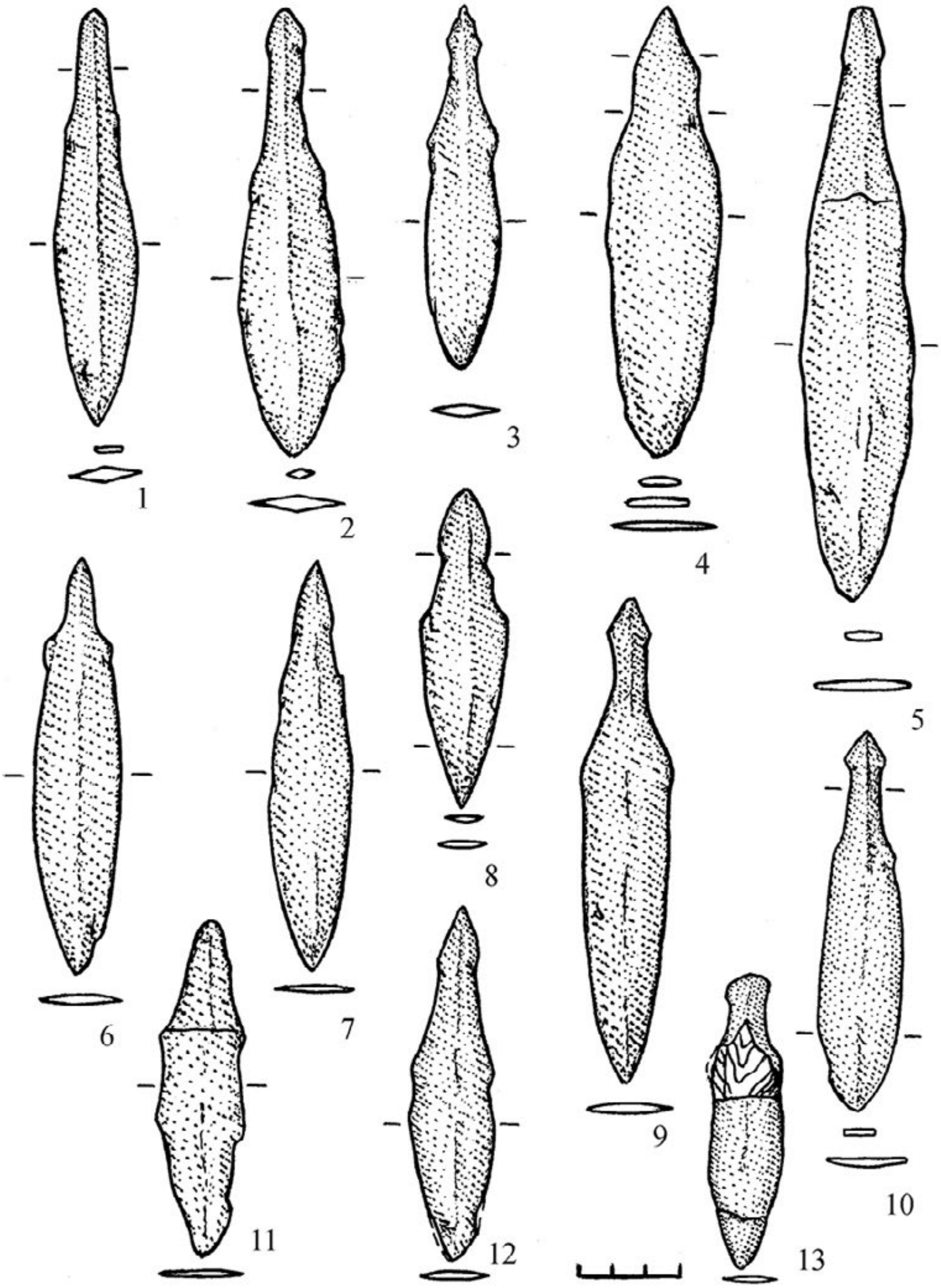


Fig. 6-11. Double-edged knives with waist and stop. 1 – Kamenniy Ambar, k. 2, g. 6, sample 113; 2 – Kamenniy Ambar, k. 2, g. 14, sample 117; 3 – Sintashta, SI, g. 1; 4 – Kamenniy Ambar, k. 2, g. 12; 5 – Kamenniy Ambar, k. 2, g. 15; 6 – Bolshekaraganskiy, k. 25. 496BK-723, sample 74; 7 – Bolshekaraganskiy, k. 25. 496BK-904, sample 75; 8 – Birskoe I, R-VII, 64/3, sample 123; 9 – Kamenniy Ambar, k. 4. 189-4-685, sample 107; 10 – Naberežniy, sample 128; 11 – Bolshekaraganskiy, k. 25, 1-27, sample 70; 12, 13 – Sintashta, SM, g. 6.

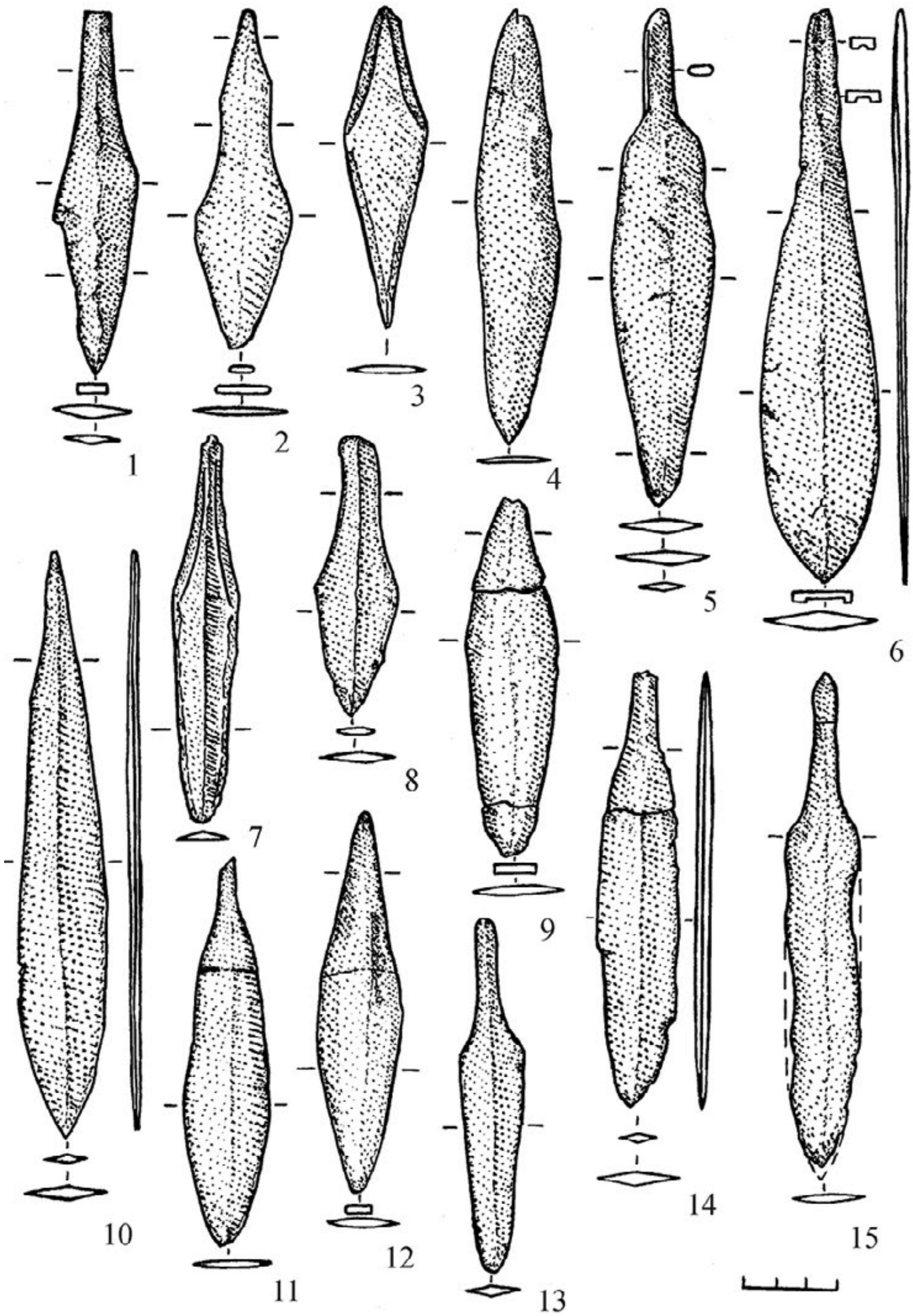


Fig. 6-12. Double-edged knives. 1 – Potapovka, k. 3, g. 5; 2 – Kamenniy Ambar, k. 2, g. 12, sample 114; 3 – Bolshekaraganskiy, k. 20, g. 7, sample 89; 4 – Potapovka, k. 5, g. 8; 5 – Potapovka, k. 2, g. 1; 6 – Potapovka, k. 1, g. 4; 7 – Potapovka, k. 5, g. 14; 8 – Potapovka, k. 3, g. 5; 9 – Sintashta, SM, g. 8; 10 – Sintashta, SII, g. 1; 11 – Sintashta, SM, g. 3; 12 – Sintashta, SM, g. 10; 13 – Bolshekaraganskiy, k. 25, 496BK-887; 14 – Sintashta, SII, g. 1; 15 – Sintashta, SM, g. 39.

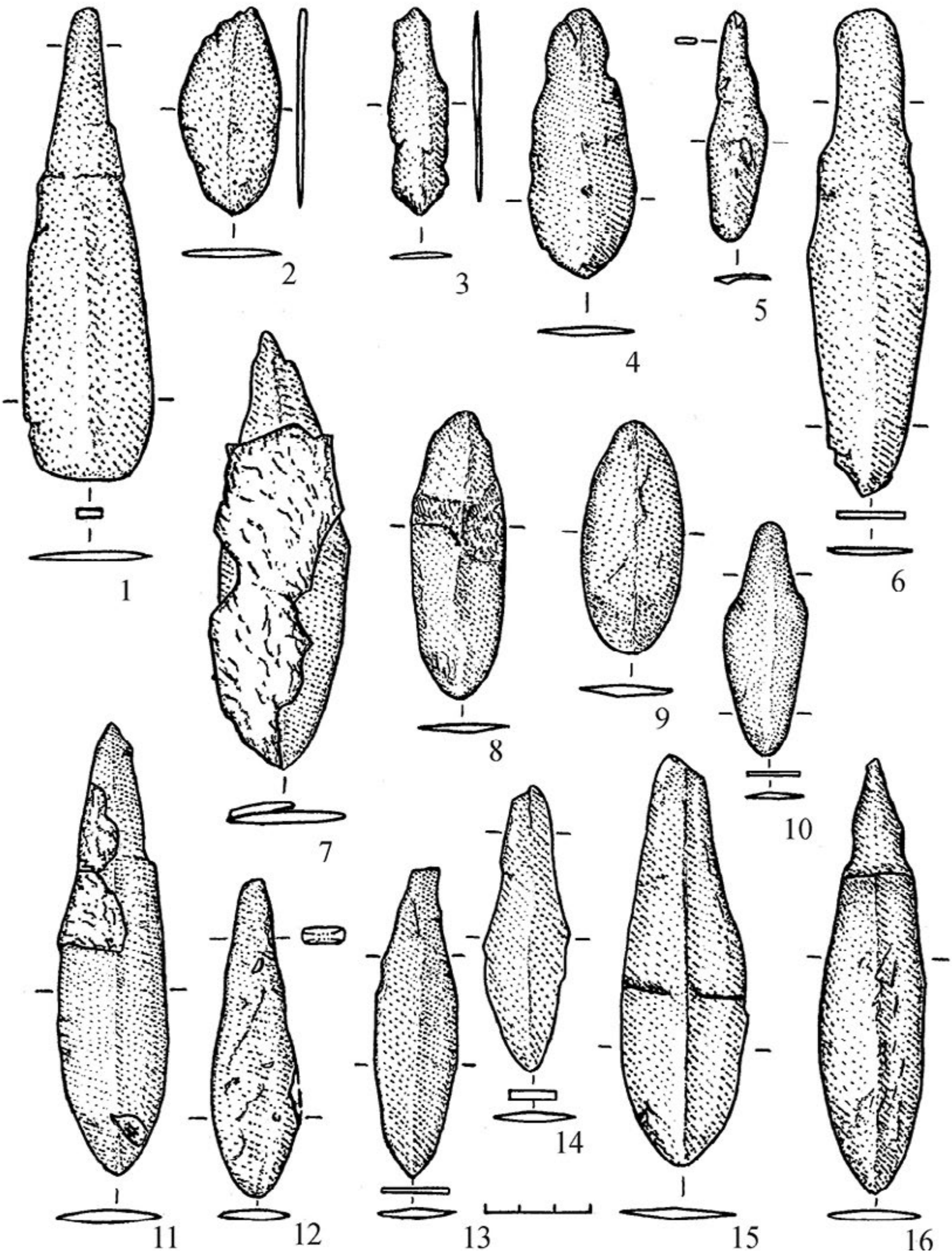


Fig. 6-13. Double-edged knives. 1 – Bolshekaraganskiy, k. 24, g. 9-2, sample 85; 2 – Potapovka, k. 1, g. 4; 3 – Potapovka, k. 3, g. 4; 4 – Bolshekaraganskiy, k. 11, mound; 5 – Sintashta, SIII, g. 1; 6 – Birskoe I, R-VII, 63/3, sample 121; 7 – Sintashta, SI, g. 4; 8, 9 – Potapovka, k. 5, g. 14; 10 – Birskoe I, R-VIII, 85/3, sample 124; 11 – Sintashta, SI, g. 4; 12 – Sintashta, SI, g. 14; 13 – Sintashta, SM, g. 21; 14 – Sintashta, SM, g. 18; 15 – Bolshekaraganskiy, k. 11, g. 5, sample 86; 16 – Potapovka, k. 5, g. 4.

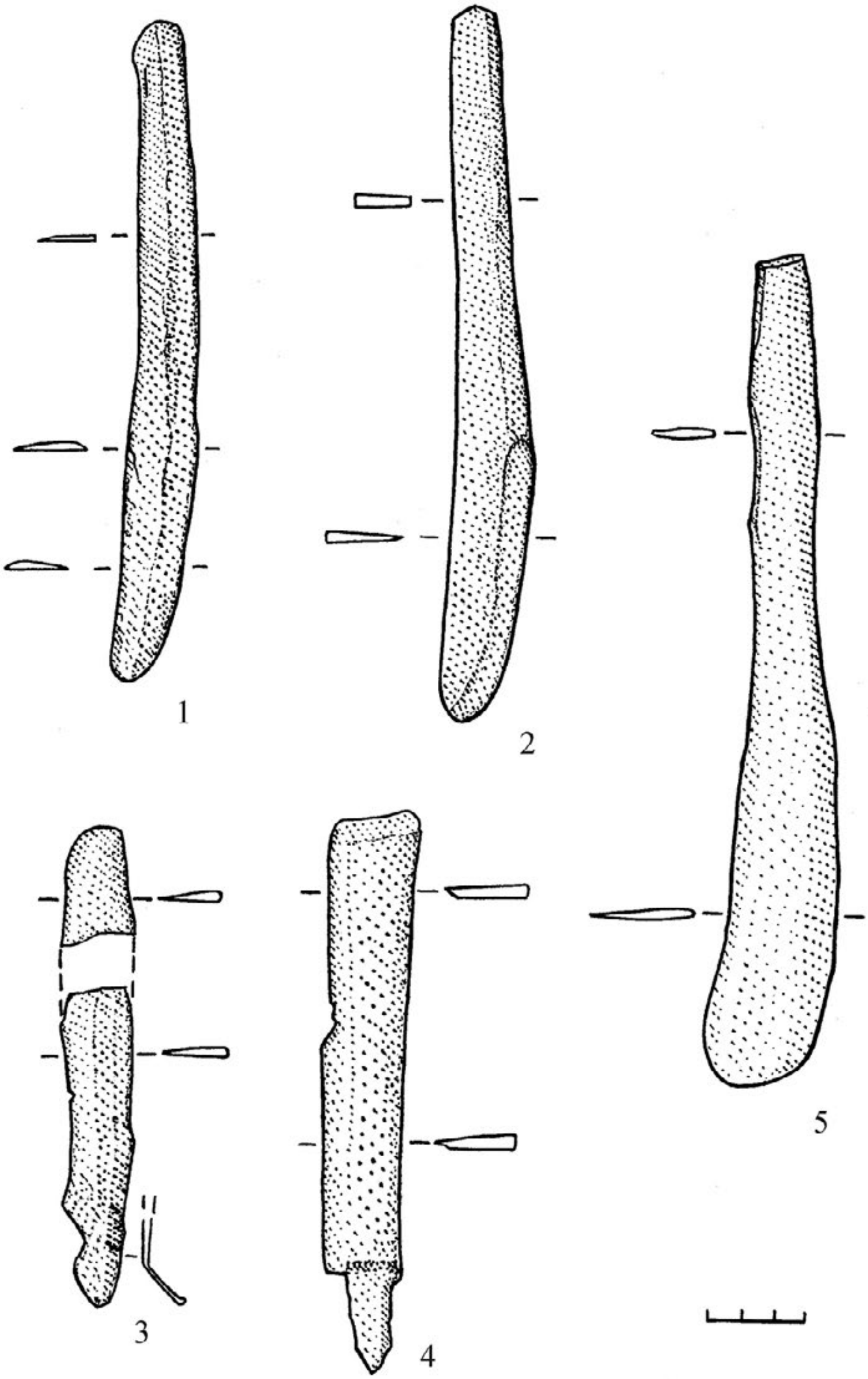


Fig. 6-14. Single-edged knives. 1 – Potapovka, k. 5, g. 13; 2 – Sintashta, SI, mound; 3, 4 (sample 59) – Sintashta, settlement; 5 – Kamenniy Ambar, k. 2, g. 8, sample 111.

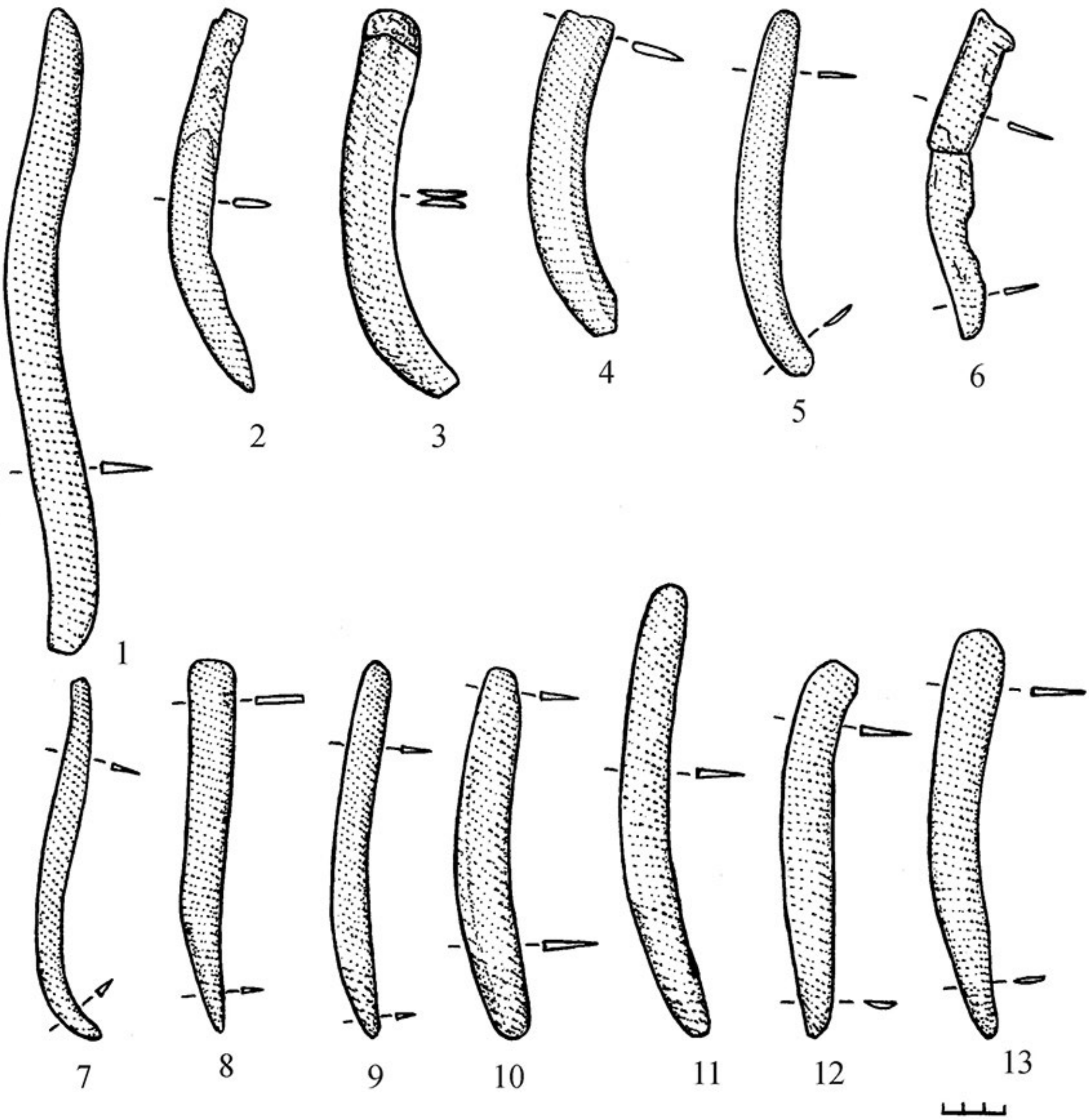


FIG. 6-15. SICKLES. 1 – SINTASHTA, SM, G. 11; 2 – SINTASHTA, SI, G.14; 3 – SINTASHTA, SI, G. 12; 4 – SINTASHTA SETTLEMENT; 5 – TYUBYAK, SECTION 3, 30\8, SAMPLE 136; 6 – KAMENNIY AMBAR, K. 2, G. 12; 7 – NABEREŽNIY CEMETERY, SAMPLE 125; 8 – BIRSKOE, DWELLING B, SECTION 87\2, SAMPLE 127; 9 – YUMAKOVO IV, R-1, 13\3, SAMPLE 131; 10 – YUMAKOVO I, 3A\3, DWELLING 1, SAMPLE 132; 11 – KAMENNIY AMBAR, K. 4, SAMPLE 106; 12 – YUMAKOVO III, SAMPLE 133; 13 – YUMAKOVO IV, SURFACE, SAMPLE 129.

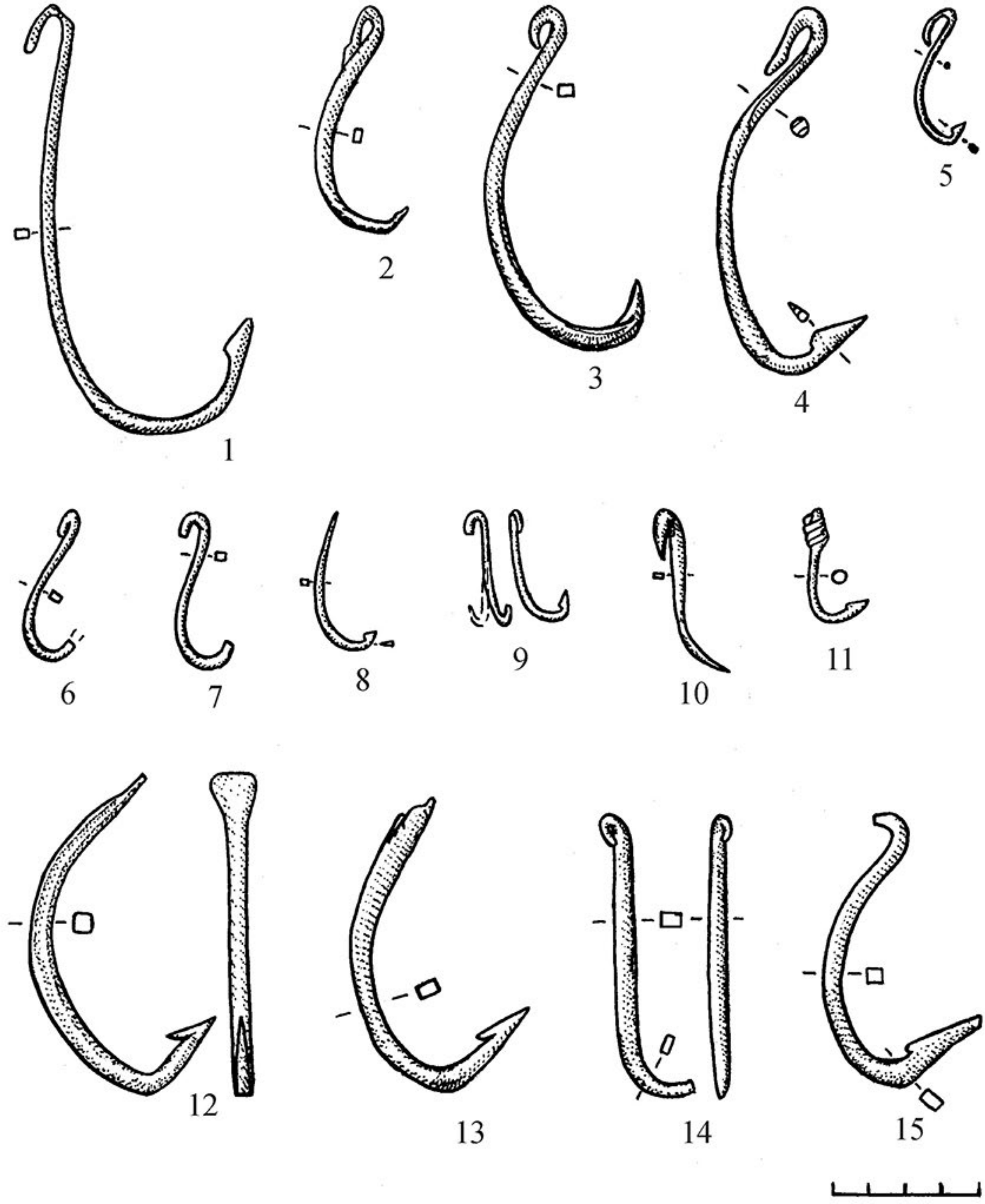


FIG. 6-16. FISHING HOOKS. 1 – ARKAIM (SAMPLE 88); 2 – POTAPOVKA, K. 5, G. 14; 3, 8 – SINTASHTA, SM, G. 39; 4, 5 – SOLNTSE, K. 11, G. 1; 6, 15 – SINTASHTA, SI, G. 14; 7 – SINTASHTA, SI, MOUND; 9 – SINTASHTA, SM, G. 35; 10 – POTAPOVKA, K. 3, G. 4; 11 – SINTASHTA, SI, G. 1; 12 – SINTASHTA, SM, G. 12; 13, 14 – SINTASHTA SETTLEMENT.

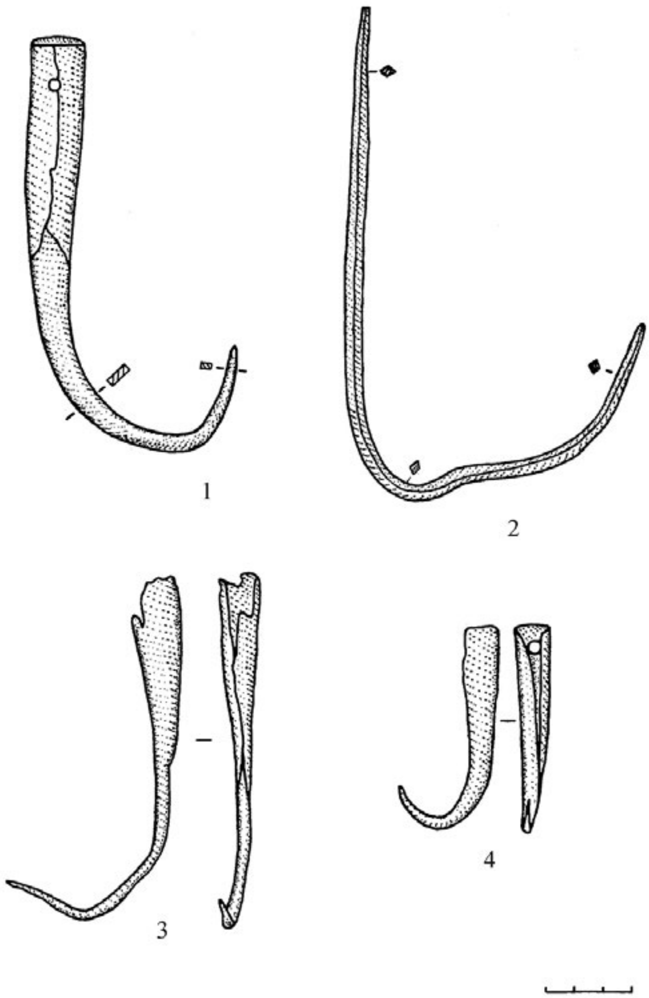


Fig. 6-17. Hooks. 1 – Tyubyak, 1990, R-3, section 3, 1\a, sample, 135; 2 – Tyubyak, 1990, sample 137 (curved rod), 3 – Shibaevo, sample, 119; 4 – Bolshekaraganskiy, k. 25, central part, sample 73.

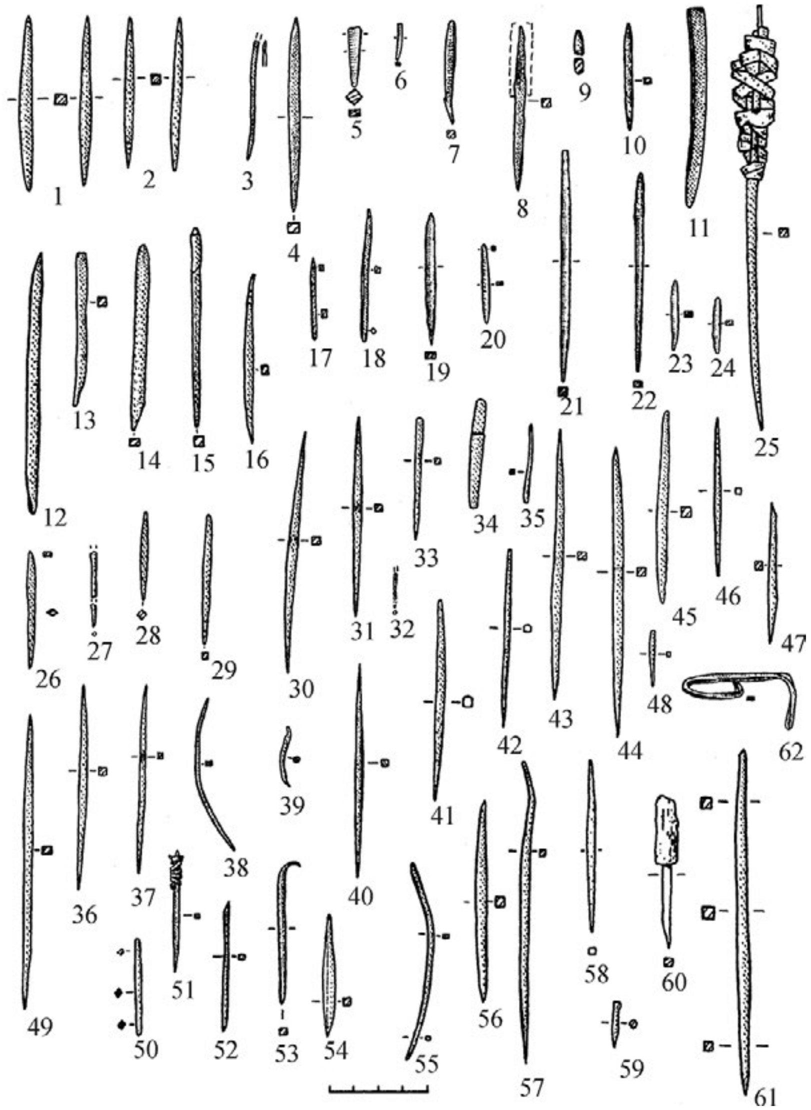


Fig. 6-18. Awls (1, 2, 4-26, 28-31, 33-38, 40-47, 49-61) and needles (3, 27, 32, 39, 48). 1 (sample 62), 2 (sample 78), 33 (sample 80), 34, 48 – Sintashta, settlement; 3, 7 – Sintashta. SM, g. 35; 4 – Sintashta. SI, g. 15; 5 – Sintashta. SM, g. 24; 6 – Sintashta, SI, g. 12; 8 – Sintashta. SI, g.1; 9 – Sintashta, S II, g. 7; 10 – Sintashta. SI, g.14; 11 – 13 – Sintashta. SI, mound; 14 – Sintashta, S II, g. 3; 15 – Sintashta, S II, g. 7; 16 – Potapovka, k. 3, g. 5; 17, 18 – Sintashta, S III, g. 1; 19 – Sintashta, SM, g. 2; 20 – Sintashta, SM, g. 3; 21 – Sintashta, SM, g. 4; 22 – Sintashta, SM, g. 9; 23, 24 – Sintashta, SM, g. 6; 25 – Bolshekaraganskiy, k. 24, g. 1, sample 53; 26 – Sintashta, SM, g. 11; 27 – Sintashta, SM, g. 13; 28 – Sintashta, SM, g. 18; 29 – Sintashta, SM, g. 22; 30 (sample 82), 31 (sample 90), 45 (sample 58) – Arkaim; 32 – Sintashta, SM, g. 23; 35, 38 – Tyubyak, 1990, R-III, section 3; 36 – Kamenniy Ambar, 189-K2-162; 37 – Kamenniy Ambar, k. 2, g. 5, sample 91; 39 – Sintashta, SI, g. 1; 40 – Bolshekaraganskiy, k. 24, g. 9-1; 41 (sample 115), 42 – Kamenniy Ambar, k. 2, g. 12; 43 – Bolshekaraganskiy (sample 72); 44 – Bolshekaraganskiy (sample 71); 46 – Bolshekaraganskiy, k. 22, g. 8; 47 – Potapovka, k. 1, g. 4; 49 – Tyubyak, 1989, R-III, section 3, 20/4, sample 140; 50 – Birskoe I, section 55; 51 – Bolshekaraganskiy, k. 24, g. 7; 52, 59 – Potapovka, k. 5, g. 11; 53 – Bolshekaraganskiy, k. 11, g. 3; 54 – Potapovka, k. 2, g. 1; 55 – Potapovka, k. 3, g. 8; 56 – Potapovka, k. 3, g. 5; 57 – Potapovka, k. 3, g. 4; 58 – Kamenniy Ambar, k. 2, g. 5; 60 – Solnce, k. 4, g. 3; 61 – Potapovka, k. 5, g. 8; 62 – Sintashta, SII, g. 1.

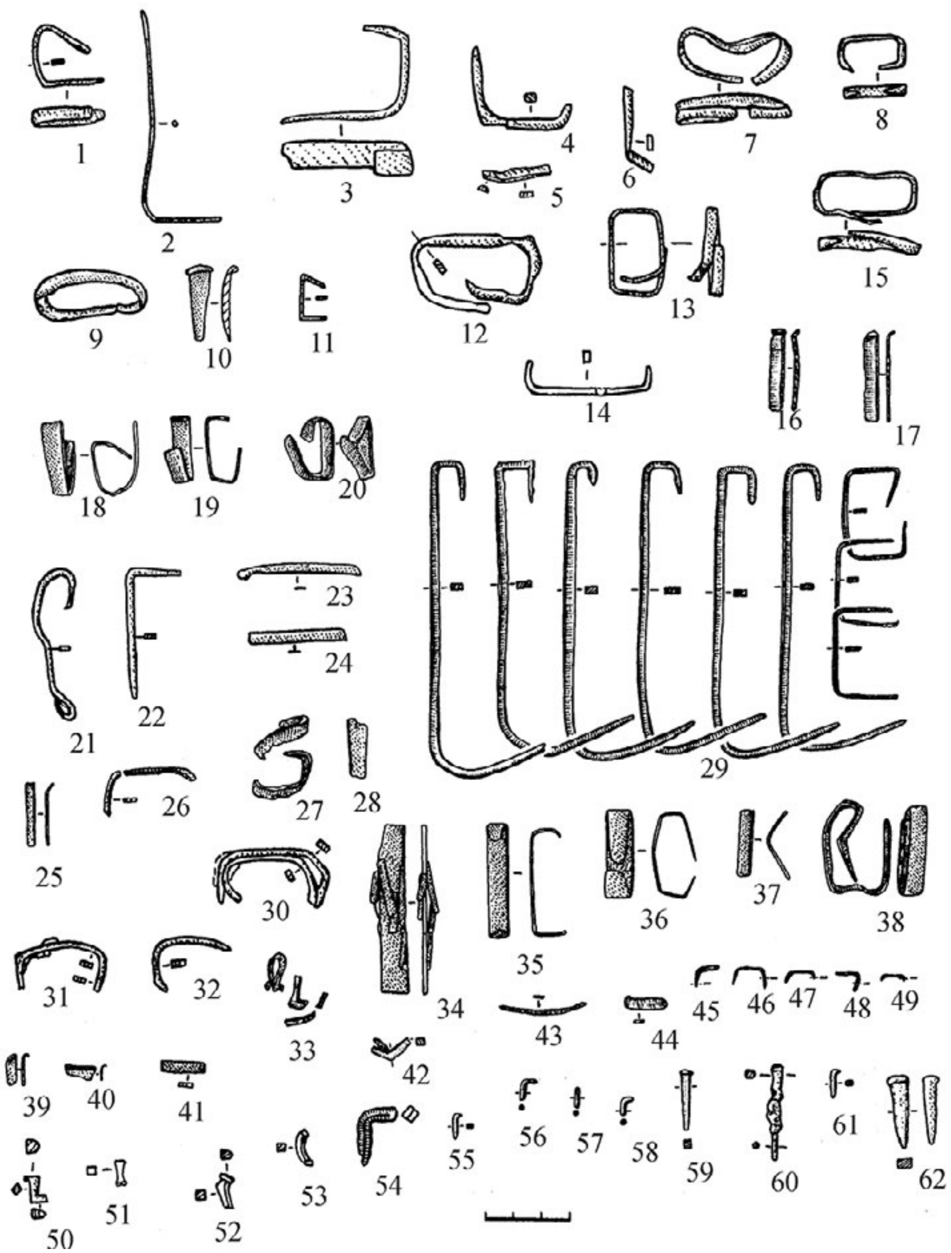


FIG. 6-19. CLIPS (3-9, 11-15, 18-20, 23, 24, 26, 35-38, 41, 43, 44), STAPLES (1, 22, 29, 30-32, 45-49, 54), NAILS (55, 59-62), FRAGMENTS OF SMALL PLATES (10, 16, 17, 25, 27, 28, 33, 39, 40, 42), RIVETS (50-53, 56-58), WIRE (2, 21). 1, 2 – KAMENNIY AMBAR. K. 2, G. 17; 3, 60 – KAMENNIY AMBAR. K. 2, G. 8; 4 – KAMENNIY AMBAR. K. 2, MOUND; 5, 6 – SINTASHTA, SII, G. 2; 7 – POTAPOVKA, K. 3, G. 8; 8 – POTAPOVKA; 9 – SINTASHTA, SETTLEMENT, SAMPLE 79; 10, 18 – 20 – SINTASHTA, SM, G. 28; 11 – BOLSHEKARAGANSKIY, 496BK-708, SAMPLE 68; 12 – SINTASHTA SETTLEMENT, SAMPLE 61; 13 – KAMENNIY AMBAR. K. 2, G. 5; 14 – SINTASHTA, SI, G. 14; 15 – POTAPOVKA, K. 3, G. 4; 16, 17 – SINTASHTA, SM, G. 24; 21 – TYUBYAK, R-VII, SAMPLE 143; 22 – TYUBYAK, 1990, R-3, SAMPLE 142; 23, 24, 43, 44 – SINTASHTA, SII, G. 1; 25 – SINTASHTA, SM, G. 22; 26, 28 – SINTASHTA, SM, G. 23; 27 – SINTASHTA, SM, G. 25; 29 – SINTASHTA, SM, G. 2; 30 – 32, 50 – 53 – SINTASHTA, SII, G. 7; 33 – SINTASHTA, SIII, G. 1; 34 – 38 – SINTASHTA, SM, G. 35; 39, 40 – SINTASHTA, SM, G. 13; 41 – SINTASHTA, SII, G. 2; 42, 59 – SINTASHTA, SM, G. 12; 45 – 49, 55, 61 – SINTASHTA, SM, G. 6; 54 – SINTASHTA, SM, G. 8; 56 – 58 – SINTASHTA, SM, G. 39; 62 – SINTASHTA, SM, G. 3.

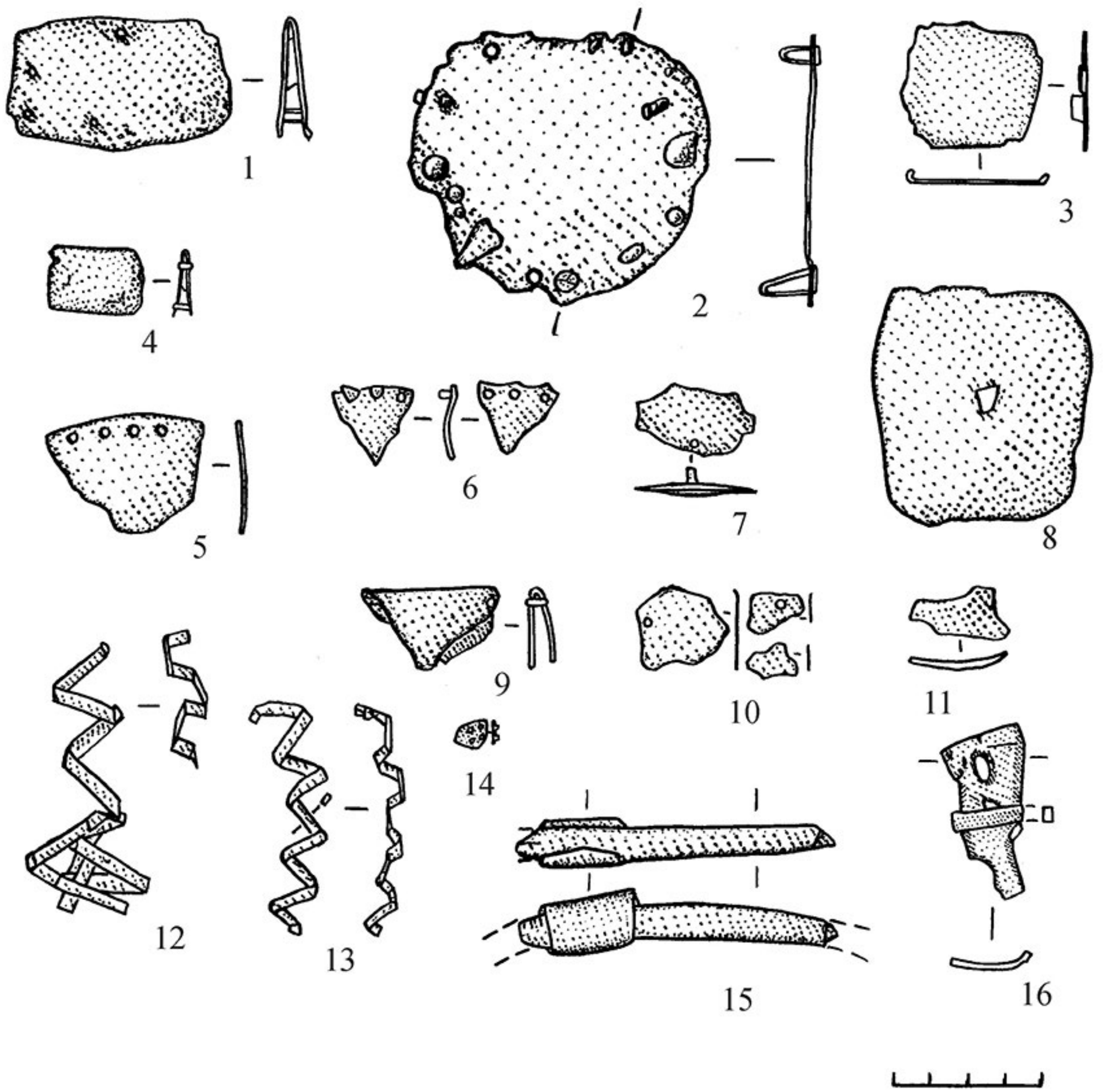


FIG. 6-20. PLATES AND OTHERS (1, 4 – 6, 9 – FLAT PLATES ON THE RIM OF WOODEN VESSELS; 2, 3, 7, 8, 10, 11 – FLAT PLATES; 12, 13 – BANDS; 14 – FRAGMENT OF AN UNCERTAIN PLATE; 15 – ROD; 16 – FRAGMENT OF AN UNCERTAIN ARTICLE). 1 – BOLSHEKARAGANSKIY, K. 24, G. 1, SAMPLE 54; 2, 16 – BOLSHEKARAGANSKIY, K. 24, G. 2; 3 – KAMENNIY AMBAR. K. 2, G. 6; 4 – BOLSHEKARAGANSKIY, K. 24, G. 9-1; 5, 6, 9 – SINTASHTA, SI, G. 16; 7 – SINTASHTA, SII, G. 2; 8 – TYUBYAK, 1988, R-III, 26/1, SAMPLE 141; 10 – SINTASHTA, SM, G. 15; 11 – SINTASHTA, SM, G. 28; 12 – SOLNTSE, K. 5, G. 1; 13 – KAMENNIY AMBAR, K. 2, G. 5; 14 – SINTASHTA, SM, G. 19; 15 – SINTASHTA, SETTLEMENT.

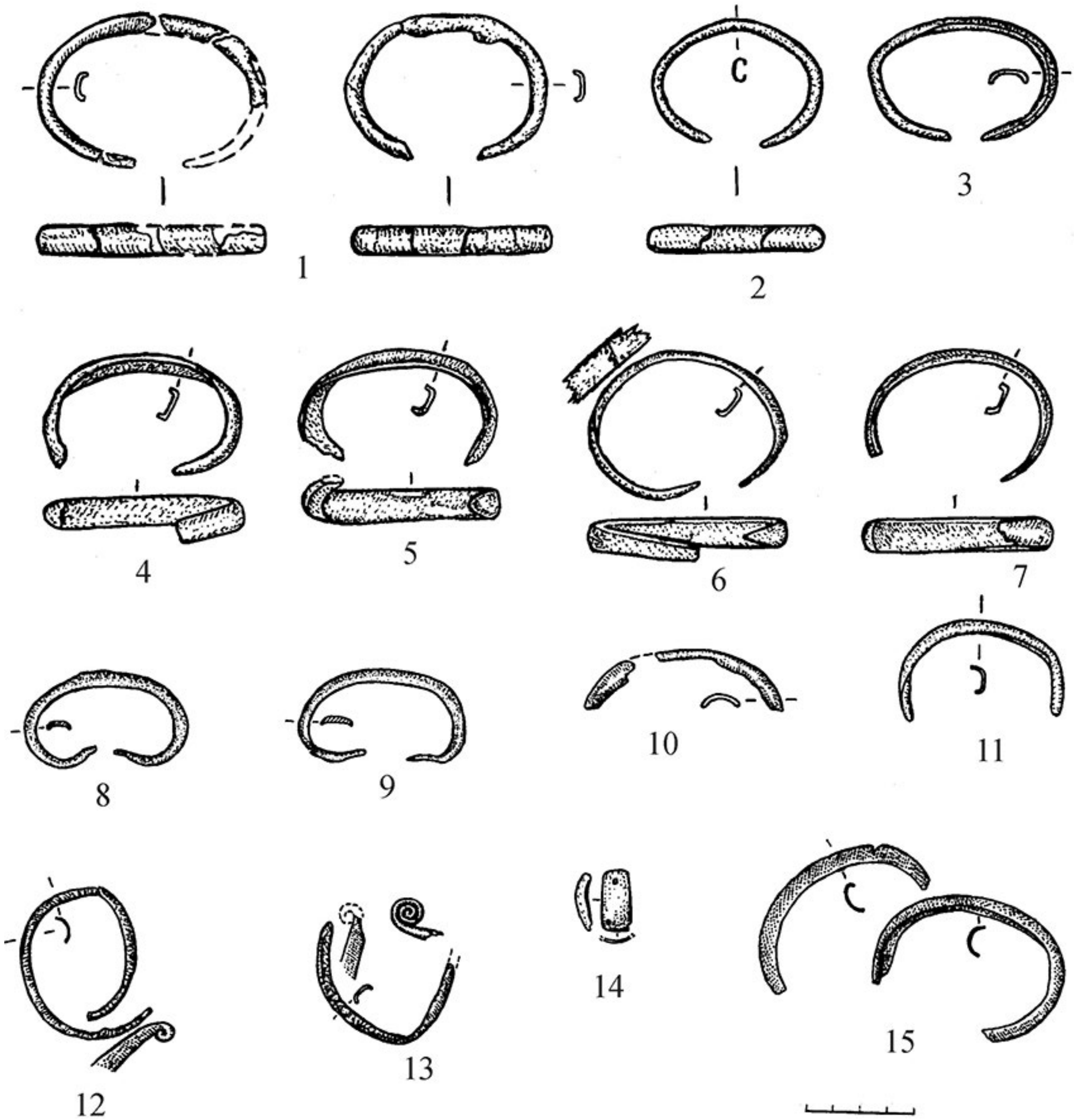


FIG. 6-21. BRACELETS. 1 – BOLSHEKARAGANSKIY, K. 20, G. 3, SAMPLE 55; 2 – SINTASHTA, SETTLEMENT; 3 – SINTASHTA, SI, G. 12; 4-7 – POTAPOVKA, K. 3, G. 8; 8, 9 – SINTASHTA, SI, G. 11; 10 – SINTASHTA, SI, G. 12; 11 – KAMENNIY AMBAR, K. 2, G. 12; 12, 13, 15 – SINTASHTA, SII, G. 2; 14 – SINTASHTA, SM, G. 13.

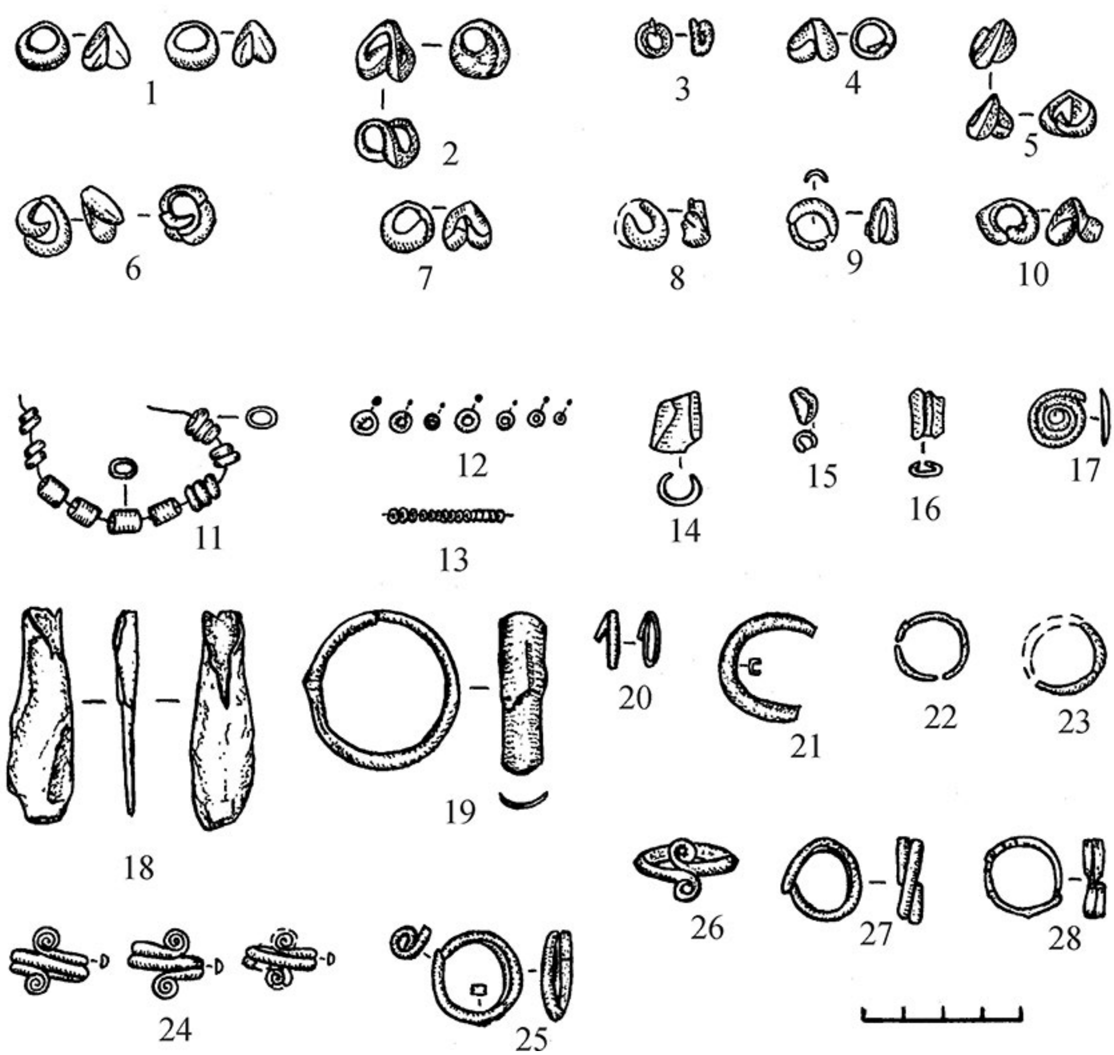


FIG. 6-22. ORNAMENTS. 1 – SINTASHTA, SM, G. 2; 2 – SINTASHTA, SI, G. 12; 3 – POTAPOVKA, K. 3, G. 5; 4 – KAMENNIY AMBAR, K. 2, G. 17; 5, 11 – BOLSHEKARAGANSKIY, K. 20, G. 3; 6 – SINTASHTA, SM, G. 13; 7, 8, 23 – SINTASHTA, SM, G. 17; 9 – POTAPOVKA, K. 3, G. 2; 10 – POTAPOVKA, K. 3, G. 8; 12, 18, 22 – POTAPOVKA, K. 5, G. 11; 13 – SINTASHTA, SM, G. 5; 14 – KAMENNIY AMBAR, K. 2, MOUND; 15 – KAMENNIY AMBAR, K. 2, G. 11; 16 – POTAPOVKA, K. 2, G. 4; 17 – POTAPOVKA, K. 3, G. 4; 19 – BOLSHEKARAGANSKIY, K. 24, G. 9-1; 20 – BOLSHEKARAGANSKIY, K. 24, G. 3; 21 – POTAPOVKA, K. 1, G. 4; 24 – SINTASHTA, SM, G. 39; 25 – SINTASHTA, SI, G. 9; 26 – SINTASHTA, SII, G. 7; 27 – SINTASHTA, SI, G. 14; 28 – KAMENNIY AMBAR, K. 2, G. 5.

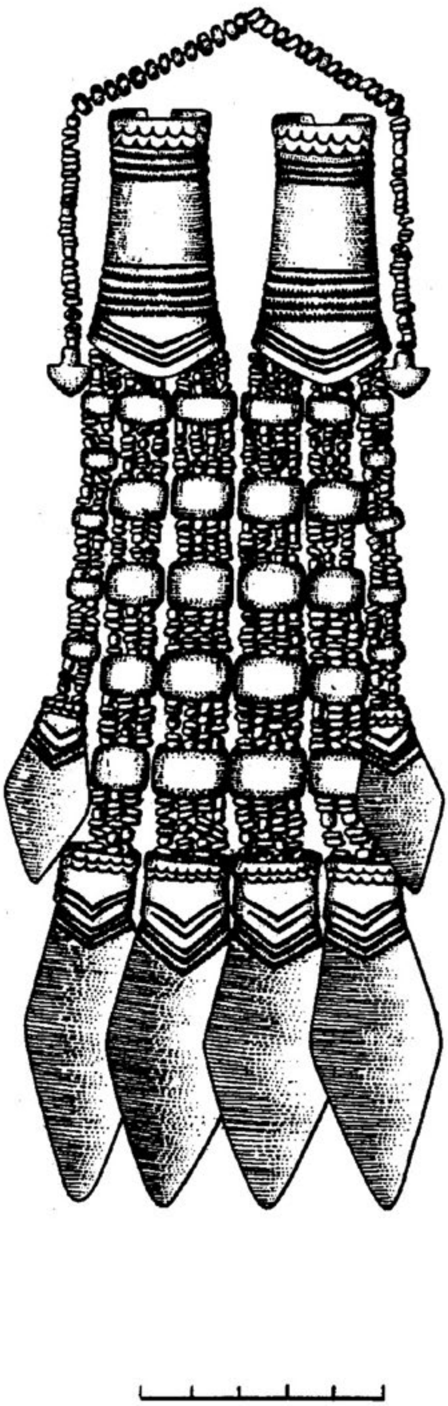


Fig. 6-23. Set of ornaments of silver, and paste beads. Sintashta, SM, g. 22.

Chapter 7.
Chronology, Genesis and Structure of Sintashta Metallurgy

Chronology of Sintashta culture

Before to discuss the possible sources of Sintashta metallurgy, it is necessary to solve problems of its chronological framework. Different authors refer the Sintashta culture to the beginning of the Late Bronze Age, some transitional stage between the Middle and Late Bronze Age or to the end of the Middle Bronze Age. This problem is caused by that chronologically Sintashta is synchronous to complexes of the Middle Bronze Age in the west and the Late Bronze Age in the east. Many years ago I explained it to that within the first stage of the Eurasian Metallurgical Province (EAMP) the forming impulses were multidirectional, and the system possessed a considerable dynamism (Grigoriev 1994). But the problem is that in the Sintashta culture there are things which earlier are present in complexes of the Circumpontic Metallurgical Province (CMP) of the MBA, and things, characteristic of complexes of the Eurasian Metallurgical Province of the LBA. It is clear that in this case historico-metallurgical criteria are most important. In this regard A.D. Degtyareva (2010, p. 142) writes that ”There are no objects, in particular axes, cast in not completely closed moulds. For these reasons Sintashta metal cannot be attributed to the Middle Bronze Age within frameworks of the Circumpontic Province that some scholars argue”. Being one of these some scholars, I should notice that from the above-stated analysis of Sintashta metalworking made by Degtyareva herself, unambiguously follows that casting in completely closed forms in Sintashta culture was used seldom, as a matter of fact, it was used only for axes, arrows and a part of knives; and complicated casting was not mastered. Moreover, attempts of use of tin alloys showed a lack of experience with this material. From here a question follows: whether we might only on the basis of axes to refer the Sintashta culture to the LBA? If so, is it necessary to reconsider the Near Eastern chronology where the shaft-bushed axes are well-known in the MBA complexes? By the way, at this time tin bronze are well-known there too, although they did not dominate. It is a question of basic technologies. Arsenic alloys are an indispensable attribute of the CMP, and they are less peculiar to the EAMP (if not to consider Sintashta and Abashevo complexes), that can find confirmation in any work of E.N. Chernykh. A.D. Degtyareva herself believes possible to correlate the Sintashta metalworking just with the Catacomb one, and, analyzing material, we really see many parallels in the Catacomb complex. The main thing is in lack of tin ligatures and complicated casting.

However any consideration of Sintashta culture (within either the MBA or the LBA) does not help to advance in solution of the problem of its metalworking formation because for this purpose the relation with other cultures is important. It is possible to give many examples of the Neolithic complexes coexisted with the Bronze Age cultures.

The question of relative chronology of Sintashta has been discussed in 2005 in Chelyabinsk within the round table “Origins and chronology of Sintashta culture”. Of course, a uniform point of view has not been accepted there, but the majority of experts inclined to the thought of synchronization of Sintashta with Abashevo culture, late Catacomb and partly with Seima-Turbino complexes (Origin and chronology … 2010). The question of relative and absolute Sintashta chronology I considered quite in detail, and, the absolute chronology was based on the typological analysis and comparison with the Near Eastern and Central European complexes, instead of on radio-carbon dating which we will discuss below (Grigoriev 2002, p. 106-108, 130-137; Grigoriev 2010a). It allowed Sintashta culture to be synchronized with Abashevo (for the Don-Volga Abashevo culture later dates are possible too), Late Catacomb, partly Seima-Turbino sites which arose later, but existed some period after Sintashta culture.

In the system of calibrated radio-carbon chronology the absolute dates of Sintashta fall within the first quarter of the 2nd millennium BC. The same interval is demonstrated also by radio-carbon dates with probability of 68.2% (Epimakhov 2010). It shows, as a whole, the correctness of this interval. It should be noted, however, that E.N. Chernykh offers another, slightly wider interval based on 42 dates at the same probability – 2200-1650 BC (Chernykh 2007, fig. 5.1 5.10). We will not discuss here the reasons of this expansion of the interval and which of them is more correct. It is a problem of specialized studies. In general, the radio-carbon method has a lot of problems[1], but it works well at large sampling and allows chronological ranges of various cultures to be compared. In this case exactly the last is interesting to us. Therefore, even at an assumption of illegality of the dates, within one technique of processing their comparison is quite correct. E.N. Chernykh gives the same ranges of dates of the Catacomb (2650-1850 BC) and Abashevo (2200-1650 BC) cultures. Respectively, we see that Abashevo culture is completely synchronous with Sintashta, as well as the late Catacomb cultures. At the same time, Sintashta can be synchronized with Seima-Turbino sites, and at its late stage with the early Timber-grave culture (ibid.). All this quite corresponds to that follows also from the material analysis, and should lie in the basis of the solution of problem of Sintashta metallurgy origins.

Roots of Sintashta metallurgy

One of characteristics of a complex of metal is the connection of metal with certain types of sites, morphological classes of objects and types of ligatures. We repeatedly discussed this problem (e.g. Grigoriev 2002, p. 74-76), therefore here we will not touch upon these questions. Eventually, the first two parameters reflect rather social and ritual aspects, than technological one, and here it would be undesirable to digress from the technological aspect. Therefore only the ratio of types of ligatures is a basic question. In previous time (the MBA) the dominating in Sintashta arsenic alloys were not almost in use in the Volga-Ural region. Exception is the Ural Abashevo metallurgy (so-called Balanbash center of production), if from the general review of the territory to go to more concrete objects. And as we will see subsequently, there are some connections based on other technological features, and not just on types of alloy and artifact. But Abashevo does not precede Sintashta. In addition to this, the same question of roots of the Ural Abashevo metallurgy is justified in the same measure as it is justified in relation to Sintashta metallurgy. In the Middle Volga it really could not origin. It is also justified for both the metalworking (Degtyareva 2010, p. 134) and metallurgy.

In the Balkan-Carpathian region the metallurgists preferred the tin bronze and pure copper, arsenic bronze follows them. The comparisons are possible with the steppe zone of Eastern Europe, the Caucasus, Anatolia, Levant and Mesopotamia (Černykh *et al.*1991, p. 601; Chernykh 2007, fig. 4.2). The last area, however, cannot be considered as metal was imported into it.

Because, as shown above, the alloying was making at the stage of ore smelting, and searches for an initial area for Sintashta metallurgy have to be carried out in an area where not only metalworking was known, but also the proper metallurgy. Several years ago it allowed me (Grigoriev 1994; 2000, p. 514) to refuse the Catacomb area of Eastern Europe as traces of metallurgy are not known there, and it was supposed that metal was imported into this area from some areas to the south from the Caucasian ridge[2] (Chernykh 1966, p. 47, 69). However it is not excluded that this question simply is not studied properly. Nevertheless, the Catacomb area as a source for emergence of Sintashta metallurgy is improbable as in Sintashta metallurgy the alloying was

[1] In particular, from the statistical point of view the confidence interval of 68.2% is not too reliable, but the intervals with the reliability of 90% are so wide that do not leave a space for intelligible discussion. And it is not the single paradox. Therefore R. Mimokhod is absolutely right, calling this chronology not 'absolute', but 'radiocarbon', emphasizing, thereby, its conditional character and correctness inside itself, instead of at the comparison with other systems of periodization and chronology (Mimokhod 2009, p. 51).

[2] A much less significant motive of this refusal was the absence in the MBA of Eastern Europe of alloys with tin, in limited quantity presented in Sintashta culture and more in the south of the CMP, but while the nature of the Sintashta tin bronzes is unclear to us. They could be introduced as a technological tradition together with the forming impulse, but then there is a question – from which sources the raw materials for this alloy were delivered in the Urals? Therefore it seems to be more justified to consider them as a sign of contacts with Seima-Turbino populations at some stage of Sintashta culture. Although it is impossible to prove such origin of this metal analytically yet, as well as its relatively late chronological position within the Sintashta culture.

carried out by any arsenic-nickel minerals, and it was closely connected with the subsequent metalworking operations. Respectively, the most acceptable is an area where nickel impurities in the arsenic bronzes are recorded. Those are well-known in Maikop culture separated from Sintashta by too wide chronological interval but where these impurities were technologically caused too. Therefore we may discuss that this technology of use of arsenic-nickel minerals as an alloying agent penetrated to the north twice.

The important parallel is also mining and melting ores in the ultrabasic rocks that was characteristic of Sintashta and of regions of the ophiolite belt of the Near East which includes Southeastern Anatolia. As a result we have even identical slag microstructures. Use of these ores in the Urals was a bad choice, and it indicates the existence of a strong technological tradition. It is not excluded that these traditions of the used ore base, technologies of smelting and alloying at the ore smelting stage were connected. Smelting of ores from the ultrabasic rocks did not demand so high temperatures and duration, as smelting of ores from acid rocks, and it prevented from the arsenic sublimation[3]. The problem, of course, could be solved, but for this purpose it was necessary to place exclusively pure pieces of malachite into the furnace and to smelt without producing slag that could not be a base for mass production. There was one more technological element closely connected with the need of ore smelting at low temperatures. In the smelting were, mainly, used oxidized ores with impurity of secondary sulfides. But when smelting this ore it was necessary to create the reducing atmosphere that was decided by generation of carbon monoxide by blasting from the well. Another constructive element of the Sintashta furnace is a flue which promoted removal of sulfur and arsenic out of room.

But technologies of metalworking were also closely connected with these technological operations, as arsenic bronzes and furthermore bronzes with nickel impurity should be forged at certain modes. From here also a set of types of metal follows which was possible to manufacture using these technologies, although in this case variations were already possible, but there were also some unconditional limiting factors hindering the possibility of manufacturing this or that type. It is obvious that the use of either pure or alloyed copper demanded different methods of objects production and allowed to manufacture different types of these objects. On the other hand, the use of tin and arsenic alloys was also focused on different types and demanded different casting and forging operations, different temperature modes of these operations (Degtyareva 2010, p. 14-19).

And here it is worthy of attention that the Sintashta metalworking focused, above all, on production of objects from arsenic copper, was characterized by perfect forging technologies, their high compliance to this type of raw materials and the lowest level of spoilage that reflects the following to a stable technological tradition.

Therefore this metalworking could arise only in a region where a long tradition of the use of arsenic copper was. On the South Ural sites of Pit-grave culture only three objects with higher arsenic concentrations are known, and for them the Caucasian origin has been supposed. In this respect the knife from arsenic copper from the Boldyrevski I mound is indicative. It was made according to a very different technological scheme (it was cast and then processed by cold forging with the reduction of 50-60%), while other Pit-grave knifes were forged in a temperature interval of 600-800 °C or 900-1000 °C from what the conclusion about direct its import has been drawn (Degtyareva 2010, p. 44, 45, 50).

From the point of view of metalworking, (the types of alloy considered above, arsenic concentrations, technologies, and types of objects) the area of their origins should be situated also within the CMP, though in the northern zone of CMP these parallels belong, mainly, to the late Catacomb time that was synchronous to Sintashta. In the southern bloc of CMP the parallels are known in the Near East. Therefore it is possible to

[3] And in this regard it seems to be quite justified to search in areas of copper deposits in the ultrabasic rocks of Ciscaucasia to find traces of mining and metallurgical production of Maikop culture.

assume that some forming impulse got from the south to the north at the transition from the MBA I to MBA II, transforming the Catacomb culture and forming the Sintashta culture.

The demonstrated facts of lead and silver metallurgy are very important too, as the roots of this technology were in Anatolia.

Discussing the formation of Sintashta metallurgy, we have to discuss not the roots of its individual elements, but a **closely interconnected** complex of consecutive production cycles when features of the following cycle are caused by the previous ones. And here we do not concern even the mining problems, although in case of attentive studying of this question it will certainly become clear that there were some specifics of search of ores in the ultrabasic rocks, in comparison with searches of ores in other rocks, some specifics of mining and the subsequent crushing and sorting at the preparation of this ore for smelting. This thought can be new for archeologists, but is unanimously accepted by archaeometallurgists who consider this production as a system of complicated interconnected operations (see e.g. Roberts *et al.*2009, p. 1016).

Basing on all said above, the most acceptable area, from where the Sintashta metallurgy in the Transurals could appear is the southeastern part of the CMP.

Analyzing the materials of Sintashta culture, I assumed the coming of its bearers from this region as a result of migration (Grigoriev 1996, 1999, 2002). The character of metallurgy supports this conclusion. It is possible to discuss as much as one wants a possibility of borrowings of features of material culture or architectural traditions through large distances, but it is impossible to argue the possibility of transfer of a very complicated interconnected technological chains without the direct coming of bearers of this technology. In archaeometallurgical literature it was already indicated the impossibility of diffusion of metallurgical technologies through barren areas (Craddock 1999, p. 176). We have discussed how it was difficult to experimenters to reproduce the process of ore smelting, though as though, all of us know about this process. Nevertheless, in archeology the statements about transfer or borrowings of ideas, without specification of both reasons and mechanisms of this transfer are quite popular.

The most surprising is that sometimes similar approach is used in technological studies. So, A.D. Degtyareva allows a possibility of transfer of technologies through thousands kilometers, in addition to this the technologies which many centuries were absent in the initial area, but existed in a latent state in the form of ideas. As an example she quotes the traditions of metalworking of the Pit-grave tribes of the Cisural area which remind stereotypes and skills of metalworking of the Eneolithic Balkan-Carpathian tribes (Degtyareva 2010, p. 58). In this regard it is represented useful to remind the examples given by E.N. Chernykh when in the 18th century AD, at the beginning of the Russian development of the Kargaly mines, V. de Gennin was compelled to look for a master, capable to smelt this type of ore. Other example is the flat refusal of the Dagestan smiths to forge a tool of a new type, and these smiths were hardly successful even with familiar objects, but having a bit different size (Chernykh 2007, p. 28, 29, 177).

In the case with Sintashta metallurgy we have the complex change of ore, technologies of its smelting, the alloying demanding an exact choice of the subsequent temperature of forging and its modes, morphology of objects and much other. Introduction of this complex was impossible without a long training process. Therefore, the migratory nature of emergence of this production seems to be undoubted.

Structure of production

Earlier, analyzing a structure of production, I paid attention to that circumstance that within the whole area of distribution of Abashevo and Sintashta sites the finds, linked with metallurgical production, were found only in two regions: on the Sintashta sites of the Southern Transurals and several Balanbash (Ural

Abashevo). Respectively within the Sintashta-Abashevo cultural community two zones were distinguished: metal consuming (Don, Volga and Western Urals) and metal producing (Southern Urals). The last includes two metallurgical centers: Sintashta (Southern Transurals) and Balanbash (middle part of the river Belaya) (Grigoriev 2000, p. 519). It did not contradict also to the picture suggested by E.N. Chernykh, who believed that arsenic bronze (in his terminology the natural bronze, received from the Tash-Kazgan mine) were distributes far to the west, into other areas of this community (Chernykh 2007, p. 82). A.D. Degtyareva (2010, p. 143) also believes that from the area of Sintashta culture metal in the form of ingots was distributed to the east, into the area of Petrovka culture, and to the west (Potapovka sites, Ural Abashevo culture, to a lesser extent Abashevo of the Volga and Don regions). Thus, in this question a certain consensus of the main researchers of the problem is present.

However this lack of local mining, especially in the areas where the local resources are known, confuses. First of all, it is necessary to pay attention to that in the Middle Volga Abashevo culture pure copper dominated. Whether follows from this, that metallurgists of the Urals delivered this copper there? It is unlikely. We have seen that the proportion of the arsenic-containing slag on the Sintashta sites is, as a whole, close to the proportion of the Sintashta arsenic bronzes. Respectively, any deliberate selection of metal was not made for the trade operations. It is possible to assume that the arsenic metal was distributed to the south of the Volga region, where it is really present. But similar selection is even more surprising, besides, to the west the proportion of this metal steadily decreases that in total only would aggravate the situation.

Therefore it is necessary to assume the existence of own, probably limited, mining and metallurgy on the Middle Volga. They have not been revealed yet because of small number of excavated settlements. It was a very low-power production as the bulk of finds is presented by small ornaments whose weight is absolutely incomparable with the products of the Sintashta metallurgists. It is not excluded that the volumes of production differed by two orders, and in this case rather pure malachite could be used in smelting which does not produce slag. There was also the deficiency of an alloying component; probably, there was also no special need in it, because types of products, casting and forging technologies did not demand it. But exactly the last forces to assume the existence of own ore smelting focused on these technologies.

The situation with the Ural Abashevo culture is another as on its settlements traces of ore smelting are presented rather well, and on the settlement of Tyubyak slag contains the same concentration of arsenic, as in the Transurals. Therefore there is no base to speak about some Sintashta imports of metal to Abashevo of the Western Urals.

The situation with Potapovka sites is more complicated. As they are presented by exclusively cemeteries, traces of local ore smelting cannot be revealed. But it is confused that two slag pieces have been found in Utyovka cemetery, and this slag was smelted from the ultrabasic rocks and is chemically the same as the slag of the main Sintashta collection. Moreover, one of these samples contained 0.1% arsenic (Tab. 5-23.), respectively, the smelting took place which gave arsenic bronze, because it would be madness to discuss a possibility of slag import. Respectively, local similar smelting took place. And a strong base to speak about the Sintashta import of metal out of borders of the Sintashta settlements does not exist.

As for import of metal to the Petrovka area in the east, owing to the late chronological position of Petrovka culture only partly coexisting with Sintashta, it could take place at the very end of Sintashta existence, and it cannot be used in reconstruction of the structure of Sintashta production. But even for this late period there are questions as the slag received at smelting of ore from the ultrabasic rocks, is found on the Semiozerki II settlement of Petrovka culture, on the Tobol (Evdokimov, Grigoriev 1996). It does not contain much arsenic, but the collection of this slag is not actually great. Unfortunately, it is impossible to divide reliably slag from the Ural multilayered Sintashta-Petrovka sites. But the Petrovka metal does not contain high arsenic concentrations. Therefore it is not possible to speak about serious supply of metal to the east until the qualitative argumentation built on analyses and considering the aforesaid reasons will appear.

It is senselessly at all to discuss the metal trade (exchange) inside the Sintashta area as there is no Sintashta settlement without traces of metallurgical production.

From everything said above it follows that some amount of metal went out of borders of the Sintashta area, some circulated within this area, but the amount of such metal was insignificant, and these hypothetical deliveries had no system character. Besides, the Sintashta migrations out of borders of the core area existed, which resulted in the formation of Potapovka sites in the west and Petrovka sites in the east. The Sintashta component is tangible also in Abashevo culture of the Western Urals and Don. A part of metal could be brought with these migrations, another part after this in the form of ingots or products, thanks to preservation of relations with the initial territory. In some instances, judging from Utyovka slag, the ore was brought. It is difficult or even impossible to determine a ratio of ways of occurrence of metal on this or that territory. But the situation with Utyovka confuses. If supply of ore (or trips for ore) through such distance took place, they could not play a noticeable role because of diseconomy of this procedure. Therefore the fact of the presence of this slag specifies, probably, the lack of systematically established deliveries of metal.

Besides, Sintashta was no specialized metallurgical center although since the discovery of these sites ones write about it rather often (e.g. Vinogradov N. 2003, p. 267-269, but it is typical for many authors). There are even the ideas that the fortified settlements were built for protection of ore sources and about control of metallurgical production by some elite (Kuzmina 2003, p. 9, 10). But these ideas are based not on concrete arguments. Of course, it is impossible to deny a possibility of existence of settlements or the whole areas specializing on metallurgical production. In some regions of Togo at the beginning of the 20th century AD hundreds furnaces were operated. The entire villages specialized on ore mining, smelting, blacksmithing, and charcoal-burning. And, everywhere in Africa metallurgy was family business (Goucher, Herbert 1996, p. 40, 44). But nobody has found proofs of such specialization for Sintashta. There were only allegations about this.

It is necessary to tell that it is rather difficult to find criteria for craft production for this period. Even for such developed society as Harappa the lack of traces of craft production is noticed, and it is in a quarter where a series of copper melting places has been excavated (Miller 2005, p. 245).

There are some other aspects of the problem. First of all, it is not proved that Sintashta society had such an abundance of metal although I understand that such a statement will cause amazement of all colleagues. Actually, the overwhelming number of finds of metal in Sintashta is connected with funeral complexes. Finds on settlements are not so numerous, as well as finds of other material. The last too is not the proof of something as specifics of the Sintashta fortified settlements is that they have few free spaces between dwellings, and the dwellings were cleaned. But even taking into account this reservation the settlements of the Late Bronze Age are saturated with metal in comparison with this. And it is hardly lawful to take into account the burials for the assessment of metal volume in this or that community. For example, basing on the Sintashta burials when in a grave the whole animals and many parts of other animals could be put, we cannot draw a conclusion about a practice of daily tortures by food in this community.

Besides, the neighborhoods of the Sintashta settlements are well studied, nevertheless, a ratio of the buried with probable number of population is disproportional. Obviously there were any different, more economic ways of burials, and it is not the fact that in these cases burials contained a lot of metal too.

Therefore any conversations about an especially metal-containing culture are lawful, so far as concerns the Sintashta archaeological culture, but they cannot be extended on the Sintashta society. Probably, a lot of metal circulated really within this society, but today it has no strong proofs.

A common point in archeology is also a statement about a role of metal in development of ancient societies, both economic, and social (e.g., regarding the Sintashta society see Hanks, Doonan 2009, p. 329). But it is true probably only for some regions and at later periods. So, the analysis which has been carried out by M. Bartelheim has shown that, despite the importance of metal and that it was prestigious, acting frequently as attribute of elite, it did not play such large role in the EBA of Middle Europe (and it was contemporary to Sintashta culture) in formation of elite or in economic development, as other products, such as salt, slaves, etc. Its role is vastly overestimated (Bartelheim 2009, p. 41). All conversations on this subject are no more, than conversations. And cattle were really important for Sintashta economy, instead of metal.

It is impossible also to discuss a control of metallurgical production by some elite. The Sintashta sites do not give evidence to reconstruct the existence of elite (Grigoriev 1999, p. 120-131; Epimakhov 2003, p. 87). It is a wrong impression of them, as well as impression about a lot of metal. And the fortified settlements did not serve for protection of mines, because as we have seen, the lion's share of ore was mined not on the richest deposits, but on those whose ore was technologically convenient for the Sintashta smelting, and these mines were located, mostly, outside the area of these fortified settlements. And a thought had struck nobody to build the fortified settlements around the mines, although funeral monuments are known there.

We will not discuss possible small mines in quartz which could be exploited by the population of nearby settlements. Here the problem is: how the exploitation of the main mines in ultrabasic rocks was organized, which are situated rather compactly (if some other mines will not be found), and outside the area of the fortified settlements? As we have seen from the slag analysis, the ore from these mines, above all from Ishkinino, was brought to different Sintashta settlements. Moreover, during the late phase of the culture this ore was brought to the area of Petrovka culture on the Tobol river and to the west, to Potapovka populations, although in the latter case it is impossible to tell, how regularly it was made. The last two cultural groups should not be separated from Sintashta culture. They formed on the Sintashta base, and those distinctions which we see in the archaeological material are not so striking that the Sintashta population perceived these groups as absolutely alien. Also it is impossible to forget about the Abashevo settlement of Tyubyak where slag of the same type has been revealed, besides, chemical links with slag and ore of the settlement of Ustye are outlined.

There are, at least, three variants. The first of them is connected with that the ore in the ultrabasic rocks is quite poor, and its transportation over large distances is economically inexpedient. I have already casted the doubts on a possibility of distant transportations of ore from the Kargaly mines (Grigoriev 2004). In this case the mining areas were not so remote, but the problem remains. It is not excluded that the solution should be looked for in character of the Sintashta sites of this region which are presented exclusively by cemeteries (Tkachev 1995, 2007). I have already written that in the area of Sintashta fortified settlements there were not enough bioresources for the cattle pasture, therefore an idea has been supposed about the domination of the Sintashta people who lay under tribute their neighbors (Grigoriev 1999, p. 131; 2002, p. 130). Without removing completely this thesis, it would be desirable to note opportunity of seasonal use of remote summer pastures, as will explain the character of sites in the Orenburg area. It could be accompanied by seasonal works on mines of this region with ore storing and its export in the autumn to the settlements. Indirectly this hypothesis can be supported by the discovery of small ore store in one of geological trenches on the Ishkinino mine (Zaykov *et al.* 2005). In this case, certainly, the population of the whole Sintashta area could not pasture the cattle in one point. Therefore this model either is unacceptable, or can be accepted only partly. A variant of this model are trips to this region of people of particular settlements. But how in this case the distribution of these ores among other settlements was organized? It will be necessary to solve this problem later on the basis of analyses of ores and slags.

Recently, on the basis of limited analyses of the Sintashta slag from the settlement of Stepnoe an idea has been suggested about the export of matte from mines, from what a conclusion about multistage process of smelting and need of control of this process has followed. These analyses have not identified ore remains in this slag, but there were inclusions of copper and sulfides. From this the conclusion has been drawn that the sulfide was smelted near the mines to produce matte, and it was brought to the settlements for re-melting (Hanks, Doonan 2009, p. 347-349). But this idea follows from incorrectly interpreted analyses of metallurgical remains, although the approach (any social reconstruction connected with metallurgy has to be based on analyses of metallurgical remains) is correct. Sintashta smelters used oxidized ores with impurity of secondary sulfides, and often the slag does not contain ore inclusions, but they are, nevertheless, present in many slags, and ore remains have been found on the settlements. But smelting of primary sulfides has not be recorded for this time, and only this type of smelting can produce matte. Therefore the process was one-stage, and the problem of ore transportation remains.

In the Alps in the Bronze Age, apparently, the groups living near deposits did not possess them. Seasonal campaigns for ore to mountains were carried out (Kienlin, Stöllner 2009, p. 89). Therefore some variations of such campaigns took place probably also in the Urals.

At last, despite the lack of the facts, it is possible to assume a possibility that some constant groups worked in the mines and exchanged then the ore. But such exchange because of poorness of the ore seems to be doubtful too.

Eventually, some clarity in this question can appear only after identification of settlements of miners here and comparison of materials of these settlements with materials of the main Sintashta area.

It is remarkable that the production was located on the settlements. Discussing the Eneolithic metallurgy, we have mentioned that it was typical of archaic stages of production. In the Late Bronze Age of the Cyprus the ore was smelted already near the mines (Koucky, Steinberg 1982, p. 128). But the reasons are unclear. During this period on the Cyprus sulfide ores were intensively smelted, therefore the refusal to smelt on the settlements could be motivated by gases produced at smelting of these ores. On the other hand, at this time on the Cyprus the smelting was conducted in huge volumes, the production had already the commodity character. However this not always causes the transfer of production to the mines. During the Harappa period in India the smelting was also carried out on the settlements which were on the large distance from the deposits. In addition to this, a lot of ore was transported: on some settlements excavations revealed up to 40-50kg of ores (Babu 2003, p. 175, 176).

Therefore the situation in other regions does not help to understand the Sintashta production. It is necessary to be based on the concrete local facts. And today facts demonstrating the essential exchange operations, both metal and ore, at the level of the Sintashta area or particular settlements are absent.

It is difficult to speak also about any specialization inside settlements as specialized workshops are completely absent, and slag is found in each dwelling. This means that there were no households specializing on metallurgical production inside the settlements. It is possible to assume an internal specialization among families, when someone smelted more often, and others, whenever it was needed, performed auxiliary works. But it cannot be designated as craft production.

At last, if to assume the supply of metal, who did act as a subject of such operations: household (if this term is applied in general to Sintashta culture) or a clan of a particular settlement (if there were patrimonial clans, instead of collectives of neighbors that we, actually, do not know too)? But for certain it was not those people who did it more often. At last, for this epoch it was not a rarity when the things connected with metallurgical production (ore, slag, stone hammers or anvils) had been placed in, so-called, ‘elite’ burials. It is possible to argue, of course, about “a special social status of metallurgists”, but in the dwelling architecture it is not shown.

It is necessary to remember also that volumes of the production were insignificant. The weight of ingots received as a result of one smelting is within the interval 50-130g. For the settlement of Shakhr-I-Sokhta in Iran where the weight of slag cakes is about 400 g, a conclusion has been drawn about the home production on the same basis (Hauptmann *et al.* 2003, p. 210).

All these facts provoke also an impression about the home character of Sintashta production. Criticizing this approach A.D. Degtyareva (2010, p. 146) after V. M. Masson has characterized this production as communal craft with highly professional production. But the last valuation is not absolute, this craft is incomparable with the level of the subsequent production of the Late Bronze Age; in general this valuation should not be considered as we have no possibility to find strict criteria for this. As for the communal character, its proofs are absent. Certainly, some campaigns for ore or ore exchange (we do not know yet what is more preferable here) were organized at the level of a settlement, and these problems were somehow coordinated with other settlements. It is not excluded that some operations, for example, production of charcoal, was organized, at least, by groups from several dwellings as wood preparation for this purpose was rather labor-consuming procedure, and the charcoal burning in small volumes is irrational. But whether the collective summer pasture of personal cattle or haymowing in medieval villages is a testimony of communal character of craft? They reflect a communal character of a part of the works. Other arguments of Degtyareva (the impossibility of smelting in each dwelling or metal imports) we have already considered.

All the facts do not make an impression that these settlements were specialized metallurgical centers. Therefore the epithet 'communal or clan craft' is not probably applicable to them. The term 'home production' is probably not felicitous too. I am not ready to insist on it definitely. It is not a question of terms, but the question what these terms actually reflect. But it seems to me that while the conversations about craft in Sintashta society should be nevertheless avoided.

In general, at reconstructing social aspects of ancient metallurgy archeologists often create some theoretical models based on early more or less successful statements of other colleagues, but not on the material analysis. Such models are necessary, but it is necessary to understand their place: they are only hypotheses which make possible to develop and realize subsequently a research procedure, i.e. to plan solutions of a problem. Unfortunately, the situation is another. These hypotheses are quickly picked up, repeated and supplemented, finding, as a result, external signs of a developed theory that saves from need of serious analytical work. But the problem of social system in which metallurgical production was operated, is particularly acute. And it is not a problem of historico-metallurgical studies, in which different points of view are present, but they are based on the material analysis therefore can be discussed, compared, and be corrected. But in archaeological studies of social structures the procedure is limited, as a rule, by the diffuse conversations. Therefore it is impossible at all to do specification of this problem in relation to metallurgical production.

Genesis of Sintashta metallurgy

Sintashta metallurgy occurred after a large-scale migratory process from a southeastern area of the CMP that resulted in considerable expansion of the territory captured by the metallurgical production. In Northern Eurasia more perfect technologies appeared both metallurgy, and the metalworking, based on the use of copper alloyed with arsenic. However these new technologies were not fated to be developed and distributed over more vast spaces, although the distribution of descendants of the Sintashta people in this region at the beginning of the LBA was more than large-scale. It was expressed in formation of Timber-Grave culture in the steppe and the forest-steppe of Eastern Europe, and Alakul culture in the Asian zone up to Central Kazakhstan and the south of Central Asia. However soon after the formation of Sintashta culture we see a new powerful impulse which led to the renewal of all the system of production in this vast territory. This impulse started in the East although its true roots are a problem of very serious discussion. It is a question of formation and distribution of Seima-Turbino metallurgy and metalworking, and then Fyodorovka (Andronovo) metallurgy. These two processes determined for a long time a nature of metallurgical production in Northern Eurasia.

Chapter 8.
Metallurgical Production in the Bashkirian Urals

Ore sources in Bashkiria

A significant ore-bearing zone of Bashkiria is the Uchaly area in the east (Fig. 8-1.). The largest here is the Uchaly massive sulfide *deposit*; however it has no ore on the surface, and could not be used in the antiquity. There is also a series of deposits with the developed oxidation zone in which mineralization is presented mainly by malachite and azurite. The ore is situated in quartz veins and quartz rocks (Tash-Kazgan, Nikolskii, Voznesenski, Narali, Polyakovskoye, etc.). Iron oxides in this ore are poorly presented (1-10%). In the ore from Tash-Kazgan considerable impurity of arsenic is present that allowed it with the arsenic bronzes of Abashevo period to be connected. The ore from the Nikolskii mine is characterized by the higher content of silver. This ore is hosted in metamorphic magmatic green rocks. On all these mines traces of early works are known (Zavaritskii 1929, p. 103, 131, 133, Chernykh 1970, p. 41-44). On the deposits of Urgun and Mayly-Yurt, with the numerous old mines, the oxidized ores are hosted in chrysotile serpentine with magnetite inclusions.

Deposits of the Tanalyk-Baymak area in the southeast of Bashkiria have numerous traces of old works. On the most of massive sulfide *deposits* of this zone the mining in antiquity was impossible (Chernykh 1970, p. 44). The exception of them is Bakr-Uzyak which is a typical massive sulfide *deposit* in porphyries and quartz, and it is blocked by the 'iron hat' 3.5-18m in thick which almost does not contain copper. The main sulfide minerals are situated at a depth of 43-58m and they were not available for mining in antiquity. However, under the 'iron hat' a zone of secondary enrichment with rich ores, chalcocite and covellite, is situated (Zavaritskii 1927, p. 117-124; Ivanov 1929). The deposit has also a powerful occurrence of the oxidized ores (malachite, azurite, cuprite) on the surface and a very large ancient pit. Here also large copper ingots in the shape of 'cast bowls' are found that marks, apparently, the ancient production. In a prospecting trench two layers of mining works have been revealed: a mightier Russian layer and the ancient one. The found slags are connected with the late layer. The ore is characterized by high concentration of antimony that is explained by its formation from chalcopyrite ores (Chernykh 1970, p. 40, 41). It is not excluded that another chalcopyrite field of the area, Youzhny Yuluk, could be also exploited, with the traces of old works and ore of the oxidized zone presented by the mix of malachite and limonite with a low quartz content and high concentrations of copper and iron (Zavaritskii 1927, p. 139). Besides, in the neighborhood, in the Chelyabinsk region between Verkhne-Uralsk and Bakr-Uzyak, there are many deposits in basalt and diabase. The ore is situated in cracks and pores and is accompanied by quartz veins. The mineralization is presented by malachite, azurite, cuprite and native copper. On many deposits traces of ancient works are found (Zavaritskii 1929, p. 120-122; Chernykh 1970, p. 40, 41).

In a huge area along the western slopes of the Urals from Perm to Orenburg the copper deposits are situated in sandstones. The Southern, Orenburg and Ufa, zone of this vast province is 600 km in length and 100 km in width. To the west from the Urals it extends for 350 km, reaching, practically, the Volga. In the east the deposits of this type begin from the longitude of Ufa. Thus, the majority of our sites are located near deposits of this type. In total, 2800 points of small deposits in the copper sandstones is known here. These fields are connected with destruction of massive sulfide fields of the Urals. The main minerals are malachite, cuprite, chalcocite, covellite, and bornite. However, the sulfide minerals are not so typical. The ore is often accompanied by limonite. There is also quartz in sandstones. Old mines are known. The richest mineralization is connected with the vegetable remains replaced by copper. Copper is present also in layers of clays, conglomerates and marl. Mineralization in sandstones is less rich. The ores are presented in the form of separated accumulations with extended bodies from 20 to 1000 m long and 0.1-0.4m thick. As a rule, the accumulations are lens-shaped; it is cement of sandstone and marl (Yagovkin, 1932 p. 54, 55; Satpaeva 1958, p. 135-145; Chernykh 1970, p. 48; Narkelyun *et al.* 1983, p. 7-13). For the understanding of a situation a following phenomenon is very important. At gradual oxidation of ore in fields of this type, its refinement from many impurities happened, that is an important characteristic of copper of the MP group. At the same time, it is necessary to take into account that this was a result of destruction of various types of the Ural deposits; therefore the compositions of ore-bearing rocks and sandstones can be different.

Mineralogical analysis of slag

In total 92 mineralogical analyses of slag by means of a microscope in reflected light, 18 visual determinations of ore and 125 spectral analyses have been made[1]. Slag from the mines of Bakr-Uzyak, Urgun and Tash-Kazgan was analyzed mineralogically too, however their description is not placed here, and the mineralogy of this slag is not discussed as this slag can be dated also to the late time. Use of these slags in the spectral analysis was caused by need to compare the chemical composition of ancient slags with the chemical composition of slag which could be smelted from ores of these deposits. The studied samples are irregularly distributed over Bashkiria. The most samples are found in the middle course of the Belaya River that is caused probably by the better ore base of this area.

Slag of the Sintashta-Abashevo period (MBA II)

Abashevo slag has been found on several settlements of the Cisural area: Beregovskoye I, Yumakovo I, Yumakovo III, Tyubyak, Urnyak (Fig. 8-1.). Unfortunately, it is impossible to take for the analysis slags from the settlement of Balanbash which has not been saved in the collection. All these settlements are situated in one region of the Middle course of the Belaya river.

On the Beregovskoye I settlement K.V. Salnikov, A.D. Pryakhin and V.S. Gorbunov during many years excavated about 3000 sq.m. On the site Abashevo and Timber-Grave ceramics has been revealed. The latter is found together with the Alakul ones in the upper horizons of the cultural deposits (Gorbunov 1986, p. 24, 25; 1992, p. 65). The studied slag belongs to the third horizon of the settlement and is dated to the Abashevo time. Besides the slag a large number the Abashevo melting bowls is found on the settlement.

The Yumakovo I settlement has been excavated by V.S. Gorbunov in 1981. On the site ceramics of the developed phase of Timber-grave culture prevails, but there are early Timber-grave, Balanbash (Abashevo) and Alakul ware. Fragments of two Abashevo melting bowls are found (Gorbunov 1992, p. 67). The found slag belongs to the Abashevo time, although it is impossible to exclude its possible connection with the early Timber-grave period.

The Yumakovo III settlement is investigated by V.S. Gorbunov in 1983. The Timber-grave ceramics is most widespread, but there are the Abashevo ceramics in the lower chronological horizon. A small number of Pokrovsk (early Timber-grave) and Alakul ware is revealed. About 100 fragments of melting bowls and ore pieces are also found (Gorbunov 1992, p. 68, 69). The studied sample of slag is taken from the horizon 3. Possibly, it belongs to the Abashevo time.

On the settlement of Tyubyak the building remains of Abashevo, Timber-Grave and Mezhovka cultures have been revealed. The early and late materials are situated in different locations (Gorbunov 1992, p. 71). The studied slag is dated to the Abashevo time. The settlement of Urnyak has been excavated by K.V. Salnikov and belongs to the Ural Abashevo culture (Salnikov 1954; 1957; Gorbunov 1992, p. 63).

[1] The author is thankful to V.S. Gorbunov, Yu.A. Morozov, M.F. Obydennov, and E.N. Chernykh, who helped to find the materials.

Abashevo slags by many parameters are close to those of Sintashta. They are presented by flat cakes with thick rims, identical to the Sintashta slag (Yumakovo I, Tyubyak), or by shapeless, occasionally flattened pieces of heavy porous slag (Yumakovo I, Tyubyak, Urnyak[2]) that is present in the Sintashta collection too, or by pieces of black friable soot slag (Beregovskoye I, Yumakovo III) (Tab. 8-2.). The last type is absolutely absent in the Sintashta collection. Here, despite a small number of samples (only 4), it is found on two settlements; therefore at increase of the sampling, for certain, it will be still revealed. The total analyzed slag is insignificant, only 28 samples; therefore distribution of individual types of slag over the settlements is not indicative, and we will not start to discuss it. All this only reflects the nature of Abashevo metallurgy in qualitative level.

The presence of slags similar to those in Sintashta in form is duplicated also by similar microstructures. Here it is possible to identify the same mineralogical groups, as the groups identified on the Sintashta material (Tab. 8-3.). The 1st group is characterized by chromite inclusions marking the connection of ore with the ultrabasic rocks. The 2nd group contains quartz inclusions and is connected with quartz rocks. The 3rd group contains inclusions of both chromite and quartz. As, judging from the Sintashta situation, it is mineralogically close to the 1st group, we will describe these two groups together, especially because the small number of samples does not allow any detailed distinctions to be done. It was difficult for these groups even on the Sintashta material. At last, the 4th group is identical to similar Sintashta-Petrovka group and includes oxidized slags from silicate rocks. The only difference with the Sintashta slags is the presence of the small 5th group where all friable soot slags have been included. Correlation of other mineralogical groups with forms of slag is identical to that of Sintashta: slag cakes are characteristic of the 1st mineralogical group, and shapeless slags – of two others that is quite explainable by more silicate composition and, respectively, by higher slag viscosity.

In slag of the **1st and 3rd mineralogical groups** the main inclusion are prismatic and polygonal olivine crystals among which needle and skeletal forms grow, and the quantity of olivine is quite high. In slags of the Tyubyak settlement a tendency is seen to that the small needle and skeletal crystals are situated at the upper surface of slag cakes. It was caused by that the speed of slag cooling in this zone was higher. Often large olivine crystals have zonal structure. Their external layer is lighter, than the internal part. It was caused by that (judging from the Sintashta slags where chemical analyses of these layers have been done) the internal part of crystals was more magnesian, and the external layer is richer in iron oxides.

Magnetite is the second main component in slag of this group. It is presented by octahedra of different sizes, skeletons and dendrites. The content of magnetite is usually no more than several percent. Often it forms a border round the chromite grains, and a part of magnetite is formed separating from these borders, but another part is formed due to disintegration of iron oxides grains. The good presence of chromites in slag marks its formation from the ultrabasic, as a rule, serpentinized rocks, which was very characteristic of slags of Sintashta culture.

Copper is presented in slag of these groups in the form of small prills, and its content is less than 1-2%. Prills of cuprite are present less often. In addition to this, in some instances it is a secondary formation for the period when slag was in cultural deposit of settlements. However, in slag from Tyubyak the cuprite prills are in some cases slightly deformed and larger than those of copper. As cuprite is more viscous and refractory than copper, such inclusions were formed obviously in the course of metallurgical reactions. In a slag sample from Yumakovo I unmelted grains of cuprite have been found.

[2] The slag sample from the settlement of Urnyak is presented by a fragment of friable flat slag cake (sample 51) with large pores and charcoal inclusions. It has not been included in the first group for the reason that this flat cake has no characteristic for Sintashta slag thick rims, marking very low slag viscosity. Therefore, in principle, it is the shapeless slag, but due to slightly lower viscosity it got more flattened form.

The ore minerals are presented by malachite grains (the main mineral), cuprite, covellite and chalcocite. In some instances there are associations of these minerals that specifies that they had been taken together, they were used in the charge incidentally (because of the character of ore), and it is not a sign of deliberate composition of furnace charge. Also rare grains of bornite and small single chalcopyrite are found. Presence of sulfides is marked also by molten prills of isotropic copper sulfide[3] and chalcocite. Occasionally sulfide border surrounds the copper prills.

Thus, we see identity of microstructures of Sintashta slag with the samples of the corresponding Abashevo mineralogical groups. It gives us the right to apply the conclusions based on the Sintashta material to this slag. The ore from the basic rocks was smelted. It is demonstrated by the good presence of chromite grains in slag. The ore varies widely: from malachite to covellite, bornite and chalcopyrite, although the last two minerals did not play a special role in smelting, and got to the furnace charge incidentally.

In slag of the **2nd mineralogical group** quartz was the gangue. Because of the silicate composition and lack of iron component (there are only small rare grains of magnetite) the olivine crystallization took place in this slag much worse. It is presented by nuclei of crystallization, needles, more rare by elongated and skeletal forms. Prills of copper, cuprite and copper sulfide formed probably from covellite are present. In some instances sulfide forms a border around copper prills that reflects direct reduction of copper from sulfide. Some areas of glass are tinted by small copper prills. But, as a whole, the content of copper prills does not exceed 2%. Cuprite was molten, but was not overheated as its prills are very often deformed and seldom form the regular form. Ore minerals are almost not found, but, judging from individual inclusions and sulfides, malachite was the main ore, however, secondary copper sulfides like covellite and chalcocite were used too, as well as in slag of the groups described above.

Technologically all three described groups are uniform[4]. Their distinction is connected only with a source of raw materials. They entirely correspond to the Sintashta technology of smelting. Special calculations of volume of the furnace charge have not been carried out in this case, but it is possible to assume that the volumes were comparable (about 1 kg of the furnace charge and 50-130g of produced copper). The smelting was conducted at a temperature of 1200-1300 ºC. The slag was cooling slowly, in the furnace, in the conditions of reducing atmosphere, metal losses were insignificant. Possibly, all told in more detail about the Sintashta technology is quite applicable also to this group of the Abashevo slag.

The **4th mineralogical group** of slag which, as well as in the Sintashta-Petrovka collection, is characterized by high degree of oxidization differs from these groups. Slag is saturated with prills, more rare grains, of cuprite. In slag from Urnyak the small dendrites of cuprite forming often around multidirectional delafossite needles have been revealed. The delafossite crystals in this slag are caused by the better, in comparison with slag from Tyubyak, presence of iron minerals. Here magnetite in form of accumulations of small octahedra, more rare small skeletons, has been identified, but its quantity is insignificant. Copper, in comparison with cuprite, is not so typical in the slag. In some instances borders of cuprite are present round, and small cuprite prills are inside the large copper globules. Not always there is a confidence that all these slags were smelted from ore. Some could be the casting slags, because in some slags from Tyubyak the ore minerals have not been found. In other slags of this group the ore is presented by malachite, especially there is a lot of ore in slag from Urnyak. From possible ore bearing rock only small inclusions of quartz have been identified.

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3 This sulfide is very widespread in slag. It is formed, mainly, from covellite and chalcocite as a result of partial removal of sulfur. In the nature such mineral does not exist. According to the color characteristics it is close to cuprite, but has no characteristic for the last internal reflexes. Unlike anisotropic secondary sulfides this mineral is isotropic.

4 There are only some variations. So, in sample 388 from Yumakovo I the viscosity of slag (judging from smaller losses of copper) was lower, and temperatures probably were slightly higher, as well as the oxidation degree. Here even delafossite needles and cuprite dendrites were formed in some cases. This resulted from the fact that because of silicate slag in aspiration to reduce the viscosity the blasting was slightly intensified that led to the oxidizing conditions.

Thus, in this smelting malachite in quartz rock was used, with the presence of a small amount of iron components. The temperatures were very high (1250 ºC or slightly higher) because the cuprite was molten, and the blasting was intensive. Possibly, the slag had the silicate composition. Lack of sulfides in the conditions of intensive blasting resulted in the considerable oxidization. After crystallization of the cuprite dendrites and solidification of its prills at the decrease of temperature lower than 1250 ºC the fused slag became very viscous and quickly solidified that hindered in formation of fayalite crystals. Besides, it was hindered by the lack of iron components and the oxidizing atmosphere. These reasons embarrassed all copper to be separated and its reduction from cuprite as well. But we do not know how economic this smelting was, as pure malachite could be used with formation of insignificant amount of slag. Thus, as well as in the Sintashta-Petrovka collection, in this case we deal with smelting of malachite from silicate rocks, and an attempt to solve the problem of slag viscosity by high temperatures that resulted in the oxidization of the slag. One sample from Yumakovo I is close, as a whole, to slag of this group, but the degree of oxidization was not so high (not so much cuprite).

At last, slag from Beregovskoye I and Yumakovo III is related to the **5th mineralogical group** which has not been identified in the Sintashta sites. Formally, these samples belong to the group of friable soot slags. Most part of the surface of samples is badly polished because of a large number of unmelted friable rocks which is often green-colored by malachite. In some areas of glass the rare needles and skeletons of fayalite crystallization, octahedra and grains are present; small unmelted magnetite dendrites are rarer. In some instances magnetite grains form accumulations. Magnetite, apparently, was formed from iron hydroxides. But the content of iron components is low. The ore was obviously connected with silicate rocks. There are quartz grains, but small and very rare. In one quartz grain the sulfide and chrysocolla inclusions have been found. In some instances small particles of reduced copper are found in quartz. Many quartz grains consist of small roundish granules, arranged in direct rows. It is not excluded that it reflects the sandstone origin of initial ore.

There are a lot of inclusions of the oxidized copper ore (malachite and chrysocolla). They are the main ore. In addition to this, grains, molten grains and prills of copper sulfide, grain and prills of chalcocite have been identified. However, they are incomparably less often. It is noteworthy that chalcocite often did not turn into isotropic copper sulfide and it is presented by grains more often than by prills that (as well as the abundance of unsmelted ore and rocks) points to short duration and low temperature of smelting. Sulfide is also found in grains. Single chalcopyrite grains have been identified too. A magnetite grain with cellular structure points also to the possible use of chalcopyrite. Probably, the secondary sulfide ran out when smelting. But it were not deliberate additions of the sulfide ore to the oxidized ones, and the better explanation is the character of initial ore, because associations of sulfide minerals with oxidized ones have been found. However the oxidized minerals prevailed. The silicate composition and oxidized character of ore led to the strong oxidization of the furnace charge.

Cuprite is well presented. More often it is presented by grains and replacement of ore bodies, but also by prills, molten grains, and occasionally small dendrites with delafossite needles (copper and iron oxide). The molten cuprite is formed often by replacement of molten sulfide. The most part of cuprite is in the form of large globules that can be evidence of its origin as a result of metallurgical process.[5] At the same time, there is also the secondary cuprite surrounding pores and filling cracks in slag. This cuprite was created already in the period when slag lay in the cultural layer. In some instances there are copper inclusions in large cuprite

5 It is almost impossible to distinguish visually the cuprite formed in the metallurgical furnace from the cuprite formed as a result of oxidation of copper prills already in the layer of settlements. The relative size of the prills can be the only sign point here. In principle, small copper prills have to be oxidized in the cultural layers much easier, than the large ones. Therefore if we see a situation when the cuprite prills are much larger, than the copper prills, we can claim that they were formed as a result of metallurgical reactions. The larger size of the cuprite prills in slag is explained by that cuprite is lighter in weight than copper. Therefore the large copper prills settle in liquid slag easier and fall on the bottom of a furnace or a crucible. All this is also connected with slag viscosity.

globules. However it is not clear whether it was a result of secondary replacement of copper or it happened still during the metallurgical reactions.

There are many copper inclusions. In some cases copper is presented by unmelted grains (instead of globules), and that points to low temperatures. There are the prills surrounded by a sulfide border, a result of replacement of sulfide grains, and small sulfide inclusions in large copper globules. In some cases copper (as well as cuprite) forms dense accumulations of prills with a clear boundary, a result of fusion of a piece of ore.

Thus, the oxidized ores, to a lesser extent the secondary sulfides, from quartz rocks were used in smelting. The use of ores from the copper sandstones is very probable. Temperatures were low – 1050-1200 ºC (not only cuprite, but in some cases even fusible secondary sulfides are present in the form of grains or deformed prills), and the smelting was not too long. Prevalence of the oxidized ores caused the oxidizing atmosphere and cuprite formation. Normal liquid slag was not formed because of the low temperature and, probably, deficiency in iron components. Because of low temperatures and silicate composition the solidification of slag happened quickly. It is not excluded that smelting was realized in melting bowls. Losses of metal are very great.

Conclusions about the Abashevo metallurgy

The analyzed slags relating to the Abashevo time, have been found on the settlements of Beregovskoye, Tyubyak, and Urnyak. Also the relation to this period of slags from the settlements Yumakovo I and III is not excluded, because these settlements have materials of both Abashevo and Timber-Grave cultures. Nevertheless, in my opinion, these slags belong to the early period, because as we will see below, the character of Timber-Grave slag is a bit different, than samples from these settlements having both cultural layers.

Formation of friable soot slag can be connected with smelting of very pure oxidized ore from silicate rocks, mainly, the malachite mixed with charcoal. In some instances there were also impurities of secondary sulfides. It is the most probable that the ore was smelted in melting bowls, and the blasting was carried out through a charcoal layer from above.

Some researchers assume that the tomb relief at Ankh-Ma-Hor-Saqqara relating to the fifth Egyptian dynasty (2450-2359 BC), representing three metallurgists blowing in tubes on the crucible located in a small heap of charcoal, can reflect smelting ore, including sulfide ore (Zwicker *et al.* 1992, p. 103, 104), however, proofs to it are not provided.

The smelting atmosphere in such conditions was strongly oxidizing, fluxes were not used, temperatures were not too high – from 1050 to 1200 °C, it is not excluded, that even slightly lower, and duration of smelting was insignificant. As a result, normal liquid slag was almost not formed; the slag was very viscous and very quickly solidified. A lot of copper oxidized into cuprite, large losses were also in the form of copper prills in slag. A lot of unmelted ore remained. Subsequently metallurgists sorted the received conglomerate and separated the reduced and molten copper. Then these pieces and prills were used for re-melting or directly to cast products. In some cases, apparently, if the ore was especially pure, the exit of slag could be small. Experiments show that smelting of malachite almost does not produce slag (Zwicker *et al.* 1992, p. 104). Against the background of obviously large volumes of ancient metallurgy in the Northern Balkans during the Eneolithic, slag of this time is presented by extremely rare and very small pieces, which is explained by the use of pure malachite (Glumac, Todd 1990). Possibly, the smelting of pure covellite could have the same result.

It is rather early stage of metallurgical production. In Spain, on the settlements of El Acequión and Morra del Quintanar crucibles are found with slagged internal surface. Ore with charcoal was smelted in crucibles without external blasting, as walls outside are not slagged. The blasting was carried out directly into the crucible. Crucibles were hemispherical, bowl-shaped and are dated to 2500-2000 BC. The furnaces appeared only in the early 2nd millennium BC (Fernandez-Miranda *et al.* 1994, p. 23, 24). The use of crucibles for ore smelting in Spain is supposed also on the early settlement of Los Millares, and also in Switzerland, in Pfyn culture. In the first case it is determined by the presence of delafossite in the slagged surface, and in the second – by inclusions of sulfide ores, including chalcopyrite (Hook *et al.* 1990, p. 68-70; Maggetti *et al.* 1990, p. 94).

At studies of the Eneolithic settlement of Wadi Fidan 4 in Palestine the crucibles have been found, 11-13cm in diameter and 5-7cm in height, having a small bush in which it was possible to insert some pole. The crucibles have the slagged glassy upper rim and surface inside; probably the blasting was carried out from above. Furnaces on the settlement have not been identified. Ore is presented, as well as in our case, by pure malachite or malachite with limonite. In slag rare skeletons of quartz grains are revealed, the remains of sandstone. Quartz turned into cristobalite and tridymite, the evidence of high temperatures. Other phases are delafossite, cuprite, magnetite, hedenbergite ($Ca (Fe, Mg) Si_2O_6$) forming in the oxidizing atmosphere, and glass. Evidences about use of fluxes are absent. It is supposed that temperatures were approximately between 1000 and 1150 °C (it is determined by copper inclusions and eutectic cuprite\delafossite). Therefore there is no tenorite (CuO) which at a temperature of 1026 °C turns into cuprite. A reaction is supposed: magnetite + cuprite → delafossite + copper, which explains the lack of limonite remains. Fayaite is not also present, but this mineral is not typical in the Eneolithic slags (Hauptmann *et al.* 1994, p. 4-6).

Our experimental studies with smelting of the oxidized ores have been not too successful. E.N. Chernykh has also written that as the ore on Kargaly in the Orenburg area is presented, mainly, by malachite and azurite in sandstones and slates, this ore was very difficult for smelting as easily turns into cuprite (Chernykh 1997, p. 8, 9, 61-63). Nevertheless, at early stages metallurgists were reconciled to it, being compelled to bear considerable losses of metal, inevitable at smelting of this type. But it is necessary to emphasize that in this case we deal with a very archaic type of smelting when the furnace charge consisted, mainly, of pure malachite.

In this case the crucible smelting was connected, mainly, with that the received product consisted of conglomerate of small ore pieces, copper and slag particles, and it was necessary to sort it carefully for extraction of copper particles. In the small volume of the crucible it was easier to be made, than investigating all filling of the furnace. These are typical features of early stages of metallurgical production which we have discussed on the example of Eneolithic metallurgy.

The most part of slag cakes was smelted from ore in the ultrabasic rocks. Slags of this form are characteristic of the Sintashta sites. As a whole, this technology and the type of raw materials is identical also to that which we have seen on the Sintashta settlements in the Transurals, with the only difference that the proportion of uses of secondary sulfides was slightly higher here. It is explained, apparently, by the character of minerals of the upper zone of deposits in the Cisural area. The proportion of ore from the ultrabasic rocks changes too: in Abashevo metallurgy it is 39.3%, that is much lower than in Sintashta metallurgy.

The furnace charge (500-1000g) was placed into the furnace. The smelting was conducted in the conditions of reducing atmosphere at temperatures fluctuating in the interval of 1200-1400 °C. The fluid olivine slag formed on the metal ingot. The separation of metal from slag occurred almost completely; therefore the subsequent crushing of slag was not required. The slag was cooled quite slowly; therefore more possibly that the charge was located in the closed furnace, instead of a melting bowl placed in a heap of charcoal. The weight of ingots fluctuated in limits of 50-130g.

Some quantity of shapeless slags is a result of smelting of the first type (e.g. Urnyak and a part of oxidized slags from Tyubyak and, probably, slags from Yumakovo I), however here the oxidized ores from silicate rocks were smelted, and significantly more rocks was present in the charge, than usually. As a result more slag was formed, but the fayalite crystallized very poorly. Therefore quite intensive blasting was used that led to the growth of temperature up to 1250 or 1300 °C and the strong oxidizing conditions. As a result, copper losses in the form of copper, cuprite and other minerals, for example delafossite, are very considerable here too. In one of groups of slags from the settlement of Tyubyak, despite smelting of ore from quartz rocks, it did not occur. Despite the high temperatures, the reducing atmosphere remained and metal losses were insignificant, although they are higher than in the case of smelting ore from the ultrabasic rocks. As a whole, the technology of this group is identical to that of Sintashta. However, there are also some differences: on the settlements the furnaces attached to wells are unknown. Therefore Abashevo metallurgists could not generate so successfully the main reducing reagent, the carbon monoxide, as it was done by Sintashta metallurgists. Nevertheless, the smelting atmosphere of this technological type was reducing, even in slags of the silicate composition for whose smelting it was necessary to increase temperature and intensify blasting that led to considerable oxygen supply in the furnace. It is explained by more active use of secondary sulfides, than it took place in Sintashta metallurgy. This small difference in ore base allows us to believe that the Abashevo people did not transport ore from the Sintashta area, although this ore is similar to the ores from Ishkinino, Dergamysh and Ivanovka deposits. Probably, it is necessary to look for some fields of similar type in the Cisural area. Most likely, the Abashevo people purposely selected the complex oxidized and sulfide ore, though, probably, they were pushed by features of the fields.

This determination for the Abashevo time of two types of smelting is confirmed also by other finds on the settlements. In the Abashevo period (the settlements of Beregovskoye I and Tyubyak) the smelting was carried out directly in dwellings, specialized constructions were absent. They appeared already in the Late Bronze Age (Gorbunov 1992, p. 192, 193). On the all Abashevo settlements the ore, crucibles, and copper globules are found. It is supposed that the Abashevo people smelted the rough copper on open fire, and then refined it in the melting bowls (Gorbunov 1992, p. 190). On the settlements of Beregovskoye I and II only open hearths have been investigated near which metallurgical slags are found. On the same settlements fragments of crucibles and melting bowls are revealed (Gorbunov 1986, p. 25-28, 30). It is necessary, however, to take into account that the Sintashta dome furnaces in most cases have been fixed as the open hearths. A discovery of their top part is an exclusive phenomenon.

Crucibles and melting bowls are very widespread finds on the Abashevo sites of the Cisural area (Fig. 8-4.). They are presented by vessels with the roundish bottom and massive walls. The majority has clearly expressed hollow pedestal, although there are simple jars too (Gorbunov 1986, p. 57, 58). The last form remained during the Late Bronze Age on the Timber-Grave and Mezhovka sites (Gorbunov 1992, p. 190-192).

The majority of such bowls was used probably for metal melting, but it is not excluded that a part from them could be used for ore smelting. Their volume could fluctuate in limits of 70-200cm^3. It was enough for producing 50-100g metal when smelting the pure malachite mixed with charcoal. For smelting of poor ores from the ultrabasic rocks containing, as far as we know from Sintashta materials, 12-15% copper, these volumes are insignificant. However, such crucibles could be applied to smelt pure pieces of malachite. On the other hand, the largest melting bowls could be used also to charge up to 800 g ores from the ultrabasic rocks. But it was impossible in this case to fill the crucible with charcoal and to carry out purely crucible smelting. However it was possible to place the crucible into the furnace or the hearth with high walls filled with charcoal. In this case the crucible or the melting bowl acts as a reservoir for ore and molten copper, but the smelting is carried out, nevertheless, in the furnace.

Thus, for the Abashevo culture in the Cisural area we can basically speak about two main schemes of metallurgical process. The first we may call ‘Abashevo’, and the second ‘Sintashta’. And there are groups of slag which because of the larger quantity of silicate gangue are slightly different from the classical standards, but it does not cause changes in the technological scheme. In principle, the Abashevo tradition is technologically more archaic, than the Sintashta one. Almost everywhere the oxidized slags correspond to those early stages in development of metallurgy when smelters were not able to form liquid slag. Studies of slag from the Sinai and Negev have shown that early Eneolithic slag of the spinel type were formed in the furnace and contain a lot of metal as well as some oxidized slags in Bashkiria. They were formed in pit-furnaces with the internal diameter of 45 cm and the depth of 45 cm. Slags of the second half of the 2nd millennium BC were tapped, although a part of the slag was formed in the furnace. These slags were fluid and metal losses in them are extremely low. They were formed at higher temperature (Bachmann 1980; Rothenberg 1992, fig. 2, 35, 40, p. 2-6, 9, 12, 19, 39). We and other experimenters have received the similar result when smelting the oxidized ore in a crucible.

A part of the Abashevo technological type gave the small oxidized slags is insignificant (14.3%), but volumes of charge at smelting of this type are unknown, the real part of these smelting is unclear too as it is difficult to find this small friable slag at excavations.

We know also later slags rich in cuprite from Atasu, Kargaly and in some settlements of the Orenburg area. But they reflect not the smelting of limited amount of rather pure malachite, but a problem with creation of the reducing atmosphere.

Timber-Grave metallurgy

Slags of the Timber-Grave period are found in Bashkiria on the settlements of Verkhnebikkuzino, Novobaryatino, Sasykul, Yumakovo II, Aitovo, Chishma, Baygildino (Fig. 8-1.). The first four settlements are located, as well as in the previous time the Abashevo sites with traces of metallurgical production, in the middle watercourse of the Belaya river; the Chishma settlement is situated nearby, to the north-west, in the valley of river Urshak; the Aitovo settlement is to the west, on the Dyoma river; and the settlement of Baygildino is to the north, in the Ufa River valley.

These are quite limited materials, only 66 samples[6]. For example, there is only one sample of slag from the Baygildino settlement, and, only it is connected with the early Timber-Grave culture. But it is impossible to fully guarantee that this slag does not belong to the period of developed Timber-Grave culture. Therefore, on the basis of this material it is only possible to outline the general tendencies, but the statistical data given below reflecting the situation with Timber-Grave metallurgy of the Cisural area, may not be considered as completely strict. The situation on many other sites is similar.

On the settlement of Yumakovo II investigated by V.S. Gorbunov (1992, p. 67, 68), the bulk of ceramics is presented by Timber-Grave ware, although the early Timber-Grave Pokrovsk type, Alakul and Mezhovka are found too. The last two types of ware can be considered as impurity to the Timber-Grave ceramics. They do not form a separate layer. Therefore this material can belong both to the Pokrovka phase, and also to the developed Timber-Grave culture. The discovery of fragments of a melting bowl and a crucible on the settlement is remarkable. The last is typical for the Abashevo metallurgy; therefore it is not excluded that this slag is dated to the Pokrovka phase.

On the settlement of Chishma (excavator Yu.A. Morozov) 714 sq.m was excavated and two main cultural layers have been identified: Abashevo and Timber-Grave separated by a sterile layer. In addition to these

[6] Five studied samples of slag from Yumakovo II have been identified as slagged ore, and in this number are not included.

materials, there was a small amount of Mezhovka ware (Gorbunov 1992, p. 61). Slag has been found in the layer belonging to the Timber-Grave culture. However typologically it is closer to earlier slags as the sample is presented by a fragment of flat cake of Sintashta type.

Other slags are more definitely connected with the developed phase of Timber-Grave culture. So, on the Verkhnebikkuzino settlement, though there are also Alakul ceramics (excavations of G.N. Garustovich in 1986 and M.F. Obydennov in 1987), slag has been found in the layer of Timber-Grave culture. The Aitovo settlement (Yu.A. Morozov's excavation in 1985 and 1986, see Obydennov, Obydennova 1992, p. 51, 52) contains almost exclusively Timber-Grave materials. The same situation is also on the Novobaryatino settlement (Yu.A. Morozov's excavation), which having impurity of other material belongs, as a whole, to the Timber-Grave culture. V.K. Kalinin's works in 1977 and 1978 on the settlement of Sasykul have revealed also only materials of this culture. Slags of the Sergeevka settlement belong to the Timber-Grave period too.

The forms of the slags are close to the groups which characterize Sintashta metallurgy, although the ratio of these groups is slightly different (Tab. 8-5.). It is noteworthy the good presence in the collection of typical for Sintashta flat cakes with thick rim. Their bottom surface formed on metal ingot is flat and porous, and the top is smooth and glassy. But it is necessary to understand that this great number is caused, mainly, by one site, Verkhnebikkuzino. It is interesting here that this settlement definitely belongs to the developed phase of Timber-Grave culture. Anyway, even visually the connection with previous production of the Sintashta-Abashevo time is evident; besides, with the technology of Sintashta type, although it could be transferred by means of Abashevo metallurgy. Formally all three samples from Novobaryatino also belong to this group. The slags are presented by fragments of black dense flat cakes. In one case (sample 707) the slag had initially no thick rim. Both surfaces are smooth, slightly uneven, with light luster. Large pores are visible on the break. In the second case (sample 708) the thick rims of the cake were broken for extraction of metal ingot. The top surface is rough, with metal luster. The bottom is even, with small pores; probably, it was formed on metal. The thickness of slag is 2cm. The third sample was chipped on all sides, and its initial form cannot be identified. Judging from the form of this slag, it was formed in the furnace. Slag from Novobaryatino differs by the larger thickness, and partly by the rough bottom surface. This means, it was very fluid too, but it has differences, not quite explainable at visual examination.

The second group is presented by heavy shapeless slag. Six samples (samples 398 from Yumakovo II, and 361, 363 from Aitovo), related to this group, are presented by flat cakes, but they are different from the first group by the absence of characteristic thick rims, and it was caused simply by slightly smaller viscosity of these samples in comparison with other slags of this group.

Several samples from Aitovo (364-367) are presented by light in weight porous conglomerates with a part of surfaces covered with fused crust. Their color varies from brown to black. In principle, they can be also related to the previous type, but have some differences. At last, three samples (419-421) of the settlement of Verkhnebikkuzino, presented by thin slag crusts differ too. They formed probably on a wall of the furnace as their upper surface is covered with a thin layer of ceramic slag. Their internal surface is rough. Such slag is absent in the Sintashta collection.

It is difficult to identify the form of some slags from Aitovo as they were crushed.

As well as in the case of Sintashta metallurgy, the form of slag substantially depended on character of the used ore. Unfortunately, there are not so many samples of investigated ore: only on the settlements of Sasykul (sample 432) Novobaryatino (sample 710) and Yumakovo II. On the last settlement the ore is presented by small molten pieces which were originally considered as slag (390-392, 396, 399). The ore was extracted from quartz rocks, but the content of quartz is different. In sample 396 the gangue has been not revealed, and in sample 392 it was serpentine. The ore was probably extracted from the cementation zone and therefore, is very inhomogeneous. Samples 396 and 399 are presented, mainly, by covellite and chalcocite with chrysocolla and malachite inclusions, but sample 399 contains a lot of cuprite and some chalcopyrite. Samples 390 and 391 are, mainly, chrysocolla, sample 432 contains malachite, cuprite and chrysocolla in quartz, but with chalcopyrite inclusions, and sample 392 is malachite in serpentine.

Thus, the differences from Sintashta ore base are shown in a larger part of ore from quartz rocks, and also in the better presence of sulfide ore. The last circumstance is seen also in the analysis of sample 393 which has been identified as a small copper ingot with essential inclusions of copper sulfide (about 3%).

1st mineralogical group

The 1st mineralogical group of Timber-Grave slag in Bashkiria was smelted from ore in the ultrabasic rocks (Tab. 8-6.). It is identical to similar Sintashta and Abashevo groups. The ***olivine*** crystallized well in these samples. Crystals of olivine are presented by the prisms, long skeletons, in some instances by polygonal forms. Between them needles and skeletons grow. It is sometimes noticeable that fayalite forms round quartz and magnetite grains. In samples from the Verkhnebikkuzino settlement it is noted that sometimes the outer layer of crystals has lighter shade. Possibly, this layer has fayalite composition, and the center of grains is more magnesian. The majority of samples of this group from Aitovo differ from other slag by that the olivine crystallized worse, it is presented by prisms and small skeletons. In sample 362 the porous areas have been found where fragments of olivine glass are combined with the olivine crystals which grew after their solidification. Probably, the temperature fell to the point of solidification of olivine melt, and a reducing, but not too intensive blasting proceeded further which, nevertheless, increased the temperature.

Magnetite is usually presented by small unmelted octahedra. It is sometimes noticeable that they were formed due to disintegration of larger grains or separating from a thick border round chromites. In some slags (sample 418 from Verkhnebikkuzino, sample 394 from Yumakovo II and sample 359 from Aitovo) a significant amount of magnetite is recorded that resulted in the increased slag viscosity and increase in losses of copper. On the settlement of Verkhnebikkuzino the magnetite dendrites are also found, and in one case these dendrites are fused. In sample 365 from Aitovo the magnetite is presented by very large dendrites, characteristic of smelting of primary sulfides. It is in some cases noticeable that magnetite was formed as a result of disintegration of larger grains of iron oxide, but a part was probably formed from bornite and chalcopyrite smelting: sometimes ore grains are transformed into cuprite and from them magnetite octahedra separate.

Chromite grains are well presented in slag too and they mark its connection with ore from the serpentinized ultrabasic rocks. The content of chromite fluctuates even in slag of one monument (Verkhnebikkuzino). In some samples its quantity is rather high, in some only individual grains have been found. Associations of chromite and serpentine are sometimes recorded. The **serpentine** is presented in slag rather well, although in some samples the amount of its grains is insignificant. In samples 404, 421 (Verkhnebikkuzino) it is absent, but a good crystallization of olivine allows us to think that it was simply transformed and smelted or pieces of ore without serpentine inclusions were selected for the furnace charge. Some serpentine grains contain ore inclusions.

The ore is presented by malachite and chrysocolla, but many sulfides have been identified too: chalcocite, copper sulfide, bornite and chalcopyrite. Malachite and chrysocolla are presented by grains. Together with secondary sulfides they were the main ore. Chalcocite in the form of prills is found seldom. Possibly, as a result of burning out of a part of sulfur it was replaced by the isotropic sulfide, the most often met ore mineral. In some cases this sulfide can be presented by grains, but usually it was smelted. Copper inclusions are found in it. Often it lead to the formation of large copper prills surrounded by the sulfide border. In some instances this sulfide replaced the bornite. There are also its association with grains of cuprite, chalcopyrite and pyrites. It is not excluded that the formation of pyrites was caused by that this sulfide was smelted from chalcopyrite, although usually in such cases in slags of other series there was the formation of wüstite. However, in general, the primary copper minerals (chalcopyrite) have been identified not too often. Oxides and secondary sulfides of copper were the basic ores. Their associations are recorded in some cases that specify that the ore was extracted from one place, from the cementation zone, and it was not a special combination for the furnace charge.

Copper is presented by small prills, occasionally the grains which replaced copper sulfide. Its quantity is insignificant, only in rare instances, when the balance between the ratio of acid and basic oxides was upset (abundance of magnetite or vice versa silicates), it could lead to the increased losses of metal. Together with copper there is **cuprite** presented by small grains, prills and filling of cracks. In some instances molten cuprite is present around these sulfides, but in this case sulfide could be molten and oxidized then into cuprite, and it does not indicate high temperatures. It is not also excluded that as a result of the exothermic reaction of combustion of sulfur in some local areas the temperature could increase that does not reflect a situation in the furnace in general. Cuprite also replaces other ore minerals of copper. The amount of cuprite is rather small and its part could be formed as a result of the subsequent secondary oxidation. Therefore the atmosphere of smelting was reducing. It is also testified by that in some samples from Verkhnebikkuzino the molten particles of reduced iron have been found, but its quantity is very insignificant. Their fused surface, as well as in the case with magnetite, can be explained by their reduction from wüstite too. Possibly, these reducing conditions were promoted by the presence of the secondary sulfides in the furnace charge.

Thus, slags of this group are identical to most Sintashta slags: ores from the zone of cementation of a field in serpentines were used in smelting. Composition of different ore types or use of fluxes, apparently, did not practice. Usually the temperatures fluctuated within 1200-1300 ºC, although in some cases it is possible to assume even higher temperature that is explained by more active use of the sulfide ores. The ratio of acid and basic oxides in ore was close to the optimum. It provided the formation of olivine slag and its low viscosity. The liquid slag was solidifying slowly. The creation of the reducing atmosphere was promoted by the sulfides. As a result, the oxidization of slag was insignificant, and metal losses were very small.

2nd mineralogical group

This mineralogical group is identical to the second group of Sintashta slag, and is smelted from ore in quartz rocks. Fayalite crystallized in samples of this group very poorly. It is presented by small needle or long skeletal forms. In some areas of the samples and completely in samples 400 from the settlement of Verkhnebikkuzino and 420 from Yumakovo II the fayalite did not crystallized at all. It is explained by the lack of iron components. Very weak fayalite crystallization has been found almost in all samples from Aitovo. An exception is sample 355 in which fayalite is well presented by elongated skeletal, needle-shaped and even prismatic crystals. The formation of fayalite in this sample was caused by the significant amount of small unmelted magnetite octahedra and small nuclei of magnetite crystallization.

The content of quartz in slag differs, in some samples (398, 400) it has not been recorded. It is not excluded that in these cases very pure ore could be used for smelting, and the silicate component in slag appeared from chrysocolla. In slag from Aitovo quartz associations with ore grains are well recorded. Quartz in samples of this settlement is, apparently, the high-temperature. It turns into quartz glass and the border between quartz and glass is not always well distinguishable. In some samples (355) three zones with different brightness and transparency are recorded. Possibly, it is quartz, tridymite and cristobalite. Round the quartz porous areas of glass were formed that points to high temperatures too.

In addition to chrysocolla, malachite was another important ore mineral. Secondary sulfides (covellite, chalcocite) were also used in smelting, but they are hardly transformed, and in a sample from Verkhnebikkuzino their contents is insignificant.

The best of all ore base was studied for the largest collection of this slag group from Aitovo. In glass matrix many copper minerals and copper prills have been found, but in various samples their contents fluctuates violently. In some instances copper prills form curved rows that points to the high slag viscosity. The oxidized ore minerals are presented by malachite and chrysocolla. There is a lot of cuprite (in some instances more, than copper, in some instances less). The cuprite replaces the oxidized and sulfide ore minerals, sometimes it forms prills and fills cracks. There is molten cuprite, a border round prills of both copper and sulfide. Cuprite together with copper tints the glass. In some instances the “melted” cuprite could be formed as a result of replacement of molten copper or sulfide. But in some cases it is visible that cuprite, replacing the oxidized copper minerals, straight away turned into the molten state. At the same time, occasionally (in individual samples) unmelted grains of cuprite are present. The smelting temperature in Aitovo, probably, fluctuated in higher intervals than in other slag of this group.

There are prills of chalcocite. However prills and solidified melt of isotropic copper sulfide are more typical. Often the sulfide forms a border round large globules of copper and cuprite (more precisely, they were formed in these globules). Possibly, the large part of this mineral formed from covellite and chalcocite. However partly it was formed as a result of replacement of bornite, whose grains and prills are found in the slag. Sometimes in the sulfide melt the emergence of red reflexes is visible, demonstrating the transformation of this mineral into cuprite. However the formation of copper from the sulfide is often visible too. Probably, a part of bornite formed from chalcopyrite. There are occasionally grains in slag with intermediate color characteristics. At the same time, chalcopyrite grains are sometimes present too. In one sample (356) several very small iron prills have been identified that definitely point to the reducing atmosphere.

In other slags of the 2nd group the amount of cuprite is higher; therefore there were more oxidizing conditions. And as the content of sulfide minerals is not less here as in slags of the 1st group, the more oxidizing atmosphere was caused by more intensive blasting. Cuprite is present here in the form of prills, solidified melt, small dendrites which were crystalized from slag, borders round the prills of copper and copper sulfide. Often cuprite and copper are dissolved in slag, painting the glass in reddish color. In slag from Aitovo this effect is absent due to larger amount of sulfides: at combustion of sulfur the surplus oxygen combined with it; in addition to this, the exothermic reaction of combustion of sulfur allowed to reach a high temperature without the intensive blasting. Because of the intensive blasting the temperature was more than 1250 ºC, reaching, most likely 1300 ºC, and on Aitovo it reached 1350 ºC, judging from the molten cuprite and wüstite. Possible the presence of cristobalite in one sample allows us to assume that sometimes the temperatures reached 1470 °C. The necessity of this was caused by the viscosity of silicate slag that demanded to increase the temperatures. In this group of slag the copper losses in the form of ore, copper and cuprite are high, but were not excessive. The ores with the high content of iron components were smelted at lower temperature. At the end of smelting the intensity of blasting even, apparently, decreased, which resulted in the gradual formation of fayalite crystals and reduction of copper. In general, losses of copper are slightly higher, than in samples of the 1st and 3rd mineralogical groups, nevertheless, they are low. In some slags (sample 435 from the Sasykul settlement) copper losses are higher. It is explained by lower smelting temperature and fast cooling of slag.

The studies of pores in slag have shown the following. In some cases the pores break crystals of fayalite. It shows that even when the temperature was reduced and the fayalite crystallization began, the blasting proceeded in the weakened mode. Possibly, it was necessary to reduce copper. After the stopping blasting the slag solidified quickly enough.

Thus, the smelters used the oxidized and sulfide ores from the cementation zone (there are associations of ores of both types), with the prevalence of secondary sulfides on Aitovo. Quartz was the ore bearing rock. Fluxes were not used. The temperatures were rather high, but the slag was viscous and solidified quickly. In many cases the smelting was not completed and there was a lot of ore, especially secondary sulfides, in slag. Copper losses are large, but not too excessive. The intensive blasting was compensated by the sulfides. Therefore the smelting atmosphere fluctuated (there is a prevalence of both as copper as cuprite), but not too violently.

3rd mineralogical group

This mineralogical group in the Timber-Grave collection of the Cisural area is distinctly present only on the Yumakovo II settlement. It has been characterized on the Sintashta sites by the use of ore mix from the ultrabasic and quartz rocks, and, it was probably not a deliberate mix, but the use of ore from deposits in the ultrabasic rocks with quartz veins. In general, even at much larger Sintashta collections it is impossible to estimate the proportions of both these types of rocks in the furnace charge. It is also impossible to do basing on two samples from Yumakovo II. But the part of quartz rocks here was higher, in comparison with the Sintashta samples. Apparently, quartz was the main ore bearing rock. The evidence to it is associations of quartz with ore minerals, ore inclusions and also reduced particles of copper in quartz. On the other hand, if there was not too much quartz, it could be rather fully processed by the melt, then turning into the silicate glass. In sample 397 the presence in quartz of two zones with different brightness and transparency is recorded. It reflects the presence of two modifications, probably, quartz and tridymite. This method does not allow it to be defined precisely. Nevertheless, the presence of two zones in quartz grains indicates relative short duration of smelting when one modification did not turn into another completely. The similar situation has been found also in the Sintashta slags.

The main inclusions in slag are prismatic olivine crystals between which its skeletal structures grow. The content of magnetite crystals is very different too. Magnetite is usually presented by small unmelted octahedra. It is sometimes noticeable that they were formed due to disintegration of larger grains. Rare small chromite grains are recorded. On edge of its grains a thin magnetite border is usually present. Chromites and accumulations of magnetite demonstrate that there was some oxidized iron mineral in slag. It is unlikely that this iron component was used in the smelting as flux. In sample 397 malachite joints with chromite are recorded that points to origins of the ore from the ultrabasic rocks.

The ore minerals are presented by malachite and chrysocolla. Some quantity of grains and prills of chalcocite has been identified in samples 397 and 398. There is also molten copper sulfide. As an exception there are small inclusions of chalcopyrite. A part of the chalcopyrite could be smelted, but in ore base it anyway did not play a significant role.

Associations of cuprite, sulfide and chrysocolla specify that a special composition of ore from oxides and sulfides was absent. The content of cuprite (grains, seldom prills) is insignificant; the smelting atmosphere was obviously reducing.

Thus, the smelters used various copper minerals (oxidized and sulfide, mainly, secondary sulfides) from the zone of cementation of deposits in quartz veins located, probably, at any field of the ultrabasic rocks containing the iron component. As a result, the ore was very heterogeneous, and the change of its composition by fluxes was not practiced. As there was a large amount of sulfides in the ore, it made possible to reduce copper, although its losses in slag are anyway greater, than in slag of the 1st group.

Smelting technology

Technologically slags of the 1st, 2nd and 3rd groups reflect a single type of smelting. Smelting of this type in many respects succeeds to traditions of Sintashta metallurgy. These groups are distinguished only by the ratio of ores from the ultrabasic and acid rocks in the furnace charge. Depending on it metallurgists were compelled to regulate the intensity of blasting: in case of prevalence of acid rocks the blasting was more intensive to form the fluid slag. As a result the smelting atmosphere became more oxidized, and the partial oxidization of slag and formation of cuprite began. In some instances (Aitovo) this problem did not arise, thanks to the good presence of sulfides in the furnace charge. In other cases to cope with it, at the final stage of smelting the blasting was reduced to keep the furnace hot, but to reduce the air supply. Air, thus, went not so intensively, and passed more slowly through the layer of burning coal. As a result the carbon monoxide was formed more actively. Temperature, as well as in the Sintashta metallurgy, fluctuated within 1200-1300 ºC, but in the case with acid slag it could be sometimes higher, reaching in rare instances and in the local areas 1360 or 1470 ºC.

4th mineralogical group

This mineralogical group in the Cisural Timber-Grave collection is revealed only on the Sergeevka settlement. In the most samples fayalite crystallized very poorly. Generally, the slag is presented by pure silicate glass with rare small fayalite crystals: prisms, extended skeletons, needles, nuclei of the fayalite crystallization. It was caused by weak presence of iron components in the slag. Magnetite (small octahedra and skeletons or very small nuclei) has bound very seldom. Chromite grains are occasionally fixed, sometimes round them there is small fayalite crystallization. Probably it originated from magnetite borders which often surround the grains of chromite. In these slags such borders are absent, probably it is completely smelted. Small grains of magnetite disintegrating into octahedra are extremely rare.

Quartz was the main gangue. Its grains are well presented in slag and contain often the ore inclusions. Often the quartz grains have a peculiar structure. They consist from the small granules grouped in direct rows. Between the granules cuprite is sometimes fixed, that points to the sandstone origins of the ore.

Because of the lack of iron component the slag was very viscous. It resulted in considerable losses of metal in the form of copper, cuprite and ore. The copper often forms the prills set in long curved lines. In some cases it is visible that copper was reduced from cuprite. At the same time, copper was often formed directly from copper sulfide, replacing it in prills and grains. As a result, the borders and small inclusions of sulfide in copper prills formed.

Often copper and cuprite dissolved in the melt and paints the glass. In some instances it is possible to see also the back process when the large prills gather from very small ones. In some areas of polished sections both copper and cuprite (sometimes also the copper sulfide) form small dense accumulations of prills. Possibly, it demonstrates the melting of ore grains. In one case among them there are small crystals of magnetite, the result of melting of a grain of primary sulfide. There is also the formation of magnetite “needles” along the cuprite replacing the sulfide.

Cuprite is presented by prills, grains, replacement of ore grains. Only in one sample (384) the formation of cuprite dendrites round the prills of sulfide and cuprite, and even in one case cuprite crystallization in the form of elongated and prismatic skeletons is recorded. Sometimes cuprite prills separate from its grains, this means that the cuprite melted. In one case (386) delafossite has been identified.

Ore remains are presented by malachite, chrysocolla, covellite and the isotropic sulfide forming from covellite. The covellite (prills, some grains) therefore has been rather seldom detected. The copper sulfide is widely presented by prills, solidified melt, and grains. It, as well as malachite, often replaces cuprite on its borders. Small inclusions of bornite and chalcopyrite are occasionally recorded although they did not play a significant role in the smelting.

In some instances covellite grains are replaced with the copper sulfide. The grains of ore containing, mainly, covellite, and also malachite and chrysocolla, or covellite, malachite and some iron oxide are recorded. Malachite and covellite are found also together in quartz grains. All this demonstrates that the oxidized and secondary sulfide ores were in the deposit together, but, probably, the proportion of secondary sulfides was, nevertheless, higher.

Because the cuprite melt has been found, we can speak about the temperatures reaching an interval of 1250-1350 ºC. However, despite it, due to the low presence of iron component the slag was very viscous and quickly solidified that resulted in large losses of metal. The smelting conditions were, more likely, slightly oxidized. Considerable presence of sulfides affected. Fluxes were not used.

Samples 370 and 385 are slightly different: due to the presence of iron components the olivine crystallized slightly better and copper losses are slightly lower.

The fifth mineralogical group of the Abashevo sites, distinguished by oxidized slag and smelting in crucibles of the pure oxidized ore, is not found here.

6th mineralogical group

Unlike slag of the Sintashta-Abashevo period the Timber-Grave series of slag from the Cisural area shows a new group of slag presented by a sample (436) from Baygildino (therefore, it is not excluded that this group appeared already in the early Timber-Grave time), one from Sergeevka (380), two (405, 408) from Verkhnebikkuzino and three (707-709) from Novobaryatino. Similar slags are well-known on the forest-steppe sites of the Late Bronze Age.

Slag is saturated with accumulations of molten grains, particles, skeletons and octahedra of magnetite and wüstite. In the slag from Novobaryatino it is visible that magnetite was formed from larger grains. There are many wüstite dendrites, forming often ordered structures. In some cases dendrites of wüstite form dense lattice structures. Sometimes accreted very large wüstite dendrites with fused surface occupy almost all field of a sample and set so densely that form grains with streaks. Elongated and prismatic fayalite crystals are much worse presented (their contents fluctuates from the total absence to rather good presence). In these cases wüstite dendrites become thinner as they were processed into fayalite. The better fayalite crystallization took place in slag from Novobaryatino where fayalite is presented by polygonal, elongated and prismatic crystals, more rare by elongated and skeletal forms and where it is the main inclusion.

Grains of pyrite are less often. In addition to this, there are larger grains of pyrite, usually with a set of empty cavities formed as a result of run of copper sulfides from chalcopyrite. In sample 436 from Baygildino a large such inclusion is found from which run the sulfide with cuprite inclusions. Actually the “pyrite” is in some cases too light. Probably, a part of sulfur disappeared from it and it is a transitional stage of its transformation into wüstite. Some similar particles according to their optical characteristics are close to iron. Particles of the reduced iron are found too. There are some cases of contacts of copper sulfide grains with the grains “pyrite-iron”. The molten copper sulfide is revealed in all samples although often it is replaced by cuprite. From other copper minerals the grains of malachite partly replaced with cuprite, and chrysocolla are found. There are a lot of copper minerals, but the main components anyway are iron oxides. Against this background the samples from Novobaryatino where ore and copper inclusions are practically absent differ. It points to the low slag viscosity. In sample 707 a cuprite grain, a copper prill, a grain of ore similar to chalcopyrite hardly defined because of the small sizes are found, and in sample 709 a copper prill.

Quartz particles are extremely seldom. Quartz was probably completely used at the fayalite formation, and it is impossible to define whether it was connected with ore bearing rocks or its occurrence in the furnace charge had casual character. In one sample from Novobaryatino (707) individual chromite grains are recorded. But their content is so small that does not allow this slag with the ultrabasic rocks to be connected.

These are well-known for the LBA types of microstructures. Chalcopyrite was obviously used in the smelting, and, it was the leading component in the furnace charge. The oxidized minerals played a supporting role. Copper is, practically, absent in the slag. It is presented only in the form of copper sulfide and cuprite. Possibly, it separated quite well from slag. Its reduction is undoubted as even the conditions for limited reduction of iron were formed in the furnaces.

Slag was solidified relatively quickly (small crystals of fayalite and dendrites of wüstite). It is difficult to determine the temperature, but, judging from wüstite, it could be above 1360-1400 ºC. Such high temperatures were promoted by exothermic reaction of combustion of sulfur and opportunity to do intensive blasting as oxygen connected with sulfur and did not lead to the oxidizing atmosphere.

In the presence of identical ore bearing rocks samples from Novobaryatino are strongly different in this slag group. In these samples the fayalite crystallized perfectly. It is presented by polygonal, elongated and prismatic crystals, more rare by long skeletal forms. It is the main inclusion in slag. There are many molten on the surface dendrites of wüstite, particles, skeletons and octahedra of magnetite, especially in sample 707. Magnetite was formed from larger grains. Quartz particles are extremely seldom fixed. Quartz probably turned completely into fayalite in the course of smelting. Despite the abundance of magnetite and wüstite, ore and copper inclusions are, practically, absent that point to the low viscosity of slag. In one sample (707) individual grains of chromite and small particles of iron are recorded. But these chromite grains are very rare, and the slag was not connected with ultrabasic rocks.

Thus, in this smelting chalcopyrite from quartz rock was, probably, the main ore. The smelting was long. Probably, temperatures were very high (judging from the molten on the surface wüstite dendrites) that was promoted by the combustion of sulfur. The slag cooled down slowly, in the conditions of reducing atmosphere and probably in the furnace. Losses of metal are absent. It is possible to call this smelting ideal.

Conclusions about Timber-Grave metallurgy

Thus, the Timber-Grave metallurgy substantially succeeds to the traditions of Abashevo time. It is shown even in the ore base (Tab. 8-6.): the proportions of ore from the ultrabasic and acid rocks are close to those of the Abashevo time. The differences are in more active use of the sulfide ores. However, it is difficult to speak about a purposeful combination of the furnace charge from these minerals as in the ore inclusions their associations have been found. Possibly, it reflects the character of initial ore. But it is impossible to exclude a deliberate choice of ores with such composition. It and also the weak blasting at the end of smelting allowed smelters to keep the reducing atmosphere even in the case of use of ores from acid rocks. Exception are the oxidized slags from Sergeevka, but this oxidation was not immensely high that was connected with the active use of sulfides too. There is no group of the archaic oxidized Abashevo slags received at smelting of pure malachite. The orientation to large volumes of production is obvious, than it was available in this archaic technology. As it has been noted above, the general technological principles correspond to the Sintashta-Abashevo traditions (and therefore we do not describe here the details of this technology again), although sometimes (in case of necessity to smelt the ore from quartz rocks) the temperatures could be higher. At the same time, on the Timber-Grave sites a new for this area technology of smelting of chalcopyrite is found too.

It should be noted that the slag connected with the fields in copper sandstones is present only on the Sergeevka settlement, although other settlements are situated in close proximity to the zone of distribution of these fields (Fig. 8-1.). It is explained in some cases by the succeeding to the Sintashta-Abashevo tradition of the use of ore from the ultrabasic rocks, and in the case with the acid rocks, probably, by aspiration to use the sulfide ores, not so typical in the sandstones. It resulted in low losses of metal and its reduction in the conditions of intensive blasting and high temperatures that would be completely impossible when using the ore from sandstones. This means that the sandstones were poorly used (their part in this sampling is 27.5%) for the reason that their properties did not correspond to the technological traditions. It is not excluded that in the future samples connected with fields of this type will be revealed among the Timber-Grave slag of Bashkiria, but against the background of the studied collection of 66 slag samples and 7 ore samples it is possible to claim that the situation hardly will essentially change.

As well as in Sintashta metallurgy, smelting was carried out directly in the furnace. It is hardly to say something about the construction of furnaces. On the Timber-Grave Tavlykayevo settlement (besides the Timber-Grave, on the settlement impurities of Alakul and Cherkaskul ware were found) in the Bashkirian Transurals a metallurgical workshop has been investigated which was situated on the periphery of the settlement. Possibly, this fact indicates the emergence of specialization in the production that was characteristic of metallurgy of this time in many areas. A metallurgical furnace has been investigated: a rectangular pit with the size of 27×22cm and the depth of 16 cm, filled with charcoal and slag (Fig. 8-7.). The furnace walls were inclined and faced with limestone plates. In the lower part of the furnace a copper ingot 105 g in weight has been found. It indicates that the volumes of smelting were the same as in Sintashta. In the dwelling stone pestles and hammers for ore crushing and slag pieces have been found. According to the analysis of metal objects from the settlement they relate to the chemico-metallurgical groups VK (Volga-Kama) and MP (copper sandstones) (Morozov 1981, p. 61, 62).

This technology is close to that of Alakul culture that, however, no wonder as Sintashta was in the basis of formation of both Timber-Grave and Alakul cultures (Vasiliev *et al.* 1995; 1995a; Grigoriev 1999, p. 142; 2000, p. 295). The presence of early Alakul ceramics on the Timber-Grave settlements of Bashkiria is noted in various areas, but it is most characteristic of the southern sites located on the middle course of Belaya River. It characterizes the Timber-Grave sites since the early phase (Beregovskoye I, Verkhnebikkuzino, Yumakovo III) (Obydennov, Obydennova 1992, p. 144-145; Rutto 1982, 1987; Grigoriev 2000, p. 291-299). Therefore, the spread of this technology into Bashkiria was connected as with Sintashta culture itself and similar to it sites of the Cisural area (Tyubyak), as also with those processes of disintegration of the culture which caused impulses of the Sintashta people to the west and led to the formation of the Timber-Grave-Alakul world.

Smelting of chalcopyrite became a new phenomenon. It was the new for the region technology which had not been connected with the Sintashta-Abashevo tradition. It was earlier supposed that the smelting of sulfides had several stages: at first to produce matte, the mix of iron and copper sulfides, then in the oxidizing conditions the copper should be reduced (Tylecote 1980, p. 5, 7). There are also opinions that the smelting of sulfides was carried out at a single stage, without intermediate stage of producing matte (Hauptmann *et al.* 1993, S. 560). Our study shows that even from chalcopyrite it was possible to produce copper directly. The smelting stage with the matte production is already the next step in the development of metallurgy, focused on large volumes of smelting. Actually, this transition to the sulfides is observed in the LBA everywhere. Besides, the information on roasting for receiving matte is absent everywhere (Tylecote 1982, p. 99). The presence of the reduced iron in slag is remarkable too as we have not seen it in Sintashta metallurgy. During the Late Bronze Age the iron in slag melted from copper sulfides is a typical situation, although sometimes it is also considered as a sign of the later date of this slag. Iron is well presented, for example, in the LBA slags found near Mitterberg in Austria where chalcopyrite and fahlores were used, and, the smelting of sulfides was carried out directly, without smelting stage for matte production. In copper in this case the sulfide inclusions are fixed too, and it was necessary to refine it (Moesta 1995, p. 262; Romanow 1995, p. 264; Shennan 1995, p. 287, 299). It was solved by re-melting in a crucible. The re-melting drastically reduces the content of iron in copper. When blasting the iron is easily oxidized and comes to the surface (Tylecote 1987, p. 192, 193).

Mezhovka metallurgy

Slag of Mezhovka culture has been found in the Cisural area only on two sites: Novokizganovo and Yukalekulevo[7] (Obydennov, Shorin 1995, p. 53). The quantity of the sites is very small, as well as the quantity of samples from each of these sites (4 samples from Novokizganovo and 3 samples from Yukalekulevo). It makes impossible to divide them into some groups. Besides, the slags of these sites differ from each other, and this distinction, probably, is more significant, than the distinction of samples from a particular settlement. Therefore, the description of slag from individual settlements is given below.

Novokizganovo

All samples from Novokizganovo are presented by pieces of the shapeless slag. The slag has clearly expressed zonal structure. The first zone is glass with small pores. Near the surface the crystallization practically did not take place. Below, nuclei or small needles of olivine crystallization are only visible. Other inclusions are presented more weakly here. These are small melting grains of quartz, occasionally small prills of copper, and particles of iron, chromite, chalcopyrite, and magnetite.

The olivine crystallization increases in the middle part of the samples. It is presented here by needles and small prisms. However this crystallization is not fixed in some areas of polished sections. Glass in such cases is often tinted by copper and cuprite. The number of copper prills increases. Some of them are surrounded by either cuprite or sulfide borders. Rare prills of covellite and cuprite, grains of malachite and chalcopyrite (in some cases replaced with copper and sulfide) are present. Occasionally there are small slightly fused on the surface wüstite octahedra. In some instances pieces of glass which had solidified earlier and then broken again have been found. In sample 442 a piece of rock with a quartz vein has been identified with the inclusions of cuprite, chalcopyrite, pyrite, and malachite.

Near another surface the olivine crystallization decreases again. In sample 439 an interesting situation is recorded: almost pure glass matrix at the surface contain inclusions of two fragments of glass with clearly borders and good fayalite crystallization (very long parallel needle-shaped structures) and accumulations of the dense fused dendrites of wüstite among them. These fragments had solidified obviously in another place not here and then did get here before this part of the slag solidification.

Thus, ones smelted the oxidized ore and sulfides (covellite and chalcopyrite) in quartz rock. However, inclusions of chromites allow us to assume the quartz veins in the ultrabasic rocks, or such rock was used as flux. Probably there is no ground to speak about a special composition of the furnace charge from different ores as the ore fragment with different ore types (malachite, chalcopyrite and so on) is revealed.

Temperatures are not perfectly clear, but they were very high. They could reach 1360 °C as the fused on the surface dendrites of wüstite have been identified, but the latter could also occur without such high temperatures. However it is possible to speak with some confidence about a temperature framework of 1200-1300 °C. The smelting atmosphere was reducing. The material is well molten. The zonal structure of the slag has analogies in some slags in the south of Central Asia (Grigoriev 1996a). Most likely, such structures could be formed on the wall and bottom of the furnace, and the weakness of crystallization under one surface (contacting to the furnace lining) could be caused by the lack of necessary components, and on the another by

[7] On this settlement, besides the Mezhovka ware, the Cherkaskul ceramics is found too, but the slag is connected, according to the author of the excavation, with the Mezhovka time.

that the temperature in the furnace quickly fell for some reason (for example, the furnace cover was removed, and the mouth was rather wide). But it is impossible to exclude completely the possibility that the slag was partly tapped. In this case the zone contacting to soil and the top part cools down quickly, and in the middle zone the crystals grow slightly slower. The part of the slag left in the furnace solidifies not so quickly. A part of such slag could be tapped too that led to the formation of pieces of the solidified slag in the glass solidified later. But it is impossible to confirm this assumption without knowledge about the furnace design.

Sample 441 presented by a small lump of slag differs from the samples discussed above. Fayalite crystallization did not occur in it too, but many octahedra and skeletons of magnetite, prills of copper, large molten inclusions and prills of cuprite, malachite replaced with cuprite (often malachite is present in quartz) have been found. One cuprite globule has a sulfide border. This sample is very small.

Yukalekulevo

In dwelling 1 of the Yukalekulevo settlement a pedestalled crucible has been found. Nearby four heavy slag cakes formed in a depression were situated. Both their sides are rough, but one is convex, and another is concave (463-466). A light porous slag is found too. All its edges are chipped. One surface is rough, smooth, and covered with ceramic slag. The second surface consists of rough, porous and heavy slag (460, 461). The last sample is presented by a small very flat piece of slag (462).

The slag is non-uniform, but it is difficult to distinguish some accurately divided groups. The microstructure of slag depended on the ratio of acid and basic oxides which participated in smelting, and on the speed of slag cooling. As a result, olivine crystallized irregularly. In some samples the olivine crystallization is expressed poorly, in some (sample 461) it is not expressed at all, in others the fayalite formed prismatic crystals, although usually they are not very large. It is remarkable that in sample 461 where the olivine crystallization did not occur, all components are well smelted, and copper completely separated from the slag. Usually in viscous silicate slags it does not occur. Therefore, the reason of the lack of crystallization is the high speed of slag cooling.

The iron component presented by magnetite is distributed very irregularly too, although in general there is a lot of magnetite in slags of this settlement. In some instances the magnetite particles are grouped in the large molten fields. Accumulations of octahedra and grains of magnetite are often fixed. Its main part was obviously formed from some larger grains, but it is difficult to determine whether they were deliberate fluxes. Nevertheless, in this case it is impossible to exclude this possibility although reliable facts in favor of it are absent. It is more likely that all iron components came from chalcopyrite and gangue. A part of magnetite in the form of small skeletons grew from liquid slag. Wüstite forms dendrites, in some instances quite large and molten (Fig. 8-8.). There are occasionally accumulations of small particles of magnetite and cuprite, a result of disintegration of some primary copper sulfide or copper ore in iron oxide. Possibly, wüstite was not a result of crystallization of dendrites; it was rather a result of dissociation of chalcopyrite grains, run of copper sulfide from them and oxidation of iron sulfide. Therefore the chalcopyrite was present in the charge, but its quantity was insignificant. Extremely seldom chromite grains have been found. In some cases they are incorporated in grains of serpentine. Quartz grains are well presented in all slags.

Generally the number of copper prills is insignificant although in some samples its losses increase because of the oversaturation of slag with magnetite (sample 462).

The behavior of cuprite in slags differs. As a whole, the content of cuprite is small. But in some samples it is presented only by grains (465), and in others there are its dendrites among the needles of delafossite (466). Prills, melt, and replacement of ore grains occur, but the molten forms could be formed also by the replacement of sulfide.

In some samples the reduced particles of iron are revealed, although it is not a widespread phenomenon. Slightly better they are presented in sample 463 where in addition to this a particle consisting of copper and iron is found. Apparently, there it was reduced from chalcopyrite.

The ore minerals are very variable: malachite, chrysocolla, azurite, covellite, isotropic sulfide (it forms standard associations with cuprite and copper), bornite, chalcopyrite, pyrite grains. But these inclusions are not numerous. And the copper and cuprite are presented poorly. Therefore the slag was not viscous although fayalite crystallized badly. There is a feeling that the smelting duration was relatively long that promoted the good processing of all components. Possibly, in the course of smelting the viscosity was low because of as the temperatures, as well as of that the slag was not too acid. And the weak fayalite crystallization was caused by the high speed of the slag cooling.

Thus, the oxidized and sulfide ores came from the cementation zone in quartz rocks. However, it is not excluded that it were quartz veins in the serpentinized ultrabasic rocks.

In one sample (466) fragments of slag glass are recorded. It is possible that this is evidence of use of old slag as a flux. But there is a probability that the slag was tapped, and the part of quickly solidified (glass) was crushed and mixed with liquid slag during the tapping. But the crystallization of long delafossite needles contradicts this assumption. The smelting atmosphere was, in general, reducing that promoted sometimes to the formation of iron, but in some cases a local oxidation of slag took place.

Temperature fluctuated from 1200 to 1300 ºC, judging from the crystallization of fayalite and cuprite, cuprite melt, and the fused dendrites of wüstite show a possibility for some cases even a higher temperature. Nevertheless, the temperatures of some samples were lower than 1250 ºC. Therefore, temperature characteristics either were unstable or we have simply not enough data because of the small number of samples.

Conclusions about Mezhovka metallurgy

Unfortunately, the number of investigated Mezhovka slags is very insignificant, besides they occur from only two settlements of the Cisural area that forces to be careful with the conclusions drawn on this basis. It is obvious that in the smelting a mix from rather wide range of ores from malachite to chalcopyrite was used. These ores were connected with quartz rocks although in one case the quartz veins in the ultrabasic rocks are not excluded. But the aspiration to take the ore from the ultrabasic rocks, as it took place in the Sintashta-Abashevo time, in the Mezhovka period was absent. There are also no data on the use of fluxes. A special composition of ore mix from the sulfide and oxidized ore is a little probable too. Most likely, this mix was initially present in the deposits. Therefore the ratio of the oxidized and sulfide ores differed that resulted in some variability of slag. But just the presence of sulfides promoted both to creation of the reducing atmosphere, and reaching the high temperatures.

The variant of a partial tapping of slag is not excluded as the part of the slag cooled down quickly enough. In other parts of the Old World in the LBA the slag tapping is recorded. In Europe and Egypt rather large volumes of production within one smelting operation have been reconstructed for this time. The Egyptian furnaces in the Negev with pits for tapped slag are accompanied by flat slag cakes weighting 30 kg. Besides, in Europe copper ingots weighing 3-4kg, and in the Eastern Mediterranean up to 30-40kg are known, and they could not be molten in a crucible. Therefore in some cases the copper tapping is possible too (Tylecote 1980a, p. 190, 194, 195). But in the Cisural area such large slag cakes are unknown.

Crucible smelting and a spitting of slag from a crucible are less probable. On many sites of the Urals the crucibles dated to the Mezhovka period have been found (Fig. 8-9.). They have a bowl-shaped or cylindrical form and, in some instances, a support or pedestal. Some of these crucibles had quite large sizes. Their volumes varied in the limits of 500-1000cm^3 (Obydennov, Shorin 1995, p. 85). As the specific weight of copper is 8.9 g/cm^3, in such crucibles it was possible to melt 3.5-6kg metal that was too much for metalworking production. Therefore these crucibles could be used for ore smelting. In such crucibles it was possible to smelt 100-200g copper. But in the Mediterranean the large crucibles for copper melting are known. So, the LBA crucible from Serabit could contain 7.6 kg bronze (Tylecote 1980a, p. 201). Therefore this variant is not excluded completely, but it has to indicate in this case the commodity nature of the production in the Cisural area.

Another approach is possible too if to rely on known analogies. So, smelting of sulfide ores in a crucible has been revealed in Switzerland that was fixed by inclusions of sulfides in crucible walls (Maggetti *et al.* 1990, p. 94). Study of slagged walls of the crucible found on the Cyprus, in Enkomi, and dated to the LBA, has shown the presence of copper and copper-iron sulfides, iron silicates and magnetite. From what it is possible to conclude that in the crucible the ore was smelted. Experiments with similar smelting in a laboratory gave the same microstructures (Zwicker *et al.* 1992, p. 104, 106).

One more circumstance should be also noted. The use of primary copper ore (chalcopyrite) could create in some cases the conditions when iron could be produced as a by-product. Let us pay attention that small inclusions of the reduced iron are present in slags of the Mezhovka series and in some Timber-Grave slags.

Kurmantau metallurgy

At the end we will discuss single samples from the settlement of Kakrykul. On the settlement the ceramics of Kurmantau is found, so, it is possible to consider as the continuation of the Mezhovka tradition and to date to the Final Bronze Age, although the Eneolhic Garino-Bor ceramics is found there too. Judging from the slag characteristic it is dated probably to the Kurmantau time, but we know slags smelt from similar ores in the Eneolithic.

The samples are presented by large pieces of heavy shapeless, slightly flat slag. Mainly sulfide ores (chalcopyrite and bornite) were used in the smelting. Its atmosphere, thanks to it, was reducing. A plenty of wüstite in the slag is characteristic of smelting of these sulfides. Slag cooled down with the average speed. Judging from the abundance of secondary copper sulfide and almost total absence of copper, it is not excluded that metallurgists produced a mix of matte with copper that demanded the subsequent melting, but it is questionable being based on such a small series, and is not confirmed while by other analyses. The smelting temperatures could be higher than 1360 ºC, but it is difficult to determine the upper limit. The slag from the settlement of Kakrykul was formed in the furnace. Possibly, the smelting was short-term as the sulfides did not react with oxygen completely. However, it is possible (these are only two samples) that here we deal with a defective smelting of the same type.

Spectral analyses of slag

Slags of the Middle Bronze Age

Chemical studies of metal, ore and slags of the Cisural area have a deep history. A large work on the analysis of metal of the area was carried out by E.N. Chernykh. The spectral analysis of Abashevo and Balanbash (the Ural Abashevo) metal allowed him to divide it into two chemico-metallurgical groups MP and TK connected with the copper sandstones of the Urals and the mine of Tash-Kazgan. The second group differs by high concentration of arsenic and has been considered as natural bronze. In addition to this, there is a clear regularity of prevalence of the TK copper in the Balanbash series and MP copper in Abashevo (Chernykh 1970, p. 27, 28). In particular, it has been supposed that the analyzed ore from the settlements of Balanbash and Urnyak were mined from Tash-Kazgan (Chernykh 1970, p. 42). Our studies of slags of Sintashta culture, discussed above, have demonstrated that the TK group was not the natural arsenic copper, it was the artificial bronze alloyed at the stage of ore smelting. Therefore it is necessary to assume that the situation in the Cisural area repeats that in the Transurals. It is also remarkable that the frequency diagram of trace-elements concentration in Abashevo (the Volga) and Balanbash (the Urals) TK metal have, in general, an identical configuration, however the content of arsenic in the Balanbash series is much higher. Besides, if in the Volga Abashevo series 14 objects relate to the TK group, and 50 objects to MP, in the Ural Abashevo 55 objects are related to TK, and 17 to MP (Chernykh 1970, fig. 18, 22, p. 28). But taking into account the already discussed tendency of the use of MP copper, mainly, in ornaments, in the weight relation the difference of the ratio of these groups is more essential. Therefore, in slag the proportion of arsenic bronzes has to be higher.

Indeed, 7 from 20 (35%) analyzed slags of the Abashevo time have shown the content of arsenic lower than 0.01%, and 13 (65%) above 0.01% (Tab. 8-10.). Just this number of 0.01% arsenic in Sintashta slag we considered as a border indicating the smelting for production of arsenic bronzes. However, the frequency diagram of arsenic distribution in Abashevo slag (Fig. 8-11.) shows two tops with the border about 0.03%. Therefore it is not excluded that it marks here the slags at whose smelting the artificial alloying was applied, and a part of arsenic bronzes with the low arsenic content was smelted from ores with arsenic impurity. It is also possible because the part of sulfide ores in the Cisural area was higher, and slightly higher arsenic concentrations are peculiar to them.

As well as in Sintashta metallurgy of the Transurals, the dependence between high arsenic concentration and the 1st and 3rd mineralogical groups connected with ore from the ultrabasic rocks is present: from 13 samples 9 with the high arsenic content belong to these groups, and only one sample from the ultrabasic rocks has shown low concentration of arsenic. Contrary to it, the groups connected with quartz rocks, contain usually a little arsenic. And we have already discussed that as the ore in Tash-Kazgan is situated in the quartz rocks, we would have to expect to see another ratio. It is also remarkable that a sample of the 5th group (402, Yumakovo III) which is, apparently, a sign of the archaic Abashevo technology, has shown rather high content of arsenic. But none sample connected with the quartz rocks, contains more arsenic than 0.03% while in all samples (except for one) connected with the ultrabasic rocks, the content of arsenic starts from 0.05% and above.

This connection of arsenic with the ores in the ultrabasic rocks is also perfectly shown by the correlation diagram of As-Cr on which the vast majority of samples shows a direct interdependence between these elements, and the slags smelted from ores in the ultrabasic rocks contain higher concentration of these elements (Fig. 8-12.). Thus, here we deal with the same, as in Sintashta metallurgy, tradition of the combined smelting of copper ores and arsenic minerals. As well as in Sintashta, in many instances the alloying was carried out by minerals with essential impurity of nickel although here it is expressed not so distinctly, as it is shown by the diagram of As-Ni, and in the slags smelted from ores in quartz rocks this dependence is absent at all (Fig. 8-13.).

Thus, the arsenic copper of the TK group in the Abashevo series, as well as in Sintashta, reflects, mainly, the ore from the ultrabasic rocks alloyed with arsenic or arsenic-nickel minerals at the stage of ore smelting. Not alloyed smeltings produced the second group of copper – MP. It was the ore from different fields in quartz rocks, but its part could be really connected with the copper sandstones.

Slags of the Late Bronze Age

The Timber-Grave metal demonstrates other groups – MP (pure copper) – 45.6%, tin bronzes (some of them are alloyed also with arsenic) – 45.4%, arsenic and antimony-arsenic bronzes – 8.2% and antimony bronze – 0.7% (Chernykh 2007, tab. 6.3). Proceeding from our purposes, we may ignore the tin ligature as the alloying with tin was carried out into metal. In this case we have a bit different ratio of metal (it must be kept in mind that this sampling is made on the all Timber-Grave metal and not only on that from the Cisural area).

From table Tab. 8-14. follows that in the Timber-Grave time the former tradition of arsenic bronzes production remained, but its proportion became immeasurably lower. However, in the Cisural area its proportion was probably higher, but anyway it was lower than in the previous Abashevo time. The found by slag studies preservation of tradition of smelting the ore in the ultrabasic rocks quite corresponds to it.

Alloying with arsenic

Using the former barrier of 0.01% (see corresponding chapter about Sintashta slag) to divide the slag into groups, we see that in the Cisural Timber-Grave series (63 analyses) 63.5% of samples is low-arsenic, and 36.5% – high-arsenic slag (Fig. 8-15.). The first group is presented by only 5 samples connected with the ultrabasic rocks, and the second one is by 19 samples. This means that the tendency of the Sintashta-Abashevo time remains being only less expressed. All slags of 2nd mineralogical group, in this case, are the low-arsenic. Almost all slags received at smelting of chalcopyrite (6th mineralogical group), belong to the low-arsenic group. At first sight, it contradicts our assumption that arsenic-antimony VK bronzes were connected with smelting of primary sulfides (Grigoriev 2004). However, it is not excluded that the high smelting temperatures in slag of this group are the reason of the lack of arsenic.

There is no accurate dependence between the contents of arsenic and chrome. That is, a certain correlation is visible, but it is not very distinct. It could be caused by different reasons: higher smelting temperatures, another ore base, and also by the rarer use of the Sintashta-Abashevo principle of alloying.

Barium as a flux

At the same time, the analysis of chemical data has revealed a new type of additions into furnace charge. Slags from the settlements of Sergeevka, Aitovo, Verkhnebikkuzino, and Sasykul contain 3% and more barium (Tab. 8-10., Fig. 8-16.). The settlements are located in a large distance from each other; therefore it is doubtful that it was caused by ore from one field. These are slags of different mineralogical groups, though smelted, mainly, from quartz rocks, as the high content of barium is found only in four samples of the slag connected with ultrabasic rocks. For the Sergeevka settlement it is possible to speak more definitely about the ore origin from the copper sandstones.

Barium is often obviously connected with silver. But there are many samples where high concentrations of barium are not accompanied by high concentrations of silver. There are also samples with high concentrations of both elements, and samples where both barium and silver show the low concentrations.

Barium is present in ore from Novobaryatino and Yumakovo II. And, in three of five cases it is accompanied by the high content of silver that is similar with the situation which is seen in slag. But the content of barium in this ore is low (0.05 and 0.3%). Taking into account that, according to our estimates, barium from ore goes into slag with the decreasing coefficient 0.353 (see introduction), and it is obviously not enough to give such high concentration in slag. However, silver has to decrease in slag in even larger degree; at such concentration in slag, in copper its content would have to appear so high that in metal of the region the part of billons would be extremely high. The billons are really present, but not in such quantities. It is possible to assume that our estimates of transition of these elements are incorrect, or they do not take into account some local characteristics of smelting, being calculated statistically.

If to look at the diagram of ratio of barium and silver, we see that the samples fall into four distinct groups (Fig. 8-16.). The casual presence of barium in ore would not give such clearly expressed groups. It allows us to assume an artificial character of this addition. The majority of samples contain low concentrations of barium and silver. In some samples the high concentrations of silver are accompanied by the low concentrations of barium. Both these groups include samples of all cultural types of the Bronze Age from various areas. The high content of silver was connected probably with chemical peculiarities of Cisural deposits that is confirmed also by the notable presence of silver in some ore samples. But the large concentration of barium in ore is not detected. And hardly it may be explained by the use of ore from the Nikolskii mine (it is supposed that ores of this mine gave the copper-silver alloys) where the ore bearing rock is quartz, because very often the high concentrations of silver are present in slag of the 1st mineralogical group smelted from ores in the ultrabasic rocks.

There is also a group of slag with high concentration of barium, but with insignificant impurity of silver. This group includes slags of the Abashevo and Timber-Grave cultures. It allows us to assume additions of some mineral containing barium, for example, barite ($BaSO_4$) into the furnace charge. For smelting on the Kargaly mines E.N. Chernykh has assumed similar possibility, explaining it by the need of additions of sulfide minerals to reduce the oxidizing conditions in the furnace (Chernykh 1997, p. 62, 63). In principle, it quite corresponds to the tradition of Sintashta-Abashevo metallurgy with its additions of arsenic minerals. Besides, in the Cisural area, since the Abashevo time, we see the aspiration to use sulfide minerals in smelting for the best reduction of ore. In the absence of the furnaces attached to wells, it was necessary. The obvious succeeding to the Abashevo traditions explains the presence in this group of many Timber-Grave samples. Besides, in the Timber-Grave period more active exploitation of some fields with higher silver contents began. Additions of barite to this ore could give the large group of Timber-Grave slag with the high concentrations of these elements. It is remarkable that Mezhovka slag does not show such high concentrations of barium, i.e. these traditions of fluxing were absent in the Mezhovka metallurgy.

In principle, silver is characteristic of the copper sandstones in the Cisural area (Chernykh 1970, p. 17). But our study of slag mineralogy has revealed few samples which can be connected with the sandstones, and these samples do not show high contents of silver. As deposits in sandstones had been formed from deposits of different type, these latter have higher concentrations of silver too.

Deliberate fluxing of the furnace charge with barium is the most probable variant, but it should be supported by other analytical data, for example, by means of electronic microscope. Until this it can be considered only as a hypothesis. Examples of such fluxing are known. In Phoenician colonies in Spain in slags of lead ore smelting for silver production silicates and a lot of barium are present. Barium could not get to the furnace charge together with ore. It was intentionally added as it is the best flux for lead smelting because it destroys the lead silicates (Kassianidou 2003, p. 202). However, I do not know, whether it makes the same influence in case of copper ore smelting. As it has been detected only in slags smelted from ore in quartz rocks, it is not excluded.

Sources of this ore rich in silver, as well as barite sources, are unclear too. In principle, silver and barium are present in the copper sandstones of the Orenburg area (Chernyakov 2002, p. 28), but come closer sources are possible too. Spectral analyses are not able to answer this question. But it is not excluded that this fluxing component was delivered from there, or this tradition came to Bashkiria from there.

It is also noteworthy that all samples with higher contents of barium are found on the settlements (except for Verkhnebikkuzino) located in the area of the copper sandstones. But the Sasykul settlement is too removed from sandstones of the Orenburg zone (Fig. 8-1.). Therefore, most likely, this phenomenon is somehow connected with the sandstones, but it is early to put a final end in this question.

Chemico-metallurgical group VK

The last problem that is worthy of our notice is the problem of antimony-arsenic bronzes VK (Volga-Kama) groups which are considered as a result of artificial alloying (Chernykh 1970, p. 16). In principle, this situation does not contradict the existence of arsenic alloying in the previous time. As we have seen above, probably, also the barium additions at the ore smelting stage took place. However, earlier I have raised doubts about the alloys with antimony and arsenic for the reason that the area of these bronzes, appearing in the LBA, as a whole, coincides with the area of chalcopyrite smelting. And the increased concentrations of arsenic and antimony are often present in these ores (Grigoriev 2004). But the coincidence of the areas does not always mean the connection between bronzes and smelting technologies. Therefore it is necessary to try to study the question in more detail.

Above we have noted that if not to consider the tin bronzes, the part of copper-arsenic-antimony bronzes in Timber-Grave metal is 1.2%, and copper-antimony bronzes – 0.8% (Tab. 8-14.). In this case also the most probable source of these elements is either ore or special ligatures to it; the alloying with metal copper is, almost, excluded. Therefore, they have to be present also in slag. But in slag we do not know a situation when at the noticeable presence of antimony there is no arsenic. Therefore, in view of the absence of data, the technology of production of actually antimony alloys cannot be understood. In general it is rather strange alloy demanding more complicated metalworking operations. Right after the casting it is very fragile and hard (Charles 1980, p. 171). And the finds of metal antimony during this period are unknown. The earliest in Armenia are dated to the Early Iron Age. These are four objects from the settlement of Chambarak and one from Bjni (Meliksetian 2003a).

In total in the Cisural collection there are 14 samples of slag with antimony and arsenic impurity. It is 10.4% of the collection; however, four samples are found on the Bakr-Uzyak mine, whose dating is uncertain. The average value of arsenic concentrations in this sampling is 0.14%, and antimony concentrations – 0.1%. The total value of these elements is 0.24%. Taking into account that concentrations of these elements decrease in slag and increase in copper, these contents are enough to produce arsenic-antimony bronzes. For these bronzes alloyed with tin, the average contents of the sum of these elements is 0.72%, and for unalloyed with tin – 1.43% (Chernykh 1970, p. 16), this means, the values easily achievable at such concentrations in slag. Correspondently, we may to claim that during the smelting operations which left these slags, arsenic-antimony bronzes of the VK group was produced.

But there is a difference between the slags containing antimony in Timber-Grave and Mezhovka cultures[8] (Fig. 8-17.). In the Timber-Grave slags the average value of arsenic concentrations is 0.25%, and antimony concentrations – 0.002%, their total value is 0.252%. In principle, the total value quite corresponds to the VK group, but that its part which contains the minimum concentration of antimony. Contrary to it, in the Mezhovka slags with antimony the average value of arsenic concentrations is much lower, 0.12%, but that of antimony concentrations is 0.35%, and the total value – 0.47%.

The correlation diagram of As-Sb made for the Timber-Grave and Mezhovka slag shows that accurate interdependence between arsenic and antimony is absent. The only thing that it is possible to tell surely is that the antimony is present only in the samples of Timber-Grave slag with the arsenic content above 0.1% (Fig. 8-18.). Antimony contains in five samples, but only in two of them its contents is 0.003%. Correspondently, in the Timber-Grave collection the part of slag which could give the arsenic-antimony bronzes is 7.9%, if to include insignificant contents, and 3.1%, if to include only samples with the content of antimony of 0.003%. The last figure is probably more lawful. This connection of antimony with arsenic reflects probably its ore source. That fact that for the Timber-Grave metallurgy the use of sulfide ores was more characteristic than for

[8] This statistical processing does not include the overwhelming number of samples that does not contain the antimony.

the Sintashta metallurgy allows, as though, to connect antimony with the initial sulfide ore containing higher concentrations of both antimony and arsenic. As a result, we see that the increase of antimony concentrations is accompanied by the increase of arsenic concentrations.

At the same time, there are samples with the higher contents of arsenic which do not contain antimony. The last, as it has been discussed above, reflect preservation of the Sintashta tradition of alloying with arsenical minerals at the stage of ore smelting. Possibly, the samples with the higher concentrations of antimony (and these concentrations as we have seen, are insignificant and are detected seldom), reflect simply an alloying with minerals in which also the antimony impurity was present. But for Abashevo metallurgy of the Cisural area the use of sulfide ores was typical too, but antimony in the Abashevo slags has not been detected. Probably, in the Timber-Grave time a new source of alloying component was found. Nevertheless, as in Novobaryatino the ore with the contents of antimony and arsenic of 0.15% is noted too, the part of slag with low concentrations of these elements could be smelted from such ore. A probability of origins of many samples of the VK group from the smelting of the sulfide ores enriched with arsenic and antimony remains too. This probability is indirectly demonstrated by that the small impurities of antimony (0.0015-0.005%) have been found only in slag samples from the mine of Bakr-Uzyak (Tab. 8-10.), that is characteristic of sulfide deposits (Chernykh 1970, p. 40, 41).

Mezhovka slags show essentially another picture: the content of antimony (in case of its presence) in them, mainly, considerably exceeds the content of arsenic. A connection between them is seen (the growth of antimony is accompanied by the growth of arsenic), but this connection is very disproportionate. We see the obvious alloying with a mineral containing antimony, and essential impurity of arsenic. And, it was carried out at the stage of ore smelting. A corresponding mineral, antimony sulfide (Sb_2S_3), was known and used in antiquity. The variant of use of ore with natural impurities of antimony and arsenic is less probable as settlements where these slags (Novokizganovo and Yukalekulevo) have been found are located at a considerable distance from each other. Besides, similar impurity can be assumed for primary sulfides, but their part in these smeltings was obviously insignificant. Therefore, it is more lawful to raise a question of the alloying.

Thus, it seems lawful to discuss three sources of antimony-arsenic bronzes of the VK groups. In the Timber-Grave period the copper with low contents of these elements, most likely, was produced from ore with the high contents of the corresponding impurities, and the copper with the high contents did as a result of alloying with arsenical minerals having considerable impurity of antimony. For Mezhovka metallurgy it is obviously possible to speak about the alloying with antimony minerals having considerable impurity of arsenic at the stage of ore smelting. In case the impurity of arsenic was absent, a relatively rare alloy Cu+Sb could be produced. In metal these three possibilities of producing this copper, almost, cannot be distinguished. Theoretically, it can be done by complicated statistical procedures, but, taking into account the permanent re-melting of metal, the real result of these procedures is more than doubtful.

In principle, from literature I know only one case of description of the alloying with antimony, although its proofs have rather logical than analytical character. Investigations by U. Zwicker of ore and slag of the Early Bronze settlement of Noršun tepe in Eastern Anatolia have revealed two types of ore: chemically pure from sandstone, and enriched with arsenic and antimony impurities from quartz veins. However the investigation of slags has not detected similar impurities from what a conclusion has been drawn that in the smelting only the ore from sandstone was used. The ore from quartz was no good for smelting because of too high contents of antimony and was used only as a ligature (Zwicker 1980, p. 13-17). But it is problematic to imagine the metal alloyed with ore, and the research has not revealed smelting of such ores for producing an alloying concentrate. Our studies have not found anything similar too, but, unlike the situation described by Zwicker, antimony is present in slag.

One more variant is not excluded too. It has been shown above that the LBA slags contain the higher concentrations of arsenic. Therefore in the case of alloying of copper having this impurity with the antimony, the metal, chemically close to the VK metal could be produced. However the analytical facts in favor of this assumption are absent, although we may assume the existence of alloys of copper with antimony in rare cases. But for the proof of this opportunity it would be quite good to find on sites the metal antimony, some minerals of antimony, probably, the corresponding slags. Before this the variant is not a subject to discussion.

How all this correlates with the metal of the VK group? First of all, it is necessary to specify the figures concerning the proportion of arsenic-antimony and antimony bronzes of the VK group in Timber-Grave metal. Above, at the recalculation of date of E.N. Chernykh (2007, tab. 6.3) the figure about 2% has been discussed that is slightly less than the figure calculated here for the Cisural area, but, nevertheless, within a statistical error, and it is possible to speak about the basic compliance. It is necessary to understand also that it is the part in the whole Timber-Grave sampling including materials of Orenburg and further to the west, up to Ciscaucasia, Don and Dnieper. And the VK group is widespread, mainly, in the Volga region and is worse presented in Bashkiria (Chernykh 1970, fig. 28). In the analysis of all Volga-Ural material the proportion of the VK group is about 41% of the Timber-Grave metal collection and 70.8% of the collection of Prikazanskaya culture (Chernykh 1970, p. 34), but this figure is so great, thanks to materials from the Volga region. As Prikazanskaya materials in cultural sense are close to Mezhovka and Suskan-Lebyazhinka therefore the same sites can even be considered by different authors within different cultures, which corresponds to the tendency discovered on the slag material when in the Timber-Grave slags of the Cisural area only traces of producing arsenic-antimony bronzes are fixed, and in the Mezhovka series it is already about a half of the samples.

Problem of chemico-metallurgical group MP

It is considered that in metal the higher contents of silver and relative absence of other impurities are a sign of its connection with copper sandstones of the Cisural area and a ground to relate it to the MP chemico-metallurgical group (Chernykh 1970, p. 17). However, the analysis of slag from Bashkiria does not confirm it.

In the studied sampling, only the samples from the Sergeevka settlement and some samples of the 5th Abashevo mineralogical group belong reliably to the slags smelted from ore in sandstones. However, in comparison with other samples, they contain slightly lower concentrations of zinc. The behavior of almost all other trace-elements does not differ from the main massif. The exceptions are barium and strontium, whose contents in the slags connected with the sandstones are in some instances higher (Fig. 8-19.). Therefore, it is possible to assume that the other samples smelted from ore in quartz rocks have the same origin. But some of these samples are connected with smelting of ores from the ultrabasic rocks, others occur from settlements where other samples do not show such contents of these elements. And, taking into account a possible fluxing by barite which has been discussed above, it is not excluded that strontium was connected with it. In this case these elements also are not a marker of the sandstone ore.

It is possible that the problem is in not in the ore origins at all, but in technology. It is experimentally demonstrated that the increase of concentrations of nickel and arsenic in metal occurs only in case of smelting the oxidized ore as it took place in the Sintashta time. In case of smelting the sulfide ore which is more polluted by impurities, owing to higher temperatures the refinement of metal from all impurity occurs, including even nickel and arsenic (Tylecote 1980, p. 7). It should be noted also that this regularity is not always shown in slag, and the slags smelted from the sulfide ores at high temperature can be polluted by impurities.

High concentrations of silver (>1%) are noted in 22 samples of slag from the Cisural area, but in 14 cases it is connected with the high content of barium, and is explained by additions of some flux component. Three other samples have been found on the Mezhovka settlement of Yukalekulevo located far outside the area of the copper sandstones. And a bit different samples are smelted from the serpentinized ultrabasic rocks. Correspondently, the higher silver content can be present in the copper sandstones, but can be present also in the main Ural deposits from which these deposits in sandstones were formed. Other chemical sign of the MP copper (its purity) can have different reasons too: the ore could be mined in the upper oxidized zone of the deposit, technologies of smelting and refinement lead to purification of metal. Chemically it is, almost, insoluble problem.

Thus, for the materials of the Bashkirian Cisural area it is impossible now to determine which slag (and all the more which metal) can correspond to the copper sandstones, although the part of metal, apparently, was really is connected with this source. Basing on mineralogical analysis it is possible to claim unambiguously only that the samples smelted from the serpentinized ultrabasic rocks, were not connected with this group of fields. The samples containing quartz inclusions could belong both to copper sandstones and to fields in quartz veins. But in them the mineralogical signs of sandstones are revealed only in rare Abashevo samples from the settlements of Beregovskoye I and Yumakovo III and the Timber-Grave samples of the Sergeevka settlement in which, however, there was little silver.

From said above the next conclusion follows. The MP group distinguished for metal (if its statistical determination is lawful) was not always connected with the copper sandstones. If its diagnosing sign is the purity of metal, the reasons (as well as in the case of VK copper) can be different. The same is true in the case of higher silver concentrations. Judging from this sampling for the Bashkirian Cisural area this sign is insignificant.

Slags with higher tin concentrations

Some analyses have raised a question of alloying with tin. In three Mezhovka (Yukalekulevo, Novokizganovo) and one Timber-Grave (Yumakovo II) samples the higher tin concentrations, from 0.1 to 0.3%, have been detected. Unfortunately, the behavior of tin in metallurgical reactions is not quite clear. In general, it was alloyed with metal. Nevertheless, the slag with high content of tin has been found on the settlement of Uzerlik-Tepe in Transcaucasia (Kushnaryova 1965, p. 79). We saw the higher tin concentrations in some Eneolithic slags of the Urals, Europe and Anatolia. Probably, offspring of the old principles of alloying into ore remained in some places. In this case we can also assume it, but the variant of the use of ore with this impurity is more probable as it occurs too seldom and tin concentrations are too low. It is necessary to pay attention to this problem in the future but now it is insoluble. Completely without a discussion neither variant should be rejected, even from chronological reasons. For example, for Iberian sites of the Phoenician period (the Early Iron Age) joint smelting of copper and tin ores has been identified (Hunt Ortiz 2003, p. 356), but it has been done by the analysis of only single sample. This situation can be a freak of chance too. Therefore, it seems to me the explanation by the casual occurrence of a small amount of stannite ($FeSnS_4$) in the furnace charge together with chalcopyrite which looks like this mineral is more preferable.

Chemical groups of slag

Taking into account all discussed earlier about problems of the spectral analysis, we have carried out processing of slag analyses by means of the Brookhaven Date Handling Programs that has allowed five chemical clusters to be distinguished [9] (Tab. 8-20.). However, this division was not always faultless in comparison with the similar procedure for Sintashta slag. Besides, such small quantity of clusters for such territory and different periods obviously specifies that each cluster includes not the slags smelted from ores of a single origin, but reflects some types of ore.

[9] For the processing the following elements have been used: Ti, Mn, As, Ba, Sr, Ni, Co, V, Sc, Pb, Sn, Zr, Ga, Ge, Ag, Mo, Be, and Cr.

Cluster 1 is presented by the samples smelted from ores in serpentines and ultrabasic rocks of the settlements of Aitovo, Verkhnebikkuzino, Tyubyak, Chishma, Yumakovo II, and also single samples from the settlements of Yukalekulevo and Kakrykul. On the Yukalekulevo settlement on the basis of the mineralogical analysis it has been supposed that slag was smelted from ore in quartz veins, but these veins, nevertheless, were situated in serpentinized ultrabasic fields. The ore is presented by secondary sulfides, more rare by chalcopyrite and malachite. The smelting atmosphere was reducing, copper losses were insignificant. On the diagram of Cr-As this cluster is situated in the right top part (Fig. 8-12.).

Cluster 2 probably has been identified illegally as it includes only two samples. Besides, the joining of these two samples happens at high level of the tree of clusters that for this program points to a wrong result.

Cluster 3 includes samples from the quartz rocks of the settlements of Baygildino, Kakrykul, Novobaryatino, Novokizganovo, and a half of samples from Yukalekulevo. Two samples from Yumakovo II, probably, should not be included into this cluster as come from quartz veins in the serpentinized rocks. The ore is presented, mainly, by secondary sulfides and chalcopyrite, to a lesser extent, by the oxidized ore minerals. The smelting atmosphere was reducing, losses of metal were insignificant, temperatures were quite high (except for samples from Yumakovo II in which chalcopyrite is not recorded).

Cluster 4 includes samples from serpentines and quartz, found on the settlements of Aitovo, Verkhnebikkuzino, Tyubyak, Yukalekulevo, and Yumakovo I. Ore is, mainly, oxidized and secondary sulfides. The cluster is also various in the technological sense. But temperatures were not as high as in the previous cluster. The samples contain higher concentrations of arsenic, but the contents of chrome differ that is also duplicated by the mineralogical analysis.

Cluster 5 unites samples from quartz rocks of the settlements of Aitovo, Tyubyak, and Yumakovo I. Ore is presented, mainly, by oxidized and secondary sulfides. The smelting atmosphere was reducing, except the smelting shown by slag from Yumakovo I.

As we see, there is a certain relationship between the contents of some elements (and clusters distinguished on their basis) and a particular site, but this relationship is much worse, than it took place in the analysis of materials of Sintashta culture. At the investigation of the Sintashta slags we have faced with extremely unified technology, types of ore and a single way of alloying. The initial ore material was the main factor which made impact on the chemical composition of slag. Therefore, it was succeeded to receive a rather accurate relationship between mineralogical types of slag and chemical groups, although some samples broke out this, in general, harmonious pictures. In the case of Bashkiria we deal with slag of various epochs, very different ore sources (both type of ore and gangue), different technologies and temperatures. The situation becomes complicated also because of the different ways of alloying (arsenic and antimony with arsenic) at the ore smelting stage, and also, in some instances, with barite additions into furnace charge. As a result, the distinguished chemical clusters correlate with the sites not so well. There are some weak relationships only with type of deposit and, partly, with the arsenic alloying. However, for this multicomponent situation this statistical procedure seems to be low-informative. But here we are able, at least, to control a situation, having the data of mineralogical analyses. In the case with metal we are devoid of such possibility, and problems of re-melting of metal scrap with different origins are added to the listed problems. And we have no opportunity to discuss something at all, besides the character of alloys.

Particular trace-elements can strongly vary in both ore and slag. And it is quite difficult to tell something definite about their behavior in metal at this or that technology. But it is obvious that these groups distinguished for slag will coincide only partially with groups distinguished for metal.

Ore base and smelting technology in the Bronze Age in the Cisurals

Ore base

As we see, the majority of the studied sites with the remains of metallurgical production is found in the middle course of the Belaya River. E.N. Chernykh supposes that ore from Kargaly mines was delivered to these areas, as well as in the 18-19th centuries AD (Chernykh 1997, p. 68; 2002, p. 104; Kargaly 2002, p. 49). Identification in this zone of the slag smelted from the ultrabasic rocks allows us to assume also the ore import from the Transurals, from deposits of the Cyprian type on which ancient mines are known (Ishkinino, Ivanovka, Dergamysh, etc.). But all these mines are situated at a very long distance (150-300km) from the hypothetical places of these ores smelting (see the map: Fig. 8-1.); therefore similar assumptions are very doubtful. There are local large copper deposits in sandstones of Bashkiria. Any analytical capabilities to distinguish these materials from the Kargaly ones are absent even if to analyze ore. There are also serious problems with identification of slag smelted from ore in the sandstones. But the copper sandstones were not the only source of ore at all. Deposits in the ultrabasic rocks (Abashevo and partly Timber-Grave metallurgists) and some sulfide deposits (Timber-Grave and Mezhovka metallurgists) were exploited too. These deposits are situated, mainly, on the Ural Ridge.

It is possible to assume, in some instances, the ore export from the east, but it could not be a basis of the production. As we have already discussed above, the ultrabasic ores of the Cisural settlements contained relatively larger amount of secondary sulfides than in the Transurals; therefore it is more logical to assume for them some local sources. The situation with deposits of primary sulfide ores is the same. The concentration of metallurgical complexes near the middle course of the Belaya River allows us to assume that these ore sources could be situated exactly here. And, the deposits in sandstones are located, mainly, to the west from the Belaya, and other fields could be located to the east. Therefore search for local ore base of ancient metallurgy in Bashkiria seems to me the most justified.

Nevertheless, some imports can be assumed, but it demands a serious analytical study. Ore import over such distances was hardly profitable. It was much simpler to carry out the smelting near the deposits and to transport already metal. But it is possible to assume the import of alloying component. For the Sintashta time it could be minerals with arsenic impurity, mined, apparently, on the same Ishkinino deposit. In the Timber-Grave period we see additions of barite as a flux. As higher concentrations of barium (as well as silver) are characteristic of the Orenburg mines, it is possible to assume the import of this component from there. In some instances it is possible that ore also was delivered from Orenburg or the Transurals, but distinct data in favor of it are absent. Even the delivery of fluxes and alloying components from the outside is no more than an assumption, and it will be extremely difficult to prove it on the basis of analyses.

Technology development

As it has been already noted, the situation in the MBA and LBA metallurgy of the Cisural region is more various, than that in the Transurals, although a part of technologies are quite comparable with Sintashta, and can be considered as a continuation of the Sintashta tradition (Tab. 8-21.).

In Sintashta culture the part of the 1st and 3rd mineralogical groups connected with the ultrabasic rocks is 81.6%. The exploitation of these ores is present in Abashevo metallurgy of the Cisural area, but in much more limited volume: 39.3% of smelting operations. But the part of exploitation of deposits in quartz rocks grows considerably. In Sintashta culture it was insignificant, and in Abashevo (taking into account the 5th mineralogical group probably connected with sandstones) it is 60.7%. Of course, it is necessary to have in mind that on this limited material, without having ideas of chronological correlation of these slags (the relative chronology of Abashevo culture in the Cisural area is absent today too) it is difficult to draw reliable conclusions as during this period there were some technological changes. But such prevalence of ores from acid (in comparison with Sintashta) rocks, allows us to assume the use of some local sources.

The part of these sources was probably connected with the copper sandstones, although it is possible to speak about it definitely only for the 5th group, i.e. 14.3% of Abashevo slag. But because of the difficulty of searching this slag at excavations it is logical to assume that this part was higher. It was rather simple smelting in a crucible of the pure oxidized ore with minimum inclusions of gangue. These slags have no analogy in Sintashta metallurgy and obviously were a local technological tradition. This tradition was synchronous to the Sintashta one (see in the description of Sintashta metallurgy about its chronological correlation with Abashevo).

More complicated production connected with slag-based metallurgy was probably stimulated by the Sintashta tradition as together with the use of ore from the ultrabasic rocks occurred, as well as the alloying with arsenic minerals, at the ore smelting stage. The volumes of smelting increased probably too. There are also small differences. There were no furnaces attached to the well that did not allow the reducing conditions to be effectively created when smelting the oxidized ores, but it was compensated by more active use of sulfide ores. It is hard to say whether it was doing purposely, or was connected with the nature of local ore base. It is obvious that it was no deliberate composition of furnace charge from the mix of different ores, but miners could choose those places of deposits which contained this mix. When the proportion of the oxidized ore was more, it led to more oxidizing conditions in the furnace that was expressed in rather high part of slag of the 4th mineralogical group. On the proper Sintashta sites similar slag was absent, but it is found on the Petrovka sites and sites containing both Sintashta and Petrovka layers. Therefore it is dated probably already to the Petrovka time.

One more difference is that Abashevo slag does not show such accurate relationship between arsenic and nickel impurities. In some cases the alloying was carried out by the arsenic-nickel minerals, as well as in Sintashta culture, but it was not always. And, as we remember, impurity of nickel promoted saving of arsenic in metal, and was technologically caused. This means, as well as in the case with lack of the furnaces attached to wells, we see a certain degradation of the technology.

To late character of this trend is demonstrated by its continuation in the Timber-Grave time. The part of ore from the ultrabasic rocks during this period is 37% that is much less than its part in Sintashta metallurgy, but is comparable with Abashevo. The archaic Abashevo way of smelting pure ore in crucibles (the 5th group) disappears, but the smelting of ore from sandstones is carried out in furnaces, according to the Sintashta tradition that is reflected in the 4th group of slag which is present in the Abashevo sites, but also in sites having either Sintashta-Petrovka or Petrovka layers in the Transurals. The difference is only that now this group was connected with the smelting ore from the copper sandstones in conditions of the oxidizing atmosphere, but in Abashevo culture and in the Transurals it did with deposits in quartz rocks. In addition to this, the arsenic alloying at the ore smelting stage remains (although its proportion, in comparison with Sintashta, decreases) as well as connection of this way of alloying with ores in the ultrabasic rocks that was technologically caused. As a result, Timber-Grave metallurgy of the Cisural region in many parameters is very close to Abashevo one, but gets rid of archaic technologies of the latter. Possibly, it was connected with that the early Timber-Grave culture formed on the Abashevo-Sintashta basis.

But in the Timber-Grave time an absolutely new phenomenon occurs: the beginning of smelting of primary sulfides, first of all, chalcopyrite, that was not earlier present, neither in Sintashta, nor in Abashevo metallurgy. And at this stage of study it is hard to say whether it was a result of borrowings from the east or internal development, as introduction of smelting of chalcopyrite coincides with another introduction: tin alloys and typological transformation of metal objects. The latters were, certainly, the eastern impulses.

As well as in the case with formation of Sintashta metallurgy we see here a complex transformation: the transition to ores whose smelting was conducted at higher temperatures. As a result, arsenic could not remain in metal and the transition to tin alloying into metal occurred. It is possible to allow rare attempts to smelt tin minerals with the ore, but these evidences are limited and are not convincing. Tin ligatures allowed to make revolution in metalworking and to cast new types of thin-walled objects into the bi-fold moulds, the objects demanding insignificant forge operations. Former traditions of alloying remained only due to the preservation of the old Sintashta traditions of smelting ore from the ultrabasic rocks, the low-temperature smelting. This combination of two traditions is also visible in the organic combination of sets of metal with different origins: going back to Sintashta and Seima-Turbino stereotypes. The same is shown in arsenic-antimony bronzes of Timber-Grave culture which were connected as with the alloying by arsenic minerals containing antimony (that is a direct continuation of the Sintashta-Abashevo tradition), as with the use of the sulfide copper ores enriched with these impurities that was already a new phenomenon. Besides, we may assume that after the Sintashta-Abashevo time the basic changes in volume of smelting did not happen as far as we can judge from a single ingot from Toktubayevo. But the changes in structure of the production are undoubted: its traces have been found not on all settlements as it took place in Sintashta, we see rather a situation typical of the Cisural Abashevo. However, all this is the most general trend as the number of studied slag is not so great, and it almost has no accurate connection with different phases of the Timber-Grave culture development in the Cisural area.

There is one more serious problem. As it has been already told above, the archaic Abashevo smelting of limited amount of pure ore in a crucible, most likely, was the heritage of local tradition. While we have no possibility to judge whether it was heritage of the local Eneolithic or influence of Fatyanovo-Balanovo metallurgy of the EBA-MBA traditions from the Volga region. But it was not connected with the Sintashta tradition. Therefore in principle, having looked at the table Tab. 8-21., we can present a situation as follows. In Abashevo metallurgy of the Cisural region the transition to ore smelting in large volumes occurred, still from the acid rocks, but already directly in the furnaces. Then ones started to use the ore from ultrabasic rocks and add arsenic minerals in the case of this smelting[10]. This new tradition was transferred already from the Abashevo people to Sintashta culture and Timber-Grave culture of the Cisural region, and the former archaic tradition fades. But, as it has been already discussed, there is no ground to date the Abashevo metallurgy to the earlier time than Sintashta. Besides, in Sintashta metallurgy we see a very complex chain of production of the certain ore from the certain rocks[11], the smelting technology connected with it, the subsequent technologies of metalworking and a set of types of object. And all this took place in the Near East, and, partly, in the Maikop metallurgy connected with the Near East. It is duplicated by the silver extraction from lead ore that had the same roots, and also by other features of material culture. Therefore the model suggested above seems to be more lawful.

In the forest zone of the Bashkirian Cisurals in the LBA the Mezhovka technological tradition arose. It was based on smelting of the oxidized ores and sulfides, but it is impossible to tell whether it was purposeful. The alloying with antimony-arsenic minerals occurred, but it is hard to say too, whether it was the development of traditions of Timber-Grave metallurgy with its alloying by arsenic-antimony minerals. The presence of similar copper in the east, as though, points to the eastern roots of this tradition.

It is remarkable that samples of the LBA slag show direct reduction of copper from ore, despite the widespread opinion that in case of sulfide ores smelting at first it was necessary to carry out the ore roasting

[10] The single mentioned sample of archaic slag (5th group) containing arsenic from Yumakovo III it is possible to treat as the origins of similar tradition of alloying, but more likely this was influenced by the Sintashta tradition.

[11] In this case, if to imagine an independent transition of the Abashevo miners from the ore in quartz rocks and sandstones to the ores in ultrabasic rocks, we face with unclear technological logic: why it was needed to begin the use of much poorer ores if the smelting of richer ores was already mastered? For the simplicity of smelting? And why it was needed after this to add here the smelting with arsenic minerals whose convenience could not be predicted before the transition to this ore?

and then to smelt producing matte as it takes place in the modern production. More often it is based on old publications, for example on Forbes, without support on slag analyses (e.g. Jianjun, Yanxiang 2003, p. 114, but it is rather widespread). It is supposed that after this the matte was roasted to make oxide and then just this oxide was smelted. The analysis by Bachmann of the LBA flat slag cakes (40 cm in diameter and 8 cm thick) from Austria has shown that it was quite normal slag from fayalite, wüstite and magnetite, without matte. Therefore it has been decided that this slag remained from the last stage of this multiphase process. Discussing this result, Tylecote has assumed that it is not excluded that all this smelting was carried out in one phase, and additional studies are necessary to understand it as in some instances the matte in slag occurs (Tylecote 1987, p. 130, 131).

In our LBA slags copper sulfides often remain. It is possible that they could be selected and placed again in the furnace charge together with the next portion of ore, although it was only in cases of large ore inclusions and rejected smelting. But the matte is not recorded. The single case are two examples of Kurmantau culture, the latest in the Cisural Bronze Age, allows us to assume the production of sulfides as the copper in slags is not found. But it was rather a result of the rejected smelting.

Such are, in general, the characteristics of the main cultural types of the Bashkirian Cisurals during the Bronze Age.

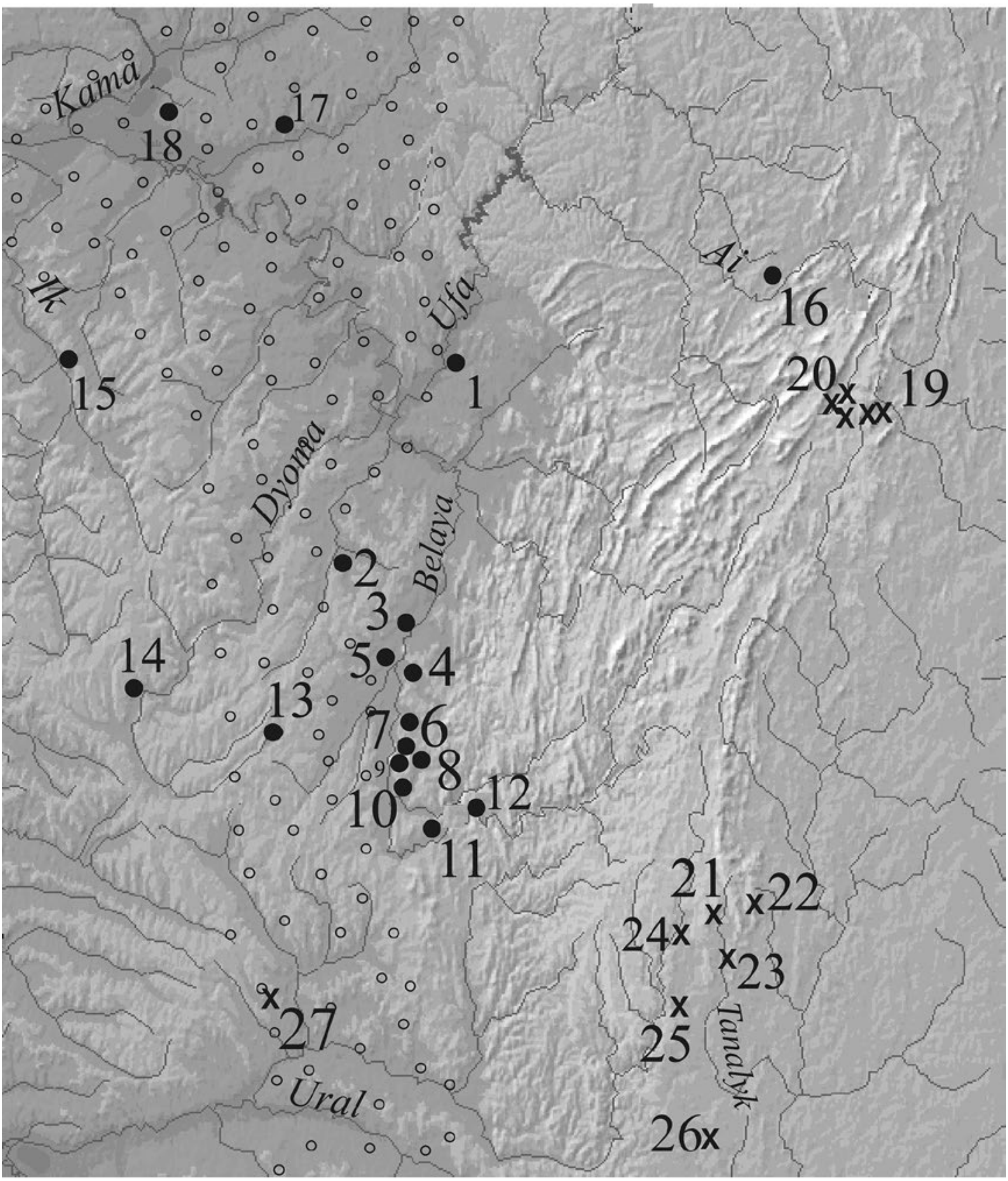


FIG. 8-1. MAP OF SETTLEMENTS AND MINES IN BASHKIRIA. SETTLEMENTS: 1 – BAYGILDINO; 2 – CHISHMY; 3 – BALANBASH; 4 – URNYAK; 5 – NOVOBARYATINO; 6 – YUMAKOVO I; 7 – YUMAKOVO II; 8 – YUMAKOVO III; 9 – BEREGOVSKOYE I; 10 – BEREGOVSKOYE II; 11 – TYBYAK; 12 – VERKHNEBIKKUZINO; 13 – SERGEEVKA; 14 – AITOVO; 15 – SASYKUL; 16 – YUKALEKULEVO; 17 – NOVOKIZGANOVO; 18 – KAKRYKUL; MINES: 19 – TASH-KAZGAN, NIKOLSKII; 20 – VOZNESENSKI, NARALI, POLYAKOVSKOYE, URGUN, MAYLY-YURT, UCHALY; 21 – BAKR-UZYAK; 22 – SIBAI; 23 – BAIMAK; 24 – YULUK; 25 – IVANOVKA; 26 – ISHKININO; 27 – KARGALY. CIRCLES – A ZONE OF COPPER SANDSTONES.

Tab. 8-2. Distribution of different forms of slag over the Abashevo sites in Bashkiria.

Settlement	Flat slag cakes	Shapeless slag	Friable soot slag	Total
Beregovskoye I			3	3
Tyubyak	6	14		20
Yumakovo I	1	2		3
Yumakovo III			1	1
Urnyak		1		1
Total	**7**	**17**	**4**	**28**

Tab. 8-3. Distribution of mineralogical groups of slag over the Abashevo sites in Bashkiria.

Settlement	I	II	III	IV	V	Total
Beregovskoye I					3	3
Tyubyak	7	4	3	6		20
Yumakovo I	1	2				3
Yumakovo III					1	1
Urnyak				1		1
Total	**8 (28.6%)**	**6 (21.4%)**	**3 (10.7%)**	**7 (25%)**	**4 (14.3%)**	**28 (100%)**

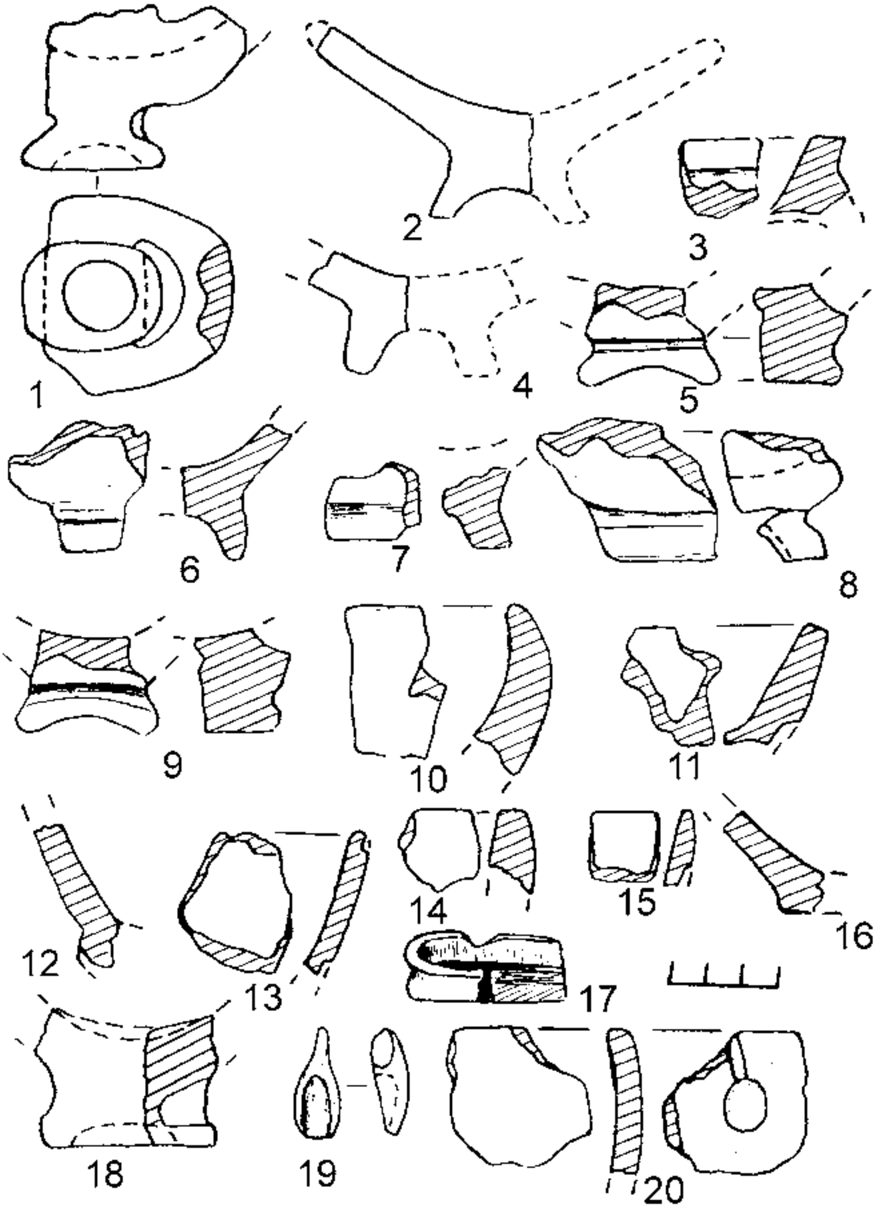


Fig. 8-4. Abashevo crucibles, melting bowls and scoop (19) from Bashkiria (after Gorbunov 1992): 1-3,5,7,9-11,16 – Beregovskoye II; 4,8,12-14,18-20 – Beregovskoye I; 17 – Sakhaevskaya.

Tab. 8-5. Distribution of different forms of slag over the Timber-Grave sites in Bashkiria.

Settlement	Flat cakes	Shapeless slag	Light porous slag	Thin slag crusts	Total
Aitovo	3	6	4		13
Baygildino		1			1
Verkhnebikkuzino	16			3	19
Sasykul		1			1
Novobaryatino	3				3
Chishma	1				1
Yumakovo II	1	4			5
Sergeevka		18			18
Total	**26** **41.5%**	**30** **48.5%**	**4** **6%**	**3** **4%**	**61** **100%**

Tab. 8-6. Distribution of mineralogical groups of slag over the Timber-Grave sites in Bashkiria.

Settlements	I	II	III	IV	V	VI	Total
Aitovo	4	13					17
Baygildino						1	1
Verkhnebikkuzino	16	1				2	19
Novobaryatino						3	3
Sasykul		1					1
Sergeevka				18		1	19
Chishma	1						1
Yumakovo II	1	2	2				5
Total	**22** **33.7%**	**17** **26.2%**	**2** **3.3%**	**18** **27.5%**		**6** **9.3%**	**66** **100%**

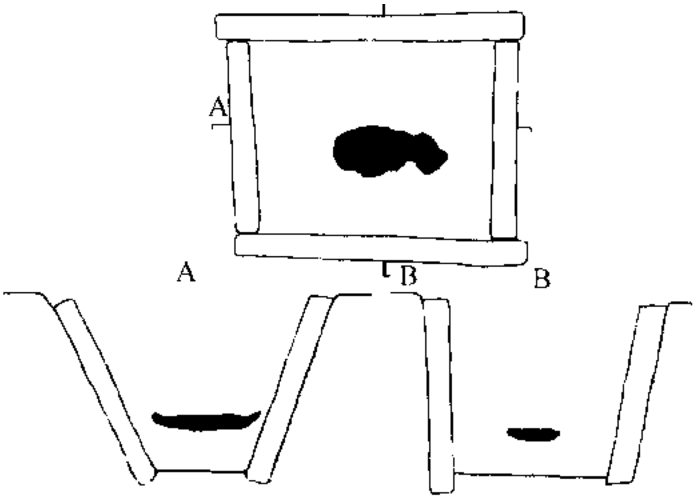


FIG. 8-7. TIMBER-GRAVE FURNACE OF THE TAVLYKAYEVO SETTLEMENT (AFTER MOROZOV, 1981).

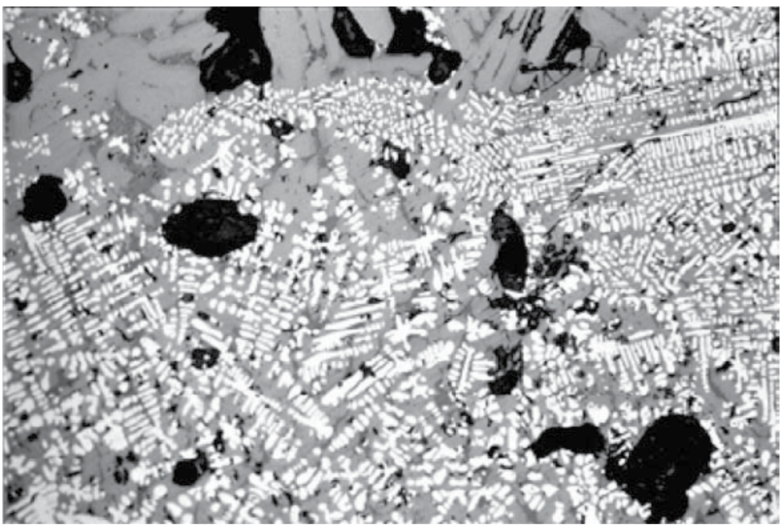


FIG. 8-8. LATTICE STRUCTURES OF WÜSTITE (WHITE) IN SLAG (SAMPLE 463) OF THE YUKALEKULEVO SETTLEMENT IN BASHKIRIA.

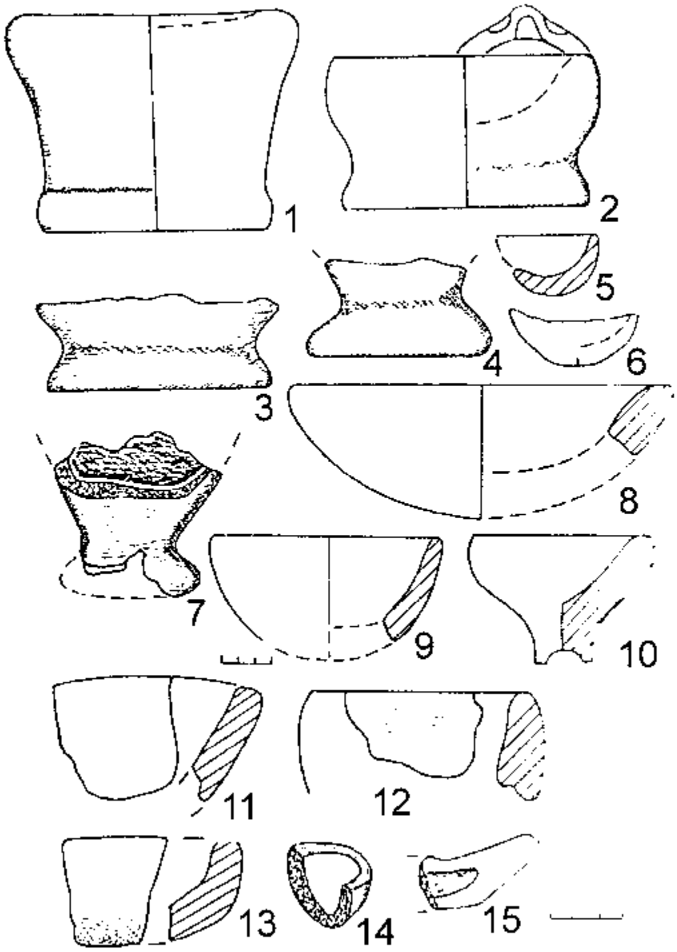


FIG. 8-9. MEZHOVKA CRUCIBLES, MELTING BOWLS AND SCOOPS (14-15) (AFTER OBYDENNOV, SHORIN 1995): 1-3, 12-14 – TYUBYAK; 4 – YUKALEKULEVO; 6 – KUZMINKI VII; 7 – PALKINO; 8 – BATRAK-AIRATOVO; 9 – VERKHNEBIKKUZINO; 10 – BIRSKOE; 11 – NIZHEGORODSKOE III; 15 – STARO-YALLAROVO I.

Tab. 8-10. Emission spectral analyses of slag from Bashkiria (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).

Site	Material	Mineralogical groups	Sample	Ni	Co	Cr	Mn	V	Ti	Sc	Ge
Urgun	Slag		51	0.01	0.007	0.007	1	0.015	0.3	0.001	<0.0003
Tash-Kazgan	Slag		100	0.07	0.002	0.015	0.15	0.01	0.5	0.001	0.00015
Tash-Kazgan	Slag		101	0.003	0.002	0.007	0.15	0.0015	0.3	<0.0005	<0.0003
Urgun	Slag		200	0.001	0.0015	0.001	0.05	0.007	0.3	0.001	<0.0003
Urgun	Slag		201	0.001	0.0015	0.0015	0.02	0.01	0.3	0.0005	<0.0003
Urgun	Slag		202	0.005	0.005	0.007	0.07	0.007	0.3	0.001	<0.0003
Urgun	Slag		203	0.001	0.0015	0.001	0.02	0.005	0.2	0.001	<0.0003
Urgun	Slag		204	0.001	0.0015	0.001	0.03	0.003	0.1	0.0005	<0.0003
Urgun	Slag		205	0.0015	0.001	0.001	0.03	0.005	0.2	0.001	<0.0003
Chishma	Slag	I	344	0.01	0.003	0.3	0.02	0.007	0.15	<0.0005	0.001
Aitovo	Slag	II	355	0.007	0.01	0.01	0.02	0.015	0.2	0.0005	0.003
Aitovo	Slag	II	356	0.005	0.003	0.03	0.02	0.02	0.2	0.001	0.007
Aitovo	Slag	II	357	0.003	0.001	0.02	0.02	0.015	0.5	0.001	0.002
Aitovo	Slag	II	358	0.005	0.005	0.02	0.1	0.03	0.5	0.001	0.007
Aitovo	Slag	I	359	0.01	0.005	0.5	0.02	0.007	0.1	<0.0005	0.00015
Aitovo	Slag	I	360	0.007	0.002	0.15	0.03	0.0015	0.1	<0.0005	0.00015
Aitovo	Slag	II	361	0.005	0.007	0.015	0.03	0.015	0.2	0.0005	0.005
Aitovo	Slag	I	362	0.007	0.0015	0.1	0.03	0.0015	0.07	<0.0005	0.0003
Aitovo	Slag	II	363	0.005	0.003	0.03	0.1	0.02	0.3	0.001	0.01
Aitovo	Slag	II	364	0.005	0.002	0.02	0.03	0.02	0.3	0.0015	0.007
Aitovo	Slag	I	365	0.005	0.003	0.02	0.1	0.02	0.3	0.0015	0.007
Aitovo	Slag	II	366	0.005	0.005	0.02	0.05	0.02	0.3	0.001	>0.01
Aitovo	Slag	II	367	0.005	0.003	0.02	0.015	0.02	0.2	0.001	0.007
Sergeevka	slag	IV	368	0.007	0.003	0.07	0.02	0.015	0.3	0.0015	0.002
Sergeevka	slag	IV	369	0.005	0.002	0.02	0.015	0.015	0.2	0.0005	0.0015
Sergeevka	slag	IV	370	0.003	0.001	0.015	0.02	0.015	0.15	0.0005	0.01
Sergeevka	slag	IV	372	0.005	0.002	0.02	0.02	0.01	0.2	0.0005	0.0015
Sergeevka	slag	IV	373	0.01	0.003	0.02	0.02	0.015	0.2	0.001	0.005
Sergeevka	slag	IV	374	0.005	0.002	0.015	0.015	0.015	0.2	0.001	0.003
Sergeevka	slag	IV	375	0.007	0.003	0.2	0.07	0.015	0.3	0.0015	0.002

Site	Material	Mineralogical groups	Sample	Ni	Co	Cr	Mn	V	Ti	Sc	Ge
Sergeevka	slag	IV	376	0.01	0.003	0.02	0.03	0.015	0.2	<0.0005	0.003
Sergeevka	slag	IV	377	0.007	0.002	0.05	0.03	0.015	0.3	0.0015	0.003
Sergeevka	slag	IV	378	0.005	0.002	0.015	0.02	0.015	0.3	0.001	0.002
Sergeevka	slag	IV	379	0.005	0.003	0.03	0.03	0.015	0.3	0.0015	0.003
Sergeevka	slag	VI	380	0.005	0.003	0.02	0.015	0.015	0.3	0.001	0.002
Sergeevka	slag	IV	381	0.005	0.002	0.03	0.03	0.015	0.2	0.0005	0.003
Sergeevka	slag	IV	382	0.005	0.002	0.02	0.02	0.02	0.2	0.001	0.0015
Sergeevka	slag	IV	383	0.005	0.002	0.03	0.03	0.015	0.2	0.001	0.0015
Sergeevka	slag	IV	384	0.01	0.002	0.03	0.02	0.015	0.2	0.001	0.002
Sergeevka	slag	IV	385	0.007	0.002	0.03	0.03	0.015	0.2	0.001	0.003
Sergeevka	slag	IV	386	0.02	0.002	0.03	0.15	0.02	0.3	0.001	<0.0003
Yumakovo I	Slag	II	387	0.01	0.002	0.03	0.05	0.02	0.3	0.0015	0.0015
Yumakovo I	Slag	II	388	0.01	0.0015	0.03	0.02	0.015	0.7	0.0015	<0.0003
Yumakovo I	Slag	I	389	0.003	0.001	0.1	0.015	0.001	0.02	<0.0005	0.0002
Yumakovo II	Ore	II	390	0.007	0.0007	0.02	0.1	0.01	0.5	0.001	<0.0003
Yumakovo II	Ore	I	392	0.007	0.0007	0.03	0.02	0.015	0.3	<0.0005	<0.0003
Yumakovo II	Slag	III	394	0.005	0.0015	0.1	0.15	0.0015	0.1	<0.0005	0.00015
Yumakovo II	Slag	II	395	0.01	0.0015	0.05	0.1	0.007	0.3	<0.0005	0.00015
Yumakovo II	Ore	II	396	0.01	0.001	0.005	0.2	0.007	0.07	<0.0005	0.00015
Yumakovo II	Slag	III	397	0.007	0.001	0.01	0.02	0.007	0.15	0.0005	<0.0003
Yumakovo II	Slag	I	398	0.005	0.0007	0.005	0.02	0.005	0.15	0.0005	<0.0003
Yumakovo II	Ore	II	399	0.02	0.0015	0.015	0.1	0.05	0.15	0.001	0.00015
Yumakovo III	Slag	V	402	0.0015	0.0005	0.005	0.07	0.01	0.1	0.0005	0.0007
Verkhnebikkuzino	Slag	I	403	0.03	0.005	0.5	0.02	0.01	0.2	<0.0005	0.00015
Verkhnebikkuzino	Slag	I	404	0.01	0.005	0.1	0.02	0.001	0.07	<0.0005	<0.0003
Verkhnebikkuzino	Slag	VI	405	0.005	0.0015	0.07	0.015	0.001	0.02	0.0005	0.00015
Verkhnebikkuzino	Slag	I	406	0.005	0.0015	0.07	0.03	0.001	0.05	<0.0005	0.00015
Verkhnebikkuzino	Slag	I	407	0.015	0.003	0.3	0.07	0.007	0.15	0.0005	0.0003
Verkhnebikkuzino	Slag	I	409	0.05	0.005	0.15	0.15	0.003	0.1	0.0005	0.0003
Verkhnebikkuzino	Slag	I	410	0.03	0.005	0.2	0.1	0.005	0.15	0.0005	0.00015
Verkhnebikkuzino	Slag	I	411	0.03	0.005	0.7	0.05	0.01	0.2	0.001	<0.0003
Verkhnebikkuzino	Slag	I	412	0.02	0.005	0.3	0.05	0.01	0.2	0.001	<0.0003

Site	Material	Mineralogical groups	Sample	Ni	Co	Cr	Mn	V	Ti	Sc	Ge
Verkhnebikkuzino	Slag	I	413	0.02	0.003	0.2	0.1	0.005	0.15	<0.0005	0.00015
Verkhnebikkuzino	Slag	I	415	0.02	0.002	0.3	0.03	0.007	0.15	<0.0005	0.00015
Verkhnebikkuzino	Slag	I	416	0.007	0.002	0.5	0.07	0.007	0.2	0.0005	<0.0003
Verkhnebikkuzino	Slag	I	417	0.05	0.003	0.2	0.05	0.005	0.15	0.0005	0.00015
Verkhnebikkuzino	Slag	I	419	0.03	0.003	0.15	0.05	0.0015	0.15	0.0005	0.00015
Verkhnebikkuzino	Slag	II	420	0.007	0.002	0.02	0.05	0.015	0.3	0.001	0.005
Verkhnebikkuzino	Slag	I	421	0.01	0.002	0.1	0.02	0.0015	0.1	<0.0005	0.0002
Verkhnebikkuzino	Slag	I	423	0.005	0.0015	0.02	0.05	0.015	0.3	0.001	0.003
Verkhnebikkuzino	Slag	I	424	0.005	0.002	0.03	0.05	0.015	0.3	0.001	0.005
Verkhnebikkuzino	Slag		425	0.005	0.0015	0.015	0.05	0.015	0.2	0.0005	0.003
Tyubyak	Slag	II	426	0.0015	0.0003	0.005	0.05	0.003	0.1	<0.0005	0.00015
Tyubyak	Slag	III	427	0.01	0.002	0.07	0.005	0.001	0.07	<0.0005	0.0003
Tyubyak	Slag	I	428	0.003	0.001	0.07	0.02	0.0015	0.07	<0.0005	0.00015
Tyubyak	Slag	I	429	0.007	0.0015	0.07	0.01	0.003	0.03	<0.0005	0.0003
Tyubyak	Slag	III	431	0.015	0.002	0.15	0.03	0.0015	0.1	<0.0005	0.0002
Sasykul	Slag		434	0.005	0.0015	0.03	0.05	0.015	0.5	0.001	0.0015
Sasykul	Slag	II	435	0.003	0.002	0.02	0.1	0.01	0.15	0.0005	0.003
Baygildino	Slag	VI	436	0.07	0.02	0.001	0.03	0.0015	0.07	<0.0005	0.00015
Kakrykul	Slag		437	0.005	0.0015	0.01	0.05	0.0015	0.3	0.0005	0.00015
Kakrykul	Slag		438	0.015	0.003	0.0015	0.015	0.001	0.02	<0.0005	0.0015
Novokizganovo	Slag	VII	439	0.007	0.002	0.02	0.03	0.007	0.3	0.001	0.00015
Novokizganovo	Slag	VII	441	0.03	0.005	0.02	0.05	0.015	0.2	0.001	0.00015
Novokizganovo	Slag	VII	442	0.01	0.0015	0.02	0.1	0.007	0.3	0.001	<0.0003
Novokizganovo	Slag	VII	443	0.015	0.002	0.03	0.03	0.01	0.5	0.0015	<0.0003
Tyubyak	Slag	I	445	0.007	0.002	0.03	0.05	0.015	0.3	0.001	0.003
Tyubyak	Slag	II	446	0.005	0.001	0.015	0.05	0.015	0.2	0.001	0.0015
Tyubyak	Slag	II	447	0.005	0.002	0.015	0.03	0.015	0.2	0.0005	0.007
Tyubyak	Slag	II	448	0.005	0.003	0.02	0.05	0.015	0.2	0.0015	0.007
Tyubyak	Slag	IV	449	0.01	0.0015	0.03	0.03	0.01	0.3	0.001	0.0015
Tyubyak	Slag	III	450	0.015	0.0015	0.1	0.07	0.007	0.1	0.0005	<0.0003
Tyubyak	Slag	IV	451	0.005	0.003	0.01	0.07	0.02	0.3	0.001	0.007
Tyubyak	Slag	I	452	0.015	0.003	0.003	0.02	0.005	0.07	<0.0005	0.0003

Site	Material	Mineralogical groups	Sample	Ni	Co	Cr	Mn	V	Ti	Sc	Ge
Tyubyak	Slag	I	454	0.007	0.0015	0.15	0.03	0.003	0.15	0.001	0.0002
Tyubyak	Slag	IV	455	0.002	0	0.007	0.05	<0.001	0.05	<0.0005	0.00015
Tyubyak	Slag	I	459	0.007	0.0015	0.15	0.07	0.0015	0.1	0.0005	0.0003
Yukalekulevo	Slag	VII	462	0.3	0.1	0.007	0.01	<0.001	0.05	<0.0005	0.0003
Bakr-Uzyak	Slag		471	0.005	0.001	0.003	0.1	0.0015	0.2	<0.0005	0.00015
Bakr-Uzyak	Slag		471	0.005	0.001	0.003	0.1	0.0015	0.2	<0.0005	0.00015
Bakr-Uzyak	Slag		472	0.005	0.0015	0.02	0.15	0.007	0.15	0.0015	0.00015
Bakr-Uzyak	Slag		472	0.005	0.0015	0.02	0.15	0.007	0.15	0.0015	0.00015
Bakr-Uzyak	Slag		473	0.007	0.002	0.03	0.1	0.007	0.5	0.001	0.00015
Bakr-Uzyak	Slag		473	0.007	0.002	0.03	0.1	0.007	0.5	0.001	0.00015
Bakr-Uzyak	Slag		474	0.007	0.0015	0.01	0.15	0.01	0.3	0.001	<0.0003
Bakr-Uzyak	Slag		474	0.007	0.0015	0.01	0.15	0.01	0.3	0.001	<0.0003
Bakr-Uzyak	Slag		475	0.005	0.002	0.01	0.07	0.007	0.3	0.0015	0.00015
Bakr-Uzyak	Slag		475	0.005	0.002	0.01	0.07	0.007	0.3	0.0015	0.00015
Bakr-Uzyak	Slag		476	0.015	0.005	0.015	0.07	0.007	0.3	0.001	0.00015
Bakr-Uzyak	Slag		476	0.015	0.005	0.015	0.07	0.007	0.3	0.001	0.00015
Bakr-Uzyak	Slag		477	0.005	0.002	0.01	0.05	0.01	0.3	0.0015	0.0005
Bakr-Uzyak	Slag		477	0.005	0.002	0.01	0.05	0.01	0.3	0.0015	0.0005
Bakr-Uzyak	Slag		478	0.005	0.002	0.005	0.05	0.007	0.3	0.0015	<0.0003
Bakr-Uzyak	Slag		478	0.005	0.002	0.005	0.05	0.007	0.3	0.0015	<0.0003
Bakr-Uzyak	Slag		479	0.03	0.003	0.03	0.3	0.007	0.3	0.001	0.00015
Bakr-Uzyak	Slag		479	0.03	0.003	0.03	0.3	0.007	0.3	0.001	0.00015
Bakr-Uzyak	Slag		480	0.015	0.002	0.02	0.15	0.007	0.3	0.0015	<0.0003
Bakr-Uzyak	Slag		480	0.015	0.002	0.02	0.15	0.007	0.3	0.0015	<0.0003
Bakr-Uzyak	Slag		481	0.005	0.002	0.002	0.2	0.01	0.2	0.001	<0.0003
Bakr-Uzyak	Slag		481	0.005	0.002	0.002	0.2	0.01	0.2	0.001	<0.0003
Bakr-Uzyak	Slag		482	0.007	0.002	0.01	0.15	0.005	0.2	0.0015	<0.0003
Bakr-Uzyak	Slag		482	0.007	0.002	0.01	0.15	0.005	0.2	0.0015	<0.0003
Novobaryatino	Slag	VI	707	0.005	0.0007	0.015	0.7	0.0015	0.1	0.0005	0.00015
Novobaryatino	Slag	VI	708	0.003	0	0.005	0.5	0.001	0.1	<0.0005	0.00015
Novobaryatino	Slag	VI	709	0.002	0	0.007	1	0.0015	0.2	<0.0005	0.00015
Novobaryatino	Ore		710	0.003	0	0.003	0.03	0.015	0.1	0.0005	<0.0003

Site	Material	Mineralogical groups	Sample	Ni	Co	Cr	Mn	V	Ti	Sc	Ge
Tash-Kazgan	Ore		1136	0.001	0.0003	0.007	0.03	<0.001	0.07	0.0005	<0.0003
Tash-Kazgan	Ore		1137	0.0015	0.0003	0.003	0.005	0.005	0.3	0.0005	<0.0003
Tash-Kazgan	Ore		1138	0.003	0.0003	0.005	0.015	0.007	0.15	<0.0005	<0.0003
Tash-Kazgan	Ore		1139	0.0015	0	0.007	0.03	0.0015	0.15	0.0005	0.0003
Yukalekulevo	Slag	VII	1162	>0.3	>0.1	0.007	0.02	<0.001	0.07	<0.0005	0.0005
Yukalekulevo	Slag	VII	1163	0.2	0.1	0.0015	0.01	<0.001	0.05	<0.0005	0.00015
Maily-Yurt	Ore		1170	0.05	0.015	0.003	0.03	<0.001	0.03	<0.0005	<0.0003
Maily-Yurt	Ore		1171	0.15	0.02	0.015	0.03	0.0015	0.03	<0.0005	<0.0003
Maily-Yurt	Ore		1172	0.15	0.03	0.03	0.1	0.003	0.05	0.0005	<0.0003
Maily-Yurt	Ore		1173	0.3	0.03	0.01	0.07	0.0015	0.03	0.0005	<0.0003
Maily-Yurt	Ore		1174	0.15	0.085	0.02	0.1	<0.001	0.02	<0.0005	<0.0003
Maily-Yurt	Ore		1175	0.85	0.03	0.007	0.1	0.0015	0.02	<0.0005	<0.0003
Maily-Yurt	Ore		1176	0.15	0.03	0.007	0.1	<0.001	0.05	<0.0005	<0.0003
Maily-Yurt	Ore		1177	0.3	0.05	0.07	0.1	<0.001	0.03	<0.0005	<0.0003
Maily-Yurt	Ore		1178	0.05	0.03	0.07	0.07	<0.001	0.02	<0.0005	<0.0003
Maily-Yurt	Ore		1179	0.2	0.03	0.05	0.01	<0.001	0.015	<0.0005	<0.0003
Aitovo	Slag	II	363a	0.005	0.0015	0.015	0.02	0.02	0.3	0.001	0.003
Sergeevka	slag	IV	379a	0.005	0.005	0.015	0.1	0.01	0.15	0.001	0.002
	Sensitivity of the analysis										
				Ni	Co	Cr	Mn	V	Ti	Sc	Ge
				0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.0003

Tab. 8-10. Emission spectral analyses of slag from Bashkiria (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30)(contd.).

Site	Material	Mineralogical groups	№	Cu	Zn	Pb	Ag	As	Sb	Cd
Urgun	Slag		51	>>1	0.2	0.5	0.0005	0.005	<0.003	<0.001
Tash-Kazgan	Slag		100	0.2	0.1	0.003	0.00003	0.01	<0.003	<0.001
Tash-Kazgan	Slag		101	0.2	0.005	0.0007	0.0001	0.005	<0.003	<0.001
Urgun	Slag		200	0.1	0.015	0.0007	0.00003	0.005	<0.003	<0.001
Urgun	Slag		201	0.1	0.5	0.0015	0.00003	0.005	<0.003	<0.001
Urgun	Slag		202	0.07	0.5	0.01	<0.00003	0.005	<0.003	<0.001
Urgun	Slag		203	0.07	0.2	0.001	<0.00003	0.005	<0.003	<0.001
Urgun	Slag		204	0.1	0.07	0.0005	0.00005	0.005	<0.003	<0.001
Urgun	Slag		205	0.5	0.5	0.005	0.00015	0.005	<0.003	<0.001
Chishma	Slag	I	344	0.2	nd	0.003	0.00015	0.1	0.003	<0.001
Aitovo	Slag	II	355	>>1	0.015	0.02	0.0003	0.005	<0.003	<0.001
Aitovo	Slag	II	356	>>1	0.007	0.03	>3	0.005	<0.003	<0.001
Aitovo	Slag	II	357	>>1	0.007	0.02	0.003	0.005	<0.003	<0.001
Aitovo	Slag	II	358	>>1	0.007	0.02	>3	0.005	<0.003	<0.001
Aitovo	Slag	I	359	0.15	nd	0.0005	0	0.03	<0.003	<0.001
Aitovo	Slag	I	360	0.7	0.02	0.002	0.0003	0.02	<0.003	<0.001
Aitovo	Slag	II	361	1	0.02	0.03	0.0015	0.01	<0.003	<0.001
Aitovo	Slag	I	362	>1	0.05	0.002	>3	0.5	0.003	<0.001
Aitovo	Slag	II	363	>>1	0.02	0.1	>3	0.005	<0.003	<0.001
Aitovo	Slag	II	364	>>1	0.007	0.07	>3	0.005	<0.003	<0.001
Aitovo	Slag	I	365	>>1	0.01	0.05	>3	0.005	<0.003	<0.001
Aitovo	Slag	II	366	>>1	0.015	0.05	>3	0.005	<0.003	<0.001
Aitovo	Slag	II	367	>1	0.007	0.05	>3	0.005	<0.003	<0.001
Sergeevka	slag	IV	368	1	0.01	0.03	0.0007	0.01	<0.003	<0.001
Sergeevka	slag	IV	369	1	0.01	0.02	0.0003	0.01	<0.003	<0.001
Sergeevka	slag	IV	370	>>1	0.01	0.05	>3	0.01	<0.003	<0.001
Sergeevka	slag	IV	372	1	0.01	0.015	0.0002	0.01	<0.003	<0.001
Sergeevka	slag	IV	373	>1	nd	0.05	0.0015	0.01	<0.003	<0.001
Sergeevka	slag	IV	374	1	0.01	0.03	0.0005	0.01	<0.003	<0.001
Sergeevka	slag	IV	375	>>1	nd	0.03	0.003	0.01	<0.003	<0.001

Site	Material	Mineralogical groups	№	Cu	Zn	Pb	Ag	As	Sb	Cd
Sergeevka	slag	IV	376	>1	0.01	0.03	0.0007	0.01	<0.003	<0.001
Sergeevka	slag	IV	377	>1	0.01	0.03	0.0007	0.01	<0.003	<0.001
Sergeevka	slag	IV	378	>>1	0.01	0.03	0.003	0.01	<0.003	<0.001
Sergeevka	slag	IV	379	>>1	0.01	0.1	0.003	0.01	<0.003	<0.001
Sergeevka	slag	VI	380	1	0.01	0.02	0.001	0.01	<0.003	<0.001
Sergeevka	slag	IV	381	>>1	nd	0.03	0.002	0.01	<0.003	<0.001
Sergeevka	slag	IV	382	>>1	0.01	0.02	0.0015	0.01	<0.003	<0.001
Sergeevka	slag	IV	383	>>1	0.01	0.02	0.002	0.01	<0.003	<0.001
Sergeevka	slag	IV	384	>>1	nd	0.03	0.003	0.01	<0.003	<0.001
Sergeevka	slag	IV	385	1	0.01	0.05	0.0015	0.01	<0.003	<0.001
Sergeevka	slag	IV	386	>>1	0.01	0.015	0.0002	0.01	<0.003	<0.001
Yumakovo I	Slag	II	387	>>1	nd	0.05	0.002	0.005	<0.003	<0.001
Yumakovo I	Slag	II	388	1	0.007	0.007	0.002	0.01	<0.003	<0.001
Yumakovo I	Slag	I	389	>>1	0.015	0.003	>3	0.15	<0.003	<0.001
Yumakovo II	Ore	II	390	>1	nd	0.007	>3	0.005	<0.003	<0.001
Yumakovo II	Ore	I	392	>>1	0.005	0.007	0.002	0.005	<0.003	<0.001
Yumakovo II	Slag	III	394	1	0.03	0.02	0.0005	<0.01	<0.003	<0.001
Yumakovo II	Slag	II	395	>1	0.02	0.003	0.0005	<0.01	<0.003	<0.001
Yumakovo II	Ore	II	396	>>1	0.01	0.015	>>3	0.005	<0.003	<0.001
Yumakovo II	Slag	III	397	>1	0.005	0.007	0.002	0.005	<0.003	<0.001
Yumakovo II	Slag	I	398	>1	0.005	0.03	>3	0.005	<0.003	<0.001
Yumakovo II	Ore	II	399	>>1	nd	0.3	0.001	0.01	<0.003	0.0005
Yumakovo III	Slag	V	402	>>1	0.005	0.003	0.002	0.01	<0.003	<0.001
Verkhnebikkuzino	Slag	I	403	1	nd	0.007	0.0015	0.2	0.0015	<0.001
Verkhnebikkuzino	Slag	I	404	1	0.02	0.003	0.0005	0.05	<0.003	<0.001
Verkhnebikkuzino	Slag	VI	405	1	0.007	0.0015	0.0005	0.1	<0.003	<0.001
Verkhnebikkuzino	Slag	I	406	0.5	0.015	0.001	0.0015	0.02	<0.003	<0.001
Verkhnebikkuzino	Slag	I	407	0.5	nd	0.0007	0.0003	0.03	<0.003	<0.001
Verkhnebikkuzino	Slag	I	409	>>1	0.05	0.005	>3	0.3	<0.003	<0.001
Verkhnebikkuzino	Slag	I	410	1	0.02	0.0015	0.0015	0.07	<0.003	<0.001
Verkhnebikkuzino	Slag	I	411	0.5	nd	0.001	0	0.07	<0.003	<0.001
Verkhnebikkuzino	Slag	I	412	0.5	nd	0.001	0.00007	0.05	<0.003	<0.001

Site	Material	Mineralogical groups	№	Cu	Zn	Pb	Ag	As	Sb	Cd
Verkhnebikkuzino	Slag	I	413	0.7	0.015	0.001	0.0003	0.07	<0.003	<0.001
Verkhnebikkuzino	Slag	I	415	1	0.03	0.0015	0.0015	0.1	<0.003	<0.001
Verkhnebikkuzino	Slag	I	416	0.3	nd	0.0007	<0.00003	0.015	<0.003	<0.001
Verkhnebikkuzino	Slag	I	417	>1	nd	0.001	0.0015	0.3	<0.003	<0.001
Verkhnebikkuzino	Slag	I	419	>>1	0.05	0.02	>3	0.3	0.0015	<0.001
Verkhnebikkuzino	Slag	II	420	>>1	nd	0.07	>3	0.005	<0.003	<0.001
Verkhnebikkuzino	Slag	I	421	>1	0.03	0.003	>3	0.15	0.0015	<0.001
Verkhnebikkuzino	Slag	I	423	>>1	nd	0.02	>3	0.005	<0.003	<0.001
Verkhnebikkuzino	Slag	I	424	>>1	nd	0.03	>3	0.01	<0.003	<0.001
Verkhnebikkuzino	Slag		425	>>1	0.007	0.03	>3	0.005	<0.003	<0.001
Tyubyak	Slag	II	426	1	0.01	0.002	0.003	0.03	<0.003	<0.001
Tyubyak	Slag	III	427	1	0.02	0.003	0.0015	0.3	<0.003	<0.001
Tyubyak	Slag	I	428	1	0.01	0.0015	0.001	0.05	<0.003	<0.001
Tyubyak	Slag	I	429	1	0.03	0.003	0.003	0.15	<0.003	<0.001
Tyubyak	Slag	III	431	1	0.03	0.002	0.0015	0.2	<0.003	<0.001
Sasykul	Slag		434	>1	nd	0.02	>3	0.005	<0.003	<0.001
Sasykul	Slag	II	435	1	0.015	0.015	0.0007	0.005	<0.003	<0.001
Baygildino	Slag	VI	436	0.05	0.007	0.0007	0.00003	0.005	<0.003	<0.001
Kakrykul	Slag		437	0.15	0.007	0.0007	0.0001	0.005	<0.003	<0.001
Kakrykul	Slag		438	0.7	0.007	0.0007	0.003	0.2	0.007	<0.001
Novokizganovo	Slag	VII	439	0.5	0.007	0.002	0.0003	0.01	<0.003	<0.001
Novokizganovo	Slag	VII	441	>1	0.15	>1	0.002	0.05	0.1	<0.001
Novokizganovo	Slag	VII	442	0.7	0.007	0.007	0.001	0.01	0.0015	<0.001
Novokizganovo	Slag	VII	443	0.3	0.01	0.05	0.0007	0.005	<0.003	<0.001
Tyubyak	Slag	I	445	1	nd	0.05	0.003	0.005	<0.003	<0.001
Tyubyak	Slag	II	446	1	0.007	0.02	0.003	0.005	<0.003	<0.001
Tyubyak	Slag	II	447	1	nd	0.03	0.003	0.005	<0.003	<0.001
Tyubyak	Slag	II	448	1	nd	0.03	0.003	0.003	<0.003	<0.001
Tyubyak	Slag	IV	449	1	0.007	0.015	0.002	0.005	<0.003	<0.001
Tyubyak	Slag	III	450	1	0.02	0.007	0.002	0.1	<0.003	<0.001
Tyubyak	Slag	IV	451	1	0.007	0.03	0.003	0.005	<0.003	<0.001
Tyubyak	Slag	I	452	1	0.015	0.005	0.003	0.15	<0.003	<0.001

Site	Material	Mineralogical groups	№	Cu	Zn	Pb	Ag	As	Sb	Cd
Tyubyak	Slag	I	454	1	0.015	0.0015	0.003	0.5	<0.003	<0.001
Tyubyak	Slag	IV	455	1	0.03	0.015	0.003	0.02	<0.003	<0.001
Tyubyak	Slag	I	459	1	0.015	0.0015	0.003	0.5	<0.003	<0.001
Yukalekulevo	Slag	VII	462	>>1	0.02	0.03	>3	0.1	0.3	<0.001
Bakr-Uzyak	Slag		471	1	1	0.02	0.00015	0.05	<0.003	<0.001
Bakr-Uzyak	Slag		471	1	1	0.02	0.00015	0.05	<0.003	<0.001
Bakr-Uzyak	Slag		472	0.7	0.15	0.03	0.0002	0.02	<0.003	<0.001
Bakr-Uzyak	Slag		472	0.7	0.15	0.03	0.0002	0.02	<0.003	<0.001
Bakr-Uzyak	Slag		473	0.15	0.02	0.003	0.00003	0.005	<0.003	<0.001
Bakr-Uzyak	Slag		473	0.15	0.02	0.003	0.00003	0.005	<0.003	<0.001
Bakr-Uzyak	Slag		474	0.7	0.05	0.03	0.0001	0.02	<0.003	<0.001
Bakr-Uzyak	Slag		474	0.7	0.05	0.03	0.0001	0.02	<0.003	<0.001
Bakr-Uzyak	Slag		475	0.3	0.15	0.007	0.00015	0.01	<0.003	<0.001
Bakr-Uzyak	Slag		475	0.3	0.15	0.007	0.00015	0.01	<0.003	<0.001
Bakr-Uzyak	Slag		476	0.3	0.03	0.005	0.00007	0.02	<0.003	<0.001
Bakr-Uzyak	Slag		476	0.3	0.03	0.005	0.00007	0.02	<0.003	<0.001
Bakr-Uzyak	Slag		477	0.7	0.07	0.01	0.0001	0.1	<0.003	<0.001
Bakr-Uzyak	Slag		477	0.7	0.07	0.01	0.0001	0.1	<0.003	<0.001
Bakr-Uzyak	Slag		478	0.5	0.15	0.03	0.00007	0.005	0.005	<0.001
Bakr-Uzyak	Slag		478	0.5	0.15	0.03	0.00007	0.005	0.005	<0.001
Bakr-Uzyak	Slag		479	0.2	0.03	0.0015	0.00007	0.005	<0.003	<0.001
Bakr-Uzyak	Slag		479	0.2	0.03	0.0015	0.00007	0.005	<0.003	<0.001
Bakr-Uzyak	Slag		480	0.3	0.07	0.07	0.0002	0.02	0.0015	<0.001
Bakr-Uzyak	Slag		480	0.3	0.07	0.07	0.0002	0.02	0.0015	<0.001
Bakr-Uzyak	Slag		481	0.2	0.05	0.003	0.00003	0.01	<0.003	<0.001
Bakr-Uzyak	Slag		481	0.2	0.05	0.003	0.00003	0.01	<0.003	<0.001
Bakr-Uzyak	Slag		482	0.3	0.15	0.01	0.00007	0.01	<0.003	<0.001
Bakr-Uzyak	Slag		482	0.3	0.15	0.01	0.00007	0.01	<0.003	<0.001
Novobaryatino	Slag	VI	707	0.1	0.02	0.003	0.00003	<0.01	<0.003	<0.001
Novobaryatino	Slag	VI	708	0.3	0.15	0.01	0.00005	0.005	<0.003	<0.001
Novobaryatino	Slag	VI	709	0.1	0.01	0.001	0.00003	0.005	<0.003	<0.001
Novobaryatino	Ore		710	>>1	nd	0.007	>10	0.015	0.015	<0.001

Site	**Material**	**Mineralogical groups**	**№**	**Cu**	**Zn**	**Pb**	**Ag**	**As**	**Sb**	**Cd**
Tash-Kazgan	Ore		1136	1	0.02	0.003	0.003	0.07	<0.003	<0.001
Tash-Kazgan	Ore		1137	1	0.007	0.002	0.00015	0.01	<0.003	<0.001
Tash-Kazgan	Ore		1138	1	0.02	0.005	0.003	1	<0.003	<0.001
Tash-Kazgan	Ore		1139	1	0.01	0.005	0.003	0.15	<0.003	<0.001
Yukalekulevo	Slag	VII	1162	>>1	0.02	0.1	>3	0.3	1	<0.001
Yukalekulevo	Slag	VII	1163	0.7	0.015	0.015	>3	0.01	<0.003	<0.001
Maily-Yurt	Ore		1170	1	0.01	0.0003	<0.00003	<0.01	<0.003	<0.001
Maily-Yurt	Ore		1171	1	0.01	0.0003	0.00003	<0.01	<0.003	<0.001
Maily-Yurt	Ore		1172	1	0.015	0.0003	0.0003	<0.01	<0.003	<0.001
Maily-Yurt	Ore		1173	1	0.015	0.0007	0.0001	<0.01	<0.003	<0.001
Maily-Yurt	Ore		1174	1	0.02	0.0003	0.00015	<0.01	<0.003	<0.001
Maily-Yurt	Ore		1175	1	0.01	0.0003	0.00003	<0.01	<0.003	<0.001
Maily-Yurt	Ore		1176	1	0.01	0.0003	0.002	<0.01	<0.003	<0.001
Maily-Yurt	Ore		1177	1	0.02	0.0003	0.0001	<0.01	<0.003	<0.001
Maily-Yurt	Ore		1178	1	0.1	0.0007	0.0001	<0.01	<0.003	<0.001
Maily-Yurt	Ore		1179	1	0.02	0.0003	0.0001	<0.01	<0.003	<0.001
Aitovo	Slag	II	363a	>1	0.007	0.02	0.002	0.005	<0.003	<0.001
Sergeevka	slag	IV	379a	>>1	0.01	0.03	0.003	0.01	<0.003	<0.001
	Sensitivity of the analysis									
				Cu	Zn	Pb	Ag	As	Sb	Cd
				0.001	0.003	0.0003	0.00003	0.01	0.003	0.001

Tab. 8-10. Emission spectral analyses of slag from Bashkiria (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30)(contd.).

Site	Material	Mineralogical groups	Number	Bi	Mo	Ba	Sr	W	Sn	Be
Urgun	Slag		51	<0.001	0.0007	0.5	0.03	<0.001	0.001	0.003
Tash-Kazgan	Slag		100	<0.001	0.0003	0.1	0.05	<0.001	0.0003	0.0002
Tash-Kazgan	Slag		101	<0.001	0.00015	0.2	0.07	<0.001	<0.0005	0.0002
Urgun	Slag		200	<0.001	0.00015	0.5	0.01	<0.001	<0.0005	0.00005
Urgun	Slag		201	<0.001	0.0007	0.5	0.01	<0.001	<0.0005	0.00005
Urgun	Slag		202	<0.001	0.0007	0.5	0.015	<0.001	0.0003	0.00007
Urgun	Slag		203	<0.001	0.0007	0.7	0.02	<0.001	<0.0005	0.00005
Urgun	Slag		204	<0.001	0.00015	0.03	0.01	<0.001	<0.0005	0.00003
Urgun	Slag		205	<0.001	0.00015	0.03	0.015	<0.001	0.0003	0.00005
Chishma	Slag	I	344	<0.001	0.0007	0.02	0.01	<0.001	0.0007	<0.00003
Aitovo	Slag	II	355	<0.001	0.007	>3	0.5	<0.001	<0.0005	0.0002
Aitovo	Slag	II	356	<0.001	0.03	>3	0.7	<0.001	<0.0005	0.00015
Aitovo	Slag	II	357	<0.001	0.01	>3	1	<0.001	<0.0005	0.0002
Aitovo	Slag	II	358	<0.001	0.005	>3	0.5	<0.001	0.0003	0.0002
Aitovo	Slag	I	359	<0.001	0.00015	0.03	0.01	<0.001	<0.0005	<0.00003
Aitovo	Slag	I	360	<0.001	0.0002	0.02	0.01	<0.001	0.0003	<0.00003
Aitovo	Slag	II	361	<0.001	0.0015	3	0.15	<0.001	0.0003	0.0002
Aitovo	Slag	I	362	<0.001	0.0003	0.02	0.015	<0.001	0.001	<0.00003
Aitovo	Slag	II	363	<0.001	0.003	>3	0.5	<0.001	0.0003	0.0002
Aitovo	Slag	II	364	<0.001	0.005	>3	0.7	0.001	<0.0005	0.00015
Aitovo	Slag	I	365	<0.001	0.001	3	0.2	0.001	<0.0005	0.00015
Aitovo	Slag	II	366	<0.001	0.002	3	0.3	<0.001	<0.0005	0.00015
Aitovo	Slag	II	367	<0.001	0.01	>3	0.5	<0.001	<0.0005	0.0002
Sergeevka	slag	IV	368	<0.001	0.003	>3	0.5	<0.001	<0.0005	0.0002
Sergeevka	slag	IV	369	<0.001	0.002	>3	0.2	<0.001	<0.0005	0.0002
Sergeevka	slag	IV	370	<0.001	0.01	>3	0.2	<0.001	<0.0005	0.0002
Sergeevka	slag	IV	372	<0.001	0.002	3	0.15	<0.001	<0.0005	0.0002
Sergeevka	slag	IV	373	<0.001	0.01	>3	0.3	<0.001	0.0003	0.0002
Sergeevka	slag	IV	374	<0.001	0.002	>3	0.3	<0.001	<0.0005	0.0002
Sergeevka	slag	IV	375	<0.001	0.005	>3	0.3	<0.001	0.0005	0.0002

Site	Material	Mineralogical groups	Number	Bi	Mo	Ba	Sr	W	Sn	Be
Sergeevka	slag	IV	376	<0.001	0.003	3	0.2	<0.001	<0.0005	0.0002
Sergeevka	slag	IV	377	<0.001	0.002	>3	0.3	<0.001	<0.0005	0.0002
Sergeevka	slag	IV	378	<0.001	0.005	>3	0.3	<0.001	<0.0005	0.0002
Sergeevka	slag	IV	379	<0.001	0.003	>3	0.3	<0.001	0.0005	0.0002
Sergeevka	slag	VI	380	<0.001	0.003	>3	0.3	<0.001	<0.0005	0.0002
Sergeevka	slag	IV	381	<0.001	0.01	>3	0.3	<0.001	0.0005	0.0002
Sergeevka	slag	IV	382	<0.001	0.003	>3	0.3	<0.001	<0.0005	0.0002
Sergeevka	slag	IV	383	<0.001	0.005	>3	0.3	<0.001	<0.0005	0.0002
Sergeevka	slag	IV	384	<0.001	0.01	>3	0.3	<0.001	0.0003	0.0002
Sergeevka	slag	IV	385	<0.001	0.003	>3	0.3	<0.001	0.0003	0.0002
Sergeevka	slag	IV	386	<0.001	0.002	1	0.5	<0.001	0.0003	0.0001
Yumakovo I	Slag	II	387	<0.001	0.03	>3	0.5	<0.001	0.0005	0.0003
Yumakovo I	Slag	II	388	<0.001	0.00015	0.05	0.01	<0.001	0.0005	0.0002
Yumakovo I	Slag	I	389	<0.001	0.00015	0.02	<0.01	<0.001	0.0015	<0.00003
Yumakovo II	Ore	II	390	<0.001	<0.0001	0.05	0.01	<0.001	0.0003	0.00015
Yumakovo II	Ore	I	392	<0.001	0.00015	0.03	0.01	<0.001	0.0005	0.00015
Yumakovo II	Slag	III	394	<0.001	0.00015	0.1	0.01	<0.001	0.1	0.00005
Yumakovo II	Slag	II	395	<0.001	0.0001	0.02	0.01	<0.001	>0.1	0.00015
Yumakovo II	Ore	II	396	<0.001	0.0001	0.3	0.01	<0.001	0.0005	0.00003
Yumakovo II	Slag	III	397	<0.001	0.001	0.03	0.01	<0.001	<0.0005	0.00003
Yumakovo II	Slag	I	398	<0.001	0.005	0.05	0.01	<0.001	<0.0005	<0.00003
Yumakovo II	Ore	II	399	<0.001	0.05	3	0.2	<0.001	0.003	0.00015
Yumakovo III	Slag	V	402	<0.001	0.002	1.5	0.1	<0.001	<0.0005	0.00005
Verkhnebikkuzino	Slag	I	403	<0.001	0.0007	0.015	0.01	<0.001	0.0003	<0.00003
Verkhnebikkuzino	Slag	I	404	<0.001	0.0002	0.01	0.01	<0.001	<0.0005	<0.00003
Verkhnebikkuzino	Slag	VI	405	<0.001	0.0002	0.01	0.01	<0.001	<0.0005	<0.00003
Verkhnebikkuzino	Slag	I	406	<0.001	0.0002	0.015	0.01	<0.001	0.0003	<0.00003
Verkhnebikkuzino	Slag	I	407	<0.001	0.00015	0.03	0.01	<0.001	<0.0005	0.00003
Verkhnebikkuzino	Slag	I	409	<0.001	0.0015	0.03	0.01	<0.001	0.0007	0.00003
Verkhnebikkuzino	Slag	I	410	<0.001	0.0002	0.02	0.01	<0.001	<0.0005	<0.00003
Verkhnebikkuzino	Slag	I	411	<0.001	0.00015	0.02	0.015	<0.001	<0.0005	0.00003
Verkhnebikkuzino	Slag	I	412	<0.001	0.001	0.07	0.01	<0.001	0.0003	0.00007

Site	Material	Mineralogical groups	Number	Bi	Mo	Ba	Sr	W	Sn	Be
Verkhnebikkuzino	Slag	I	413	<0.001	0.0003	0.015	0.01	<0.001	0.0003	<0.00003
Verkhnebikkuzino	Slag	I	415	<0.001	0.00015	0.02	0.01	<0.001	0.0005	<0.00003
Verkhnebikkuzino	Slag	I	416	<0.001	0.00015	0.015	0.01	<0.001	0.0003	0.00003
Verkhnebikkuzino	Slag	I	417	<0.001	0.00015	0.015	0.01	<0.001	0.0003	<0.00003
Verkhnebikkuzino	Slag	I	419	<0.001	0.0003	0.02	0.01	<0.001	0.0007	<0.00003
Verkhnebikkuzino	Slag	II	420	<0.001	0.02	>3	0.3	<0.001	0.0003	0.0002
Verkhnebikkuzino	Slag	I	421	<0.001	0.00015	0.03	0.01	<0.001	0.0007	<0.00003
Verkhnebikkuzino	Slag	I	423	<0.001	0.015	>3	0.15	<0.001	0.0003	0.00015
Verkhnebikkuzino	Slag	I	424	<0.001	0.03	>3	0.15	<0.001	<0.0005	0.0002
Verkhnebikkuzino	Slag		425	<0.001	0.015	>3	0.2	<0.001	<0.0005	0.0001
Tyubyak	Slag	II	426	<0.001	<0.0001	0.03	<0.01	<0.001	<0.0005	0.00003
Tyubyak	Slag	III	427	<0.001	0.0003	0.01	0.01	<0.001	0.0003	<0.00003
Tyubyak	Slag	I	428	<0.001	0.0001	0.02	0.015	<0.001	<0.0005	<0.00003
Tyubyak	Slag	I	429	<0.001	0.0003	0.01	0.01	<0.001	<0.0005	<0.00003
Tyubyak	Slag	III	431	<0.001	0.00015	0.02	0.01	<0.001	0.0005	<0.00003
Sasykul	Slag		434	<0.001	0.0005	>3	1	<0.001	0.0003	0.00015
Sasykul	Slag	II	435	<0.001	0.0001	0.05	0.1	<0.001	<0.0005	0.0001
Baygildino	Slag	VI	436	<0.001	0.0003	0.02	0.01	<0.001	<0.0005	<0.00003
Kakrykul	Slag		437	<0.001	0.0007	1	0.01	<0.001	<0.0005	0.0001
Kakrykul	Slag		438	<0.001	0.0015	0.015	0.01	<0.001	0.01	<0.00003
Novokizganovo	Slag	VII	439	<0.001	0.0002	1	0.02	<0.001	0.005	0.00015
Novokizganovo	Slag	VII	441	0.003	0.001	0.15	0.07	<0.001	>0.3	0.0003
Novokizganovo	Slag	VII	442	<0.001	0.00015	0.1	0.02	<0.001	0.03	0.0001
Novokizganovo	Slag	VII	443	<0.001	0.0002	0.07	0.03	<0.001	0.015	0.0002
Tyubyak	Slag	I	445	<0.001	0.01	3	0.5	<0.001	0.0003	0.0002
Tyubyak	Slag	II	446	<0.001	0.001	3	0.3	<0.001	0.0003	0.00015
Tyubyak	Slag	II	447	<0.001	0.01	3	0.3	<0.001	0.0003	0.00015
Tyubyak	Slag	II	448	<0.001	0.02	3	0.5	<0.001	0.0003	0.0002
Tyubyak	Slag	IV	449	<0.001	0.0005	0.7	0.15	0.001	0.0003	0.0002
Tyubyak	Slag	III	450	<0.001	0.00015	0.02	0.015	<0.001	0.0007	<0.00003
Tyubyak	Slag	IV	451	<0.001	0.015	3	0.2	<0.001	<0.0005	0.0002
Tyubyak	Slag	I	452	<0.001	0.0001	0.1	0.01	<0.001	<0.0005	<0.00003

Site	Material	Mineralogical groups	Number	Bi	Mo	Ba	Sr	W	Sn	Be
Tyubyak	Slag	I	454	<0.001	0.00015	0.2	0.02	<0.001	0.001	0.00005
Tyubyak	Slag	IV	455	<0.001	<0.0001	0.05	<0.01	<0.001	<0.0005	<0.00003
Tyubyak	Slag	I	459	<0.001	0.0003	0.1	0.03	<0.001	0.0007	0.00007
Yukalekulevo	Slag	VII	462	<0.001	0.0001	0.01	<0.01	<0.001	0.3	0.00003
Bakr-Uzyak	Slag		471	<0.001	0.0015	0.03	0.01	<0.001	0.0007	0.00005
Bakr-Uzyak	Slag		471	<0.001	0.0015	0.03	0.01	<0.001	0.0007	0.00005
Bakr-Uzyak	Slag		472	<0.001	0.0002	0.1	0.03	<0.001	0.02	0.0001
Bakr-Uzyak	Slag		472	<0.001	0.0002	0.1	0.03	<0.001	0.02	0.0001
Bakr-Uzyak	Slag		473	<0.001	0.0001	0.07	0.015	<0.001	0.0005	0.0001
Bakr-Uzyak	Slag		473	<0.001	0.0001	0.07	0.015	<0.001	0.0005	0.0001
Bakr-Uzyak	Slag		474	<0.001	0.0005	0.1	0.03	<0.001	0.005	0.00015
Bakr-Uzyak	Slag		474	<0.001	0.0005	0.1	0.03	<0.001	0.005	0.00015
Bakr-Uzyak	Slag		475	<0.001	0.00015	0.1	0.05	<0.001	0.0003	0.00015
Bakr-Uzyak	Slag		475	<0.001	0.00015	0.1	0.05	<0.001	0.0003	0.00015
Bakr-Uzyak	Slag		476	<0.001	0.00015	0.07	0.015	<0.001	0.0007	0.0001
Bakr-Uzyak	Slag		476	<0.001	0.00015	0.07	0.015	<0.001	0.0007	0.0001
Bakr-Uzyak	Slag		477	<0.001	0.0002	0.1	0.015	<0.001	0.007	0.0001
Bakr-Uzyak	Slag		477	<0.001	0.0002	0.1	0.015	<0.001	0.007	0.0001
Bakr-Uzyak	Slag		478	<0.001	0.00015	0.1	0.015	<0.001	0.1	0.0001
Bakr-Uzyak	Slag		478	<0.001	0.00015	0.1	0.015	<0.001	0.1	0.0001
Bakr-Uzyak	Slag		479	<0.001	0.0001	0.07	0.02	<0.001	0.0003	0.00015
Bakr-Uzyak	Slag		479	<0.001	0.0001	0.07	0.02	<0.001	0.0003	0.00015
Bakr-Uzyak	Slag		480	<0.001	0.0002	0.15	0.03	<0.001	0.02	0.0001
Bakr-Uzyak	Slag		480	<0.001	0.0002	0.15	0.03	<0.001	0.02	0.0001
Bakr-Uzyak	Slag		481	<0.001	0.0001	0.07	0.01	<0.001	0.0003	0.00007
Bakr-Uzyak	Slag		481	<0.001	0.0001	0.07	0.01	<0.001	0.0003	0.00007
Bakr-Uzyak	Slag		482	<0.001	0.0002	0.01	0.02	<0.001	0.0003	0.0001
Bakr-Uzyak	Slag		482	<0.001	0.0002	0.01	0.02	<0.001	0.0003	0.0001
Novobaryatino	Slag	VI	707	<0.001	0.0002	0.03	0.01	<0.001	0.0003	0.00005
Novobaryatino	Slag	VI	708	<0.001	0.00015	0.01	0.01	<0.001	0.0003	0.00003
Novobaryatino	Slag	VI	709	<0.001	0.0003	0.03	0.01	<0.001	<0.0005	0.00007
Novobaryatino	Ore		710	>0.05	0.1	0.3	0.01	0.0015	<0.0005	0.0003

Site	Material	Mineralogical groups	Number	Bi	Mo	Ba	Sr	W	Sn	Be
Tash-Kazgan	Ore		1136	0.015	0.00015	<0.01	<0.01	<0.001	<0.0005	0.00005
Tash-Kazgan	Ore		1137	<0.001	0.0001	<0.01	0.03	0.001	<0.0005	0.00003
Tash-Kazgan	Ore		1138	<0.001	0.007	0.01	0.01	0.001	0.0003	0.00007
Tash-Kazgan	Ore		1139	<0.001	0.0003	3	0.15	<0.001	<0.0005	0.00015
Yukalekulevo	Slag	VII	1162	0.001	0.0001	<0.01	<0.01	<0.001	>0.3	<0.00003
Yukalekulevo	Slag	VII	1163	<0.001	0.00015	0.01	<0.01	<0.001	0.007	<0.00003
Maily-Yurt	Ore		1170	<0.001	<0.0001	<0.01	0.01	<0.001	<0.0005	0.00005
Maily-Yurt	Ore		1171	<0.001	0.0001	<0.01	0.01	<0.001	<0.0005	<0.00003
Maily-Yurt	Ore		1172	<0.001	<0.0001	<0.01	0.01	<0.001	<0.0005	<0.00003
Maily-Yurt	Ore		1173	<0.001	<0.0001	0.01	0.01	<0.001	<0.0005	<0.00003
Maily-Yurt	Ore		1174	<0.001	0.0001	0.01	0.01	<0.001	<0.0005	<0.00003
Maily-Yurt	Ore		1175	<0.001	<0.0001	<0.01	0.01	<0.001	<0.0005	<0.00003
Maily-Yurt	Ore		1176	<0.001	0.0001	<0.01	0.01	<0.001	<0.0005	<0.00003
Maily-Yurt	Ore		1177	<0.001	<0.0001	0.01	0.01	<0.001	<0.0005	<0.00003
Maily-Yurt	Ore		1178	<0.001	0.0001	<0.01	0.01	<0.001	<0.0005	<0.00003
Maily-Yurt	Ore		1179	<0.001	0.0001	<0.01	0.01	<0.001	<0.0005	<0.00003
Aitovo	Slag	II	363a	<0.001	0.005	>3	0.5	<0.001	0.0003	0.00015
Sergeevka	slag	IV	379a	<0.001	0.005	>3	0.3	<0.001	0.0003	0.0002
	Sensitivity of the analysis									
				Bi	Mo	Ba	Sr	W	Sn	Be
				0.001	0.0001	0.01	0.01	0.001	0.0005	0.00003

Tab. 8-10. Emission spectral analyses of slag from Bashkiria (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30)(contd.).

Site	Material	Mineralogical groups	Number	Zr	Ga	Y	Yb
Urgun	Slag		51	nd	0.001	>0.03	>0.003
Tash-Kazgan	Slag		100	0.015	0.0015	0.002	0.0002
Tash-Kazgan	Slag		101	0.01	0.001	<0.001	0.0001
Urgun	Slag		200	0.005	<0.0005	0.001	0.00015
Urgun	Slag		201	0.007	<0.0005	0.001	0.0001
Urgun	Slag		202	0.01	0.001	0.0015	0.0002
Urgun	Slag		203	0.007	0.0005	0.001	0.00015
Urgun	Slag		204	0.003	0.0005	0.001	0.00015
Urgun	Slag		205	0.003	0.001	0.001	0.00015
Chishma	Slag	I	344	0.0015	0.0005	<0.001	<0.0001
Aitovo	Slag	II	355	0.02	0.001	0.002	0.0002
Aitovo	Slag	II	356	0.02	0.0015	0.003	0.00015
Aitovo	Slag	II	357	0.02	0.0015	0.003	0.00015
Aitovo	Slag	II	358	0.02	0.0015	0.003	0.00015
Aitovo	Slag	I	359	0.001	0.0005	0.002	0.00015
Aitovo	Slag	I	360	nd	0.0015	0.001	0.00015
Aitovo	Slag	II	361	0.02	0.001	0.002	0.00015
Aitovo	Slag	I	362	nd	0.0015	<0.001	<0.0001
Aitovo	Slag	II	363	0.02	0.002	0.003	0.00015
Aitovo	Slag	II	364	0.02	0.002	0.002	0.0001
Aitovo	Slag	I	365	0.02	0.0015	0.002	0.0001
Aitovo	Slag	II	366	0.02	0.0015	0.002	0.00015
Aitovo	Slag	II	367	0.03	0.002	0.003	0.0002
Sergeevka	slag	IV	368	0.03	0.002	0.002	0.0003
Sergeevka	slag	IV	369	0.02	0.0015	0.002	0.0002
Sergeevka	slag	IV	370	0.02	0.002	0.002	0.0002
Sergeevka	slag	IV	372	0.02	0.0015	0.002	0.0002
Sergeevka	slag	IV	373	0.02	0.002	0.002	0.0002
Sergeevka	slag	IV	374	0.02	0.002	0.002	0.0002
Sergeevka	slag	IV	375	0.02	0.002	0.002	0.0002

Site	Material	Mineralogical groups	Number	Zr	Ga	Y	Yb
Sergeevka	slag	IV	376	0.015	0.0015	0.001	0.0002
Sergeevka	slag	IV	377	0.02	0.0015	0.002	0.0002
Sergeevka	slag	IV	378	0.015	0.0015	0.002	0.0002
Sergeevka	slag	IV	379	0.02	0.002	0.002	0.0002
Sergeevka	slag	VI	380	0.02	0.002	0.002	0.0002
Sergeevka	slag	IV	381	0.015	0.002	0.002	0.0002
Sergeevka	slag	IV	382	0.015	0.0015	0.002	0.0002
Sergeevka	slag	IV	383	0.015	0.002	0.002	0.0002
Sergeevka	slag	IV	384	0.015	0.002	0.002	0.0002
Sergeevka	slag	IV	385	0.02	0.002	0.002	0.0002
Sergeevka	slag	IV	386	0.01	0.001	0.002	0.0002
Yumakovo I	Slag	II	387	0.02	0.0015	0.003	0.0002
Yumakovo I	Slag	II	388	0.02	0.0015	0.002	0.00015
Yumakovo I	Slag	I	389	nd	0.001	<0.001	<0.0001
Yumakovo II	Ore	II	390	0.015	0.001	0.0015	<0.0001
Yumakovo II	Ore	I	392	0.01	0.0005	<0.001	<0.0001
Yumakovo II	Slag	III	394	nd	0.0005	<0.001	0.0001
Yumakovo II	Slag	II	395	0.01	0.0005	0.001	0.0001
Yumakovo II	Ore	II	396	nd	0.0005	<0.001	<0.0001
Yumakovo II	Slag	III	397	nd	0.0005	0.001	<0.0001
Yumakovo II	Slag	I	398	nd	0.0005	0.001	<0.0001
Yumakovo II	Ore	II	399	0.005	0.001	0.001	<0.0001
Yumakovo III	Slag	V	402	nd	0.0005	<0.001	<0.0001
Verkhnebikkuzino	Slag	I	403	0.0015	0.001	<0.001	0.0001
Verkhnebikkuzino	Slag	I	404	0.001	0.0015	<0.001	0.0001
Verkhnebikkuzino	Slag	VI	405	0.001	0.001	<0.001	0.0001
Verkhnebikkuzino	Slag	I	406	0.001	0.001	<0.001	0.0001
Verkhnebikkuzino	Slag	I	407	0.001	0.001	<0.001	0.0001
Verkhnebikkuzino	Slag	I	409	nd	0.0015	<0.001	0.0001
Verkhnebikkuzino	Slag	I	410	nd	0.001	<0.001	0.0001
Verkhnebikkuzino	Slag	I	411	0.003	0.0005	<0.001	0.0001
Verkhnebikkuzino	Slag	I	412	0.005	0.001	0.001	0.0001

Site	Material	Mineralogical groups	Number	Zr	Ga	Y	Yb
Verkhnebikkuzino	Slag	I	413	0.001	0.001	<0.001	0.0001
Verkhnebikkuzino	Slag	I	415	0.001	0.0015	<0.001	0.0001
Verkhnebikkuzino	Slag	I	416	0.0015	0.0005	<0.001	0.0001
Verkhnebikkuzino	Slag	I	417	0.001	0.001	<0.001	0.0001
Verkhnebikkuzino	Slag	I	419	nd	0.0015	<0.001	0.0001
Verkhnebikkuzino	Slag	II	420	0.015	0.0015	0.0015	<0.0001
Verkhnebikkuzino	Slag	I	421	nd	0.002	<0.001	0.0001
Verkhnebikkuzino	Slag	I	423	0.015	0.0015	0.0015	<0.0001
Verkhnebikkuzino	Slag	I	424	0.02	0.0015	0.002	<0.0001
Verkhnebikkuzino	Slag		425	0.015	0.0015	0.0015	<0.0001
Tyubyak	Slag	II	426	nd	0.0005	<0.001	<0.0001
Tyubyak	Slag	III	427	0.001	0.0005	<0.001	0.0001
Tyubyak	Slag	I	428	0.001	0.0005	<0.001	0.0001
Tyubyak	Slag	I	429	0.001	0.0015	<0.001	0.0001
Tyubyak	Slag	III	431	0.001	0.001	<0.001	<0.0001
Sasykul	Slag		434	0.015	0.001	0.002	0.0001
Sasykul	Slag	II	435	0.01	0.0015	0.002	0.0002
Baygildino	Slag	VI	436	0.001	0.0005	<0.001	0.0001
Kakrykul	Slag		437	0.015	0.001	0.001	0.0001
Kakrykul	Slag		438	0.001	0.0005	<0.001	<0.0001
Novokizganovo	Slag	VII	439	0.01	0.001	0.0015	0.00015
Novokizganovo	Slag	VII	441	0.01	0.001	0.01	0.0015
Novokizganovo	Slag	VII	442	0.015	0.001	0.0015	0.00015
Novokizganovo	Slag	VII	443	0.03	0.0015	0.003	0.0002
Tyubyak	Slag	I	445	0.02	0.0015	0.002	0.0001
Tyubyak	Slag	II	446	0.01	0.001	0.0015	<0.0001
Tyubyak	Slag	II	447	0.01	0.0015	0.0015	0.00015
Tyubyak	Slag	II	448	0.015	0.0015	0.003	0.00015
Tyubyak	Slag	IV	449	0.015	0.00015	0.002	<0.0001
Tyubyak	Slag	III	450	nd	0.0015	0.001	0.0001
Tyubyak	Slag	IV	451	0.03	0.0015	0.003	0.00015
Tyubyak	Slag	I	452	nd	0.0005	<0.001	<0.0001

Site	Material	Mineralogical groups	Number	Zr	Ga	Y	Yb
Tyubyak	Slag	I	454	nd	0.001	0.001	0.0001
Tyubyak	Slag	IV	455	nd	<0.0005	<0.001	<0.0001
Tyubyak	Slag	I	459	nd	0.001	<0.001	0.0001
Yukalekulevo	Slag	VII	462	nd	<0.0005	<0.001	0.0001
Bakr-Uzyak	Slag		471	0.007	0.0015	0.002	0.0002
Bakr-Uzyak	Slag		471	0.007	0.0015	0.002	0.0002
Bakr-Uzyak	Slag		472	0.01	0.0015	0.003	0.0002
Bakr-Uzyak	Slag		472	0.01	0.0015	0.003	0.0002
Bakr-Uzyak	Slag		473	0.015	0.0015	0.003	0.0002
Bakr-Uzyak	Slag		473	0.015	0.0015	0.003	0.0002
Bakr-Uzyak	Slag		474	0.007	0.0015	0.003	0.0002
Bakr-Uzyak	Slag		474	0.007	0.0015	0.003	0.0002
Bakr-Uzyak	Slag		475	0.01	0.0015	0.007	0.0007
Bakr-Uzyak	Slag		475	0.01	0.0015	0.007	0.0007
Bakr-Uzyak	Slag		476	0.005	0.0015	0.003	0.0002
Bakr-Uzyak	Slag		476	0.005	0.0015	0.003	0.0002
Bakr-Uzyak	Slag		477	0.007	0.0015	0.002	0.00015
Bakr-Uzyak	Slag		477	0.007	0.0015	0.002	0.00015
Bakr-Uzyak	Slag		478	0.007	0.0015	0.003	0.0002
Bakr-Uzyak	Slag		478	0.007	0.0015	0.003	0.0002
Bakr-Uzyak	Slag		479	0.01	0.001	0.002	0.00015
Bakr-Uzyak	Slag		479	0.01	0.001	0.002	0.00015
Bakr-Uzyak	Slag		480	0.01	0.001	0.003	0.0002
Bakr-Uzyak	Slag		480	0.01	0.001	0.003	0.0002
Bakr-Uzyak	Slag		481	0.003	0.001	0.001	0.00015
Bakr-Uzyak	Slag		481	0.003	0.001	0.001	0.00015
Bakr-Uzyak	Slag		482	0.007	0.0015	0.01	0.0005
Bakr-Uzyak	Slag		482	0.007	0.0015	0.01	0.0005
Novobaryatino	Slag	VI	707	0.0015	0.0005	<0.001	0.0001
Novobaryatino	Slag	VI	708	0.003	0.001	<0.001	0.0001
Novobaryatino	Slag	VI	709	0.007	0.001	0.0015	0.0001
Novobaryatino	Ore		710	nd	0.0005	<0.001	<0.0001

Site	Material	Mineralogical groups	Number	Zr	Ga	Y	Yb
Tash-Kazgan	Ore		1136	nd	0.0005	<0.001	<0.0001
Tash-Kazgan	Ore		1137	0.01	0.0015	<0.001	<0.0001
Tash-Kazgan	Ore		1138	0.007	0.0005	0.001	<0.0001
Tash-Kazgan	Ore		1139	0.007	0.001	<0.001	<0.0001
Yukalekulevo	Slag	VII	1162	nd	<0.0005	<0.001	<0.0001
Yukalekulevo	Slag	VII	1163	nd	<0.0005	0.0015	0.00015
Maily-Yurt	Ore		1170	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	Ore		1171	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	Ore		1172	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	Ore		1173	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	Ore		1174	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	Ore		1175	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	Ore		1176	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	Ore		1177	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	Ore		1178	<0.001	<0.0005	<0.001	<0.0001
Maily-Yurt	Ore		1179	<0.001	<0.0005	<0.001	<0.0001
Aitovo	Slag	II	363a	0.02	0.0015	0.0015	0.00015
Sergeevka	slag	IV	379a	0.007	0.0015	0.002	0.0001
	Sensitivity of the analysis						
				Zr	Ga	Y	Yb
				0.001	0.0005	0.001	0.0001

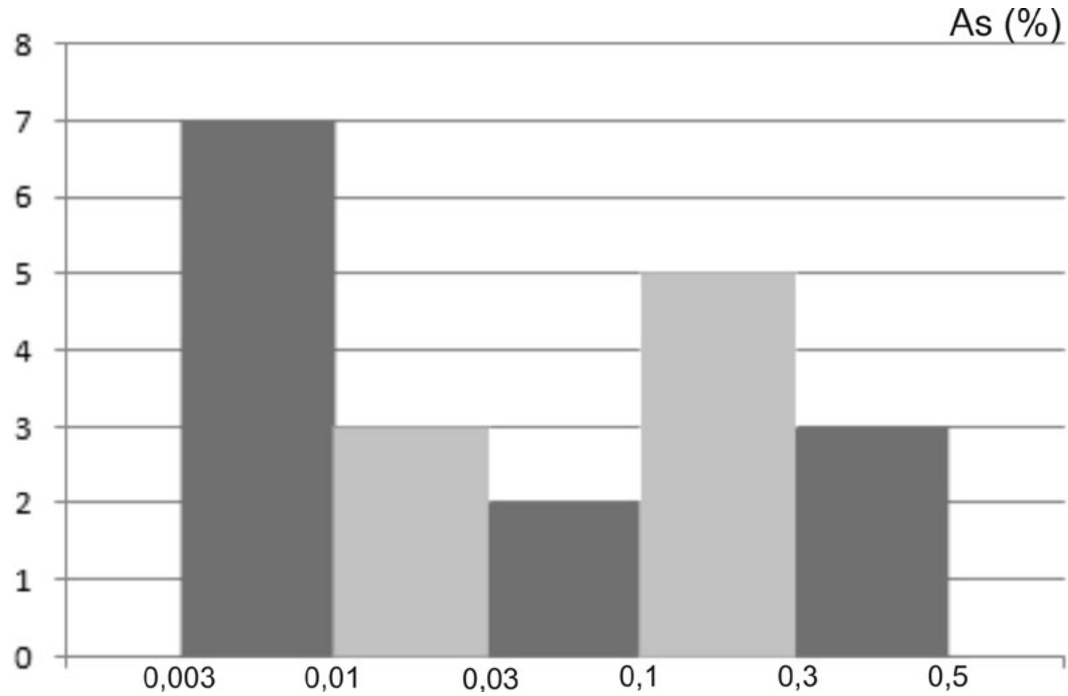


FIG. 8-11. FREQUENCY DIAGRAM OF DISTRIBUTION OF ARSENIC IN THE ABASHEVO SLAG OF THE WESTERN URALS.

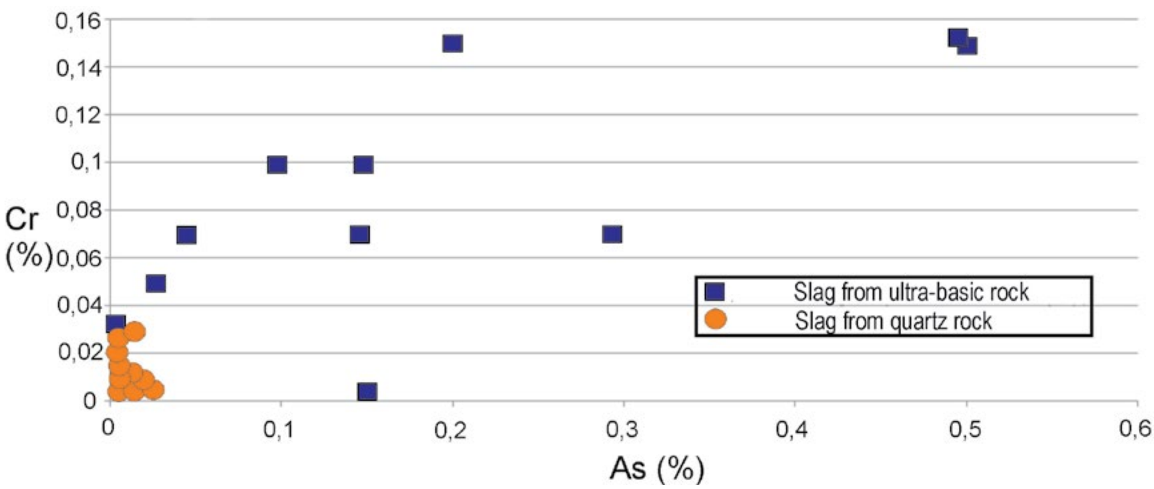


FIG. 8-12. CORRELATION OF CONCENTRATIONS OF AS-CR (%) IN SLAG OF BASHKIRIA. SQUARES – SAMPLES CONNECTED WITH ULTRABASIC ROCKS, CIRCLES – SAMPLES CONNECTED WITH QUARTZ ROCKS.

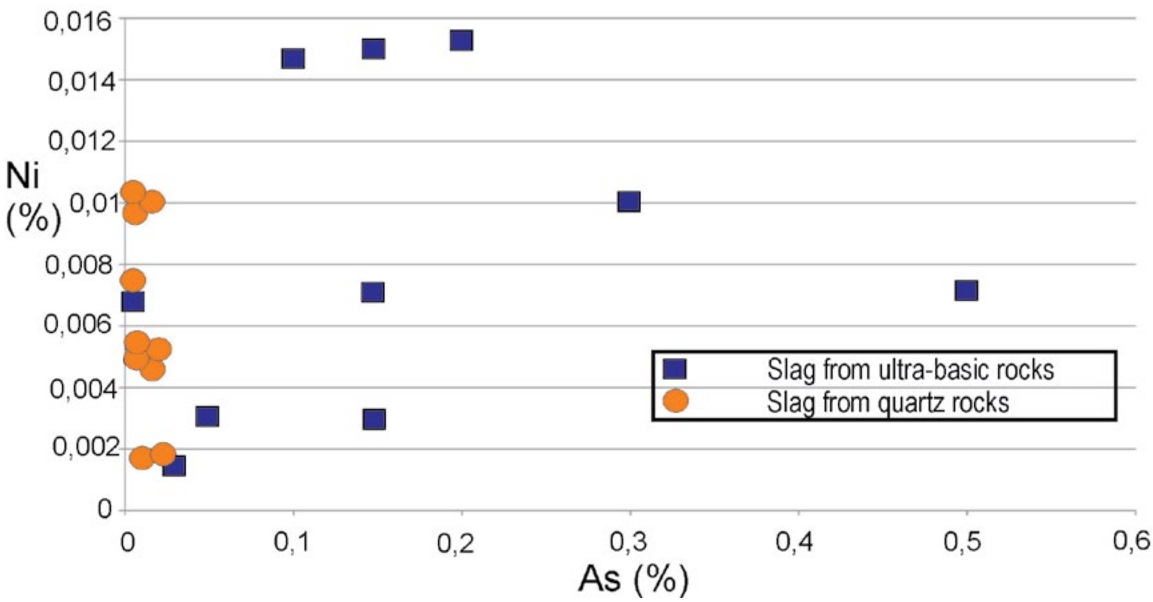


FIG. 8-13. CORRELATION OF CONCENTRATIONS OF AS-NI (%) IN SLAG OF BASHKIRIA. SQUARES – SAMPLES CONNECTED WITH ULTRABASIC ROCKS, CIRCLES – SAMPLES CONNECTED WITH QUARTZ ROCKS.

Tab. 8-14. Types of copper-based alloys in the Timber-Grave culture (without tin alloys).

Cu	Cu+As	Cu+As+Sb	Cu+Sb	Total
583	89	8	6	686
85%	13%	1.2%	0.8%	100%

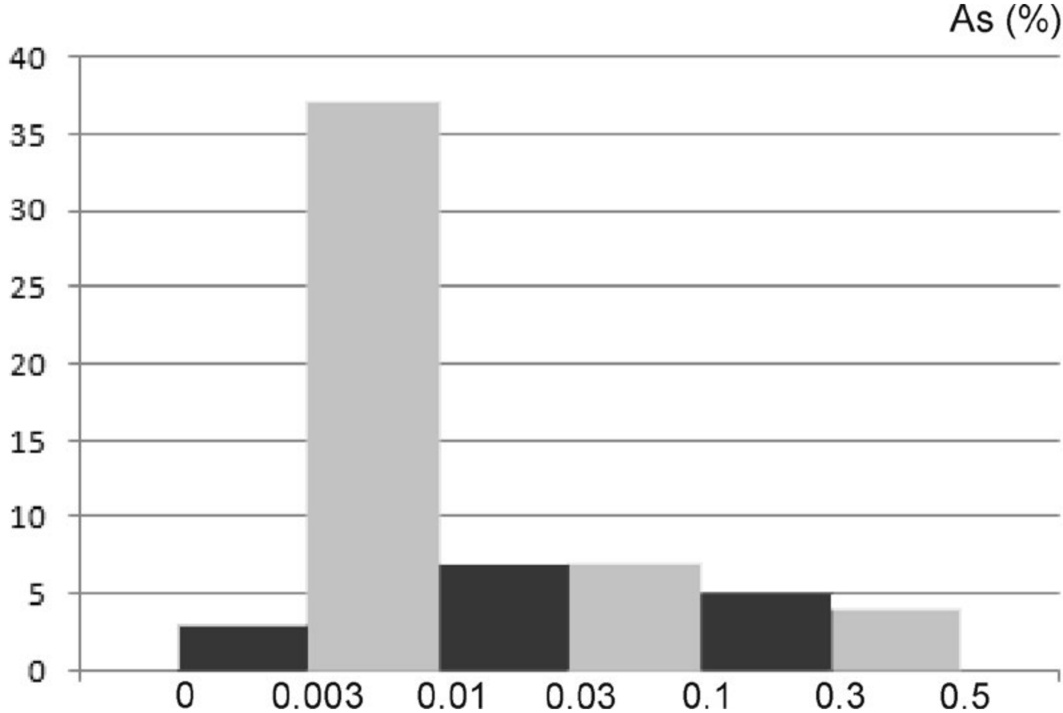


FIG. 8-15. FREQUENCY DIAGRAM OF DISTRIBUTION OF ARSENIC IN THE TIMBER-GRAVE SLAG OF THE WESTERN URALS.

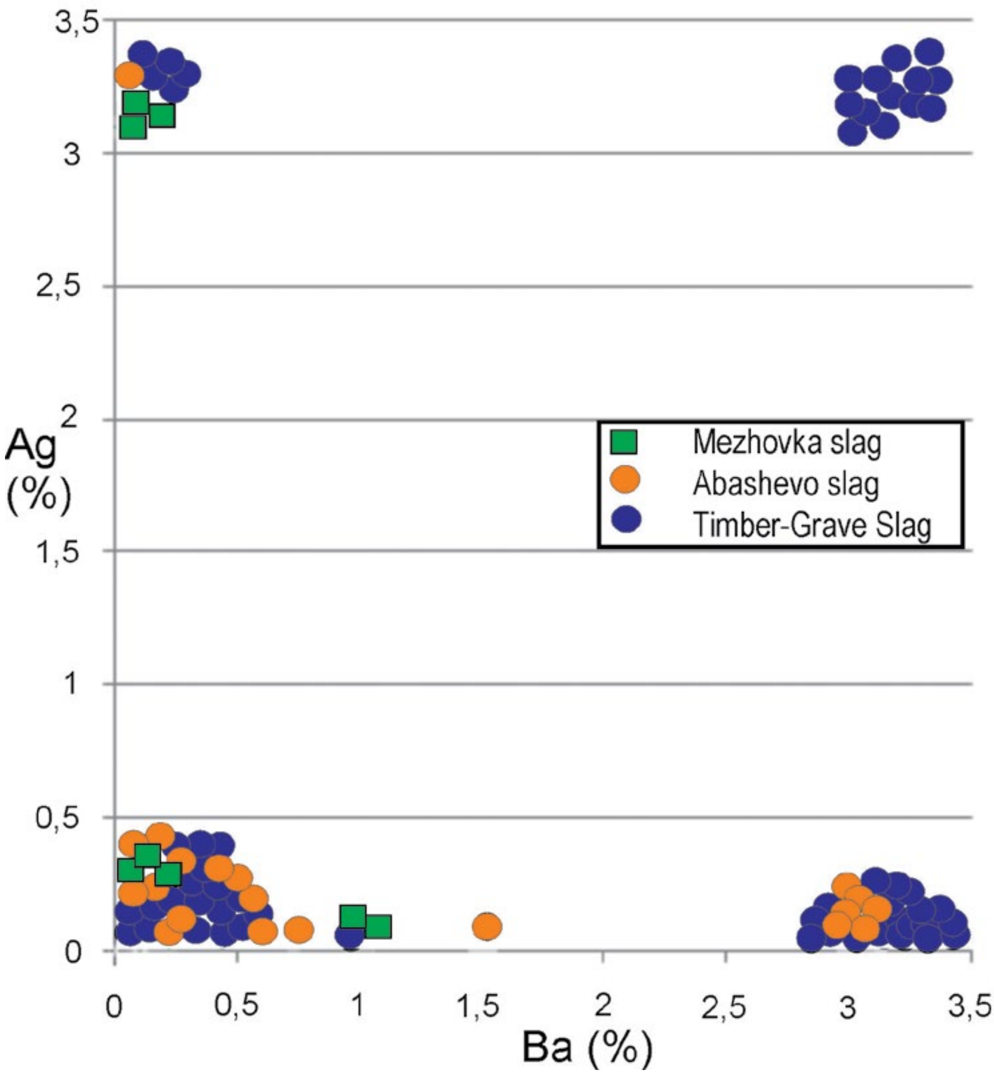


FIG. 8-16. CORRELATION OF CONCENTRATIONS OF BA-AG (%) IN SLAG OF BASHKIRIA: SQUARES – MEZHOVKA SLAG, ORANGE CIRCLES – ABASHEVO SLAG, BLUE CIRCLES – TIMBER-GRAVE SLAG.

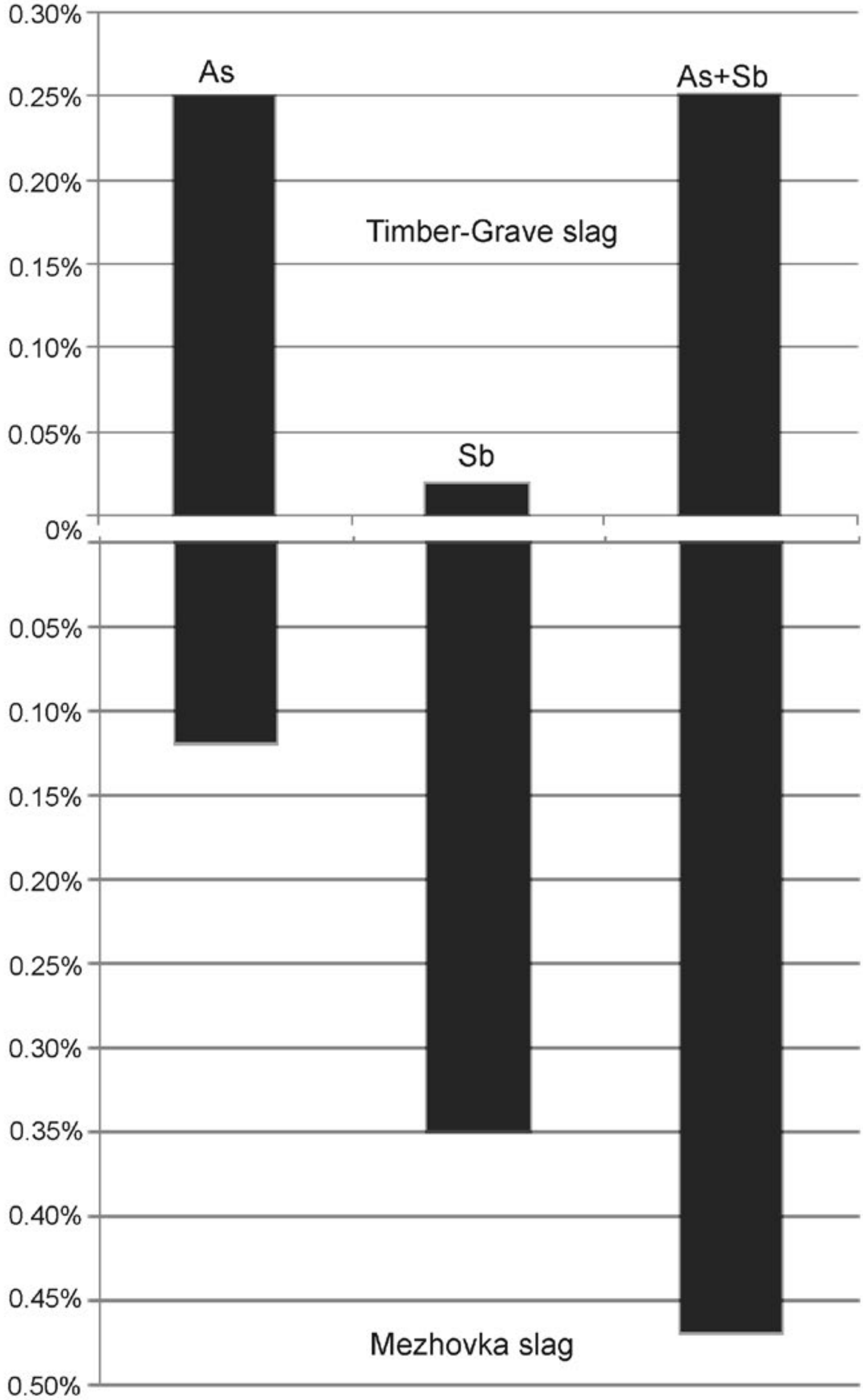


FIG. 8-17. DIAGRAMS OF CONCENTRATIONS OF ARSENIC AND ANTIMONY IN THE TIMBER-GRAVE AND MEZHOVKA SLAGS CONTAINING ANTIMONY.

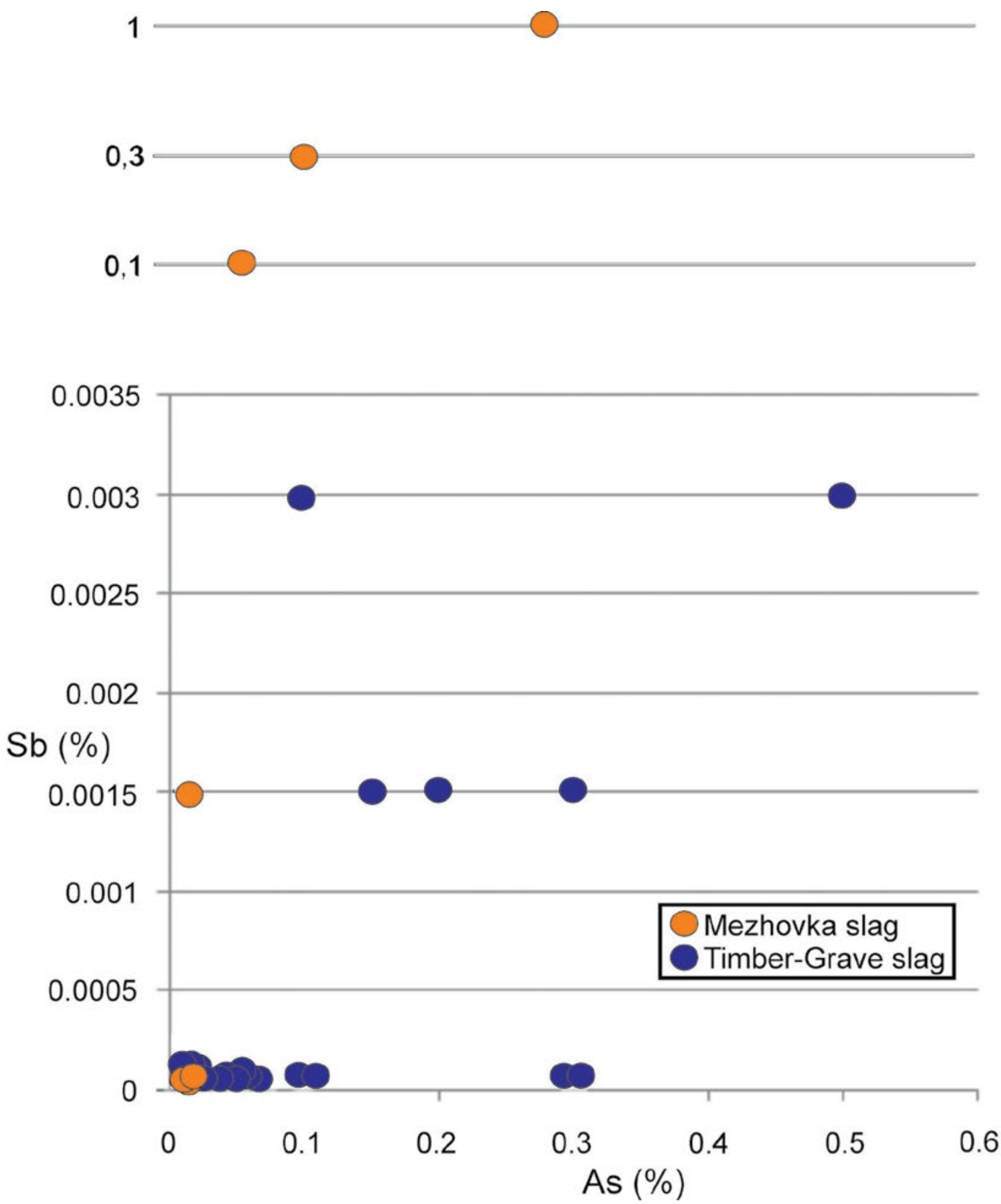


FIG. 8-18. CORRELATION OF CONCENTRATIONS OF AS-SB IN THE TIMBER-GRAVE AND MEZHOVKA SLAG OF BASHKIRIA: ORANGE CIRCLES – MEZHOVKA SLAG, BLUE CIRCLES – TIMBER-GRAVE SLAG.

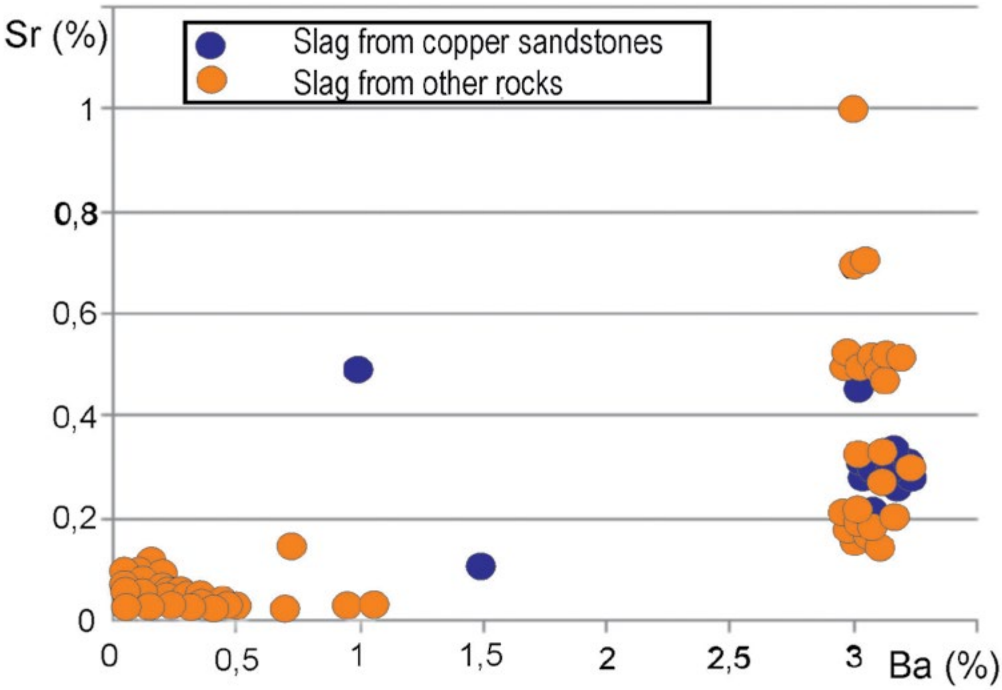


FIG. 8-19. CORRELATION OF CONCENTRATIONS OF BA-SR IN SLAG OF BASHKIRIA: BLUE CIRCLES – SLAG RELIABLY CONNECTED WITH COPPER SANDSTONES.

Tab. 8-20. Chemical clusters of slag from the settlements in Bashkiria.

Clusters	1	2	3	4	5
Aitovo	2			6	5
Baygildino			1		
Verkhnebikkuzino	12			7	
Kakrykul	1		1		
Novobaryatino			3		
Novokizganovo		1	3		
Tyubyak	8		1	1	5
Urnyak		1			
Chishma	1				
Yukalekulevo	1		4	3	
Yumakovo I				1	1
Yumakovo II	2		2		

Tab. 8-21. Distribution of mineralogical groups of slag over cultural groups in Bashkiria and the Sintashta culture in the Transurals.

Mineralogical group / Culture	I	II	III	IV	V	VI	VII	Ceramic slag
Sintashta	45 (59.2%)	12 (15.8%)	17 (22.4%)					2 (2.6%)
Abashevo	8 (28.6%)	6 (21.4%)	3 (10.7%)	7 (25%)	4 (14.3%)			
Timber-Grave	22 (33.7%)	17 (26.2%)	2 (3.3%)	18 (27.5%)		7 (9.3%)		
Mezhovka							7 (100%)	

Chapter 9.
Metallurgy of the Late Bronze Age in the Volga and Orenburg Regions

Problem of exploitation of the copper sandstones in the EBA – LBA

As we have seen in the previous chapter, in the LBA period there is no enough reliable evidence in the Bashkirian Cisural region about smelting of ore from the copper sandstones, although settlements with traces of ore smelting are situated either directly near these fields or thereabouts. It is explained by the use of technologies which had not been adapted for smelting these ores, and by the availability of other, more convenient fields. Therefore an impression can be created that these numerous sandstone deposits were not exploited. But the situation changes in the Volga region and the Orenburg Cisural area where copper deposits are presented almost exclusively by the copper sandstones. And, for the Pit-Grave culture of the EBA this source, almost for certain, was the single. Unfortunately, evidences of ore smelting of this time are absent, we only know about isolated cases of finds of sandstone ore in barrows of the Western Orenburg area (Chernykh 2007, p. 69, 70). There are no evidences also in the MBA period, except for slag finds in barrows of the Potapovka cultural type described in the chapter about Sintashta metallurgy. But these slags were not connected with the copper sandstones.

Therefore the absence of information on ore smelting during the MBA in the area of rich deposits of Orenburg is surprising. Analyzing this problem E.N. Chernykh wrote about the decay of exploitation of the copper sandstones by this epoch and the subsequent renewal of this exploitation in the Timber-Grave time (Chernykh 2007, p. 70). This conclusion was based on a wrong operation: on the basis of considerable morphological similarity of Pit-Grave and Poltavka metal their integration in the united Pit-Grave-Poltavka metallurgical center was done. Further at the comparison of maps of distribution of the MP copper (connected with the copper sandstones) and arsenic bronzes during the EBA and MBA periods all Pit-Grave-Poltavka metal has been considered together within the EBA map and has not been placed on the MBA map (Chernykh 2007, p. 48, fig. 4.9 4.10). Just from this the impression of the decay of these ores exploitation follows.

However, in reality the Poltavka metallurgy chronologically existed in some areas to the beginning of the MBA II, in the others to the beginning of the LBA. Its morphological similarity with the Pit-Grave metallurgy really complicates the distinguishing of these complexes, but it does not allow us to say that during this period the production disappeared. In the Southern Cisurals there are blameless complexes of this time (Tkachev 2007, p. 228-257) and the population for certain continued to exploit this type of deposits.

The problem is only in absence of data on direct smelting of ore. But, similarly, we have no sample of Pit-Grave slag that does not allow a question to be raised of lack of smelting during this period. The fact is that the ore smelting could be carried out only on settlements[1] which for the EBA and MBA periods of this zone are studied extremely poorly. Partly it is connected with features of this cultural model when large settlements were absent, and small ones were extremely rare, but partly also with the traditions of archaeological science of the region where many years the main attention concentrated on studies of burial monuments.

Against this background the question of smelting technologies of all this EBA-MBA period remains open, but the opinion of E.N. Chernykh about the exploitation of deposits in the copper sandstones is the truest, in my opinion. If metallurgists mined and smelted the pure ores with minimum quantity of rock (as it is recorded by the described above archaic type of smelting of Abashevo culture), it is not so simple to find

[1] In this case it is not important whether they were usual settlements or settlements near mines.

traces of this production. This variant seems to be the most probable, but it is impossible to argue this opinion by facts today.

The situation changed since the beginning of the LBA for which the settlements of Timber-Grave culture are found, and many of them have traces of metallurgical production. Only in the Western (Cisural) Orenburg region the traces of metallurgical production are known on 15 settlements (Khalyapina 2000, p. 85). And in this area (owing to the already noted tradition of studies) the number of excavated settlements is not too great. Only 12 settlements of the 45 known have been partly excavated (Khalyapina 2000, p. 84). And it is incomparable with the research situation, for example, in the Transurals. Therefore, the metallurgical production was practiced on the majority of settlements of this zone during this period.

In the neighboring areas of the Volga region probably owing to poorer ore base, the metallurgical production is presented not so well, but on a number of sites it is nevertheless revealed. Certainly, in comparison with the previous period the total productions increased, but the cultural model changed, as well as the number of studied sites that allows us to tell, eventually, something more certain about the nature of production during this period.

Sites included in the research

The studied sampling includes (and some published analyses have been taken into account) slag and ore materials from 12 objects (Fig. 9-1.). Almost all of them are situated in the steppe zone. Exceptions are settlements of the Volga region in the southern part of the forest-steppes: Shigonskoye II, Popovo Ozero and Lipovii Ovrag.

The settlement of Shigonskoye II has been investigated in 1982 by O.V. Kuzmina, and materials of the early Timber-Grave time have been found. Possibly, it is the earliest site in this sampling. Excavations of the Popovo Ozero settlement have been realized by Yu.I. Kolev in 1984; on the settlement the Timber-Grave and Suskan-Lebyazhka ceramics have been revealed. I have touched upon some problems of the Suskan-Lebyazhka cultural type, its rather early position since the end of the early Timber-Grave time is not excluded, although now it is very debatable problem (Grigoriev 1999, p. 257; 2002, p. 258). But for this work it is important for us that this type belongs to the period after the early Timber-Grave of Pokrovka type. Local Timber-Grave complexes were, apparently, a basis of the Suskan-Lebyazhka type formation, but Fyodorovka-Mezhovka impulses from the Transurals made influence on its formation (Kolev *et al.* 1995; Grigoriev 1999, p. 254). The settlement of Lipovii Ovrag belongs to Timber-Grave culture (Agapov, Ivanov 1989).

The settlement of Mikhaylo-Ovsyanka is very interesting. The settlement is situated near the ancient mines. The copper mineralization of hydrothermal origins is connected with fine-crystalline limestone and is presented by copper carbonates and oxides: malachite, azurite, and cuprite. On the settlement the remains of four dwellings and mine up to 4-5m in depth are investigated. The remains of galleries and wooden supports are recorded. The site belongs to the Timber-Grave culture (Matveeva 1979; Gorbunov 1992, p. 78, 79, Matveeva *et al.* 2004, p. 70, 71).

The easternmost site of the Volga region is the settlement of *Syezh*'ye on which the materials of Timber-Grave culture are found. It is the nearest site to the Cisural area, and as we will see further, its slags are more comparable to this area's, than to the Volga region's materials.

The westernmost in the group of Orenburg settlements is Kuzminkovskoye, excavated by O.I. Porokhova in 1986. The settlement is well stratified, with two clearly distinguished layers: the early and late. The early layer contains materials of the Sintashta-Early Alakul type. Materials of the Timber-Grave-Alakul period on the settlement are absent. The late layer is presented by ceramics comparable with Fyodorovka, Cherkaskul, Mezhovka, Sargari and Ivanovka-Khvalynsk (Morgunova *et al.* 2001)[2]. The metallurgical remains are connected probably with the late complex.

In the northern part of the area, near the Bashkirian Cisurals, the settlements of Ivanovskoye and Tokskoye are situated. On the well investigated Ivanovskoye settlement the upper layer (from where the slag occurs) contains Abashevo and Timber-Grave materials. As well as in the majority of sites of the Orenburg area, also some Transural Alakul features are noted in the ceramics. Four pits with slag, pieces of ore, fragments of slagged ceramics which were connected with the Timber-Grave time are found (Morgunova, Porokhova 1989, p. 169; Gorbunov 1992, p. 75). Excavations on the Tokskoye settlement have been carried out by N.L. Morgunova and O.I. Porokhova in 1978 and 1990. On the settlement a small area has been excavated, with ceramics of the Timber-Grave culture and four vessels with the Alakul features (Morgunova, Porokhova 1989, p. 163).

To the south a very important metallurgical center of the Timber-Grave time, the Kargaly mines, is located. It is the most large-scale deposit of this zone. The ore presented by malachite and azurite is situated in sedimentary grey-colored sandstones and marls. The ore is widespread in the area of about 500km^2. The scales of the production here were huge. On the surface 32,000-34,000 of mines are present, although I believe that the most part of the mining here has to be dated to the 18-19th centuries AD. Contrary to this E.N. Chernykh thinks that here in the Bronze Age 2.5-5 million tons of ore had been extracted that allowed to smelt 55-60 or 100-120 thousand tons of copper. The copper from Kargaly was distributed in Eastern Europe on the area of 1 million km^2. Judging from the late written sources, in the ancient time the ore containing above 10% copper was used here (Chernykh 2002, p. 88, 91, 94, 95; Kargaly 2002, p. 10, 23-38, 45, 46).

On the Kargaly ore field about 20 settlements of the Bronze Age are known. On the majority of them cultural deposits are rather poor, but it is necessary to take into account that owing to the difficulty of searching the true number of the Bronze Age settlements in this area is unknown (Chernykh 2002, p. 95; Kargaly 2002, p. 58-75). The largest settlement, excavated by Chernykh, is Gorny.

On the settlement 880m^2 have been excavated. The quantity of finds of slag, copper, bones and ceramics here is extremely great (Chernykh 2002, p. 97). Three building phases have been revealed, with several sub-phases. The earliest is the horizon with so-called dwellings-burrows or pits. Actually, they are very deep shelters with the area of 1.5-4m^2 (Kargaly 2002a, p. 26-49). In the later phase capital constructions with large dwellings and the area of 115-120 m^2 appeared there (Kargaly 2002a, p. 71).

The calibrated dates of the settlement fall in the 17-15th (14th) centuries BC (Chernykh *et al.* 1999, p. 98; 2002, p. 104; Kargaly 2002, p. 124). It belongs to the Timber-Grave culture. At the same time, it would be desirable to pay attention to the presence on the settlement of vessels having Fyodorovka-Mezhovka features, and, they occurred since the early period (phase A) and within the phase B (see Lunkov 2004, fig. 1.7.1,2,10; 1.11.11).

I have investigated only ore from these mines, but a lot of slag has been analyzed by S. Rovira (2004).

To the south of the Kargaly mines, at the Ural River the settlements of Pokrovskoe, Rodnikovskoye and Nizhnyaya Pavlovka are situated. The Pokrovskoe settlement has a single-layer and contains Timber-Grave-Alakul ceramics. Two dwellings and economic constructions have been excavated (Gorbunov 1992, p. 75). The Rodnikovskoye settlement has been investigated by O.I. Porokhova in 1982-1983. The settlement contains the ceramics of Abashevo, Timber-Grave-Alakul, Cherkaskul and Sargari types (Gorbunov 1992,

2 In my opinion, the early complex cannot be considered as proper Sintashta. It is the poorly divided late Sintashta material of early Alakul or Pokrovka shape.

p. 75). The Nizhnyaya Pavlovka settlement has been investigated by L.N. Morgunova in 1989 and belongs to the Timber-Grave culture.

Thus, in the Volga zone the earliest, relating to the early Timber-Grave time, is the settlement of Shigonskoye II. Materials of settlements the Lipovii Ovrag, Mikhaylo-Ovsyanka and *Syezh*'ye belong to the Timber-Grave culture. Probably, the Timber-Grave traditions of metallurgy are reflected also by materials of the settlement of Popovo Ozero, although the eastern Fyodorovka-Mezhovka impulses are not excluded here.

In the Orenburg zone the settlement of Pokrovka containing ceramics of the Timber-Grave-Alakul type, probably, shows the earliest traditions. Very often this type reflects not contacts between the Timber-Grave and Alakul populations in the developed phase, but the early formative phase of the both Timber-Grave and Alakul complexes on the Sintashta basis when the following clearer cultural stereotypes were not yet created. This means it can be rather early materials in the Timber-Grave series, although already not the materials of the Pokrovka phase which was partially synchronous in Transurals to Sintashta culture, but, those contemporary to Petrovka. The settlements of Tokskoye, Ivanovskoye and Nizhnyaya Pavlovka are similar to this series, and certainly belong to the Timber-Grave culture; although in the analysis it is necessary to consider the presence of Abashevo ceramics on the Ivanovskoye settlement. Slags from Gorny which will be discussed, belong to this time too, although there are impurities of the Fyodorovka-Mezhovka materials. It is more difficult to date the slag from the settlement of Rodnikovskoye where early materials of Abashevo and Timber-Grave-Alakul types which we can be considered as materials of the beginning of the LBA, and later materials of the Cherkaskul and Sargari types are present. It should be noted that, as a rule, the archeologists working in the steppe, rather free use the term "Cherkaskul ceramics". They are not those materials which characterize the Cherkaskul ceramics of the forest zone in the Transurals. Besides, the presence of applied cordons on the ware of Fyodorovka settlement and Cherkaskul-Mezhovka sites is very frequent forces to consider them within the Final Bronze Age or the "Cordoned chronological horizon". Without going deep in the analysis of this concrete settlement, it should be noted that anyway it belongs to either the late Timber-Grave or post-Timber-Grave time. This means the studied slag can be dated to either the time of the beginning of the LBA or of the end of the LBA – the beginnings of the Final Bronze Age[3]. And in the latter case this slag can bear traces of eastern influences. The Kuzminkovskoye settlement is probably the latest in the considered series as belongs to the late Timber-Grave or post-Timber-Grave time too, and reflects already unconditional eastern influences.

Metallurgical complexes

Identification of metallurgical furnaces as it has been discussed in the analysis of Sintashta culture materials is not a simple task. Very often these furnaces are presented by rather simple roundish structures and if their walls did not remain that is a typical situation, in the course of excavations they can be fixed as slightly burnt hearths. The situation becomes simpler only in case of presence of metallurgical slag in such hearths, but more often it was removed from there. Therefore the number of reliably fixed furnaces in this region is not too great.

In the Volga region a reliable metallurgical complex is investigated on the Mikhaylo-Ovsyanka settlement (Matveeva *et al.* 2004; Gorashuk, Kolev 2004; Kolev 2010; Garner 2010). This complex perfectly illustrates the entire cycle of metallurgical production from ore mining to metalworking. For our subject the operations revealed here on preparation of ore for smelting and smelting process itself are most important. Places for primary crushing of ore are located near mines, but its final grinding was made near the smelting complexes.

3 In principle, the Final Bronze Age is a part of the LBA, and here this not quite correct term is intentionally used to designate more precisely the probable dating of slag.

Hammers, pestles and even bone tools for crushing ore to the powdery state[4] (Fig. 9-2..3-9) were used for this purpose. And, the care of all operations indicates their unconditional technological necessity. Discussing the experimental works, we have mentioned that ore should be crushed just to this state. It is also remarkable that the tools for metalworking have been found here too. It specifies that during this period the division of labor between metallurgists and smiths inside the metallurgical settlements did not exist, although the territorial division, of course, already existed. This means, there were, as well as earlier, regions where only metalworking was practiced.

The excavators suppose that construction 16 was used for smelting operations because a lot of slag is found in it (Matveeva *et al.* 2004, p. 76, fig. 2) but, unfortunately, it has been very poorly described, and from the drawings it is possible to understand only that this is an oval pit about 1.3 m in length.

A little more certain complex has been studied in construction 1 (Fig. 9-2.1). In this construction a lot of slag, a small pit with ore and a burnt extended hearth with the size of 115×60cm were revealed. Possibly, it was a furnace bottom.

An interesting metallurgical furnace (construction 26) is investigated by the section on the edge of the area of excavation (Fig. 9-2.2). It is deepened installation, 12-14cm in depth and about 50cm long which has continuation in the form of one more deepened on 15cm part with the width of 30cm. It is remarkable that the bottom of both parts was burnt. It is supposed that the crucibles with ore were put in the most deepened part (Kolev 2010, S.8, Abb. 8.2).

On the settlement of Mikhaylo-Ovsyanka II which has excavated by G.I.Matveeva[5], two shallow pits with ashes and burnt clay near 55 cm in diameter have been revealed which, probably, were the bottoms of furnaces. Nearby an oval shallow pit, 1.3 m in length and 0.4 m in width, with bones and slag is found.

Thus, despite the scarcity of the evidence, we may discuss two possible types of furnaces: small round furnaces about 55 cm in diameter and more extended structures 0.8-1.3m in length, and the shortest of these structures has a more deep part. As in smelting on this settlement the oxidized ores were used, the first type of designs seems to be less probable for the metallurgical production although it could be quite used for metalworking. The matter is that in the furnaces of small diameter it is not difficult to create a high temperature, but it is difficult to reduce copper from the oxidized ore. This means that, in principle it is possible, but copper losses in the form of cuprite would be very high. But in the studied slags the content of copper is 5.46 and 0.81% that is declared as a sign of inefficient smelting and it is even supposed the subsequent re-melting of this slag in a crucible (Garner 2010, Tab. 1, S. 18). But in reality, we deal with the final product and in many slags of this period incomparably higher losses of copper are known. Even in the Sintashta slags where they were insignificant, the content of copper is 1-2%, but there apart from oxides, secondary sulfides were often used in the smelting, and the carbon monoxide generation by means of blasting from wells was applied. Therefore we cannot reject completely the use of these small furnaces, probably, they were somehow combined with smelting in crucibles, it is difficult to tell. But smelting in longer constructions is more probable. The bottom of these constructions is burnt along the entire length that specifies that the high temperatures were everywhere. The presence of the deeper part allowed ore to be places exactly here. And if the tuyere was inserted in the other end, this distance was more than enough for creation of the reducing atmosphere.

4 Bone tools were used on the final stage for ore grinding by a rib of animals on skin, and, the operation was made in water. It is clarified as from microtraces on tools, and regular distribution of an oxide pellicle on surfaces of these tools (Gorashuk, Kolev 2004, p. 93).

5 I thank Yu.I. Kolev for provided information.

It is confirmed by discovery of a long metallurgical "hearth" with the burnt filling and finds of copper prills on the settlement of Lipovii Ovrag (Agapov, Ivanov 1989, p. 136) where slag of ore smelting is found too, and, this slag shows the reducing smelting atmosphere, despite rather high temperatures.

It is less possible to speak definitely about metallurgical furnaces of the settlement of Kibit I (Kuznetsov *et al.* 2005)[6]. Here metallurgical constructions 1 and 2 have been revealed; near and inside those the pieces of ore in sandstone lay, but slags have not been nearby found. These are round structures 50-70cm in diameter and 20-40cm in depth. Next to one of them an area of burnt clay is investigated (Fig. 9-3.). In principle, such constructions could be used for ore smelting, but in case of smelting of the oxidized ore from sandstones the problems with considerable losses of metal would be appear because of the slag oxidation. However, in many other areas metallurgists reconciled with these problems. Unfortunately, in this case it is now impossible to solve this question as slag on the settlement is not revealed.

On settlements of the Orenburg area a series of hearths, some with stone lining, is investigated, but whether they were metallurgical furnaces is unclearly. Two stone "baths" attached to a well with a stone facing are most remarkable on the Tokskoye settlement. Next to them a lot of ore, slag and pieces of partly fused sandstone have been found. It is supposed, however, that these structures served for ore washing (Khalyapina 2000, p. 85, 86). But the principle of these structures is similar to the Sintashta furnaces attached to wells.

Metallurgical complexes have been investigated also in such important center, as the settlement of Gorny on the Kargaly mines. As it has been already noted above, on this settlement three phases of use have been found. Already in layers of the early phase (A) there is a significant amount of ore and slag. Nevertheless, metallurgical furnaces relating to this phase are not revealed.

In the later phase (B-1) two complexes are investigated (Kargaly 2002a, p. 71). In the complex 1 a furnace made of stony plates put on the edge is excavated, with the size of 140-160cm. It was adjoined by a pit with ashes, crushed bones and slag. Probably, here near the furnace the slag was broken to extract small copper ingots. Then the copper was re-melted in this furnace (Kargaly 2002a, p. 72-76).

Nearby a smelting court with a significant amount of slag has been investigated. Within its borders a clay platform is revealed with the size of 1.8-2×1.2×0.3-0.35m. A furnace on the platform has not been identified; therefore it is supposed that the smelting was carried out in crucibles placed in charcoal heaps. Ore in crucibles was placed by turn together with charcoal layers. Many bones, slag and copper have been nearby found. Next to it the ore court (13-15m^2) was situated, where preparation of ore for smelting and its storage was carried out. A deep trench for waste is also nearby found. Near a small round hearth (No. 5) about 55 cm in diameter, with stone walls is found, but slag in the furnace was absent, and it is considered as a magic construction (Chernykh 1997, p. 37, 38, 61; Chernykh *et al.* 1999, p. 83; Kargaly 2002a, p. 73-83).

The second complex (Fig. 9-4.) contains the hearth No. 6 which functioned long enough. It had a complicated design. Initially the pit with the diameter of 180-200cm had been dug, filled then with clay. Its surface is partly burnt. Any construction is not recorded. It has been supposed that it was an open fire for smelting in crucibles placed in charcoal heaps. Nearby smaller hearths have been found. One of them has a bottom covered with small stone plates. The others are seen as usual burnt places. Constructions are not found too. The sizes of these hearths vary between 30 and 70 cm. By presence of slag and slagged surfaces it has been determined that some hearths (No. 7, 10) were used for ore smelting, but it is supposed that they functioned a short period. Two more furnaces used for metal melting are found. One of them is presented by burnt flat round and shallow pit (70×80cm) with charcoal and fragments of slagged melting crucibles. Another is an

[6] I am deeply grateful to P.F. Kuznetsov who put at my disposal the unpublished report and suggested to use in this publication the illustrations from it.

accumulation of burned pieces of sandstone with burned clay. It, probably, was used to heat casting molds (Kargaly 2002a, p. 98-101).

One more type of constructions should be noted. These are long trenches (No. 19, 23, 93, 106) which have at the end either a small bulge or a larger roundish part. Their building had preceded the early floor of the smelting court, and they are regarded as magic constructions of the phallic form (Kargaly 2002a, p. 84-86, 102-106). However their identity to Sintashta furnaces with flue allows us to doubt in this supposition. Probably, it is necessary to look for more rational explanation. It is not excluded that they were also some types of either furnace or hearth.

During the next period (sub-phase B-2) two hearths with a diameter of 70-80cm is noted, but their connection with casting operations is only definitely determined, and for the final period (sub-phase B-3) metallurgical installations are not revealed at all (Kargaly 2002a, p. 114, 115, 120-123).

Thus, the smelting constructions have been revealed only for two sub-phases (B-2,3). And, the crucible smelting in charcoal heaps with blasting into crucible through a charcoal layer is supposed. This situation demands a short discussion. The matter is that the charcoal, unlike firewood, badly burns in the open fire. In the furnace the air access through it is provided by the air pressure. In case of the blasting on the charcoal heap the air should be stopped by the upper layer. It could not allow to reach the high temperatures (and as we will see further, on Gorny very high smelting temperatures were reached). We have no bases to reject such an opportunity completely[7]. But as a variant we can assume a crucible smelting also in small furnaces (hearths) found on the settlement.

In principle, as it has been already discussed, it is a difficult analytical task to prove the crucible smelting. But in this case the huge number of melting bowls (457) attracts the attention. Their volumes are different. Bowls of the first group have volumes between 680 and 1750 cm^3. It is supposed that they were used for metal melting (Lunkov 2004, p. 70-75). But a part from them could quite serve as smelting crucibles for ores, which is also supposed for this settlement.

However, there are some problems also with the crucible smelting of the oxidized ore typical of the Kargaly mines. It was not incidentally, the organizers of experimental works on copper smelting on Kargaly even did not try to examine similar process, and conducted the smelting directly in the furnace, but, as it often happens with the oxidized ore, these experiments were not quite successful (Rovira, App 2004). As we have discussed in the description of our experimental works, it is extremely difficult to extract copper from the oxidized ore in a crucible even if blasting is carried out through a charcoal layer. In this case only carbon dioxide has time to be created, and reduction of copper does not happen. In this way it is possible to produce either the mass of cuprite or crucible charge becomes covered by a slag crust which protects ore from further smelting. I do not mean in this case the smelting of pure malachite, but the smelting of oxidized ores containing essential impurity of rocks which needs to be molten. Namely such ores were used on Kargaly. But smelting of this ore directly in furnaces as has been shown by our experiments, as well as by the experiments of Rovira and App is low effective too, with the extraction of 5-7% of copper containing in ore. Probably, ancient metallurgists could increase this per cent of extraction, but anyway the losses were great.

[7] In principle, the charcoal heaps could be small, and blasting with use of several tuyeres very intensive. Something similar was possible for incidental smelting operations, but it is inexplicable for a constantly operating large metallurgical complex: metallurgists had to understand perfectly that the construction of small walls round the hearth sharply improved a situation and increased efficiency of smelting.

Analyzed materials

The studied sampling includes 11 samples of the ore, one copper ingot, one fragment of the furnace lining, three samples of flux and 85 samples of slag from which some samples have been identified by the analyses as slagged furnace lining. In total from these sites 13 visual definitions of ore, 83 mineralogical analyses of slag by optical microscope and 100 spectral analyses of clay lining, metal, slag and ore have been done. Besides, the data of analyses of slag and ore from the settlements of Gorny and Mikhaylo-Ovsyanka have been considered.

The studied ore was connected with the sandstone rock. All ores in the sampling are oxidized, except for sample 1338 (secondary sulfide) from the Rodnikovskoye settlement. In principle, the oxidized ore contains sometimes also the sulfide inclusions which are badly visible without a special analysis, but anyway the basic ore was oxidized.

Form of the slag

The majority of samples (Tab. 9-5.) are presented by heavy shapeless pieces of the porous slag having fused surfaces and in some instances impressions of the charcoal. Some samples (No. 335 from Lipovii Ovrag and 333 from Shigonskoye II) have the roundish bottom surface specifying that this slag was created in some hollow. The bottom surface is fine-grained; some sandy material (soil or furnace lining) is adhered to it. Therefore, there is an impression that this slag was poured in the hollow, but such form could be formed also in the furnace.

On the settlement of Shigonskoye II six samples (No. 325-330) are presented by black dense flat slag. Its top surface is rough, with impressions (including those of charcoal), the second is smooth, with metal luster. Possibly, this slag was formed on the copper ingot; this means its viscosity was lower than in the others. It is similar with the Sintashta slags, but, nevertheless, its viscosity was not so low to form typical of the Sintashta slag flat cakes with thick edges embracing a copper ingot on the sides. Therefore, in the Sintashta series similar slag has been related, with reservations, to the shapeless. One sample (330) is more porous and has brownish shade.

Similar to Sintashta roundish cakes with the thick edge are revealed only on the Mikhaylo-Ovsyanka settlement (Fig. 9-6.). They are dark gray, almost black. The top part is smooth and vitreous, bottom part is porous, with metal luster (Kolev 2010, S. 15). This form is explained by very low viscosity of this slag, but the degree of viscosity was, nevertheless, higher than in Sintashta.

On the settlements of Pokrovskoe and Rodnikovskoye the most part of slags are heavy and shapeless. But there are some individual forms: on Pokrovskoe it is a flat dense slag crust (No. 1327) and easy porous pieces of slag similar to ceramic slag (No. 1328-1330), and on Rodnikovskoye – the flat caked conglomerate consisting of small oxidized particles of copper and oxidized sandstone ore (No. 1334), as a matter of fact, it is unsmelted ore, a slagged lining of the furnace (No. 1335), a copper ingot with considerable inclusions of slag (No. 1343), dense slag crusts on the clay lining (No. 1353, 1354), and pieces of Chogray ferriferous sandstone (No. 1339-1341). The last are remarkable because in the Transurals they are typical finds in metallurgical complexes of Sintashta culture.

At last, on the Nizhnyaya Pavlovka settlement only sample No. 1286 belongs to the standard shapeless slags. Other samples (No. 1287-1290) are presented by easy porous pieces of slag similar to ceramic slags.

It is impossible to determine form of slag from the settlement of Gorny as almost all slag was crushed. Only one accumulation is found, a result of unsuccessful smelting, presented by small shapeless pieces

(Kuzminykh 2004, p. 101). Probably, other slags before crushing were the same, but it is difficult to judge surely from the unsuccessful smelting.

Thus, the most samples are presented by heavy shapeless slag. Slag crusts on clay lining can be formed at any type of smelting, but they specify that the smelting was carried out in furnaces, instead of in crucibles. The same can be told about the light slags. Their prevalence on the Nizhnyaya Pavlovka settlement, owing to insignificance of the sampling, does not allow us yet to speak about some specifics of metallurgy of this settlement. Of course, it is also necessary to pay attention to the presence of flat slag on the settlement of Shigonskoye II. It points to connection with the earlier Sintashta tradition, and it is not contrary to relatively early chronological position of this settlement.

Chemical composition of slag

Coefficients of basicity of slag and ore

For understanding of characters of slag and smelting technologies in the Orenburg area it is important to understand the extreme chemical composition of the Orenburg ore. We have done only one chemical analysis of ore from the Kargaly mines and some analyses of slag (Tab. 9-7.; Tab. 9-8.). In addition to this, Rovira and Garner's data have been used (Rovira 1999; Garner 2010). First of all, coefficients of basicity of this slag reflecting a ratio of acid and basic oxides have been calculated. In Sintashta-Abashevo slag this coefficient varied within 0.1-2.52. The average coefficient for ore was 0.82, and for slag did 1.4. For the Kargaly ore this coefficient is 0.41, i.e. the ore was ultra-acid, and for slag it fluctuated within 0.25-2.15, with the average value 0.5. For the Mikhaylo-Ovsyanka ore the average coefficient is 0.51, and for slag 0.96. Respectively, the most part of slag is ultra-acid or acid.

It influenced the slag crystallization. The acid and ultra-acid slags crystallize badly, therefore it is impossible to see here large polygonal crystals, and it does not indicate the high speed of slag cooling, although it mark the high speed of its solidification. But the explanation for it is in the chemical composition of slag, instead of in a design of furnaces or slag tapping. It was in principle impossible to tap such slag from a furnace or crucible.

It is rather difficult to smelt the ore of such composition as it causes the high slag viscosity. And, as we see in the slag, an essential decrease in this viscosity due to changing the furnace charge by fluxes with basic composition did not occur. Small shift towards the basicity can be explained also by a careful sorting of ore.

Slag viscosity

The viscosity of slag has been calculated for a conditional temperature of 1400 °C according to the already described in the Introduction formula (Tab. 9-9.). It is necessary to remind that in the Sintashta slags the viscosity fluctuates between 0 and 5.94 Pa·s, with the average value of 2.82 Pa·s, and for the Cisural slags of this time between 2.18 and 9.91 Pa·s (the average value is 5.88 Pa·s) (Tab. 5-19.). For slags of the Volga and Orenburg regions the average value of this coefficient is 12.89 Pa·s. But the viscosity fluctuates violently as in slags of particular sites as in samples inside the sampling of individual settlements. It points to variability of furnace charge. So, on the settlement of Gorny the viscosity fluctuated from 1.83 to 47 Pa·s with the average value of 15.37 Pa·s, and only one sample of 22 analyzed has shown the viscosity getting into limits of the Sintashta slag.

The viscosity of slag from the settlement of Mikhaylo-Ovsyanka is also very high (2.9 and 10.42 Pa·s). It is much lower than the viscosity calculated for ore of this settlement, but nevertheless is too high for the formation of the flat slag cakes found on this settlement. Therefore, some components which have not been included in these calculations had to be used in the furnace charge. Or the analyzed sampling is insufficient and incorrect (we have no evidence that it was just the analysis of flat slags were made).

On the Orenburg settlements, except for Gorny, the average viscosity is 7.63 Pa·s. But on Ivanovskoye, Kuzminkovskoye and Pokrovskoe settlements it is relatively lower and varies within the limits of 3.78-6.09 Pa·s, and on Rodnikovskoye – within the limits of 4.97-16.4 Pa·s, with the average value of 10.44 Pa·s. Thus, the viscosity of the Orenburg slags considerably exceeds the viscosity of Sintashta slag, although the viscosity of slag from the settlements of Ivanovskoye, Kuzminkovskoye and Pokrovskoe is still comparable with the most viscous Sintashta slags. But the viscosity of slag from Rodnikovskoye and especially from Gorny is too high for normal separation of metal from slag. It must be kept in mind that this calculated viscosity does not quite correspond to the real one. For example, as we will see below, in ore of some settlements of the Orenburg region (Ivanovskoye, Kuzminkovskoye, and a part of slags from Rodnikovskoye) a proportion of sulfide minerals was high; these minerals melt at rather low temperatures and, respectively, their melting promotes the decrease in viscosity. Therefore, in general, on these settlements it was possible to create rather admissible slag compound. Metallurgists of the settlement of Gorny were completely devoid of such possibility, and in the chemical analyses we see no attempt to improve the situation by the use of fluxes.

Mineralogy of slag

In principle, the form of slag described above is rather well explained by its microstructures revealed by the mineralogical analysis carried out by means of optical microscope. Thus, mineralogical groups of slag in this case have distinctly expressed territorial connection. In this sampling the slags of the Volga and Orenburg regions are accurately divided from each other, and in the Volga region the differences of the earliest slag of the settlement of Shigonskoye II from slag of other settlements have been identified. Therefore the description of slag ordered according to the mineralogical groups, applied in this work, in general, corresponds to the description by the territorial principle. And, the mineralogy of slag has some differences from that in the Transurals, but here the same structure of mineralogical groups is saved, with discussion of available differences.

1st mineralogical group

In the Transural collections this group has been characterized by the slag smelted from ore in the ultrabasic serpentinized rocks. In the Volga and Orenburg sampling this group is recorded only on the settlement of Shigonskoye II and one sample (No. 1327) on the settlement of Pokrovskoe. Taking into account that this type of smelting genetically goes back to the Sintashta-Abashevo metallurgy, the presence of slags of this group at the earliest settlement in this sampling is quite logical.

In the majority of slag samples the polygonal, elongated prismatic and elongated skeletal crystals of olivine formed well (Fig. 9-I.1). In some samples even the borders between individual grains are poorly distinguishable. Wüstite presented usually by large dendrites with fused surface was formed before the olivines. In some instances these dendrites are very long. Therefore, they were formed already in the area of furnace bottom when slag leaked down and did not move any more. In some cases the large fused octahedra and smaller dendrites of magnetite occur.

Quartz grains are occasionally present, but quartz for this slag is not typical. Usually it is solute in the smelt and turns into fayalite. In sample 327 a large serpentine grain with cuprite inclusions in cracks is recorded. Chromite is almost absent. Only in sample 327 and in a sample from the Pokrovskoe settlement it is well presented. It is surrounded by a thick magnetite border, and its associations with the grains similar to serpentine are found in some cases. Possibly, the rock was, mainly, of the basic compound with inclusions of silicate components. Thus, it is identical to similar Sintashta group, but in the last the chromite was better presented acting even as a faultless marker of this group. In this case the chromite, although is present, but is much rarer. Possibly, it is explained by peculiarities of this concrete field in the basic rocks. In the case of the Pokrovskoe settlement where the main massif of ore was connected with sandstones, on the basis of one sample it is hardly true to speak about a possibility of exploitation of one more deposit. Most likely, it was caused by existence in sandstone deposits of some inclusions with a specific mineralization especially as there is an impurity of small quartz fragments in this sample.

Ore minerals are presented in some cases by malachite, but more often by copper sulfide forming grains, solidified smelt and prills. Cuprite replaces often the malachite. Sometimes cuprite is presented by small prills round a sulfide grain, respectively, at the formation cuprite melted. In some instances the sulfide surrounds pyrite grains. Round the cuprite and copper the thin border of magnetite can be formed. All this can reflect chalcopyrite and bornite smelting. Small grains of chalcopyrite are revealed in the slag.

Copper is presented by small prills surrounded sometimes with a border of sulfide or cuprite. Sometimes together with cuprite it replaces the sulfide grains. The amount of copper (as, by the way, also ores) in slag is very insignificant.

All samples contain the reduced, often molten particles of iron. Their fused surface, however, does not testify in favor of temperatures of iron melting, and reflects only its reduction from the molten particles and prills of wüstite. There is another variant of explanation, possible for all cases when in the LBA slag the molten iron is found. The matter is that the pure iron melts at a temperature of 1534 °C, but in case of the reducing atmosphere and abundance of charcoal, it can be enriched with carbon. Iron with the carbon content of 4.3% melts already at a temperature of 1147 °C (Amborn 1976, S. 15; Tylecote 1980a, p. 209; Childs 1996, p. 299). Therefore the molten iron in all cases indicates the reducing atmosphere, but not so surely is a testimony of high temperatures.

Thus, it is rather standard slag, characteristic of the Sintashta-Abashevo metallurgy, and all told concerning the smelting technology of these earlier complexes is also quite applicable to the metallurgy of Shigonskoye II. The differences are observed only in continuation of dynamics in the ore base transformation which had been started earlier. If in the Sintashta period the oxidized ore and secondary sulfides were used in smelting, in the Abashevo smelting of this type in the Cisural area the share of secondary sulfides increased. Here this tendency proceeds in the form of the further growth of this share and the beginning of additions of primary sulfides to the furnace charge: chalcopyrite and bornite. Another difference is that there is no arsenic impurity in this slag (Tab. 9-13.).

Two samples in which the fayalite is not crystallized differ slightly from the described series. It is sample 334, oversaturated with unmelted magnetite octahedra that resulted in higher viscosity and large losses of copper. Besides, in this slag more oxidizing atmosphere is fixed that is marked by the presence of delafossite. These features allow us to relate this sample to the 4th mineralogical group. It should be noted that this group will be described below in detail, and in this region it was connected, mainly, with the sandstone ore. In sample 331 the fayalite crystallization has not been detected too, but there are also no signs of the oxidizing atmosphere. It did not lead to increase in viscosity and metal losses. Probably, the smelting was long, and the temperatures high. Most likely, the slag belongs to the basic group, but there were no components for the fayalite crystallization.

In general, the temperatures in furnace could even reach 1350 ºC, judging from smelted cuprite and wüstite. Then there was a gradual decrease in temperature with slight reducing blasting. Mainly, the secondary sulfide ores were smelted. The iron component came probably from rock; it was not a result of flux additions, although there is no full confidence of it.

2nd mineralogical group

The 2nd mineralogical group includes samples from the quartz rock, smelted in the reducing conditions. In the Volga region only one sample related to this mineralogical group from the settlement of Lipovii Ovrag is recorded (sample 335). The slag contains a lot (up to 40%) of quartz grains of the average sizes. The ore from quartz rocks was obviously smelted. In quartz grains single impregnations of copper are found that testifies that the mineralization was holded by quartz. Small and rare fayalite crystallization (needles, nuclei) is seen round these grains in glass matrix. The weak crystallization of this mineral can be explained by both shortage of iron components and very high speed of slag cooling. Unfortunately, the absence of chemical analyses of the slag glass does not allow us to determine it definitely. In case of too acid silicate slag its viscosity would be very high that would result in considerable losses of metal in slag. However the analysis has identified only one copper prill surrounded with a cuprite border. It would be possible to reduce the viscosity also by the increase of temperature, but for this purpose it was required to intensify blasting that would result in the oxidizing atmosphere. And the atmosphere of this smelting was reducing: in slag some molten particles of wüstite are revealed, there are no magnetite and cuprite.

The smelting temperatures were probably about 1300 ºC or slightly higher. But the duration of the smelting was long that allowed ore to be completely smelted and metal to be separated.

This mineralogical group is well presented also in the Orenburg Cisural area. However from the sample described above, and from samples in the Transurals it differs by that was smelted from ores in the copper sandstones, it was not a result of smelting ore from quartz veins.

Here this group is the base of slag on the Ivanovskoye and Kuzminkovskoye settlements and to a lesser extent it is present on the settlements of Pokrovskoe, Rodnikovskoye and Tokskoye (Tab. 9-10.). The overwhelming number of slags is acid and ultra-acid (Tab. 9-11.).

The connection of ore with deposits in copper sandstones is visible rather clearly. In all samples the quartz grains and fragments of sandstone with characteristic laminated granular structure are found. Sometimes grains of quartz in crossed nicols show similar structure or quartz is present there in the form of small roundish grains. Ore inclusions are very often present between the grains of sandstone, being its "cement" (Fig. 9-I.2,3). In samples of this mineralogical group from the Pokrovskoe settlement the sandstone structures have not been revealed, but these are single samples, and, most likely, this ore was connected with sandstones too, especially as for slags of the 4th mineralogical group of this settlement, differing only by more oxidizing atmosphere, this fact is established.

Malachite is presented by prills and grains, it is the main ore (Fig. 9-I.4,5). In some instances it is replaced with cuprite. The most part of malachite was present in ore initially although in sample 1304-1 from the Ivanovskoye settlement a secondary formation of malachite in pores is noted, that happened after the slag solidification. As an exception in individual slags azurite veins (sample 1304) and a round grain of malachite and azurite (sample 1306-1) are recorded. Sometimes small grains (sometimes fused) of chrysocolla have been detected too.

But the slag contains also many inclusions of the sulfide ores. Covellite is present in all samples (Fig. 9-I.4,5), usually in the form of prills and large grains, in some cases the latters have fused surface. There are three malachite grains and some copper and cuprite prills with covellite border. This border is obviously a secondary formation created in the course of smelting. The association of covellite with malachite is found.

The initial quantity of covellite was obviously more as there is in slag a significant amount of prills of the copper sulfide formed from covellite. Its solidified molten inclusions and borders round copper prills which are well presented in slag reflect the direct reduction of copper from this sulfide. There are also relatively large prills and, in isolated cases, grains of this sulfide, in some cases of the large size. Individual grains form associations with cuprite. They are sometimes surrounded with a cuprite border or small copper prills. Copper was obviously reduced directly from this sulfide.

In one sample from the settlement of Rodnikovskoye (No. 1348-1) fine grains of chalcopyrite and chalcopyrite particles in malachite grain have been identified. This mineral did not play a significant role in the smelting and was only a casual impurity to the main ore in this particular case.

The described sulfide minerals, malachite and cuprite are sometimes present in the same grains and prills, all they form associations with sandstone and quartz particles, therefore, they were extracted from one deposit or deposits, and this situation is not a sign of a purposeful combining the furnace charge from mix of the oxidized ore and secondary sulfides. It reflects specifics of the ore base, although the purposeful choice of such deposits cannot be excluded.

Cuprite is weakly presented in the slag (Fig. 9-I.6). Occasionally it is present in the form of grains, but usually it melted. There is a crack filled with cuprite, which demonstrates its late formation in a settlement layer. But in some instances the cuprite filling of cracks connects with cuprite prills, therefore, the filling was started when these prills were liquid. Respectively, the solidification of the silicate matrix sometimes happened at a higher temperature, than the melting point of cuprite, and at the moment of the solidification the fusion had a very acid compound.

In some cases the cuprite prills form accumulations with prills of copper, which have the smaller sizes. Therefore, the cuprite prills were formed in the course of smelting[8]. However the content of cuprite is not so considerable that may be explained by the lack of strong oxidizing smelting conditions, because of the active use of sulfide ores.

In some slags the olivine crystallization is not found at all. However in the other samples the olivine is crystallized rather poorly, that is well explained by mainly acid chemical composition of slag. The olivine is presented in the form of small nuclei of crystallization and small needle or prismatic crystals, but in all slags the areas prevail where the olivine crystallization is absent (Fig. 9-II.1-4). The exception is sample 1303-1, in which olivine is the main inclusion in slag (up to 60%), it is presented in the form of small needle and prismatic crystals. In some samples (No. 1303) it is recorded that the quantity of olivine crystals is more in the central part of slag (up to 40%), although the crystals are rather small also there. The crystals of olivine have different orientations that specify that the cooling came from various sides. Therefore the slag cooled down more slowly in the center, allowing to olivine crystals grow better.

As a rule, the olivine is light and not zonal, having, probably, the fayalite compound. In one case (sample 1304) it is visible that it was formed round magnetite particles. Silicates of the slag were the second component at its formation.

Magnetite is presented by small rash of particles, including the small skeletons and dendrites crystallizing from the liquid slag (Fig. 9-II.1,2,4-6). In some samples the magnetite crystallization round copper prills is found (sample 1304, Fig. 9-II.6). Sometimes copper prills can be strongly deformed and concluded in a magnetite octahedron. Therefore, the last had time to crystallize from the slag, and they are not a result of disintegration of larger grains. But in some instances there are dense accumulations of magnetite particles separating from some larger grains. In some cases these accumulations even keep the border of a primary

[8] We have already repeatedly mentioned that this combination is a sign of the formation of cuprite in the course of smelting, instead of during the subsequent oxidation of copper.

grain. In one of such accumulations (sample 1307) there are many small prills of copper (Fig. 9-III.1). It once again specifies that iron components were initially present in the initial ore, instead of were added as fluxes.

It should be noted that the crystallization of magnetite is carried out also at lower temperatures, than its melting point, and the presence of its rare grains with fused surface does not indicate the high temperatures too as this can occur also due to impact of fusion.

In all samples the grains of chromite (Fig. 9-II.2) are recorded. However they are rare single (1-2 in a sample) grains of the small size, and they do not indicate the use in the smelting of the ultrabasic rocks. Possibly, they got to the furnace charge together with iron hydroxides. But for individual cases it is possible to assume a possibility that some quantity of ultrabasic serpentinized rocks got in the smelting. In sample 1291-1 from the Tokskoye settlement some olivines have a zonal structure: lighter external part (richer in iron) and a darker, more magnesian center differ. Cuprite prills in this sample fill the space between the olivine crystals, and cracks filled with cuprite divide these crystals. Therefore, the crystallization of olivine happened at a higher temperature, than the melting temperature of cuprite. In this case we may suppose the temperature no less than 1250-1300 ºC, that is above the temperatures of fayalite crystallization, therefore a magnesian component could be really present in the olivine, but it is more likely a special case, which cannot be applied to this series as a whole. Possibly, this sample indicates a certain ore inhomogeneity and existence of different inclusions in sandstone.

In particular cases copper prills form very dense accumulations keeping borders of a primary ore grain (samples 1304, 1308). Such direct copper reduction from malachite is improbable. Rather a secondary sulfide was reduced. There are other indicators of the direct reduction of copper from these sulfides: copper reduction inside a large sulfide prill (sample 1303-1), copper prills with sulfide border and sulfide prills with copper inclusions (samples 1304, 1304-1, 1305). Grains of malachite are usually replaced with cuprite round which in turn the reduction of copper occur (e.g. sample 1304). Copper reduces also in the cuprite fusion (sample 1307). In the same sample the deformed prills of copper were reduced directly in pieces of sandstone which had not been smelted.

But usually copper is presented by rather rare small prills. In some areas of polished sections the accumulations of prills are detected, but their sizes are very small, therefore the total quantity of copper in slag is insignificant. Glass matrix in some samples is painted in red color because of very small copper and cuprite inclusions solute in slag. In some instances larger prills have been found. The copper prills often form accumulations with the sulfide prills, and more rarely with small prills of cuprite. In some samples in areas where the olivine crystallization is not fixed, the quantity of small copper prills is more. They form the curved chains indicating the higher slag viscosity (Fig. 9-III.2). Especially it is characteristic of the areas of more viscous porous glass. But for such viscous composition the losses copper are anyway insignificant that is confirmed also by the chemical analysis (Tab. 9-7.). In two slags of this group they are less than 0.5% (samples 1355, 1356), but, as it will be shown below, it is the slag formed, mainly, from the furnace lining. And in two other slags (samples 1285, 1304) these losses (including cuprite and unmelted ore) are 5-6%.

Three samples of slag from the Rodnikovskoye settlement are slightly different from this series as the furnace lining, probably, took part in their formation. It also influenced the chemical analysis of this slag (Tab. 9-7.): there are maximum in this series contents of SiO_2 and Al_2O_3, and the minimum of Fe_2O_3 and copper. Two of these samples (No. 1355, 1356) are presented by more porous and light slag in which fayalite crystallization grew very poorly, and there are rare inclusions of quartz grains, magnetite, and copper. One sample is a rather typical slag formed on the furnace lining (No. 1351). It has zonal structure: its lower ceramic part is convex; the proper slag part is above. In the ceramic part very small and rare prills of copper, a large grain of malachite and cuprite, grains of covellite and cuprite have been identified. It unambiguously specifies that the slag was not formed as a result of metal casting.

In the lower part of the slag mass (on contact with the ceramic part) there are molten inclusions and prills of sulfide with cuprite, malachite grains, small olivine prisms, and prills of cuprite. The copper prills are very small and more often present in places of accumulations of sulfide and cuprite. In some areas of polished section the olivine is absent; in the others it is presented by many very small needles. There are areas of rather pure glass. There are in some cases very small nuclei of magnetite crystallization, but it is not too typical. In the upper part of the slag the number of ore inclusions and copper decreases, as well as the size of olivine needles.

Formation of similar structure in a crucible is doubtful: for this it had to be very strongly molten. It was, therefore, the furnace lining, and the ore smelting was carried out directly in the furnace.

Thus, the ore is presented by copper hydroxides (malachite, in some instances azurite) from the copper sandstones. Therefore the slag was saturated with silicate components. At the same time, iron oxides took part in the smelting. We have no ground for statements that this component was added as a flux, there are more evidences that iron-containing inclusions were often present in initial ore. Besides, there were many secondary sulfides in ore: covellite, rarer chalcocite. The presence of sulfur minerals allowed smelters to keep the reducing atmosphere in the furnace during the smelting. Thanks to it the formation of fayalite slag occurred, and the oxidization was minimal. The crystallization of fayalite and molten cuprite specify that the smelting temperature was in the limit of 1200-1300 ºC.

The smelting was carried out, apparently, during not too long time, in any case, in the zone of high temperatures. As a result, covellite is present relatively often in slag, it kept the sulfur, and did not turn into the more typical for slags sulfide.

The smelting was probably organized directly in the furnace, instead of in a crucible. It is testified by that the fayalite crystallized in the center of samples better, and its crystals have various orientation. One more fact is the studied fragment of lining.

It is not quite clear, how fast the temperature in the furnace decreased. On the one hand, the olivine crystals have small sizes that can point to the fast cooling, but another reason of it can be in a lack of iron components. However, as the chemical analysis of slag from the Ivanovskoye settlement shows, the balance of SiO_2 and Fe_2O_3 was quite sufficient for the fayalite formation (Tab. 9-7.). Magnetite could not pass into fayalite for the reason that the formation of wüstite is a necessary stage of this process.

And at some moment of the smelting, after burning out of the most part of sulfur from sulfides, the formation of wüstite could be troubled. Therefore the weak fayalite crystallization does not reflect a design of furnaces or slag tapping.

In general, it is possible to speak about this smelting, as about a quite technological one. Copper separated well from the slag and its losses are insignificant.

4th mineralogical group

It is the most representative mineralogical group of slag in this sampling, and it was connected here with smelting ores from the copper sandstones. In principle, owing to the unified origin of raw materials and similarity of technology, microstructures of this mineralogical group are very close to the above described 2nd group. The differences are only in the degree of oxidation of this slag.

Sandstone fragments in slag and fine quartz grains are here markers of origins of ore in the copper sandstones too. As the ore is situated between the sandstone grains it was obviously connected with the sandstone (Fig.

9-III.3-6; Fig. 9-IV.1). It is worth of attention that fragments of sandstone are found in the same samples where, as well as in the previous group, rare chromite grains have been found, that confirms again the already stated idea that in this case the grains of chromite cannot be used as a marker of origins of ore from the ultrabasic rocks.

The fayalite crystallization is expressed extremely poorly. In some samples the fayalite did not crystallized at all (for example, in all slags of the settlement of *Syezh*'ye), in others the fayalite is presented only in some areas of sections by nuclei of crystallization and small needles. Magnetite is present in the form of small skeletons and skeletal dendrites crystallizing from slag, or small octahedra and particles which separating from larger grains (Fig. 9-IV.2-6). Usually magnetite is not molten.

Ore minerals are presented rather well, above all, by malachite in the form of roundish grains, small inclusions in sandstone, 'cement' between individual grains of sandstone (Fig. 9-III.3,5,6; Fig. 9-IV.1,3,6; Fig. 9-V.1,2). At the same time, sulfide minerals are revealed in the slag (Fig. 9-III.1,6; Fig. 9-IV.3-5; Fig. 9-V.2,3).

The main sulfide mineral used in the smelting was, apparently, covellite. Covellite is presented in slag in the form of grains with molten surface, but more often by molten prills. Isotropic copper sulfide is usually in the form of prills, although in some instances there are also its partly molten grains. Chalcocite is less often, in the form of molten inclusions, rarer the grains with fused surface. However probably it was present in the initial ore. Sometimes these sulfides form borders round malachite, cuprite and copper prills.

Secondary sulfides, apparently, were initially present in the initial ore together with malachite. A special combination of furnace charge from two types of ores was not practiced, because very often we see the associations of covellite (or rarer chalcocite) with malachite. Covellite turned into cuprite, but its direct reduction into copper is sometimes fixed.

The ratio of malachite and sulfide minerals was in different slags various that influenced their microstructure. The losses of copper in the form of cuprite in slags with prevalence of the oxidized ore were much higher.

Cuprite is present in all samples (Fig. 9-V.1,3-6). It is it better presented near the accumulations of malachite grains and copper. Glass in such areas has a reddish shade (Fig. 9-VI.1-3). Prills of copper in the cuprite border have been found, and this cuprite is not secondary, but created in the course of smelting that is noticeable by the cuprite prills adjoining this border. Cuprite fusion often surrounds malachite grains. After melting they turned into cuprite, already after this the copper reduction occurred.

Often the cuprite prills have a regular round form, but in many slags they are deformed. Therefore, often the smelting temperature exceeded the melting point of cuprite, its overheat happened, that allowed the regular prills to be formed.

Cuprite is found in cracks in glass, often the filling of cracks is connected with cuprite prills. It specifies that the glass solidification happened in some cases before the cuprite solidification, or at rather similar temperature.

In individual samples the cuprite dendrites are recorded (Fig. 9-VI.4-6; Fig. 9-VII.1,2,4). It is sometimes noticeable that they were formed around the prills of copper. They were created in the course of slag cooling before the slag solidification. In one of the samples a shrinkage crack round a large copper globule divides the dendrites crystallized earlier.

In slags of the Pokrovskoe settlement the content of cuprite is though great, but not excessive. In *Syezh*'ye slag its content is incomparable more. And prills of cuprite are usually strongly deformed in it that points to the viscosity of slag.

In glass of slag from Nizhnyaya Pavlovka and in many slags from Pokrovskoe and *Syezh*'ye there are many delafossite needles between which dendrites of cuprite grow and small accumulations of iron hydroxides are fixed (Fig. 9-VI.5,6; Fig. 9-VII.1-5). Often the dendrites of cuprite are formed along the surfaces of delafossite. Sometimes the delafossite needles are bent (samples 1309, 1311, and 1313 from Pokrovskoe). In sample 1312-1 it is clearly visible that delafossite was formed when olivine had been already crystallized. The solidification of delafossite occurs at temperatures of 1175-1200 ºC (Trofimov, Mikhailov 2002, fig. 2), and the situation corresponds to a slightly higher temperatures at which olivine crystallizes.

Prills of copper (Fig. 9-VII.6) are well presented in the slag. In some cases they form accumulations with clearly expressed borders, a result of fusion of an ore piece. Some samples contain a large amount of the solute copper and cuprite, therefore the glass is painted in red color that is the most noticeable in crossed nicols. Sometimes this coloring is arranged in curved strips. There are also curved chains of copper prills in such areas (Fig. 9-VII.6). It indicates the high viscosity of slag. However, except for individual samples, the amount of copper is not too great. Despite the number of prills, they are very small, and the general copper content usually does not exceed 5-8%. Naturally, together with cuprite and ore the real losses of metal were higher, that is confirmed also by chemical analyses which have shown for this group of slag the copper content within 5-30% (Tab. 9-7., samples 1303, 1318, 1333, 1344).

Thus, the oxidized ore from the copper sandstones were smelted. The smelting atmosphere was oxidizing (in some slags, for example, from Pokrovskoe, temperate oxidizing), iron fluxes were not applied. Individual inclusions of iron oxides were connected probably with the gangue. As a result, very viscous slag was formed with a lot of copper and cuprite.

The solidification of the slag occurred, probably, quickly enough. The temperature was close to the temperature of cuprite melting. The probable temperature range is 1200-1300 ºC. This group differs from the 2nd mineralogical group only larger degree of oxidization that is caused by more limited use of sulfide ores at the essentially same technology. As a result it led to large losses of metal in slag.

Judging from the available publications, the overwhelming number of slags of the Gorny settlement on the Kargaly mines belongs to this type, and shows very close structures. Archaeometallurgical investigations of ore, slags and metal from the settlement of Gorny have been carried out by Salvador Rovira (Rovira 1999; 2004)[9]. His analyses of ore minerals from the settlement have shown that they are rich in SiO_2 and poor in iron and calcium oxides. The amount of copper oxides in ore varies, as a rule, within 20-80% (Rovira 1999, Tab. 1). The content of CuO in slag varies from 0 to 46%, but on average it is 11% (Rovira 1999, Tab. 3) that is similar to the 4th mineralogical type. About a third of samples are related to the range of 0-5% CuO, a third to that of 5-10%, and a third to more than 10% (Rovira 1999, Fig. 2). The reason of so high losses of copper was not only in the high viscosity, but also in the oxidizing atmosphere of smelting. Mineralogical research has revealed the microstructures which are very typical for smelting of oxidized ores in the oxidizing conditions. Slag contains many prills of copper and cuprite, needles of delafossite and cuprite dendrites. Only in two samples the good crystallization of fayalite is noted. In some samples the inclusions of sulfides are found, but they were not leading components in the smelting and were formed probably as a result of disintegration of barite and the subsequent compound of sulfur with copper (Rovira 1999, p. 94, 96, Tab. 4).

[9] I am very grateful to Salvador Rovira for his very prompt reply to my questions about his first article. They were very numerous as the article was written in Spanish, and I was not sure that I managed to understand it literally and quite correctly. I should concern it, despite the existence of later publication as there, as well as in the subsequent discussion, rather valuable thoughts contained.

There are ethnographic parallels to such copper losses in slag. Metallurgists of the Yoke people in Congo did not use fluxes, and from 50 kg charged into furnace they extracted 12-15kg copper. As malachite contains 55% copper, the losses were 40-50% (Bisson, 2000, p. 97).

Creation of the thermal diagram $CaO-FeO-SiO_2$ allowed three groups of slag to be distinguished, differing by the temperature range: 1400-1600 ºC, 1200-1400 ºC, and 1100-1200 ºC. Almost all samples fall in the first two groups. However, by our experience, sometimes the diagrams show higher temperatures that can be explained by thermodynamic processes and impact of liquid slag. Therefore the Rovira's conclusion that the temperatures varied, generally, within 1200-1400 ºC (Rovira 1999, fig. 3, p. 94, 97) seems to be quite lawful, although at some moments of smelting the high temperatures were quite possible[10]. It corresponds to the picture which here is reconstructed on other Orenburg sampling. However in the following publication S. Rovira corrected this conclusion and has preferred to discuss the temperatures about 1100 ºC (2004, p. 120). But it has been based on an idea that cuprite was molten and it melts at a temperature of 1080 ºC (probably, it is a mistake at the translation of the text for the Russian edition?). However the melting temperature of this mineral is much higher.

As fairly notes E.N. Chernykh it was impossible to reach so high temperatures without artificial blasting. However, on the settlement of Gorny only two fragments have been found, which can be considered as tuyeres that does not correspond to ideas of large-scale production on Kargaly. And it is a universal situation, although in comparison with crucibles and casting moulds they are steadier against operational loads (Valkov, Kuzminykh 2000, p. 73-75). Therefore some researchers assume that tuyeres were used in metalworking where the direction of blasting is important, and the smelting process could be based on natural draft (Valkov, Kuzminykh 2000, p. 77). However in this case it is possible to ask a question – why at the excavations tuyeres for metalworking are seldom presented, it was a much broader widespread production? Why the finds of crucibles and casting moulds are so rare; they should destroy much more often than tuyeres, besides it was required much more casting moulds? The reference to experimental works on iron smelting is not quite lawful. Our works with copper ore have shown that it was very difficult to operate without the intensive directed blasting.

6th mineralogical group

Slags of this mineralogical group have been found only on the Popovo Ozero settlement. In slag, except for several samples, olivine (probably, fayalite) crystallized rather well. It forms prisms of various sizes, extended skeletons, and dendrites. In some samples (No. 340, 342, 343) the olivine crystallization took place worse or did not occur at all.

Magnetite is presented by small octahedra. Completely shaped, often fused dendrites of wüstite are well presented. The molten wüstite is recorded too. Sometimes the molten wüstite or octahedra of magnetite are mixed with molten copper sulfide. Possibly, it reflects the formation of both wüstite and magnetite from the primary sulfide. At the same time, rather large grains of magnetite are present. Therefore a part of magnetite octahedra was formed from them. In some instances copper particles were reduced in magnetite. Often they have the fused form or even the form of prills, repeating the form of the magnetite particles in which they were formed. In one case an iron grain is surrounded with a magnetite border, and the surface of this border is partly replaced by hematite. Possibly, the oxygen leaving iron enriched the upper layer of the magnetite.

[10] S. Rovira explains the presence of slags lying in the high-temperature zone by that he used the bulk analysis of slag for creation of the thermal diagram that is not quite justified because of the presence of a significant amount of unfused components, first of all, silicate components. Just their presence in samples caused this group. According to him, it is more correct to build the diagrams basing on microanalysis of molten components. We have done such work with Sintashta slag, and the results are incomparably steadier. However in some cases the diagrams also have shown more high temperatures.

The particles of reduced iron are presented in slag rather well that point to the reducing atmosphere. Sometimes the iron particles have impurities with a copper shade. Lighter prills of copper have been identified too. Possibly, we deal here with different forms of alloys of copper with iron. In individual samples (No. 337) the “pure” prills of copper are simply absent. The grains containing sulfide, cuprite, magnetite and iron have been found that explains the formation of similar compounds. In some cases the copper particles are present in the reduced particles of iron. In some slags the prills of copper are present, but, as a whole, its losses in slag are insignificant.

Copper is often reduced on the border of cuprite, but can be also formed from the isotropic copper sulfide. The grains of pyrite containing copper are found out that point to its possible extraction directly from chalcopyrite.

There are occasionally the chromite grains in slag, but the ore was connected with quartz. Some quartz grains are, probably, subjected to a high-temperature. Many are partly fused, forming areas of quartz glass.

Malachite and chrysocolla are revealed (sample 339), but in the ore composition their share was very insignificant. The basic ore were sulfide minerals of copper.

The isotropic sulfide is most widespread; it forms prills, molten inclusions and grains in association with other minerals (magnetite, copper, cuprite, chalcopyrite, and pyrite). Often it is replaced on the edge with cuprite, and inside with copper. In principle, it could be formed from covellite and chalcocite. However any prills of these minerals is not revealed in the slag and it is explained by their rather easy transformation. But the chalcopyrite grains are well recorded, and rarer pyrite.

Thus, the chalcopyrite from quartz rocks was, mainly, used in the smelting. It was the main source of the iron component. The fused magnetite cannot indicate the high smelting temperatures as it was formed, probably, from wüstite. The composition of slag was optimal, and the viscosity insignificant. Losses of metal were (with rare exception) low. Slag cooled down slowly, in the furnace, in conditions of the reducing atmosphere. Probably, the blasting decreased gradually as the magnetite and olivine crystallized well. In these conditions copper and iron were reduced, and the last could even act as an insignificant by-product. Copper, probably, dripped on the furnace bottom, slag dripped too, setting over the copper, and some part of iron particles remained in slag and another part in the furnace filling.

Here it is pertinently to remember that E.N. Chernykh, analyzing the metal from the Sosnovaya Maza hoard with iron content up to 5%, has noted the impossibility of use of iron as an artificial ligature owing to its refractoriness, and he has assumed that these analytical data can fix the beginning of smelting of primary sulfide deposits (Chernykh 1970, p. 18, 19). Our analytical data of the Late Bronze Age slags confirm this conclusion.

Problem of fluxes

On the basis of RFD and ICP-OES analysis of four samples of ore and slag from the settlement of Mikhaylo-Ovsyanka it has been shown that the ore was malachite with impurities of azurite, quartz and calcite. The copper content in ore is 40.75%. The conclusion is drawn about absence of evidences on additions and alloying and that the slags correspond to the local ore (Garner 2010, S. 17, 18, Tab. 1).

However, a detailed consideration of provided analyses forces to doubt this conclusion. Barium does not contain in ore samples while in slag its contents are 1-2%. It indicates probably the deliberate additions. The majority of components in slag, in comparison with ore, really do not essentially change, but the content of silicon dioxide (SiO_2) and iron oxides (Fe_2O_3) considerably grows. And if the growth of silicon dioxide from

2-13% to 33-52% can be explained partly by removal of quartz at the ore preparation, partly by metallurgical processes in case of use of very rich ores, the growth of iron oxides from 1-5% to 24-52% is too significant, and allows us to raise a question of fluxing by iron oxides or to assume that barite was added together with them, and fluxing was, thereby, complex. Possibly, it explains a rather low viscosity of slag of this settlement that led to formation of flat cakes similar to Sintashta slag.

In the Orenburg sites, as we have seen above, evidences about the iron fluxes are absent. Iron oxide inclusions were connected with the ore bearing sandstones. S. Rovira has drawn the same conclusion having compared analyses of ore with slag analyses from the Gorny settlement. Similarly, he rejects a possibility of additions of calcium which is well presented in the Kargaly slag, explaining it by its transfer either from ore or from ashes (Rovira 2004, p. 115). In our slag samples the content of calcium varies from 4.34 to 13.03% (Tab. 9-7.). However our experimental works recorded the insignificant growth of the calcium content in slag in comparison with ore. Potassium passes from ashes at the greater extent. And its content in our slag varies within 0.46-4.1%. It allows us to assume the use of some components containing calcium for creation of more liquid slag. Fine-crushed bones of animals could be those, in principle. But these reflections cannot be considered as a solution as analyses of the slags received from experimental smelting of the Kargaly ore also show in some cases higher contents of CaO. And the additions containing calcium were not used in the furnace charge (Rovira 1999, Tab. 9).

High concentrations of barium in the slag demand a special discussion. E.N. Chernykh has explained its presence in the Kargaly copper by special additions of barium sulfate that was necessary in order that sulfur connected with oxygen of the oxidized Kargaly ores, and this promoted the copper reduction (Chernykh 1997, p. 62, 63). The investigations of slags, ore and metal of the Gorny settlement have shown that the higher concentrations of barium are often present in ore minerals and slags, they are rare in the copper inclusions concluded in slag, are typical in copper ingots, and rare in copper objects. It should be noted that the experimental smelting of the Kargaly ore gave also in some cases slags with the higher concentrations of barium (Rovira 1999, Tab. 1, 3, 4, 6, 7, 9). This situation has the following explanation[11]. Barium was initially present in the Kargaly ore. It dissolves in the molten copper at a low temperature of 1100 ºC. Therefore in copper it is possible to expect the presence of some quantity of barium. But analyses of copper in slag have been made by means of the scanning electronic microscope which cannot determine low values of elements (below 0.2%). At the subsequent re-melting the barium is oxidized and passes into slag, which explains its rarity in the objects. Therefore the higher concentrations of barium were connected, nevertheless, with the ore, instead of with special additions. One sample of this ore was sent by us for the analysis to the Activation Laboratories Ltd., Canada (Tab. 9-8.). This sample shows the concentrations of barium slightly exceeding 5%.

Above we have mentioned that the growth of the barium content in slag in comparison with its contents in ore has been detected on the settlement of Mikhaylo-Ovsyanka, where surely the local ore was smelted. On other Volga settlements barium in slag is absent. An exception is *Syezh*'ye, the nearest settlement to the Orenburg zone (Tab. 9-13.). Exactly thanks to this settlement in the studied slags of the Volga region the average concentration of barium is 0.47%, and if not to consider the *Syezh*'ye slags, on other sites this average concentration is only 0.04%. In the Orenburg region the situation is essentially other. Here the average content of barium reaches 1.42%, and this impurity characterizes slag of all settlements, both in the west and in the east, near the Kargaly mines (Tab. 9-12.).

On the settlement of Nizhnyaya Pavlovka a considerable part of slag has been identified as a furnace lining, that gave totally such low values of the barium content. And, the connection of higher barium concentration with slag of settlements where the 2nd or 4th mineralogical groups prevail is absent. Besides, slags with the

[11] I would like to express my deep gratitude to Salvador Rovira who explained me in detail the sense of these, at first sight, inconsistent results.

high and low contents of barium can be present on one settlement. The higher barium content is found also in ore from the settlements of Rodnikovskoye and Ivanovskoye, and also in the furnace lining and copper from the Rodnikovskoye settlement. But in the ore from Ivanovskoye there are also samples with low barium concentrations. Thus, it was more often connected with its presence in ore. Therefore, apparently, it is more logical to assume that this element was connected, nevertheless, with the ore, and we should not speak about its special additions into furnace charge[12].

But, investigating slags from the Bashkirian Cisurals, we have noted in some cases the high presence of barium. And there, apparently, it is more lawful to speak about its artificial additions in furnace charge.

Besides, not all Orenburg ore contains barium. Therefore metallurgists could understand that the presence of barite helped to smelt the oxidized ore successfully. In some cases it was present in ore, but in some others (as well as E.N. Chernykh thinks) it could be added purposefully. From here this tradition could spread to the neighboring areas of the Volga and Bashkirian Cisurals. Transportation of the barite is also possible. And, as it has been discussed for the Bashkirian Cisurals, it is not excluded that barium not only promoted the decrease of the oxidizing atmosphere, but also connected the silicates whose surplus was present in the furnace charge of the area.

The presence of the Chogray sandstone on the settlement of Rodnikovskoye should be also noted (No. 1339-1341). Such finds are typical in metallurgical complexes of Sintashta culture, as well as in the early Alakul sites (the settlement of Mochishche) that was a continuation of the Sintashta tradition. Earlier this sandstone was considered as a flux, but the analysis has shown its acid compound and impossibility of its use for this purpose. Therefore it is obvious that here these finds are somehow connected with the Sintashta tradition of metallurgy, but for what purpose it was used remains unclear.

Volumes of smelting

It is very difficult to judge about the volumes of smelting. Unlike Sintashta slag, the vast majority of slag of this area is shapeless, and does not allow the volume of furnace charge or extracted metal to be determined. Therefore any assumptions can be based on isolated facts only. So, on the Mikhaylo-Ovsyanka settlement in construction 1 a copper ingot is found weighing 88g. that is close to an ingot weighting 80g found in the Timber-Grave complex of Pilipchatino in the Donets basin (Kolev 2010, S. 9) and in Timber-Grave settlement of Tavlykayevo in the Transural Bashkiria (Morozov 1981, p. 61, 62). This means that the volumes of extracted copper in these cases were close to those in the Sintashta period. These are, perhaps, the only direct data. Others are already more doubtful.

We have already discussed above that the smelting in crucibles on the settlement of Gorny are doubtful. However, if these doubts are not lawful, we try to consider similar probability. Volumes of melting bowls of the Gorny settlement varied from 680 to 1750 cm^3, their upper part was not slagged, and, judging from this, they were filled for 80% of volume (Lunkov 2004, p. 70-75). Respectively, the volume of the crucibles filling was 544-1400 cm^3. If we assume the presence in this volume of some minimal quantity of charcoal, it would be possible to speak about the volumes of charge about 400-1000cm^3. The content of copper oxide in ore from Gorny varied within 20-80% (Rovira, 2004, p. 108). If we take as a basis 50%, at the specific weight of malachite about 4 g/cm^3, and that of sandstone about 2.65 g/cm^3, in this volume it is possible to place the charge containing 800-2000g malachite and 530-1325g sandstone. In this case, the gross weight of the charge could fluctuate in limits of 1330-3325g. Unfortunately, we do not know, what share of copper was produced as ingots were not obviously formed, slag was extracted, and from it small copper drops were

[12] It should be noted that Salvador Rovira holds the same opinion, although he does not pay attention to this problem in his article for the reason that he did not know the opinion of E.N. Chernykh published in the book in Russian. However at personal communication he has rejected possible additions of barite into the furnace charge.

taken. Malachite contains about 57% copper, therefore, in the above-named volumes the copper content could be in limits of 450-1140g.

As it was already spoken, on average about 11% of copper in the form of metal, cuprite and ore inclusions remained in the slag of Gorny. Therefore probably other part of copper formed some larger inclusions which could be taken. Therefore, the irretrievable losses of copper in slag were 145-365g., and its possible extraction, taking into account the losses, at most 250-700g.

There is one more remarkable fact. On the settlement of Gorny in dwelling 46 of the early phase the thrown-out accumulation of slag has been found, allegedly, a result of unsuccessful smelting as copper did not separate from slag. In total this accumulation contains 250 pieces with gross weight of 4.5 kg (Kuzminykh 2004, p. 101). Correspondently, in this case it was the weight of the entire furnace charge if slags of other smelting operations did not get to this heap. If it is really the result of a single smelting, the furnace charge volume considerably exceeded that which can be charged into one crucible, and the smelting certainly was carried out in the furnaces whose design is not yet established for this settlement. But then the weight of extracted copper could reach 1kg. But it is impossible to tell surely that this heap is a result of a single smelting.

Unfortunately, it is difficult to clear this question. Found in the Kargaly area ingots of rough copper weigh 1.5-4kg (Chernykh, 1997 p. 63). Certainly, similar ingots could not be a result of a single smelting, they were smelted in many operations. Possibly, they were intended for export out of the Kargaly mines where the production had obviously a commodity character.

Smelting technologies in the Volga and Orenburg regions in the LBA

At the comparison of mineralogical groups of slag (Tab. 9-10.) it becomes rather obvious that their structure for the Volga and Orenburg regions very differs. First of all, it is connected with different ore sources. In the Volga region only 4 samples are connected with the copper sandstones, all from the settlement *Syezh*'ye, the closest to Orenburg. Other samples are connected either with the ultrabasic rocks or with quartz. In the Orenburg region the situation is essentially other: here exclusively sandstone ores were used. As a whole in the studied sampling the share of these ores (2nd and 4th mineralogical groups) is 70%. And taking into account the production on the Kargaly mines, this share should to be higher. On the settlement of Shigonskoye II the preference of ores from the ultrabasic rocks, and appropriate technology of smelting was probably caused by that is the early Timber-Grave site and its metallurgy directly succeeded the Sintashta-Abashevo traditions. Therefore also the technology of ore smelting of this settlement was identical to that of Sintashta. But an important difference from this tradition is already present too: in slag of Shigonskoye II arsenic impurity is absent. Therefore, the alloying at the stage of ore smelting was not practiced any more.

Later slags of the Timber-Grave time reflect a tendency to use some local sources in quartz breeds (Lipovii Ovrag) or limestone (Mikhaylo-Ovsyanka). Despite the transition to these ores, the former technological scheme remained, but metallurgists managed to keep the reducing atmosphere in the furnace. Possibly, it was possible to achieve thanks to the long furnaces in which it was easier to form carbon monoxide.

The metallurgical production on the settlement of Popovo Ozero deeply differs from previous technologies; we see there the transition to smelting of chalcopyrite from quartz rocks. It resulted in the growth of smelting temperature. Together with the Timber-Grave on the settlement the Suskan-Lebyazhinka materials have been found, that is a marker of the Fyodorovka-Mezhovka influences from the east. However, in this period this technology appeared also in Timber-Grave culture of the Bashkirian Cisurals, although its part was insignificant. But, anyway, it was the result of influence from the east.

The situation in the Orenburg region was absolutely different. Here exclusively sandstone ores were used. The rare samples of slags of the 1st and 6th mineralogical groups can be explained by inhomogeneity of ores in sandstones. As a result almost all slag (except for these rare samples and fragments of furnace lining) belongs to the 2nd and 4th groups. The ratio of these two groups is follows: 35% (18 samples) and 65% (34 samples) correspondently. And, if to take into account publications of slags from Gorny, relating to the 4th mineralogical group too, the share of this low-technological, badly balanced smelting technology in the Orenburg sampling will be even higher. Domination of these technologies in the region is explained by character of the oxidized ores in sandstones when it was necessary to keep high smelting temperature because of the acid composition of charge; the oxidizing atmosphere was as a result. Attempts to change this composition were absent: we have no data on use of iron fluxes. When the furnace charge contained larger quantity of iron oxides, they were mined together with ore, and it reflects only characteristics of a particular local mine. On average, ores of more acid composition were smelted in Gorny and Rodnikovskoye, less acid – on other Orenburg settlements. Indirectly, it is evidence of a difference in ore base. At less acid slags there is also other composition of ore: along with the oxidized ores, the share of secondary sulfides is very large. Mostly it concerns of more western settlements, Ivanovskoye and Kuzminkovskoye, to a lesser extent of Tokskoye and Rodnikovskoye. An absolutely comparable situation with that on Kargaly is fixed only on the Pokrovskoe settlement located nearby these mines, partly comparable on Rodnikovskoye and Nizhnyaya Pavlova located at a distance of only 60-75km from the Kargaly mines.

Unlike the territorial, the chronological difference is not so notable. Probably, it is connected with that we are not always able to relate slag to a particular phase of the Timber-Grave culture. But, probably, the chronological distinctions did not exist. For example, the 2nd mineralogical group dominates on the Ivanovskoye and Kuzminkovskoye settlements. The first is considered as very early in the studied series, and the second as the latest. Therefore on the Orenburg materials we do not see any technological shifts, all differences are caused by character of deposits which were mined by populations of these or those settlements.

It is quite difficult to tell from where a metallurgical tradition came to this territory as it was based on the ore base which was, practically, not used before. An exception is the type of archaic Abashevo smelting of pure ore from sandstones, and in the conditions of oxidizing atmosphere too. But the real similarity is not so great because the Abashevo people selected the pure ore and smelted its insignificant volumes. That is in this case the ore source from the copper sandstones is the common feature only, all others was different.

The smelting of ore from quartz rocks was practiced in Sintashta metallurgy, and then a part of this smelting technology grew in the Petrovka time, and it was spread in Abashevo and Timber-Grave cultures of the Bashkirian Cisurals. Therefore, eventually, a probable circle of sources of this Cisural metallurgy is as follows: Sintashta-Abashevo or Petrovka production. Sintashta seems to be more preferable as on the Tokskoye settlement the furnaces attached to well, typical of Sintashta and absent in Abashevo, have been found. It is not excluded that on the Gorny settlement the furnaces with flues have been revealed, also characteristic of Sintashta, though it is not a proven fact.

However in general the situation with metallurgical constructions in the region, against the plenty of slag, seems to be depressing. If for the settlements of Mikhaylo-Ovsyanka and Lipovii Ovrag we can discuss the long furnaces designed for smelting of oxidized ores, we can also speak about the furnaces on the Tokskoye settlement, but the use of rather small hearths in the Orenburg region is unproven, although probable. They are, as a rule, too small to create the reducing conditions for smelting of the oxidized ore. However, it is possible that just it was the cause of such plenty of the oxidized slag. But also these furnaces have analogies in the Sintashta-Abashevo sites. And, it is necessary to emphasize that the smelting in furnaces (basing on evidences from the described furnaces and slag mineralogy) seems to be preferable. Smelting in crucibles is not proved today neither by the actual material, nor by analyses.

It is not excluded that a part of these furnaces (especially small hearths) were used for metalworking, as for the metal re-melting in a crucible it was enough to use small furnaces of 30-40cm in diameter with the height of walls about 15-20cm (Tylecote 1980a, p. 197).

Spectral analyses of slag

In total 100 spectral analyses of metal, furnace lining, slag and ore have been done (Tab. 9-13.). We have already noted that the determination of a source of ore by means of the spectral analysis is almost insoluble task. In this case it is especially difficult as in the studied area the majority of ore sources belong to a single type: the deposits in copper sandstones. Owing to similarity of geochemistry of many sandstone ores it is unreal to relate samples to any concrete deposit. Nevertheless, for the territory of Bashkiria we managed to draw a conclusion that the exploitation of ores from sandstones did not dominate there, but even those ores which chemically and mineralogical can be related to sandstones, could be mined in Bashkiria. The mineralogical analysis of slags from the settlements in the area Samara Bend has allowed similar conclusions to be drawn also for this region. Therefore the undertaken research pursues the aim of comparison of chemical compositions of slag from the Orenburg and Volga regions to compare these materials with each other and to appreciate a possibility to distinguish any different groups on this base.

Above all, a fleeting glance on the table of analyses is enough to be convinced that there are no samples with the high arsenic concentration in this series. Therefore, during this period and in this region the tradition of alloying by arsenic at the stage of ore smelting was completely absent. It is quite explainable as at the transition to smelting of ores from acid rocks this tradition disappeared everywhere: the duration of smelting grew and their temperature slightly increased. But even in the areas where we see a certain connection with the previous Sintashta-Abashevo tradition in the form of smelting of ore from the basic rocks (Shigonskoye II), such additions have not been identified. Possibly, this case shows that not always the choice of an ore source caused also all other technological traditions corresponding to it. In the region new traditions of smelting and alloying began already to dominate, and this factor became more determinative.

Antimony is absent completely too. Consequently, in this region the As+Sb bronzes of the chemico-metallurgical group VK were not produced, in principle. As we have seen on the example of the Bashkirian sites, metal of this group in the Mezhovka culture was made by purposeful additions of antimony-arsenic minerals. In the corresponding slags of the Timber-Grave culture the contents of antimony and arsenic is not high, and a source of this metal were natural impurities in sulfide ores, and also the alloying by arsenical minerals containing higher concentrations of antimony. In the Orenburg and Volga regions this tradition of alloying was absent, and the overwhelming number of ores was mined from the sandstones and was oxidized, more free from these impurities, although some part of secondary sulfides was also used. Respectively, this picture is quite logical, caused, on the one hand, by the technological tradition, on another – by the local ore base.

An attempt to distinguish chemical groups has been also done. In addition to the slags from the settlements discussed above, this processing has included materials from the settlement of Sergeevskoye from the neighboring area of Bashkiria, as the smelting of ore from the sandstones is noted there too. The processing of results of the analysis has been carried out by means of the Brookhaven Date Handling Programs, and eight chemical clusters have been distinguished. It must be kept in mind, however, that this program throws off in the last cluster those samples which are difficult to unite with other clusters. Therefore it is more correct to speak about seven clusters. Besides, it is necessary to remember that as ore and slag are heterogeneous materials, at the processing of data of the spectral analysis we can find an essential dispersion of the results. The majority of settlements from where the slag occurs are located near various small deposits in the copper sandstones with a similar chemical composition. At the same time, it should be noted that these deposits had been formed as a result of destruction of different sulfide deposits and, being fragmental debris, are heterogeneous too. Therefore even within a single deposit we have the right to expect presence of slightly different chemical composition. It was also influenced by a smelting technology. For the processing the following elements have been used: Ti, Mn, As, Ba, Sr, Ni, Co, V, Sc, Pb, Sn, Zr, Ga, Ge, Ag, Mo, Be, Cr. The results are presented in Tab. 9-14..

From this table we can conclude the following. All samples from the Orenburg part of the studied area are scattered very arbitrarily in different clusters. The same can be told about the settlements *Syezh*'ye and Sergeevskoye, located near the Orenburg area. Consequently, we may assume, nevertheless, the exploitation of deposits in the copper sandstones, however owing to inhomogeneity of the material, it relates to different clusters. Contrary to it, almost all samples from the Volga region are united in cluster 2 (Lipovii Ovrag, Popovo Ozero, Shigonskoye). Four samples from Popovo Ozero and one from Shigonskoye have been included in the adjoining cluster 1. Apart from the samples of the Volga region only one sample from Pokrovskoe has got into cluster 2. From this it is possible to draw an unambiguous conclusion that some local ore sources were exploited in the Volga region.

All samples are characterized by the low contents of arsenic and chrome that distinguishes this sampling not only from the Sintashta-Abashevo one, but also from the Timber-Grave sampling of Bashkiria (Fig. 9-15.). The difference in the chrome content in slags of the Volga and Orenburg regions is also felt. In the last region this contents is slightly higher that points to a certain difference in the ore base.

Dependence between the contents of lead and silver is also observed, and many samples are characterized by the higher concentration of silver that is typical of the deposits in sandstones too. As we have seen on the example of Bashkiria, there the higher concentrations of silver are not a sign allowing the ore to be connected with the copper sandstones. However in this case we see higher concentrations of silver in those samples which are connected with these deposits. By the way, the analyzed samples of sandstone ore from the Ivanovskoye settlement differ by the high silver content too. Contrary to it, slag samples from the Volga region show low concentrations of these elements (Fig. 9-16.). Exceptions here are again the slags smelted from the sandstone ore from the settlement *Syezh*'ye.

The same is shown also on the diagram of Ba-Ag (Fig. 9-17.). On it practically all samples from the Volga region (with the exception of *Syezh*'ye) show low concentrations of these elements, and the samples from the Orenburg region show, as a rule, the averages and high values. It emphasizes once again the specifics of ore base in the first region.

From everything discussed above it is possible to draw the following conclusion: the suggested by E.N. Chernykh group of metal MP in its most part is really connected with the copper sandstones of the Orenburg zone and the neighboring areas of the Volga region, but it probably cannot be applied to copper sandstones in general.

The chemical proximity of the Orenburg samples is confirmed by the diagram of Ni-Co (Fig. 9-18.), on which the majority of samples are concentrated together. The dispersion is shown only by the samples from the Volga region. However, the same samples of the *Syezh*'ye settlement and only single samples from the settlements of Shigonskoye II and Popovo Ozero got to the area of the high concentrations of these elements that absolutely corresponds to this regularity.

Thus, for the samples of slag smelted from ore in the copper sandstones of Orenburg zone, the high concentration of Ag, 3% and more, and also higher concentrations of Ni, Co and Pb in comparison with the Volga region samples are characteristic. This circumstance raises some questions. According to E.N. Chernykh (1970, tab. 2) the silver concentrations considerably increase in metal in comparison with initial ore. For slag we have calculated for this element slightly larger decreasing coefficients (Introduction, Tab.

0-6.). But in this case in metal the silver content has to be much higher, than it is actually. Others of the listed elements, according to these data, decrease their contents in slag, although this decreasing is not so large, but for the metal it is supposed either their neutral behavior or a small decrease too. Therefore the reason of such purification of the MP copper from the majority of impurities, except for silver is unclear: either some special smelting conditions (for example, its duration and higher temperatures) or subsequent refinement.

But, despite it, the general conclusion remains invariable: deposits of the Orenburg zone and the neighboring areas of the Volga region is the most acceptable candidate to be a source of the MP copper. And it was not any single deposit, but a series of deposits of this region.

Problem of ore base of Eastern Europe in the Late Bronze Age

The conclusion formulated above is quite in line with the former works of E.N. Chernykh. However, lately Chernykh supposes that the Kargaly mines located to the north from Orenburg played the leading role in formation of this chemico-metallurgical group and other metal of Eastern Europe. But analytical bases under this conclusion are absent. He thinks that all, so-called, “pure copper” was smelted from the Kargaly ores. In addition to this copper Chernykh distinguishes the tin bronzes, bronzes with arsenic and antimony impurities, and also the copper polluted with impurities which is considered as a copper of the “Kargaly origins” to which copper of other origins was added. And in the Timber-Grave sampling this latter and the “pure copper” form nearly a half (Chernykh 2007, p. 92-95).

Let us reflect what does this mean. Without any analytical arguments offering chemical ways of distinction of copper from different deposits, any unalloyed copper is proclaimed as “Kargaly copper”. In this book it has been already repeatedly discussed that it is an unreal task to connect not only metal, but even ores with any concrete deposit by means of the spectral analysis. Now it is impossible even by practically all other more modern methods. If by means of the spectral analysis of slag it is still somehow possible to discuss a type of the ore bearing rock, and to outline such connections (but not always), for the metal it is impossible at all. There is a single possibility: to establish a type of ligature and its degree. Therefore the proofs of the presence of the Kargaly metal in Eastern Europe does not exist, and at the modern level of development of archaeometallurgy it is hard to say whether there will be similar capabilities in the foreseeable future. Taking into account the metal re-melting this capability is doubtful even if we will allow any fantastic development of analytical technics.

From the beginning of archaeological works on Kargaly an impression began to appear that volumes of mining operations were so great there in the ancient time that local forest resources were insufficient to supply the smelting with fuel. It is supposed that in the Bronze Age, as well as subsequently by the Russian industrialists, about 5 million tons of ore was extracted on Kargaly from which, according to different estimates, it was smelted either 125-130 thousand or 55-60 thousand tons of copper which then spread across Eastern Europe, within the territory of 1 million km^2 (Chernykh 1997, p. 75; 2002, p. 88). But even a rough estimate of real volumes of mining and smelting is an incredibly difficult task. I have already criticized the exaggerated estimates of volumes of works on the mine of Vorovskaya Yama where extraction of 10 tons of copper was supposed (Zaykov *et al.* 1995; Grigoriev 2000, p. 500). Researchers of the Eneolithic Anatolian mine of Murgul assume the production of 20 tons of copper as slag heaps of this time weigh about 200 tons (Lutz *et al*. 1991, S. 65). Anyway, it is always based on subjective sensations, which are beyond all calculation. In the case with Kargaly there is no possibility to determine true volumes of production in antiquity as the Russian industrialists worked subsequently on the ancient mines.

It is more real to estimate an area in which the Kargaly ores could be smelted as it is supposed that because of shortage of wood the ore was transported to Bashkiria and the Volga region. And, this conclusion is drawn almost exclusively by analogy with methods of the Russian industrialists of the 18-19th centuries (Chernykh

1997, p. 68; 2002, p. 104; Kargaly 2002, p. 49). In the areas of the mass production of metal focused on its delivery to other areas the deforestation took place very often. It happened on the Cyprus where Strabo described the mighty woods which were annihilated then (Forbes 1958, p. 18; Constantinou 1982, p. 22). In the southwest of Tanzania, in the developed area of traditional metallurgy, the woods were reduced probably for the same reason (Barndon 1996, p. 62).

In the steppe Orenburg region the forests were incomparable less than in these two areas. The hypothesis about the ore export from this mining area was provoked by works on Kargaly of Spanish experts who have come to the following conclusions. In contrary to the idea that metallurgical production promoted the deforestation, palynological studies have shown that the situation with forest resources did not change, and during the Bronze Age the areas of forests were the same as now (Kargaly 2002a, p. 165). It is supposed that in the Timber-Grave time about 100,000 tons of copper were extracted. By S. Rovira's calculations, this production would demand every year 37,500 cubic meter of wood, i.e. 150ga of forest annually. Around Kargaly the forest occupies 2.6% of the area. And not the all forest could be used for metallurgical operations. If to assume the volumes of production suggested by Chernykh, it was required 9,000 hectares of the forest at a six-year cycle of restoration. Proceeding from the percent of forests in this area, the exploitation of the territory of 3,500 km^2 (350,000 hectares) was necessary, while the area of Kargaly is 7 times less (Rovira 1999 p. 110; García *et al.* 2000, p. 34, 35). It is necessary to take into account that it is extreme figures, and it is possible, these extreme figures were not used completely.

Other estimates are also possible. According to P.F. Kuznetsov's very rough estimates, during the Middle Bronze Age the population of the Volga-Ural region was about 50,000 people (Kuznetsov 1991, p. 14). For the Transurals during this period I have assumed a figure of 20-30,000 people (Grigoriev 1999, p. 125). For the Tobol valley, the area of 650 km^2 the Late Bronze Age population of 600-1400 people is supposed. And it is for the valley, the instead watersheds were less inhabited (Evdokimov, Povalyaev 1989). If we assume that the population of the territory (1 million km^2) which was provided with metal from the Kargaly mines, was 1 million people (and this figure, for certain, is very exaggerated), during the 300 years' exploitation in the Timber-Grave time each of them, including women and children, received ***annually*** 333 g copper. A family of eight people had, thus, near 2.7 kg of this metal annually. And many other deposits were mined. Besides, for certain, the metal scrap was the main raw materials at the production of tools. Therefore it seems to me that despite the obvious importance of the Kargaly mines for providing with metal in Eastern Europe, the estimation of their productivity is heavily overestimated.

It is necessary to remind that there is no possibility to distinguish ancient mines from those of the 18-19th centuries, and identical scales of mining during these epochs are only postulated. Geological investigations demonstrate that the richest ores on Kargaly contained 4-5% copper. Thus the ores of the upper horizon exploited in antiquity were poorer. They contained only 1.5% of copper. E.N. Chernykh supposes that in antiquity they were probably much richer and refers to evidences from the 18th century (Kargaly 2002, p. 23, 28, 39). But after all the opinion about poorer ores of the upper horizon is based on geological studies which cannot be ignored so simply. There are data that originally Russian industrialists exploited ancient dumps, and in antiquity poor ores were not extracted. According to P. Rychkov (traveler of the 18th century), ancient people took only the ore with the contents of more than 10% copper (Kargaly 2002, p. 45, 46). It is possible to assume that ores in the upper horizon were nevertheless not so rich, although there were, of course, richer inclusions which were mined. Therefore the volumes of ancient production were much less than that is represented. Especially, as no proof in favor of huge volumes of ancient works has been brought. It is based only on indirect signs.

One of them is comparison of quantity of finds on the settlements of Gorny and Arkaim. On Gorny within the area of 880m^2 about 4,500 pieces of slag, a huge number of ceramics, bones and other finds have been found. On Arkaim the excavated area is 10 times more, and the quantity of finds has an inverse proportion

(Chernykh 2002, p. 97, 98). Probably, from this the superiority of Gorny and its unique role in providing of Eastern Europe with metal has to follow. However similar comparisons are not quite true as they are settlements of different type. Arkaim just was striking its excavators, who got used to work on the standard settlements of steppe Eurasia with a lot of finds, by its poverty of the cultural layer. It is explained by the fact that there are, practically, no interhousing spaces on the settlements of Sintashta culture, and the excavators deal, mainly, with those finds which lie on the floors of dwellings and which were not taken away when the settlement was left. A tradition of continuous cleaning of dwellings and the adjacent territory took place. By comparison of quantity of finds on Gorny with some other settlements of the Late Bronze Age the difference will be not so notable.

There is also one more explanation. It should be kept in mind that the thoroughness of excavations of Gorny with sifting and washing layer was extraordinary, and methodical level of these works was very high. The area stated above was excavated for eight field seasons. The smallest fragments, often crumbs, of bones and slag, small drops of copper were fixed and accounted, that is not usually made on other settlements[13]. Another reason of these fantastic figures of finds is also that there is almost no on Gorny entire pieces of slag, as the slag was crushed for metal extraction. At the total of 4539 slag samples, its total weight is only 20 kg (Kuzminykh 2004, p. 101), and this figure does not strike any more. Historians of metallurgy know many examples when the weight of slag is many times more (e.g. see above about the slag heaps of Murgul) and do not hurry to call these objects the only source of metal of a huge region. Even on less known objects the amount of slag is much higher. On the Novoshulbinskoye settlement in the Altai on the area 108m^2 115 kg of slag is found (Sitnikov 2006, p. 150). This means, if to measure not by the quantity of fragments, but by the weight ratio (and only it defines the volumes of production), the layer saturation with slag on the Novoshulbinskoye settlement is 47 times more than that on Gorny! By the way, on the Sintashta settlement also the gross weight of slag was more, but there the larger area was excavated.

One more argument against the mass export of metal from the Kargaly mines is a low effectiveness of local smelting technology. At all complexity of smelting of the oxidized ores in silicate rocks it is amazing that for the long period of exploitation of these mines metallurgists did not manage to solve this problem. The percent of copper extraction from ore was too low. It seriously influenced the labor costs, did these smelting operations ineffective, and for the mass production the question of profitability was important also in the ancient time.

The transportation of ore from Kargaly is even more doubtful as in the Cisural and Volga regions it was possible to find closer ore sources, besides with the ore more convenient for smelting. Why it was needed to transport so problem ore in so remote areas? At last, we have seen that slag in the Volga region and Bashkiria has other mineral and chemical compositions, it was smelted from other ores. However there is also mineralogical difference of the Kargaly slag with slags of the western areas of Orenburg. Therefore, even there some local sources were exploited.

Therefore, noting the fact that the Kargaly mines were an important mining center, and the Gorny settlement is a site, certainly, interesting and perfectly investigated, it is necessary emphasize that a tendency to their absolutization, appeared recently, is not supported by facts.

Basing on the results of slag analyses discussed above, we can draw a conclusion that in the territory of the Orenburg Cisural area local deposits in the copper sandstones were exploited. It seems to be the most probable that smelting of ore from Kargaly was carried out on the settlements adjoining this ore field. Radius of export of the Kargaly ore was, thus, no more than 50-90km. In general, in antiquity the distant transportation of raw

[13] Recently, working on the Eneolithic settlements of the Vera Island, we apply such careful methods. On one of the settlements on the west shore of the island (Vera Island 7) in the excavated area of 16m^2 the number of finds was about 30,000, but I don't think that this was any outstanding settlement in the system of Ural Eneolithic.

materials, apparently, did not practice. The reverse examples are known, but not often. In the Roman time the best iron ore of Italy was mined on Elba. But due to the lack of forest it was delivered to Liguria by sea (Forbes 1958, p. 18). For the mighty Roman merchant navy it was not so impossible operation. Besides, after the production of bloom in furnace it was more convenient to start it forge promptly. But usually even in the iron production nobody transported ore, also the transportation of charcoal is known because it was much easier. Judging from ethnographic data, in Africa in the period when there was a great production, charcoal sometimes imported by caravans from remote areas, in a distance of 20 km and more (Goucher, Herbert 1996, p. 49). But it was some tens kilometers, instead of one hundred kilometers with ore transportation!

Especially it concerns the copper ore. Even if to assume that during the Bronze Age richer ores with the copper content of 10% were selected, which were carefully sorted and enriched near mines, all the same it were absolutely unreasonable expenses, especially as when smelting the oxidized sandstone ores the metal losses in the form of copper and cuprite were very great. Therefore it was incomparable simpler and cheaper to deliver the finished metal. Probably, in those situations when the forest resources of the region were exhausted, the production on ancient mines faded.

There is an axiom in archaeometallurgy: for ancient metallurgists the general stores of a deposit were absolutely unimportant. And it is true for any area. Such ideas, for example, are stated for Transcaucasia (Kuparadze et al. 2008, p. 251). The stores of a deposit are important for industrial production when it is necessary to incur essential costs for investigations, building of plants, mines, concentrating factories and all other infrastructure. In the Bronze Age the presence of ore on the surface, its convenience to smelting, proximity of mine to the settlement was the most important. And two last factors completely exclude the possibility of ore export from Kargaly to other regions. Therefore Yu.I. Kolev was absolutely right when he noted that in providing of Eastern Europe with metal the small deposits near settlements, such as Mikhaylo-Ovsyanka, played immeasurably larger role (Kolev 2010, S. 16, 17). A good example is the discovery in the northeast of the Samara region of traces of ore mining from copper sandstones and the settlement of Kibit I (Fig. 9-1.) where this ore was smelted (Kuznetsov et al. 2005). Therefore the problem of existence of local smelting of ore from the copper sandstones is only a problem of a level of our knowledge about this or that territory. It is confirmed also by a situation in the west, near the Don and Seversky Donets.

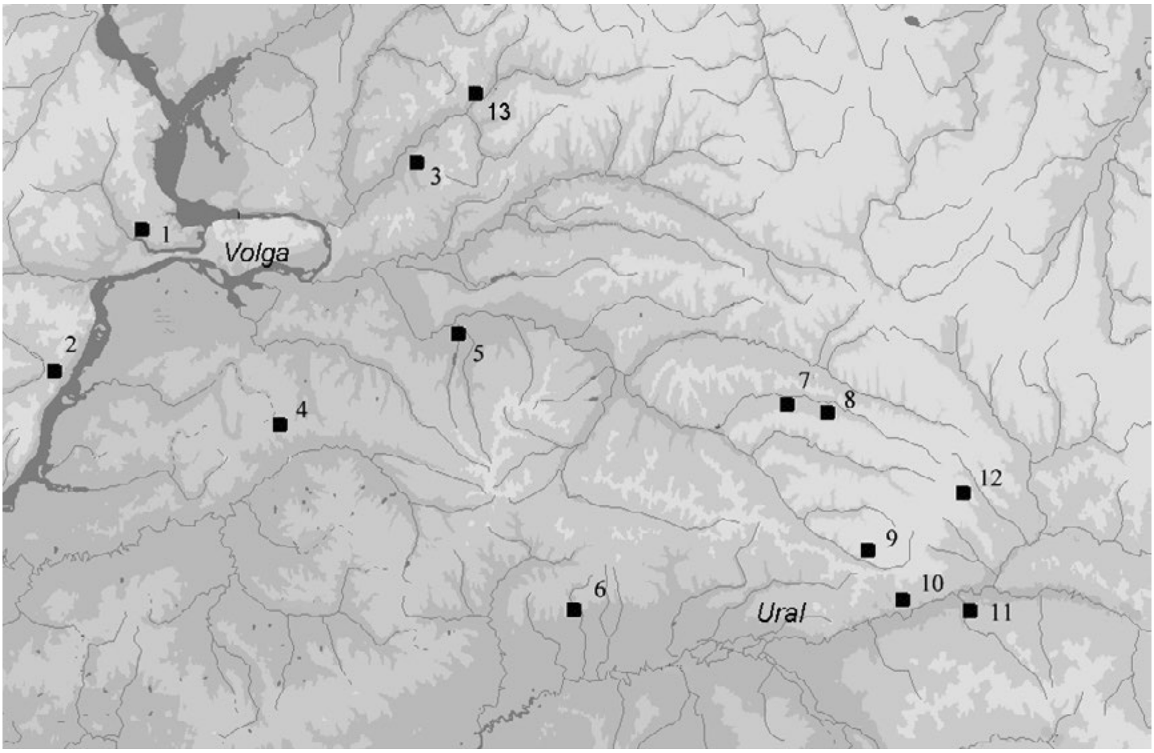


FIG. 9-1. MAP OF SITES IN THE VOLGA AND ORENBURG REGIONS: 1 – SHIGONSKOYE II; 2 – LIPOVII OVRAG; 3 – POPOVO OZERO; 4 – MIKHAYLO-OVSYANKA; 5 – SYEZH'YE; 6 – KUZMINKOVSKOYE; 7 – IVANOVSKOYE; 8 – TOKSKOYE; 9 – POKROVSKOE; 10 – RODNIKOVSKOYE; 11 – NIZHNYAYA PAVLOVKA; 12 – GORNY, 13 – KIBIT I.

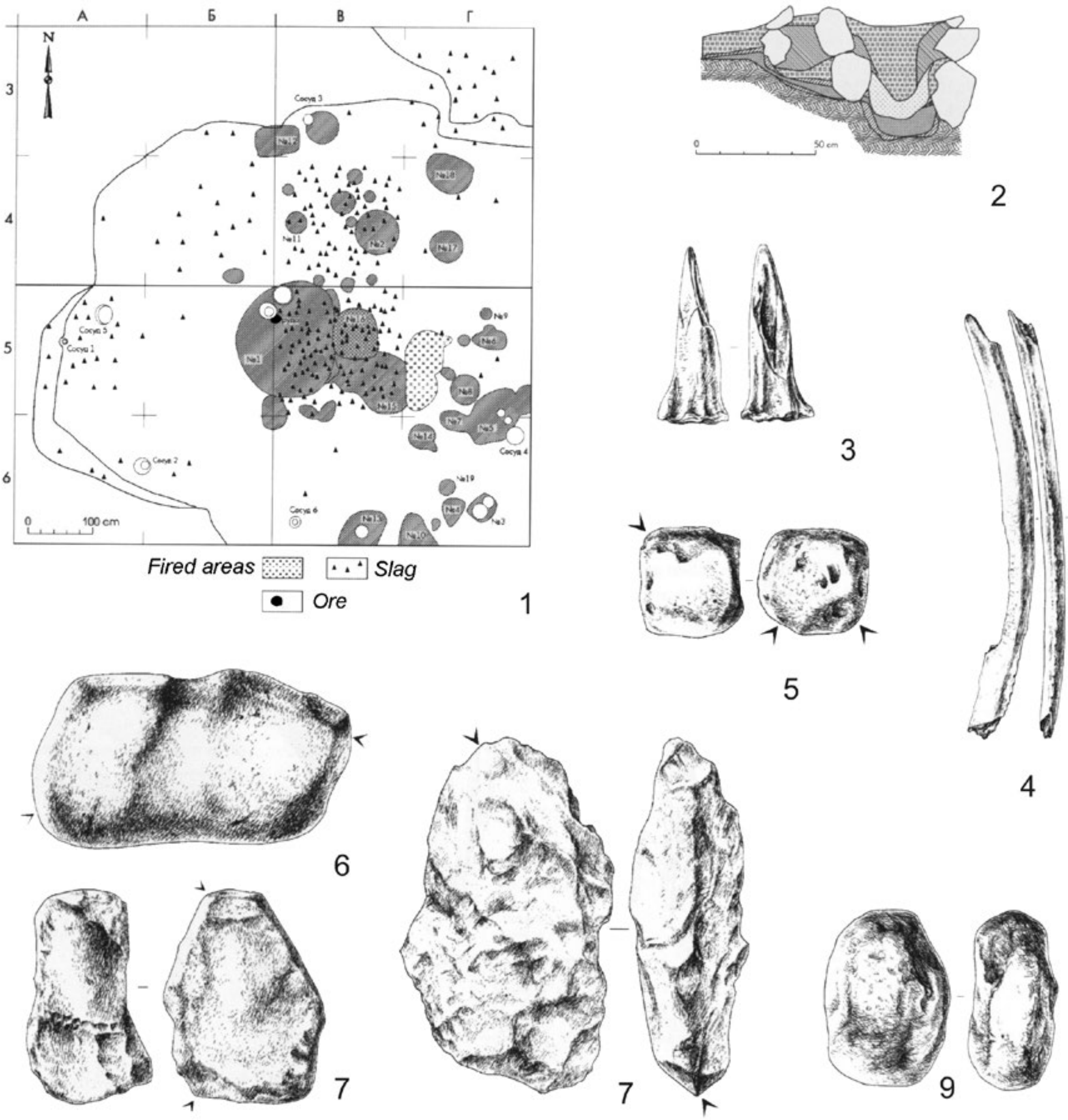


Fig. 9-2. Settlement of Mikhaylo-Ovsyanka (after Kolev, 2010). 1 – Dwelling 1, 2 – cross-section of the furnace (construction 26), bone (3, 4) and stone tools (5-9) for ore crushing.

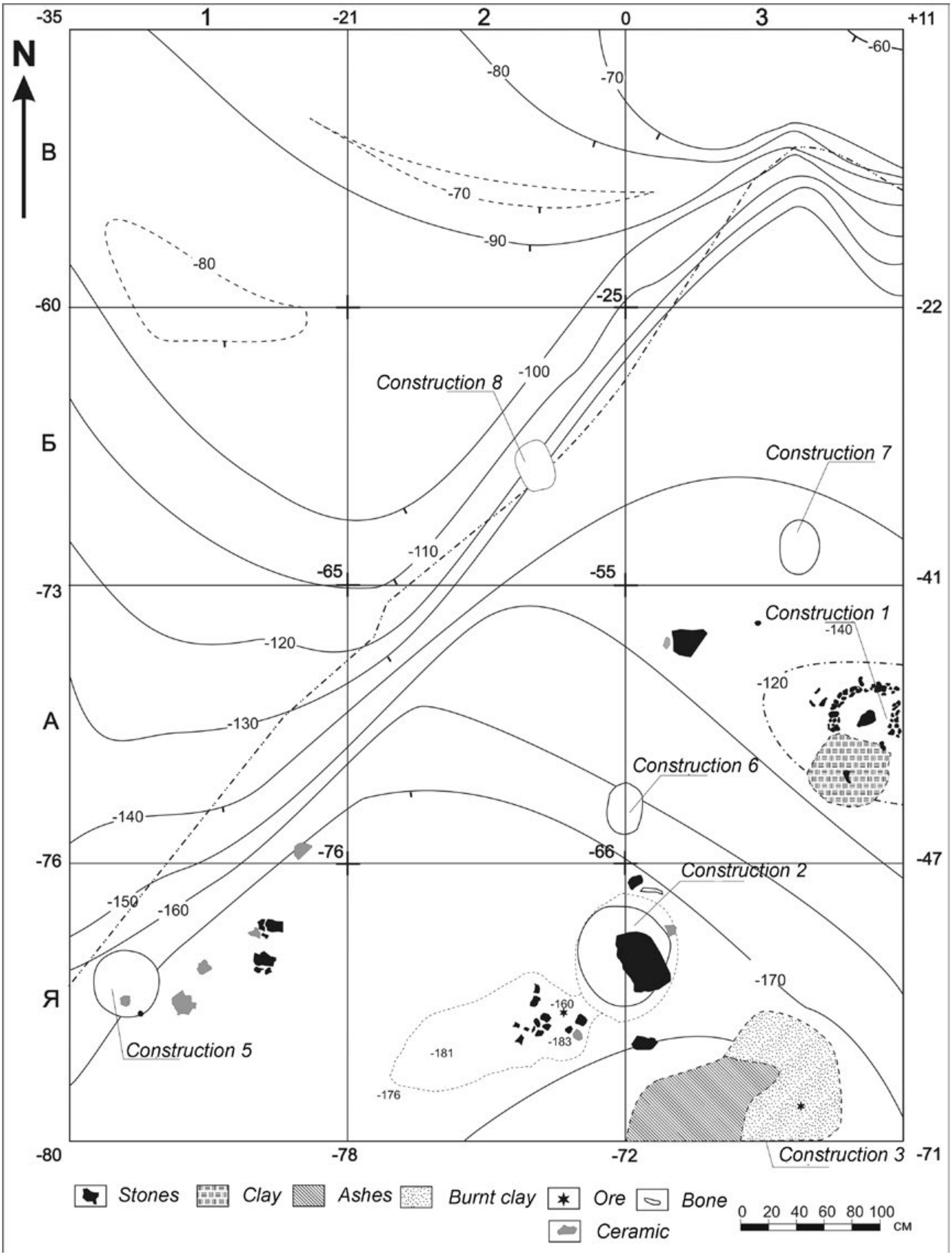


FIG. 9-3. CONSTRUCTIONS ON THE SETTLEMENT OF KIBIT I (AFTER KUZNETSOV).

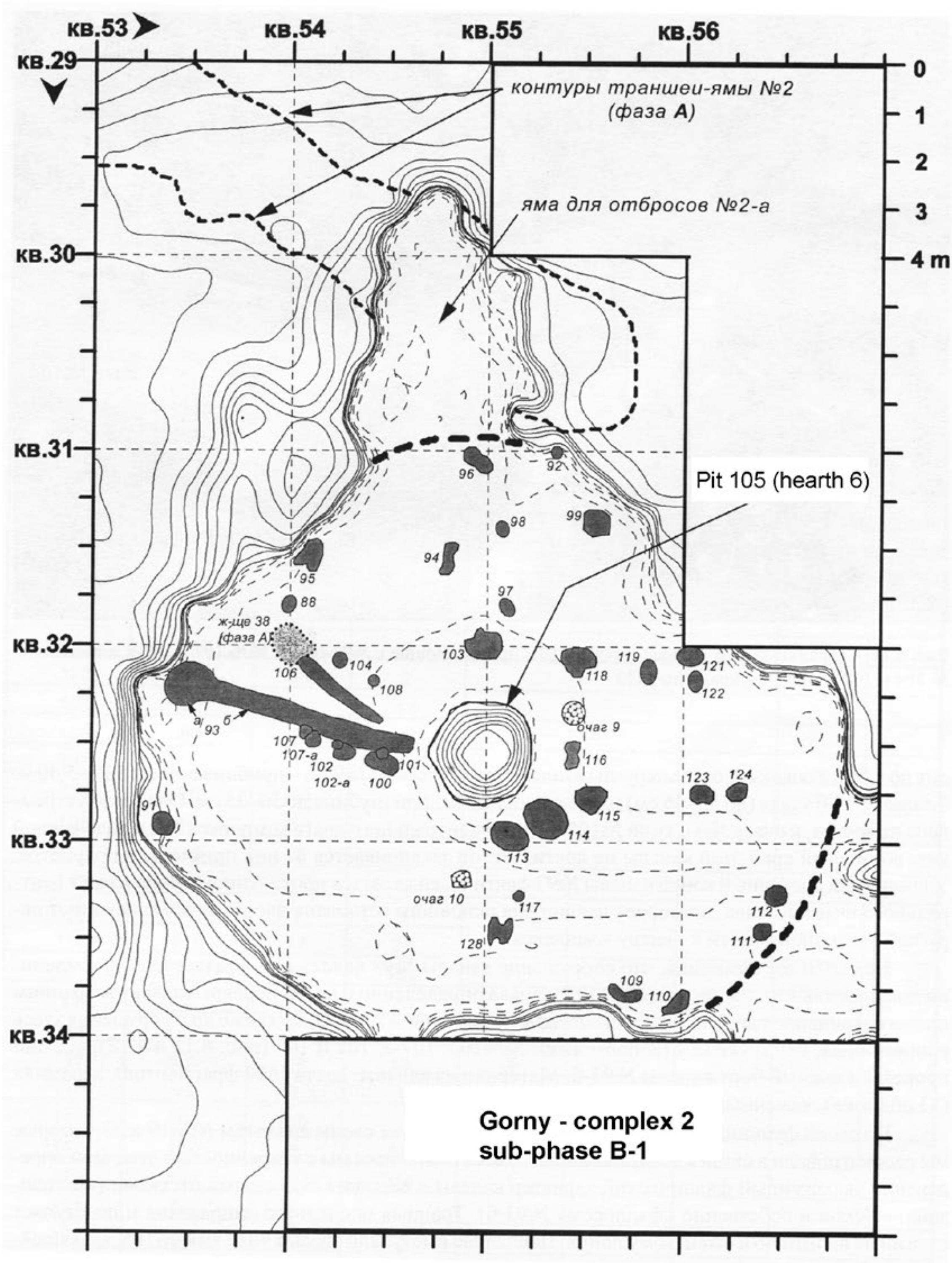


FIG. 9-4. COMPLEX 2 OF THE GORNY SETTLEMENT (KARGALY, 2002A, FIG. 4.11).

Tab. 9-5. Forms of slag in the Volga and Orenburg regions.

Form **Settlement**	**Heavy shapeless slag**	**Dense flat slag**	**Light shapeless slag**	**Slag crusts on the lining**	**Lining**
Lipovii Ovrag	1				
Popovo Ozero	8				
Shigonskoye II	4	6			
Syezh'ye	4				
Kuzminkovskoye	6				
Ivanovskoye	6				
Tokskoye	5				
Pokrovskoe	15		3	1	
Rodnikovskoye	14			2	1
Nizhnyaya Pavlovka	1		4		
Mikhaylo-Ovsyanka		?			
Gorny	?				

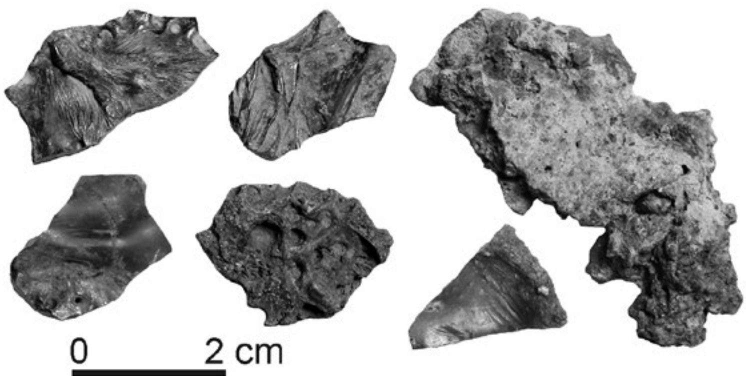


FIG. 9-6. SLAGS FROM THE SETTLEMENT OF MIKHAYLO-OVSYANKA.

Tab. 9-7. Bulk (wet) chemical analyses of slag from the Orenburg area made in the Chemical laboratory of the Chelyabinsk geological expedition (%).

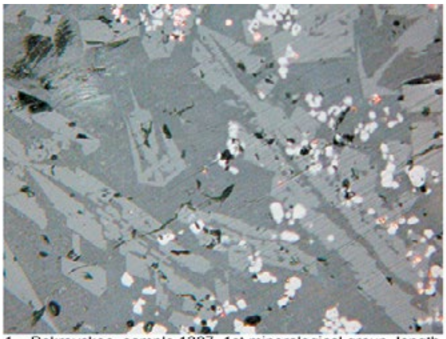
№	Site	Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	MnO	Cu	SO_3
1285	Kuzminkovskoye	slag	40.40	3.46	36.77	7.53	1.02	0.46	0.07	4.92	0.04
1303-1	Ivanovskoye	slag	40.00	4.87	26.61	12.74	0.82	0.94	0.07	4.96	0.04
1304-1	Ivanovskoye	slag	51.38	4.03	26.01	5.79	1.63	2.14	0.07	5.84	0.04
1318-1	Pokrovskoe	slag	46.28	5.97	18.70	13.03	1.83	1.15	0.35	11.05	0.14
1333-1	Rodnikovskoye	slag	39.54	5.10	4.28	4.34	1.43	0.81	0.09	29.02	0.36
1344	Rodnikovskoye	slag	44.70	6.64	6.52	5.21	1.74	1.41	0.05	22.03	0.16
1355	Rodnikovskoye	slag	60.88	7.79	4.84	11.29	2.66	3.85	0.16	0.38	0.04
1356-2	Rodnikovskoye	slag	65.54	7.54	5.00	9.12	2.35	4.10	0.15	0.45	0.08

Tab. 9-8. Chemical analyses (XRF) of ore from the Kargaly mines made in the Activation Laboratories Ltd. Ancaster, Ontario, Canada (%).

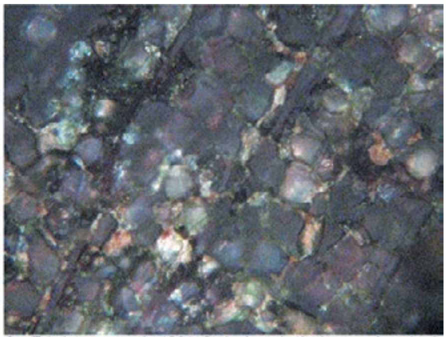
SAMPLE	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI	TOTAL	Ba	Sr	Y	Sc	Zr	Be	V
	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
2027	15.99	2.81	1.66	0.013	0.51	0.54	0.57	0.44	0.124	0.04	22.48	45.18	52580	3399	9	6	35	-1	32

Tab. 9-9. Ore and slag from the Volga and Orenburg regions: ratio of oxides decreasing viscosity (TiO_2, MgO, Fe_2O_3, MnO, K_2O, CaO, Na_2O) to those increasing it (SiO_2, Al_2O_3,) – coefficient Kz and coefficient of viscosity (Pa•s) at the temperature of 1400ºC calculated according to Bachmann et al. 1987.

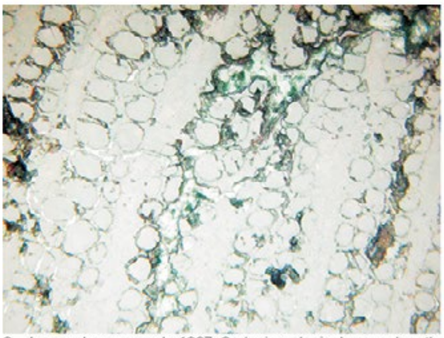
№	Site	Material	Kz	η 1400 (Pa·s)
Rus-1/1a	Mikhaylo-Ovsyanka	ore	1.07	4.14
Rus-1/1c	Mikhaylo-Ovsyanka	ore	0.51	9.25
Rus-1/1b	Mikhaylo-Ovsyanka	ore	0.31	15.17
Rus-1/2	Mikhaylo-Ovsyanka	ore	0.11	42.55
2103	Kargaly	ore	0.03	149.73
Gor-E09/3	Gorny	slag	2.15	1.83
Rus-1/6b	Mikhaylo-Ovsyanka	slag	1.46	2.9
1285	Kuzminkovskoye	slag	1.16	3.78
1303-1	Ivanovskoye	slag	1.03	4.31
1333-1	Rodnikovskoye	slag	0.9	4.97
1318-1	Pokrovskoe	slag	0.89	5.09
1304-1	Ivanovskoye	slag	0.75	6.09
Gor-E29/7	Gorny	slag	0.74	6.21
1344	Rodnikovskoye	slag	0.72	6.33
Gor-E10/1	Gorny	slag	0.64	7.17
Gor-E26/7	Gorny	slag	0.64	7.21
Gor-E01/5	Gorny	slag	0.63	7.3
Gor-E11/3	Gorny	slag	0.58	8
Gor-E12/1	Gorny	slag	0.57	8.13
Gor-E27/5	Gorny	slag	0.57	8.21
Gor-E28/6	Gorny	slag	0.49	9.48
Rus-1/6a	Mikhaylo-Ovsyanka	slag	0.45	10.42
Gor-E06/1	Gorny	slag	0.44	10.58
Gor-E23/5	Gorny	slag	0.39	11.97
Gor-E18/5	Gorny	slag	0.39	12.09
Gor-E25/6	Gorny	slag	0.37	12.8
Gor-E08/1	Gorny	slag	0.36	13.13
Gor-E20/3	Gorny	slag	0.34	13.86
1355	Rodnikovskoye	slag	0.34	14.04
Gor-E30/4	Gorny	slag	0.29	16.26
1356-2	Rodnikovskoye	slag	0.29	16.4
Gor-1-5	Gorny	slag	0.26	18.42
Gor-E22/5	Gorny	slag	0.21	23.04
Gor-E13/5	Gorny	slag	0.19	25.06
Gor-E19/8	Gorny	slag	0.17	28.41
Gor-E21/5	Gorny	slag	0.12	41.9
Gor-E24/5	Gorny	slag	0.1	47



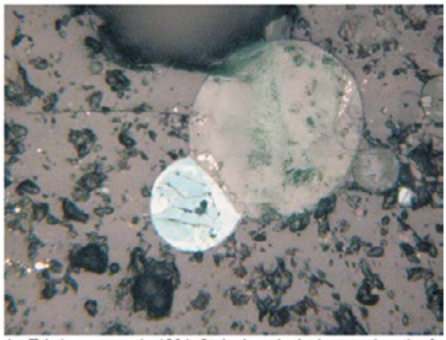
1 – Pokrovskoe, sample 1327, 1st mineralogical group, length of the photo is 0.62 mm: long skeletal crystals of fayalite (light grey) in the glass matrix (dark grey), small particles of magnetite (light) and small copper prills.



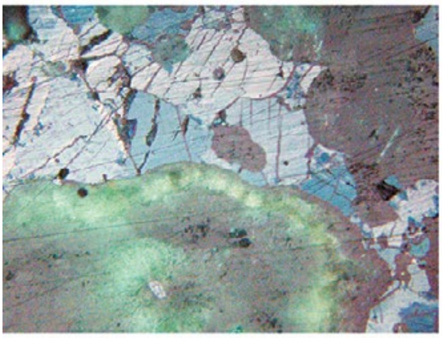
2 – Tokskoye, sample 1291, 2nd mineralogical group, length of the photo is 0.62 mm: sandstone with thin malachite 'cement'.



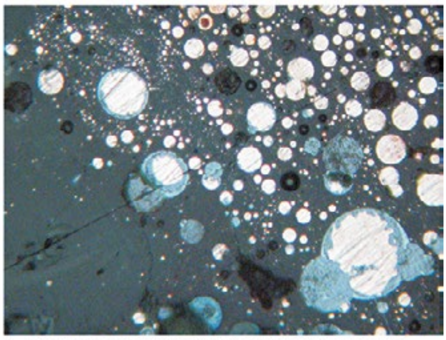
3 – Ivanovskoye, sample 1307, 2nd mineralogical group, length of the photo is 0.62 mm: sandstone with inclusions of malachite.



4 – Tokskoye, sample 1291, 2nd mineralogical group, length of the photo is 0.46 mm: large roundish grains of malachite (grey with greenish tint) with an adjoining to them molten prill of covellite (blue) in the glass matrix (dark grey), a large pore in the upper part.



5 – Ivanovskoye, sample 1304, 2nd mineralogical group, length of the photo is 0.62 mm: ore grain consisting of malachite (green) and covellite (blue).



6 – Rodnikovskoye, sample 1348, 2nd mineralogical group, length of the photo is 0.46 mm: accumulation of prills of copper and cuprite in the glass matrix.

Fig. 9-I. Microstructures of slag of the Orenburg area, reflected light: 1 – Pokrovskoe, sample 1327, 1st mineralogical group, length of the photo is 0.62 mm: long skeletal crystals of fayalite (light grey) in the glass matrix (dark grey), small particles of magnetite (light) and small copper prills. 2 – Tokskoye, sample 1291, 2nd mineralogical group, length of the photo is 0.62 mm: sandstone with thin malachite 'cement'. 3 – Ivanovskoye, sample 1307, 2nd mineralogical group, length of the photo is 0.62 mm: sandstone with inclusions of malachite. 4 – Tokskoye, sample 1291, 2nd mineralogical group, length of the photo is 0.46 mm: large roundish grains of malachite (grey with greenish tint) with an adjoining to them molten prill of covellite (blue) in the glass matrix (dark grey), a large pore in the upper part. 5 – Ivanovskoye, sample 1304, 2nd mineralogical group, length of the photo is 0.62 mm: ore grain consisting of malachite (green) and covellite (blue). 6 – Rodnikovskoye, sample 1348, 2nd mineralogical group, length of the photo is 0.46 mm: accumulation of prills of copper and cuprite in the glass matrix.

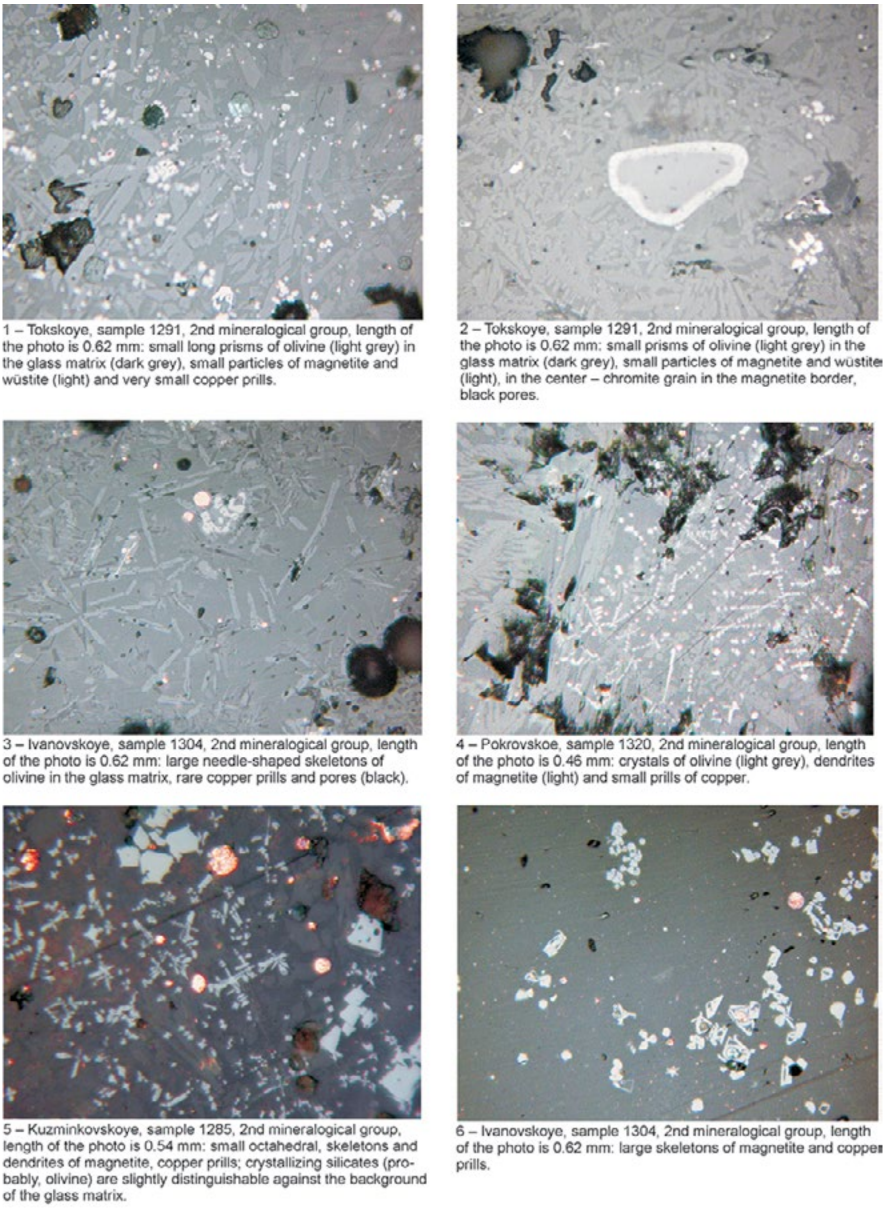
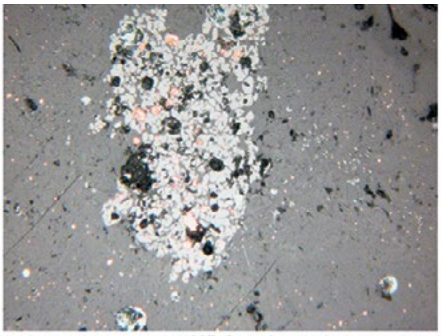
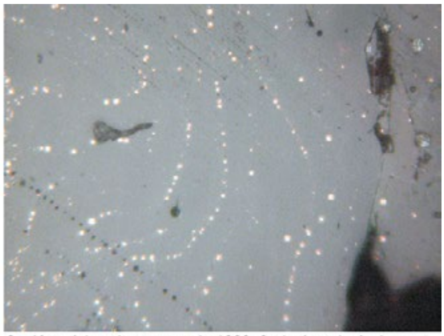


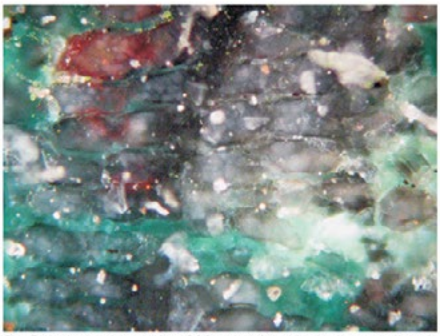
Fig. 9-II. Microstructures of slag of the Orenburg area, reflected light: 1 – Tokskoye, sample 1291, 2nd mineralogical group, length of the photo is 0.62 mm: small long prisms of olivine (light grey) in the glass matrix (dark grey), small particles of magnetite and wüstite (light) and very small copper prills. 2 – Tokskoye, sample 1291, 2nd mineralogical group, length of the photo is 0.62 mm: small prisms of olivine (light grey) in the glass matrix (dark grey), small particles of magnetite and wüstite (light), in the center – chromite grain in the magnetite border, black pores. 3 – Ivanovskoye, sample 1304, 2nd mineralogical group, length of the photo is 0.62 mm: large needle-shaped skeletons of olivine in the glass matrix, rare copper prills and pores (black). 4 – Pokrovskoe, sample 1320, 2nd mineralogical group, length of the photo is 0.46 mm: crystals of olivine (light grey), dendrites of magnetite (light) and small prills of copper. 5 – Kuzminkovskoye, sample 1285, 2nd mineralogical group, length of the photo is 0.54 mm: small octahedral, skeletons and dendrites of magnetite, copper prills; crystallizing silicates (probably, olivine) are slightly distinguishable against the background of the glass matrix. 6 – Ivanovskoye, sample 1304, 2nd mineralogical group, length of the photo is 0.62 mm: large skeletons of magnetite and copper prills.



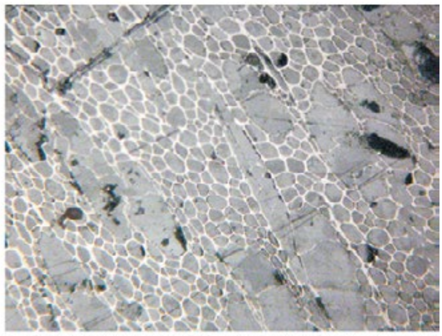
1 – Ivanovskoye, sample 1307, 2nd mineralogical group, length of the photo is 0.62 mm: accumulation of fused particles of magnetite, which keeps borders of a primary ore grain. It contains inclusions of copper sulfide (blue ones in the upper part of the 'grain') and small copper prills.



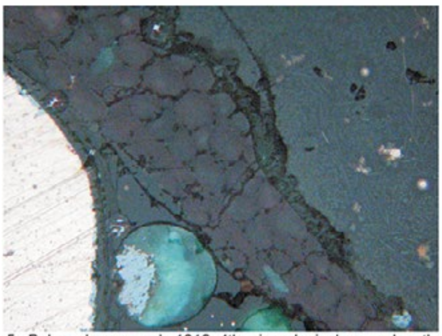
2 – Kuzminkovskoye, sample 1283, 2nd mineralogical group, length of the photo is 0.46 mm: curved chains of small copper prills.



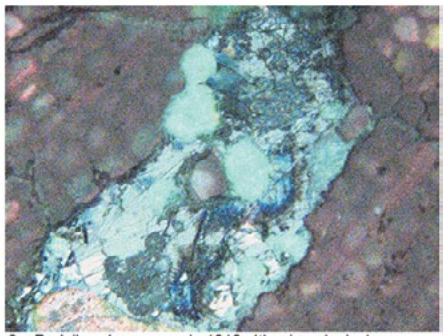
3 – Pokrovskoe, sample 1309, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: sandstone with malachite 'cement'.



4 – Pokrovskoe, sample 1312, 4th mineralogical group, length of the photo is 0.46 mm: fragment of sandstone.



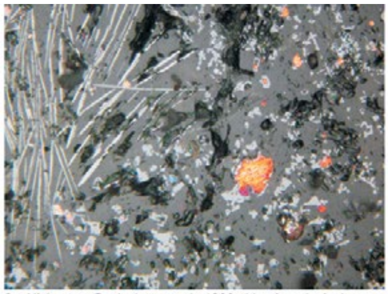
5 –Pokrovskoe, sample 1312, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: fragment of sandstone (diagonal strip through the photo), malachite; large globule of copper on the left, small needles of delafossite and small copper prills on the right.



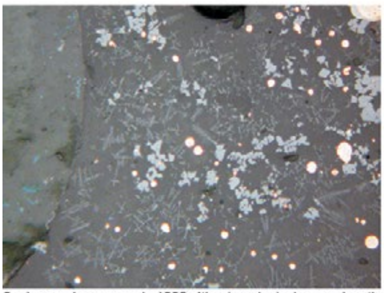
6 – Rodnikovskoye, sample 1312, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: malachite and covellite in sandstone.

Fig. 9-III. Microstructures of slag of the Orenburg area, reflected light: 1 – Ivanovskoye, sample 1307, 2nd mineralogical group, length of the photo is 0.62 mm: accumulation of fused particles of magnetite, which keeps borders of a primary ore grain. It contains inclusions of copper sulfide (blue ones in the upper part of the 'grain') and small copper prills. 2 – Kuzminkovskoye, sample 1283, 2nd mineralogical group, length of the photo is 0.46 mm: curved chains of small copper prills. 3 – Pokrovskoe, sample 1309, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: sandstone with malachite 'cement'. 4 – Pokrovskoe, sample 1312, 4th mineralogical group, length of the photo is 0.46 mm: fragment of sandstone. 5 –Pokrovskoe, sample 1312, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: fragment of sandstone (diagonal strip through the photo), malachite; large globule of copper on the left, small needles of delafossite and small copper prills on the right. 6 – Rodnikovskoye, sample 1312, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: malachite and covellite in sandstone.

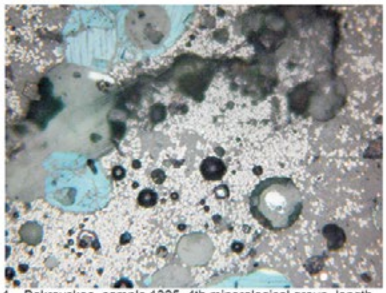
1 – Ivanovskoye, sample 1305, 4th mineralogical group, length of the photo is 0.46 mm: small needles of delafossite, copper and malachite among the fragments of sandstone.



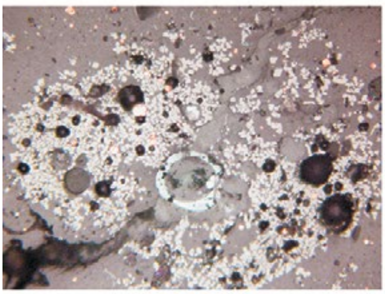
2 – Nizhnyaya Pavlovka, sample 1286, 4th mineralogical group, length of the photo is 0.46 mm: octahedral and skeletons of magnetite (light), copper prils and needles of delafossite. Some prills of copper are shapeless, magnetite forms around them.



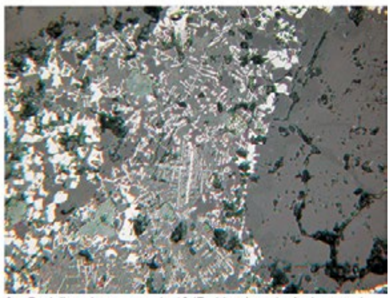
3 – Ivanovskoye, sample 1305, 4th mineralogical group, length of the photo is 0.46 mm: particles, skeletons and dendrites of magnetite (light), copper prills in the glass matrix; a large grain of malachite with small inclusions of covellite (blue) on the left. Some copper prills (in the upper right corner) have a thin sulfide border.



4 – Pokrovskoe, sample 1325, 4th mineralogical group, length of the photo is 0.62 mm: accumulation of magnetite particles keeping the form of a primary disintegrated grain, with inclusions of small copper prills. Grains of covellite (blue) and malachite (grey-greenish on the left among the grains of covellite), pores (black).

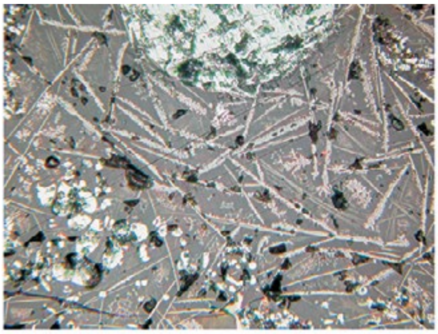


5 – Pokrovskoe, sample 1325, 4th mineralogical group, length of the photo is 0.62 mm: Round grain of chrysocolla in covellite border and copper prills in the accumulation of magnetite particles disintegrating from a larger grain.

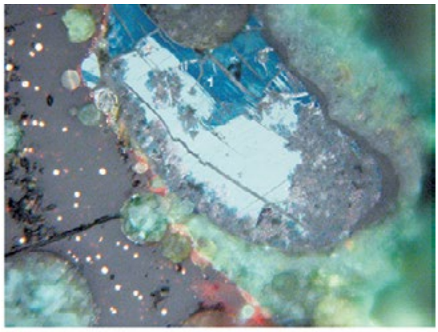


6 – Rodnikovskoye, sample 1347, 4th mineralogical group, l ength of the photo is 0.46 mm: quartz grain (dark grey on the right and on the left above), and particles, skeletons and dendrites of magnetite (light), and small grains of malachite (greenish).

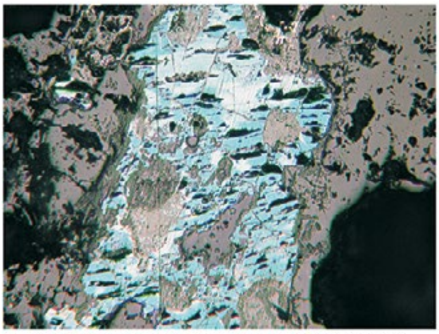
Fig. 9-IV. Microstructures of slag of the Orenburg area, reflected light: 1 – Ivanovskoye, sample 1305, 4th mineralogical group, length of the photo is 0.46 mm: small needles of delafossite, copper and malachite among the fragments of sandstone. 2 – Nizhnyaya Pavlovka, sample 1286, 4th mineralogical group, length of the photo is 0.46 mm: octahedral and skeletons of magnetite (light), copper prils and needles of delafossite. Some prills of copper are shapeless, magnetite forms around them. 3 – Ivanovskoye, sample 1305, 4th mineralogical group, length of the photo is 0.46 mm: particles, skeletons and dendrites of magnetite (light), copper prills in the glass matrix; a large grain of malachite with small inclusions of covellite (blue) on the left. Some copper prills (in the upper right corner) have a thin sulfide border. 4 – Pokrovskoe, sample 1325, 4th mineralogical group, length of the photo is 0.62 mm: accumulation of magnetite particles keeping the form of a primary disintegrated grain, with inclusions of small copper prills. Grains of covellite (blue) and malachite (grey-greenish on the left among the grains of covellite), pores (black). 5 – Pokrovskoe, sample 1325, 4th mineralogical group, length of the photo is 0.62 mm: Round grain of chrysocolla in covellite border and copper prills in the accumulation of magnetite particles disintegrating from a larger grain. 6 – Rodnikovskoye, sample 1347, 4th mineralogical group, length of the photo is 0.46 mm: quartz grain (dark grey on the right and on the left above), and particles, skeletons and dendrites of magnetite (light), and small grains of malachite (greenish).



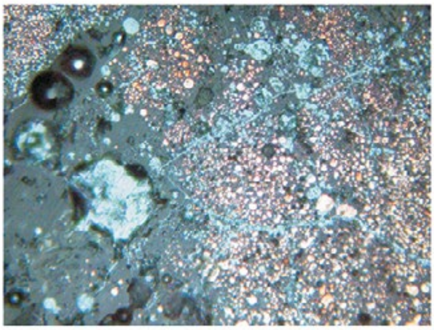
1 – Pokrovskoe, sample 1311, 4th mineralogical group, length of the photo is 0.54 mm: large grain of malachite (light green), prills of cuprite (light) and needles of dela-fossite, on edges of the latter and around the dendrites of cuprite grow.



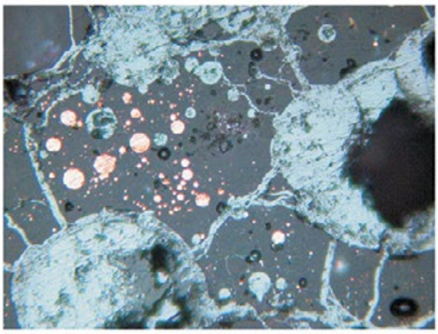
2 – Pokrovskoe, sample 1313, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: large grain of covellite (blue) included into the malachite grain (light green); small copper prills nearby in the glass matrix.



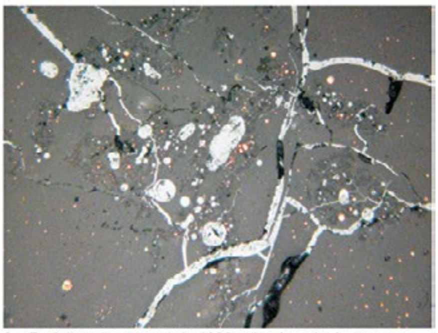
3 – Rodnikovskoye, sample 1352, 4th mineralogical group, length of the photo is 1.55 mm: large grain of covellite.



4 – Kuzminkovskoye, sample 1280, 4th mineralogical group, l ength of the photo is 0.62 mm: Accumulation of copper prils, prills and grains of cuprite (blue). Cuprite fills also cracks in the glass matrix.

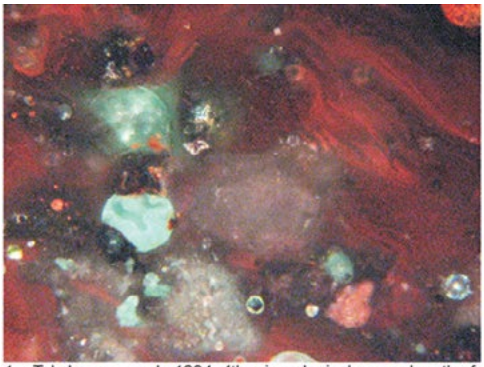


5 – Rodnikovskoye, sample 1331, 4th mineralogical group, length of the photo is 0.62 mm: accumulation of copper prills and large globules of cuprite (blue) that fills cracks.

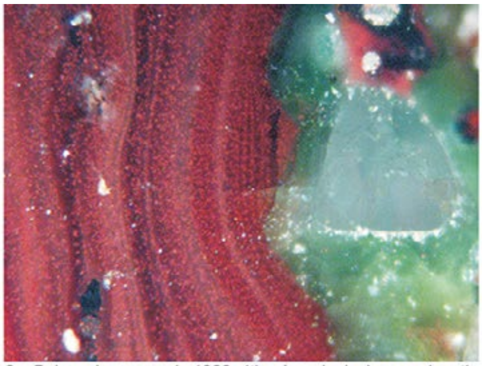


6 – Rodnikovskoye, sample 1332, 4th mineralogical group, length of the photo is 0.62 mm: small copper prills, Large cuprite globules and fillings of cracks.

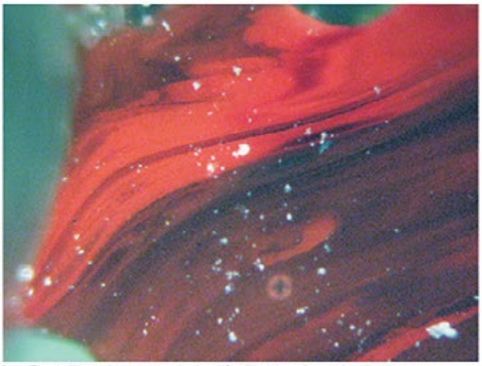
Fig. 9-V. Microstructures of slag of the Orenburg area, reflected light: 1 – Pokrovskoe, sample 1311, 4th mineralogical group, length of the photo is 0.54 mm: large grain of malachite (light green), prills of cuprite (light) and needles of delafossite, on edges of the latter and around the dendrites of cuprite grow. 2 – Pokrovskoe, sample 1313, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: large grain of covellite (blue) included into the malachite grain (light green); small copper prills nearby in the glass matrix. 3 – Rodnikovskoye, sample 1352, 4th mineralogical group, length of the photo is 1.55 mm: large grain of covellite. 4 – Kuzminkovskoye, sample 1280, 4th mineralogical group, length of the photo is 0.62 mm: Accumulation of copper prils, prills and grains of cuprite (blue). Cuprite fills also cracks in the glass matrix. 5 – Rodnikovskoye, sample 1331, 4th mineralogical group, length of the photo is 0.62 mm: accumulation of copper prills and large globules of cuprite (blue) that fills cracks. 6 – Rodnikovskoye, sample 1332, 4th mineralogical group, length of the photo is 0.62 mm: small copper prills, Large cuprite globules and fillings of cracks.



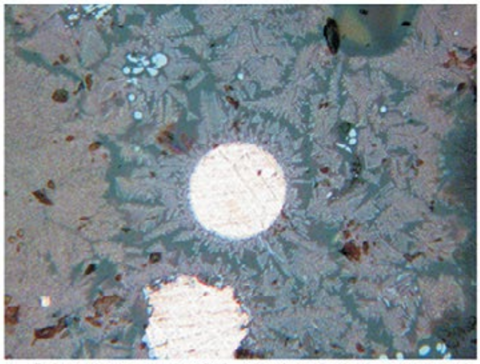
1 – Tokskoye, sample 1294, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: strips from small prills of copper and cuprite painting slag in the red color, fine roundish grains of malachite and chrysocolla (green).



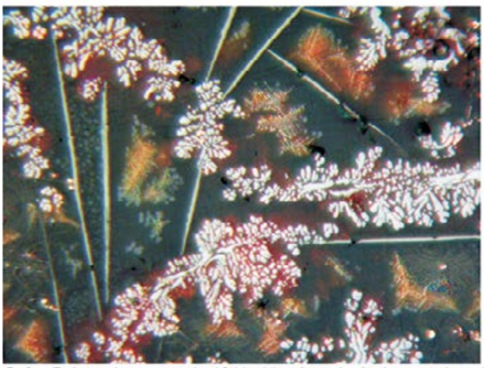
2 – Pokrovskoe, sample 1322, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: strips from small prills of copper and cuprite, quartz grain with chrysocolla on the right

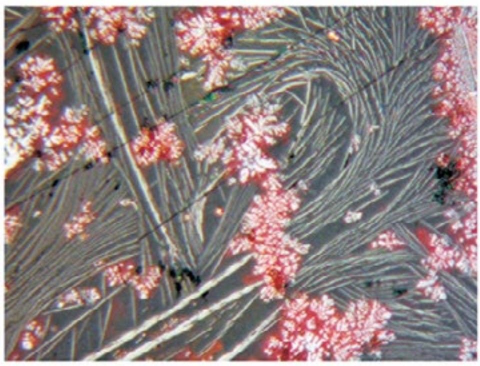


3 – Rodnikovskoye, sample 1346, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: strips from small prills of copper and cuprite.



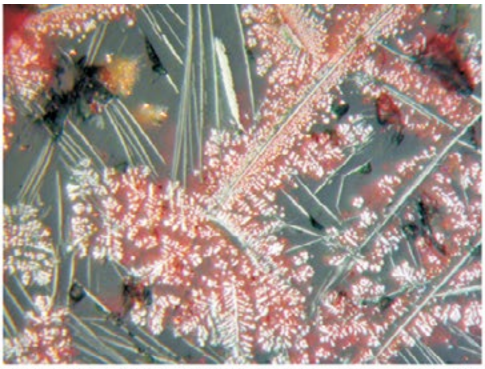
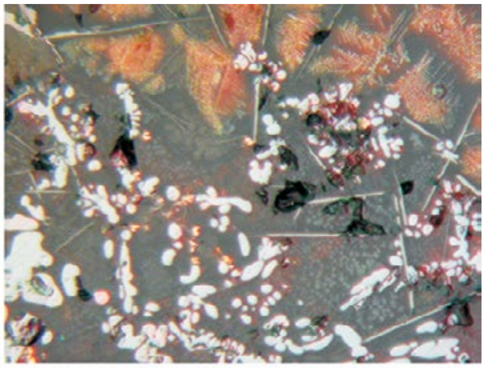
4 – Pokrovskoe, sample 1310, 4th mineralogical group, length of the photo is 0.46 mm, crossed nicols: formation of cuprite dendrites round a globule of copper.



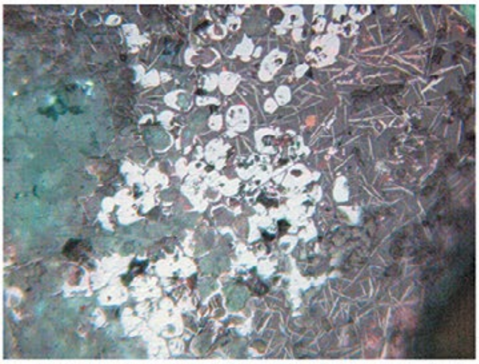


5, 6 – Pokrovskoe, sample 1311, 4th mineralogical group, length of the photo is 0.46 mm, crossed nicols: dendrites of cuprite and needles of delafossite.

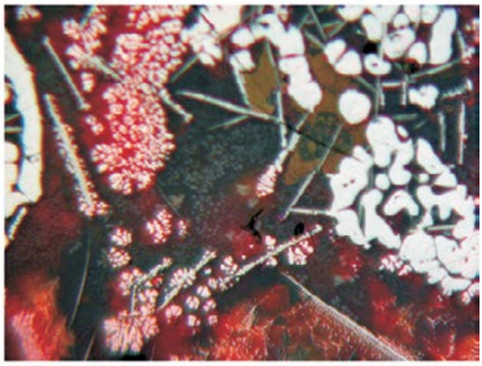
FIG. 9-VI. MICROSTRUCTURES OF SLAG OF THE ORENBURG AREA, REFLECTED LIGHT: 1 – TOKSKOYE, SAMPLE 1294, 4TH MINERALOGICAL GROUP, LENGTH OF THE PHOTO IS 0.62 MM, CROSSED NICOLS: STRIPS FROM SMALL PRILLS OF COPPER AND CUPRITE PAINTING SLAG IN THE RED COLOR, FINE ROUNDISH GRAINS OF MALACHITE AND CHRYSOCOLLA (GREEN). 2 – POKROVSKOE, SAMPLE 1322, 4TH MINERALOGICAL GROUP, LENGTH OF THE PHOTO IS 0.62 MM, CROSSED NICOLS: STRIPS FROM SMALL PRILLS OF COPPER AND CUPRITE, QUARTZ GRAIN WITH CHRYSOCOLLA ON THE RIGHT. 3 – RODNIKOVSKOYE, SAMPLE 1346, 4TH MINERALOGICAL GROUP, LENGTH OF THE PHOTO IS 0.62 MM, CROSSED NICOLS: STRIPS FROM SMALL PRILLS OF COPPER AND CUPRITE. 4 – POKROVSKOE, SAMPLE 1310, 4TH MINERALOGICAL GROUP, LENGTH OF THE PHOTO IS 0.46 MM, CROSSED NICOLS: FORMATION OF CUPRITE DENDRITES ROUND A GLOBULE OF COPPER. 5, 6 – POKROVSKOE, SAMPLE 1311, 4TH MINERALOGICAL GROUP, LENGTH OF THE PHOTO IS 0.46 MM, CROSSED NICOLS: DENDRITES OF CUPRITE AND NEEDLES OF DELAFOSSITE.

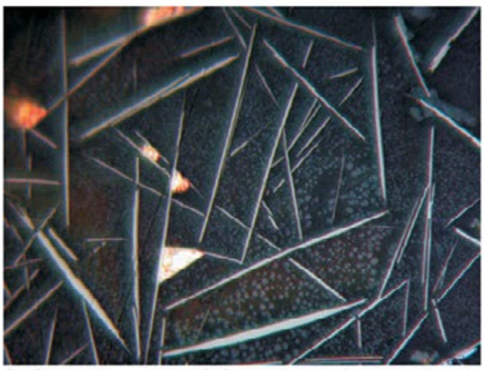
1, 2 – Pokrovskoe, sample 1311, 4th mineralogical group, length of the photo is 0.46 mm, crossed nicols: dendrites and deformed globules of cuprite and needles of delafossite.



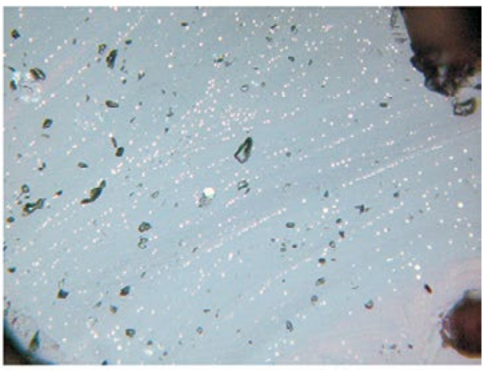
3 – Pokrovskoe, sample 1312, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: disintegrating malachite grains (greenish), prills of cuprite and needles of delafossite.



4 – Pokrovskoe, sample 1319, 4th mineralogical group, length of the photo is 0.46 mm, crossed nicols: dendrites and molten inclusions of cuprite and needles of delafossite.

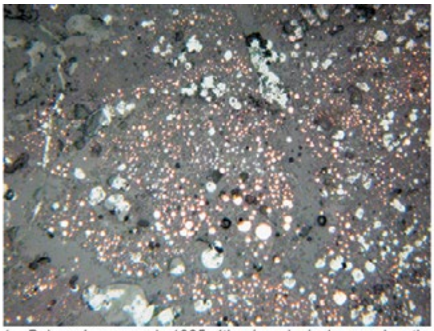


5 – Pokrovskoe, sample 1319, 4th mineralogical group, length of the photo is 0.46 mm, crossed nicols: copper and needles of delafossite.

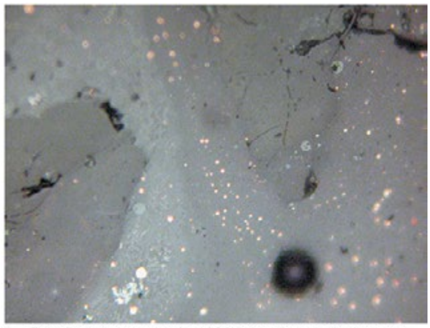


6 – Tokskoye, sample 1292, 4th mineralogical group, length of the photo is 0.62 mm: small prills of copper forming in some instances long curved chains.

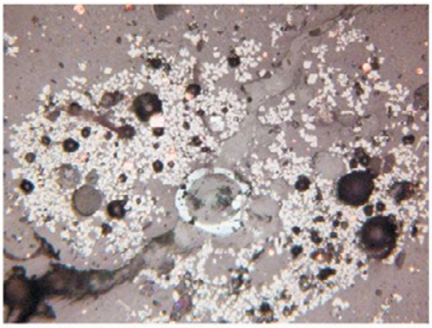
Fig. 9-VII. Microstructures of slag of the Orenburg area, reflected light: 1, 2 – Pokrovskoe, sample 1311, 4th mineralogical group, length of the photo is 0.46 mm, crossed nicols: dendrites and deformed globules of cuprite and needles of delafossite. 3 – Pokrovskoe, sample 1312, 4th mineralogical group, length of the photo is 0.62 mm, crossed nicols: disintegrating malachite grains (greenish), prills of cuprite and needles of delafossite. 4 – Pokrovskoe, sample 1319, 4th mineralogical group, length of the photo is 0.46 mm, crossed nicols: dendrites and molten inclusions of cuprite and needles of delafossite. 5 – Pokrovskoe, sample 1319, 4th mineralogical group, length of the photo is 0.46 mm, crossed nicols: copper and needles of delafossite. 6 – Tokskoye, sample 1292, 4th mineralogical group, length of the photo is 0.62 mm: small prills of copper forming in some instances long curved chains.



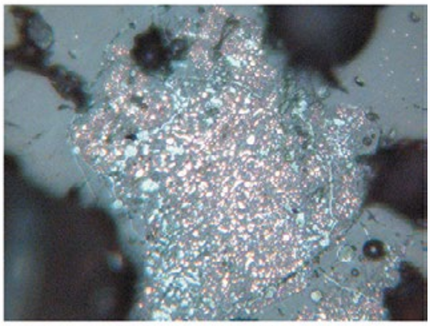
1 – Pokrovskoe, sample 1325, 4th mineralogical group, length of the photo is 0.62 mm: prills of copper and cuprite.



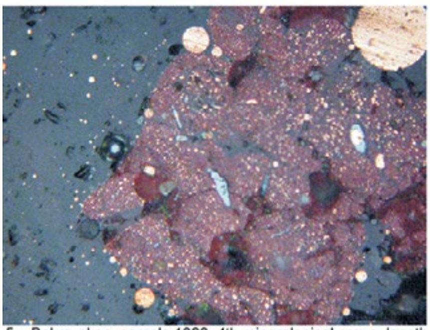
2 – Rodnikovskoye, sample 1332, 4th mineralogical group, length of the photo is 0.62 mm: quartz grains with fused borders and prills of copper, small skeletons of magnetite.



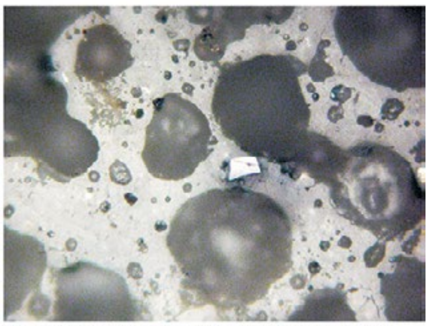
3 – Pokrovskoe, sample 1325, 4th mineralogical group, length of the photo is 0.62 mm: accumulation of magnetite particles disintegrating from a larger grain, round grain of chrysocolla within the border of covellite and copper prills.



4 – Tokskoye, sample 1293, 4th mineralogical group, length of the photo is 0.46 mm: accumulation of mol-ten inclusions of copper and cuprite keeping the form of a primary ore grain.



5 – Pokrovskoe, sample 1323, 4th mineralogical group, length of the photo is 0.62 mm: accumulation of molten inclusions of copper and cuprite keeping the form of a primary ore grain, long inclusions of unmolten sulfide (blue) in the center of the grain.



6 – Nizhnyaya Pavlovka, sample 1287, 4th mineralogical group, length of the photo is 0.62 mm: ceramic slag of the lining – very porous glass matrix with very small nuclei of olivine crystallization, small grains of quartz, rare small chromites.

Fig. 9-VIII. Microstructures of slag of the Orenburg area, reflected light: 1 – Pokrovskoe, sample 1325, 4th mineralogical group, length of the photo is 0.62 mm: prills of copper and cuprite. 2 – Rodnikovskoye, sample 1332, 4th mineralogical group, length of the photo is 0.62 mm: quartz grains with fused borders and prills of copper, small skeletons of magnetite. 3 – Pokrovskoe, sample 1325, 4th mineralogical group, length of the photo is 0.62 mm: accumulation of magnetite particles disintegrating from a larger grain, round grain of chrysocolla within the border of covellite and copper prills. 4 – Tokskoye, sample 1293, 4th mineralogical group, length of the photo is 0.46 mm: accumulation of molten inclusions of copper and cuprite keeping the form of a primary ore grain. 5 – Pokrovskoe, sample 1323, 4th mineralogical group, length of the photo is 0.62 mm: accumulation of molten inclusions of copper and cuprite keeping the form of a primary ore grain, long inclusions of unmolten sulfide (blue) in the center of the grain. 6 – Nizhnyaya Pavlovka, sample 1287, 4th mineralogical group, length of the photo is 0.62 mm: ceramic slag of the lining – very porous glass matrix with very small nuclei of olivine crystallization, small grains of quartz, rare small chromites.

Tab. 9-10. Mineralogical groups of slag in the Volga and Orenburg regions.

Mineralogical groups / **Settlements**	**I**	**II**	**IV**	**VI**	**Lining**	**Total**
Shigonskoye II	9		1			10
Lipovii Ovrag		1				1
Popovo Ozero				8		8
Syezh’ye			4			4
Ivanovskoye		5	1			6
Kuzminkovskoye		5	1			6
Nizhnyaya Pavlovka			1		3	4
Pokrovskoe	1	1	16		3	21
Rodnikovskoye		4	13	1		18
Tokskoye		2	3			5
Total	**10** **12%**	**19** **23%**	**39** **47%**	**9** **11%**	**6** **7%**	**83** **100%**

Tab. 9-11. Coefficients of basicity of ore and slag in the Volga and Orenburg regions.

Sample	Site	Material	Coefficient of basicity	Group
Rus-1/2	Mikhaylo-Ovsyanka	ore	0.13	ultra-acid
Rus-1/1b	Mikhaylo-Ovsyanka	ore	0.34	ultra-acid
2027	Kargaly	ore	0.41	ultra-acid
Rus-1/1c	Mikhaylo-Ovsyanka	ore	0.52	acid
Rus-1/1a	Mikhaylo-Ovsyanka	ore	1.04	average
Gor-E24/5	Gorny	slag	0.1	ultra-acid
Gor-E21/5	Gorny	slag	0.12	ultra-acid
Gor-E19/8	Gorny	slag	0.17	ultra-acid
Gor-E13/5	Gorny	slag	0.19	ultra-acid
Gor-E22/5	Gorny	slag	0.21	ultra-acid
1333-1	Rodnikovskoye	slag	0.25	ultra-acid
Gor-1-5	Gorny	slag	0.26	ultra-acid
1356-2	Rodnikovskoye	slag	0.28	ultra-acid
Gor-E30/4	Gorny	slag	0.29	ultra-acid
1344	Rodnikovskoye	slag	0.29	ultra-acid
1355	Rodnikovskoye	slag	0.33	ultra-acid
Gor-E20/3	Gorny	slag	0.34	ultra-acid
Gor-E08/1	Gorny	slag	0.36	ultra-acid
Gor-E25/6	Gorny	slag	0.37	ultra-acid
Gor-E18/5	Gorny	slag	0.39	ultra-acid
Gor-E23/5	Gorny	slag	0.39	ultra-acid
Gor-E06/1	Gorny	slag	0.44	ultra-acid
Rus-1/6a	Mikhaylo-Ovsyanka	slag	0.46	ultra-acid
Gor-E28/6	Gorny	slag	0.49	ultra-acid
Gor-E27/5	Gorny	slag	0.57	acid
Gor-E12/1	Gorny	slag	0.57	acid
Gor-E11/3	Gorny	slag	0.58	acid
Gor-E01/5	Gorny	slag	0.63	acid
Gor-E26/7	Gorny	slag	0.64	acid
Gor-E10/1	Gorny	slag	0.64	acid
1304-1	Ivanovskoye	slag	0.64	acid
1318-1	Pokrovskoe	slag	0.67	acid
Gor-E29/7	Gorny	slag	0.74	acid
1303-1	Ivanovskoye	slag	0.92	acid
1285	Kuzminkovskoye	slag	1.05	average
Rus-1/6b	Mikhaylo-Ovsyanka	slag	1.47	average
Gor-E09/3	Gorny	slag	2.15	basic

Tab. 9-12. Average contents of barium in slag from the Orenburg settlements.

Settlement	**Ba (%)**
Nizhnyaya Pavlovka	0.364
Pokrovskoe	1.24
Ivanovskoye	1.25
Kuzminkovskoye	1.65
Pokrovskoe	1.69
Tokskoye	2.6
Syezh’ye	2.63

Tab. 9-13. Emission spectral analyses of slag and ore from the Volga and Orenburg regions (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).

Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge
Shigonskoye	slag	325	0.003	0.0003	0.001	0.3	0.0015	0.05	<0.0005	0.00015
Shigonskoye	slag	326	0.0015	0.0003	0.002	1	0.003	0.2	0.0005	0.00015
Shigonskoye	slag	327	0.0007	0.0003	0.005	1	0.007	0.15	0.001	0.00015
Shigonskoye	slag	328	0.0005	<0.0003	<0.001	0.3	0.0015	0.07	<0.0005	<0.0003
Shigonskoye	slag	329	0.005	<0.0003	0.007	0.7	0.007	0.3	<0.0005	0.00015
Shigonskoye	slag	330	0.0015	<0.0003	0.003	0.5	0.0015	0.05	<0.0005	0.00015
Shigonskoye	slag	331	0.0007	<0.0003	0.001	0.3	0.0015	0.07	<0.0005	<0.0003
Shigonskoye	slag	332	0.0007	0.0003	0.001	0.5	0.0015	0.1	<0.0005	0.00015
Shigonskoye	slag	333	0.002	0.0003	0.001	0.3	0.001	0.07	<0.0005	0.00015
Shigonskoye	slag	334	0.005	0.015	0.007	0.15	0.015	0.1	<0.0005	>0.01
Lipovii Ovrag	slag	335	0.005	0.001	0.005	0.15	0.007	0.15	0.0005	<0.0003
Popovo Ozero	slag	336	0.01	0.005	0.003	0.15	0.001	0.05	<0.0005	0.0003
Popovo Ozero	slag	337	0.0007	<0.0003	0.01	0.05	0.0015	0.2	<0.0005	<0.0003
Popovo Ozero	slag	338	0.005	0.0015	0.01	0.02	0.0015	0.2	<0.0005	<0.0003
Popovo Ozero	slag	339	0.0015	0.0003	0.01	0.07	0.0015	0.15	<0.0005	<0.0003
Popovo Ozero	slag	340	0.01	0.005	0.007	0.02	0.0015	0.15	<0.0005	0.00015
Popovo Ozero	slag	341	0.01	0.003	0.0015	0.02	0.001	0.1	<0.0005	0.0003
Popovo Ozero	slag	342	0.005	0.0015	0.02	0.02	0.005	0.5	0.001	<0.0003
Popovo Ozero	slag	343	0.007	0.003	0.03	0.02	0.007	0.3	0.0005	<0.0003
Mikhaylo-Ovsyanka	slag	470	0.003	0.0003	0.0015	0.02	0.015	0.07	<0.0005	0.0015
Syezh'ye	slag	763	0.005	0.002	0.03	0.03	0.02	0.2	0.001	0.003
Syezh'ye	slag	764	0.007	0.003	0.03	0.1	0.03	0.2	0.0005	0.007
Syezh'ye	slag	765	0.01	0.003	0.03	0.05	0.03	0.15	0.0005	>0.01
Syezh'ye	slag	766	0.005	0.003	0.03	0.1	0.03	0.2	0.001	0.007
Kuzminkovskoye	slag	1280	0.003	0.001	0.03	0.05	0.02	0.3	0.0005	0.001
Kuzminkovskoye	slag	1281	0.003	0.0007	0.02	0.07	0.03	0.3	0.0005	0.0003
Kuzminkovskoye	slag	1282	0.005	0.001	0.03	0.05	0.01	0.5	0.0005	0.0002
Kuzminkovskoye	slag	1283	0.003	0.001	0.03	0.07	0.02	0.3	0.0005	0.0002
Kuzminkovskoye	slag	1284	0.005	0.001	0.03	0.05	0.01	0.5	0.001	0.00015
Kuzminkovskoye	slag	1285	0.005	0.005	0.01	0.03	0.015	0.2	<0.0005	0.005

Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge
Nizhnyaya Pavlovka	slag	1286	0.007	0.001	0.007	0.1	0.015	0.15	0.0005	0.001
Nizhnyaya Pavlovka	slag	1287	0.005	0.001	0.02	0.05	0.007	0.5	0.0005	<0.0003
Nizhnyaya Pavlovka	slag	1288	0.003	0.0007	0.01	0.07	0.005	0.5	0.0005	<0.0003
Nizhnyaya Pavlovka	slag	1289	0.005	0.001	0.015	0.07	0.005	0.5	0.0005	<0.0003
Nizhnyaya Pavlovka	slag	1290	0.007	0.0015	0.015	0.05	0.005	0.5	0.0005	<0.0003
Tokskoye	slag	1291	0.003	0.003	0.01	0.03	0.015	0.2	<0.0005	0.01
Tokskoye	slag	1292	0.005	0.0015	0.02	0.1	0.02	0.2	0.0005	0.001
Tokskoye	slag	1293	0.003	0.001	0.01	0.07	0.02	0.3	0.001	0.003
Tokskoye	slag	1294	0.003	0.0015	0.015	0.07	0.015	0.2	0.0005	0.002
Tokskoye	slag	1295	0.003	0.001	0.02	0.05	0.02	0.2	0.001	0.0003
Ivanovskoye	ore	1296	0.001	0.0003	0.007	0.1	0.02	0.1	0.0005	0.0007
Ivanovskoye	ore	1297	0.001	0.0005	0.007	0.05	0.03	0.07	0.0005	0.002
Ivanovskoye	ore	1298	0.005	0.0005	0.015	0.05	0.01	0.3	0.001	0.002
Ivanovskoye	ore	1299	0.003	0.0005	0.01	0.05	0.01	0.15	0.0005	0.003
Ivanovskoye	ore	1300	0.005	0.0005	0.02	0.03	0.02	0.2	0.0005	0.007
Ivanovskoye	ore	1301	0.003	0.001	0.05	0.07	0.015	0.7	0.001	0.005
Ivanovskoye	ore	1302	0.003	0.0007	0.007	0.05	0.01	0.2	0.0005	0.0015
Ivanovskoye	slag	1303	0.002	0.0015	0.007	0.05	0.01	0.15	0.0005	0.003
Ivanovskoye	slag	1304	0.005	0.003	0.01	0.03	0.015	0.15	0.0005	0.005
Ivanovskoye	slag	1305	0.005	0.003	0.01	0.05	0.02	0.15	<0.0005	0.007
Ivanovskoye	slag	1306	0.003	0.003	0.01	0.05	0.015	0.2	0.0005	0.005
Ivanovskoye	slag	1307	0.003	0.002	0.01	0.07	0.015	0.2	0.0005	0.003
Ivanovskoye	slag	1308	0.003	0.003	0.01	0.07	0.015	0.2	<0.0005	0.007
Pokrovskoe	slag	1309	0.005	0.001	0.03	0.05	0.02	0.7	0.001	0.01
Pokrovskoe	slag	1310	0.007	0.002	0.03	0.15	0.03	0.3	0.001	>0.01
Pokrovskoe	slag	1311	0.005	0.002	0.02	0.15	0.03	0.2	0.001	>0.01
Pokrovskoe	slag	1312	0.007	0.0015	0.03	0.05	0.015	0.2	0.0005	0.005
Pokrovskoe	slag	1313	0.007	0.0015	0.02	0.05	0.02	0.2	0.0005	0.01
Pokrovskoe	slag	1314	0.005	0.0015	0.02	0.03	0.02	0.2	0.001	0.007
Pokrovskoe	slag	1316	0.007	0.0015	0.03	0.05	0.015	0.2	0.001	0.007

Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge
Pokrovskoe	slag	1317	0.005	0.003	0.01	0.1	0.02	0.2	<0.0005	0.01
Pokrovskoe	slag	1318	0.007	0.0015	0.015	0.03	0.02	0.2	0.001	0.003
Pokrovskoe	slag	1319	0.007	0.002	0.03	0.1	0.02	0.2	0.001	>0.01
Pokrovskoe	slag	1320	0.005	0.002	0.015	0.05	0.01	0.2	0.0005	0.007
Pokrovskoe	slag	1321	0.005	0.001	0.015	0.05	0.03	0.2	0.001	0.002
Pokrovskoe	slag	1322	0.007	0.001	0.02	0.07	0.01	0.2	0.0005	0.0003
Pokrovskoe	slag	1323	0.005	0.0015	0.015	0.05	0.015	0.2	0.0005	0.007
Pokrovskoe	slag	1324	0.007	0.0015	0.02	0.05	0.02	0.2	0.0005	0.007
Pokrovskoe	slag	1325	0.005	0.0015	0.02	0.05	0.02	0.2	0.001	0.005
Pokrovskoe	slag	1326	0.003	0.0015	0.015	0.1	0.02	0.2	0.0005	0.001
Pokrovskoe	slag	1327	0.02	0.002	0.02	0.1	0.007	0.05	<0.0005	0.0003
Pokrovskoe	slag	1328	0.005	0.0015	0.03	0.07	0.007	0.5	0.0005	<0.0003
Pokrovskoe	slag	1329	0.007	0.001	0.02	0.05	0.007	0.3	0.0005	0.00015
Pokrovskoe	slag	1330	0.01	0.002	0.05	0.05	0.01	0.5	0.001	0.00015
Rodnikovskoye	slag	1331	0.005	0.001	0.03	0.1	0.02	0.3	0.0005	0.0015
Rodnikovskoye	slag	1332	0.003	0.001	0.02	0.07	0.01	0.2	0.0005	0.001
Rodnikovskoye	slag	1333	0.003	0.0007	0.015	0.1	0.01	0.2	0.0005	0.0005
Rodnikovskoye	slag	1334	0.007	0.0005	0.03	0.07	0.015	0.2	0.0005	<0.0003
Rodnikovskoye	lining	1335	0.002	0.0007	0.015	0.05	0.01	0.2	0.0005	0.0015
Rodnikovskoye	ore	1336	0.007	0.0007	0.02	0.03	0.02	0.5	0.001	0.005
Rodnikovskoye	ore	1337	0.005	0.0005	0.03	0.03	0.03	0.3	0.0005	0.007
Rodnikovskoye	ore	1338	0.002	0.0007	0.01	0.1	0.007	0.2	0.0005	0.001
Rodnikovskoye	flux	1339	0.02	0.002	0.01	0.05	0.02	0.2	<0.0005	0.00015
Rodnikovskoye	flux	1340	0.005	0.0005	0.003	0.1	0.01	0.15	<0.0005	0.00015
Rodnikovskoye	flux	1341	0.01	0.0015	0.02	0.05	0.015	0.07	<0.0005	<0.0003
Rodnikovskoye	ore	1342	0.002	0.0005	0.02	0.02	0.01	0.07	<0.0005	0.0003
Rodnikovskoye	copper	1343	0.003	0.0005	0.01	0.1	0.007	0.2	0.001	0.0003
Rodnikovskoye	slag	1344	0.005	0.001	0.015	0.05	0.01	0.3	0.001	0.002
Rodnikovskoye	slag	1345	0.003	0.0007	0.03	0.07	0.015	0.3	0.001	0.0003
Rodnikovskoye	slag	1346	0.007	0.0015	0.07	0.05	0.03	0.7	0.001	0.005
Rodnikovskoye	slag	1347	0.01	0.001	0.01	0.05	0.015	0.07	<0.0005	<0.0003
Rodnikovskoye	slag	1348	0.003	0.0005	0.02	0.05	0.015	0.3	0.0005	0.0003
Rodnikovskoye	slag	1349	0.005	0.001	0.015	0.1	0.015	0.3	0.0005	0.0015

Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge
Rodnikovskoye	slag	1350	0.005	0.001	0.02	0.07	0.02	0.5	0.001	0.002
Rodnikovskoye	slag	1351	0.007	0.001	0.05	0.05	0.02	0.5	0.001	0.0007
Rodnikovskoye	slag	1352	0.007	0.0015	0.03	0.03	0.015	0.3	0.001	0.0015
Rodnikovskoye	slag	1353	0.005	0.001	0.02	0.1	0.015	0.3	0.0005	0.001
Rodnikovskoye	slag	1354	0.007	0.0015	0.03	0.05	0.015	0.3	0.0005	0.0007
Rodnikovskoye	slag	1355	0.005	0.0015	0.02	0.07	0.01	0.3	0.001	<0.0003
Rodnikovskoye	slag	1356	0.01	0.0015	0.02	0.07	0.01	0.5	0.001	<0.0003
Sensitivity of the analysis			Ni	Co	Cr	Mn	V	Ti	Sc	Ge
			0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.0003

Tab. 9-13. Emission spectral analyses of slag and ore from the Volga and Orenburg regions (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30) (contd.).

Site	Material	№	Cu	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo
Shigonskoye	slag	325	0.3	0.03	0.005	0.0005	0.005	<0.003	<0.001	<0.001	0.0002
Shigonskoye	slag	326	0.03	0.05	0.0007	0.00003	< 0.01	<0.003	<0.001	<0.001	0.0003
Shigonskoye	slag	327	0.015	0.007	0.0007	0.00003	< 0.01	<0.003	<0.001	<0.001	0.0002
Shigonskoye	slag	328	0.3	nd	0.0015	0.00003	< 0.01	<0.003	<0.001	<0.001	0.00015
Shigonskoye	slag	329	0.2	nd	0.005	0.00005	< 0.01	<0.003	<0.001	<0.001	0.0001
Shigonskoye	slag	330	0.15	0.07	0.007	0.0003	< 0.01	<0.003	<0.001	0.001	0.00015
Shigonskoye	slag	331	0.015	0.02	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.00015
Shigonskoye	slag	332	0.02	0.05	0.0007	0.00005	0.005	<0.003	<0.001	<0.001	0.00015
Shigonskoye	slag	333	>1	0.03	0.007	0.003	0.005	<0.003	<0.001	<0.001	0.0001
Shigonskoye	slag	334	>1	1	0.7	>>3	0.02	<0.003	0.07	<0.001	0.1
Lipovii Ovrag	slag	335	0.015	0.007	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.0007
Popovo Ozero	slag	336	0.1	0.007	0.003	0.00015	0.005	<0.003	<0.001	<0.001	0.0005
Popovo Ozero	slag	337	0.0015	0.007	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Popovo Ozero	slag	338	0.03	0.007	0.001	0.00005	0.005	<0.003	<0.001	<0.001	0.00015
Popovo Ozero	slag	339	0.01	0.007	0.001	0.00003	0.005	<0.003	<0.001	<0.001	0.0001
Popovo Ozero	slag	340	0.003	0.007	0.0005	0.00003	< 0.01	<0.003	<0.001	<0.001	0.0003
Popovo Ozero	slag	341	0.07	0.007	0.0015	0.00003	0.005	<0.003	<0.001	<0.001	0.0005
Popovo Ozero	slag	342	0.05	0.005	0.0015	0	0.005	<0.003	<0.001	<0.001	<0.0001
Popovo Ozero	slag	343	0.02	0.007	0.0015	0	0.005	<0.003	<0.001	<0.001	0.00015
Mikhaylo-Ovsyanka	slag	470	0.5	0.03	0.007	0.0001	0.05	<0.003	0.003	<0.001	0.001
Syezh'ye	slag	763	>>1	nd	0.03	0.003	0.005	<0.003	<0.001	<0.001	0.02
Syezh'ye	slag	764	>>1	nd	0.07	>3	0.015	<0.003	<0.001	<0.001	0.03
Syezh'ye	slag	765	>>1	nd	0.15	>3	0.03	<0.003	<0.001	<0.001	0.02
Syezh'ye	slag	766	>>1	nd	0.05	>>3	0.015	<0.003	0.001	<0.001	0.01
Kuzminkovskoye	slag	1280	>1	nd	0.05	>3	0.01	<0.003	<0.001	<0.001	0.015
Kuzminkovskoye	slag	1281	>1	nd	0.03	0.003	0.005	<0.003	<0.001	<0.001	0.01
Kuzminkovskoye	slag	1282	>1	0.005	0.02	0.003	0.005	<0.003	<0.001	<0.001	0.003
Kuzminkovskoye	slag	1283	>1	nd	0.02	0.0015	0.005	<0.003	<0.001	<0.001	0.01
Kuzminkovskoye	slag	1284	0.7	0.007	0.003	0.00015	0.005	<0.003	<0.001	<0.001	0.0005
Kuzminkovskoye	slag	1285	>1	nd	0.03	>3	0.01	<0.003	<0.001	<0.001	0.005

Site	Material	№	Cu	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo
Nizhnyaya Pavlovka	slag	1286	>1	0.02	0.07	>3	0.01	<0.003	<0.001	0.001	0.007
Nizhnyaya Pavlovka	slag	1287	0.1	0.005	0.0007	0.00015	0.005	<0.003	<0.001	<0.001	0.0007
Nizhnyaya Pavlovka	slag	1288	0.15	nd	0.001	0.0001	0.005	<0.003	<0.001	<0.001	0.0005
Nizhnyaya Pavlovka	slag	1289	0.05	nd	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.0015
Nizhnyaya Pavlovka	slag	1290	0.03	0.005	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.001
Tokskoye	slag	1291	>1	nd	0.1	>3	0.005	<0.003	<0.001	<0.001	0.015
Tokskoye	slag	1292	>1	nd	0.03	0.003	0.005	<0.003	<0.001	<0.001	0.03
Tokskoye	slag	1293	>1	nd	0.02	>3	0.005	<0.003	<0.001	<0.001	0.03
Tokskoye	slag	1294	>1	nd	0.03	>3	0.005	<0.003	<0.001	<0.001	0.03
Tokskoye	slag	1295	>1	nd	0.02	>3	0.005	<0.003	<0.001	<0.001	0.015
Ivanovskoye	ore	1296	>1	nd	0.07	>3	0.01	<0.003	<0.001	<0.001	0.007
Ivanovskoye	ore	1297	>1	nd	0.05	>3	0.005	<0.003	<0.001	<0.001	0.002
Ivanovskoye	ore	1298	>1	nd	0.015	0.003	0.005	<0.003	<0.001	<0.001	0.003
Ivanovskoye	ore	1299	>1	nd	0.05	>3	0.005	<0.003	<0.001	<0.001	0.007
Ivanovskoye	ore	1300	>1	nd	0.03	0.002	0.005	<0.003	<0.001	<0.001	0.005
Ivanovskoye	ore	1301	>1	nd	0.02	>3	0.005	<0.003	<0.001	<0.001	0.007
Ivanovskoye	ore	1302	>1	nd	0.015	>3	0.005	<0.003	<0.001	<0.001	0.002
Ivanovskoye	slag	1303	>1	nd	0.015	>3	0.005	<0.003	<0.001	<0.001	0.01
Ivanovskoye	slag	1304	>1	nd	0.03	0.003	0.005	<0.003	<0.001	<0.001	0.015
Ivanovskoye	slag	1305	>1	nd	0.07	>3	0.005	<0.003	<0.001	<0.001	0.015
Ivanovskoye	slag	1306	>1	nd	0.03	>3	0.005	<0.003	<0.001	<0.001	0.01
Ivanovskoye	slag	1307	1	nd	0.03	0.002	0.01	<0.003	<0.001	<0.001	0.015
Ivanovskoye	slag	1308	>1	nd	0.03	>3	0.005	<0.003	<0.001	<0.001	0.01
Pokrovskoe	slag	1309	>1	nd	0.03	>3	0.005	<0.003	<0.001	<0.001	0.005
Pokrovskoe	slag	1310	>1	nd	0.15	>3	0.02	0.005	<0.001	<0.001	0.015
Pokrovskoe	slag	1311	>1	nd	0.15	>3	0.02	0.005	<0.001	<0.001	0.015
Pokrovskoe	slag	1312	>1	nd	0.05	>3	0.01	<0.003	<0.001	<0.001	0.02
Pokrovskoe	slag	1313	>1	nd	0.07	>3	0.005	<0.003	<0.001	<0.001	0.03
Pokrovskoe	slag	1314	>1	nd	0.03	0.003	0.005	<0.003	<0.001	<0.001	0.03
Pokrovskoe	slag	1316	>1	nd	0.03	0.003	0.01	<0.003	<0.001	<0.001	0.03

Site	Material	№	Cu	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo
Pokrovskoe	slag	1317	>1	nd	0.1	>3	0.015	<0.003	<0.001	<0.001	0.02
Pokrovskoe	slag	1318	>1	nd	0.02	0.003	0.005	<0.003	<0.001	<0.001	0.02
Pokrovskoe	slag	1319	>1	nd	0.07	>3	0.01	0.003	<0.001	<0.001	0.01
Pokrovskoe	slag	1320	>1	nd	0.02	0.002	0.005	0.003	<0.001	<0.001	0.01
Pokrovskoe	slag	1321	>1	nd	0.015	>3	0.005	<0.003	<0.001	<0.001	0.02
Pokrovskoe	slag	1322	>1	nd	0.01	0.003	0.005	<0.003	<0.001	<0.001	0.003
Pokrovskoe	slag	1323	>1	nd	0.03	0.003	0.005	<0.003	<0.001	<0.001	0.015
Pokrovskoe	slag	1324	>1	nd	0.05	0.003	0.015	<0.003	<0.001	<0.001	0.02
Pokrovskoe	slag	1325	>1	nd	0.02	0.002	0.005	<0.003	<0.001	<0.001	0.02
Pokrovskoe	slag	1326	>1	nd	0.02	0.003	0.005	<0.003	<0.001	<0.001	0.01
Pokrovskoe	slag	1327	1	0.03	0.015	0.002	0.005	<0.003	<0.001	<0.001	0.001
Pokrovskoe	slag	1328	0.5	0.007	0.003	0.0007	0.005	<0.003	<0.001	<0.001	0.001
Pokrovskoe	slag	1329	0.3	0.007	0.003	0.0007	0.005	<0.003	<0.001	<0.001	0.002
Pokrovskoe	slag	1330	0.3	0.005	0.0015	0.0003	0.005	<0.003	<0.001	<0.001	0.0002
Rodnikovskoye	slag	1331	>1	nd	0.007	>3	0.005	<0.003	<0.001	<0.001	0.02
Rodnikovskoye	slag	1332	>1	nd	0.01	>3	0.005	<0.003	<0.001	<0.001	0.015
Rodnikovskoye	slag	1333	>1	nd	0.03	0.003	0.005	<0.003	<0.001	<0.001	0.01
Rodnikovskoye	slag	1334	>1	0.007	0.003	>3	0.005	<0.003	<0.001	<0.001	0.0002
Rodnikovskoye	lining	1335	>1	nd	0.02	>3	0.005	<0.003	<0.001	<0.001	0.007
Rodnikovskoye	ore	1336	>1	0.005	0.015	0.003	0.005	<0.003	<0.001	<0.001	0.0005
Rodnikovskoye	ore	1337	>1	0.007	0.015	0.003	0.005	<0.003	<0.001	<0.001	0.001
Rodnikovskoye	ore	1338	>1	nd	0.02	>3	0.005	<0.003	<0.001	<0.001	0.007
Rodnikovskoye	flux	1339	0.3	0.07	0.0015	0.0002	0.005	<0.003	<0.001	<0.001	0.0003
Rodnikovskoye	flux	1340	0.03	0.015	0.001	0.00005	0.01	<0.003	<0.001	<0.001	0.0002
Rodnikovskoye	flux	1341	0.05	0.01	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.0002
Rodnikovskoye	ore	1342	>1	0.005	0.005	0.0015	0.005	<0.003	<0.001	<0.001	0.00015
Rodnikovskoye	copper	1343	>1	0.007	0.002	>3	0.005	<0.003	<0.001	<0.001	0.0015
Rodnikovskoye	slag	1344	>1	nd	0.02	>3	0.005	<0.003	<0.001	<0.001	0.03
Rodnikovskoye	slag	1345	>1	0.005	0.007	0.002	0.005	<0.003	<0.001	<0.001	0.003
Rodnikovskoye	slag	1346	>1	nd	0.02	>3	0.005	<0.003	<0.001	<0.001	0.02
Rodnikovskoye	slag	1347	0.5	0.015	0.002	0.0003	0.005	<0.003	<0.001	<0.001	0.0003
Rodnikovskoye	slag	1348	>1	0.007	0.003	0.003	0.005	<0.003	<0.001	<0.001	0.0007
Rodnikovskoye	slag	1349	>1	nd	0.015	>3	0.005	<0.003	<0.001	<0.001	0.015

Site	Material	№	Cu	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo
Rodnikovskoye	slag	1350	>1	nd	0.05	>3	0.005	<0.003	<0.001	<0.001	0.02
Rodnikovskoye	slag	1351	>1	nd	0.003	0.003	0.005	<0.003	<0.001	<0.001	0.005
Rodnikovskoye	slag	1352	>1	nd	0.03	0.003	0.005	<0.003	<0.001	<0.001	0.015
Rodnikovskoye	slag	1353	>1	nd	0.01	>3	0.005	<0.003	<0.001	<0.001	0.007
Rodnikovskoye	slag	1354	>1	nd	0.01	>3	0.005	<0.003	<0.001	<0.001	0.007
Rodnikovskoye	slag	1355	0.15	0.007	0.0015	0.00015	0.005	<0.003	<0.001	<0.001	0.0003
Rodnikovskoye	slag	1356	0.5	0.005	0.0015	0.00015	0.005	<0.003	<0.001	<0.001	0.0003
Sensitivity of the analysis			Cu	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo
			0.001	0.003	0.0003	0.00003	0.01	0.003	0.001	0.001	0.0001

Tab. 9-13. Emission spectral analyses of slag and ore from the Volga and Orenburg regions (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30) (contd.).

Site	Material	№	Ba	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Shigonskoye	slag	325	0.01	0.01	<0.001	<0.0005	0.00005	0.001	0.0015	<0.001	<0.0001
Shigonskoye	slag	326	0.03	0.01	<0.001	0.0003	0.0002	0.007	0.001	0.015	0.001
Shigonskoye	slag	327	0.03	0.015	<0.001	0.0003	0.00015	0.007	0.001	0.003	0.0002
Shigonskoye	slag	328	0.01	0.01	<0.001	<0.0005	0.0001	0.0015	0.0005	<0.001	<0.0001
Shigonskoye	slag	329	0.1	0.015	<0.001	<0.0005	0.00015	0.005	0.0005	0.002	0.0002
Shigonskoye	slag	330	0.02	0.01	<0.001	<0.0005	0.00007	0.001	0.001	0.0015	0.0001
Shigonskoye	slag	331	0.01	0.01	<0.001	<0.0005	0.00007	0.0015	0.0015	<0.001	0.0001
Shigonskoye	slag	332	0.02	0.01	<0.001	<0.0005	0.00007	0.001	0.0015	<0.001	0.0001
Shigonskoye	slag	333	0.01	0.01	<0.001	<0.0005	0.00005	nd	0.001	<0.001	<0.0001
Shigonskoye	slag	334	0.05	0.015	<0.001	0.0003	0.00007	nd	0.001	<0.001	<0.0001
Lipovii Ovrag	slag	335	0.03	0.015	<0.001	<0.0005	0.0001	0.007	0.001	0.002	0.00015
Popovo Ozero	slag	336	0.01	0.01	<0.001	0.0003	0.00003	0.001	0.0005	<0.001	<0.0001
Popovo Ozero	slag	337	0.05	0.015	<0.001	<0.0005	0.00007	0.01	0.0005	0.001	0.00015
Popovo Ozero	slag	338	0.07	0.015	<0.001	<0.0005	0.0001	0.007	0.001	0.001	0.0001
Popovo Ozero	slag	339	0.05	0.01	<0.001	<0.0005	0.00007	0.007	<0.0005	<0.001	0.0001
Popovo Ozero	slag	340	0.05	0.015	<0.001	<0.0005	0.00005	0.007	<0.0005	<0.001	0.0001
Popovo Ozero	slag	341	0.015	0.01	<0.001	<0.0005	0.00005	nd	0.001	<0.001	<0.0001
Popovo Ozero	slag	342	0.1	0.02	<0.001	<0.0005	0.0002	0.02	0.001	0.0015	0.0001
Popovo Ozero	slag	343	0.07	0.05	<0.001	<0.0005	0.00015	0.015	0.001	0.0015	0.0001
Mikhaylo-Ovsyanka	slag	470	0.015	0.01	<0.001	<0.0005	<0.00003	0.001	0.001	<0.001	0.0001
Syezh'ye	slag	763	>3	0.3	<0.001	0.0003	0.00015	0.02	0.001	0.003	0.0002
Syezh'ye	slag	764	3	0.15	<0.001	0.0003	0.0002	0.015	0.001	0.002	0.00015
Syezh'ye	slag	765	1.5	0.15	<0.001	0.003	0.00015	0.015	0.0015	0.002	0.00015
Syezh'ye	slag	766	>3	0.2	<0.001	<0.0005	0.0002	0.02	0.0015	0.002	<0.0001
Kuzminkovskoye	slag	1280	2	0.2	<0.001	<0.0005	0.00015	0.02	0.0015	0.002	0.00015
Kuzminkovskoye	slag	1281	3	0.5	<0.001	<0.0005	0.0002	0.02	0.001	0.001	0.0001
Kuzminkovskoye	slag	1282	0.7	0.15	<0.001	<0.0005	0.0002	0.02	0.0015	0.002	0.00015
Kuzminkovskoye	slag	1283	>3	0.3	<0.001	<0.0005	0.0002	0.02	0.0015	0.002	0.00015
Kuzminkovskoye	slag	1284	0.2	0.05	<0.001	<0.0005	0.0002	0.03	0.0015	0.002	0.00015
Kuzminkovskoye	slag	1285	1	0.1	<0.001	<0.0005	0.00015	0.02	0.0015	0.001	0.0001

Site	Material	№	Ba	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Nizhnyaya Pavlovka	slag	1286	1.5	0.07	<0.001	<0.0005	0.0002	0.01	0.001	0.002	0.00015
Nizhnyaya Pavlovka	slag	1287	0.1	0.05	<0.001	<0.0005	0.00015	0.015	0.001	0.001	0.0001
Nizhnyaya Pavlovka	slag	1288	0.05	0.015	<0.001	<0.0005	0.00007	0.015	0.001	0.0015	0.0001
Nizhnyaya Pavlovka	slag	1289	0.1	0.05	<0.001	<0.0005	0.00015	0.015	0.001	0.0015	0.0001
Nizhnyaya Pavlovka	slag	1290	0.07	0.05	<0.001	<0.0005	0.0001	0.015	0.0015	0.002	0.0001
Tokskoye	slag	1291	>3	0.2	<0.001	0.0003	0.0001	0.015	0.002	0.001	0.00015
Tokskoye	slag	1292	>3	0.7	<0.001	0.0003	0.0002	0.02	0.0015	0.002	0.00015
Tokskoye	slag	1293	1	0.15	0.001	<0.0005	0.0002	0.015	0.001	0.002	0.00015
Tokskoye	slag	1294	>3	0.5	<0.001	<0.0005	0.0002	0.015	0.002	0.001	0.00015
Tokskoye	slag	1295	>3	0.5	<0.001	<0.0005	0.0002	0.03	0.0015	0.002	0.00015
Ivanovskoye	ore	1296	0.2	0.015	<0.001	<0.0005	0.0003	0.015	0.001	<0.001	0.0001
Ivanovskoye	ore	1297	0.7	0.05	0.001	<0.0005	0.0002	nd	0.001	0.001	0.0001
Ivanovskoye	ore	1298	0.3	0.05	0.001	<0.0005	0.0002	0.015	0.001	0.002	0.0001
Ivanovskoye	ore	1299	0.05	0.01	<0.001	<0.0005	0.0001	0.01	0.001	0.001	<0.0001
Ivanovskoye	ore	1300	0.05	0.015	<0.001	<0.0005	0.0002	0.03	0.0015	0.001	<0.0001
Ivanovskoye	ore	1301	0.3	0.015	<0.001	<0.0005	0.0002	0.05	0.001	0.001	<0.0001
Ivanovskoye	ore	1302	0.1	0.015	0.001	<0.0005	0.00015	0.01	0.001	0.001	<0.0001
Ivanovskoye	slag	1303	>3	0.3	<0.001	<0.0005	0.0002	0.015	0.0015	0.001	0.0001
Ivanovskoye	slag	1304	>3	0.5	<0.001	<0.0005	0.0002	0.015	0.002	0.001	0.00015
Ivanovskoye	slag	1305	1	0.3	<0.001	0.0003	0.0001	0.015	0.002	0.001	0.0001
Ivanovskoye	slag	1306	1.5	0.2	<0.001	0.0003	0.0002	0.015	0.002	0.001	0.00015
Ivanovskoye	slag	1307	>3	0.3	<0.001	0.0003	0.0002	0.015	0.001	0.001	0.00015
Ivanovskoye	slag	1308	3	0.2	<0.001	0.0003	0.00015	0.015	0.002	0.001	0.0001
Pokrovskoe	slag	1309	0.3	0.1	0.001	<0.0005	0.0003	0.02	0.0015	0.005	0.0002
Pokrovskoe	slag	1310	0.5	0.1	<0.001	<0.0005	0.0002	0.015	0.003	0.005	0.0002
Pokrovskoe	slag	1311	0.5	0.1	<0.001	<0.0005	0.0002	0.015	0.003	0.005	0.0002
Pokrovskoe	slag	1312	>3	0.3	<0.001	<0.0005	0.0002	0.015	0.002	0.0015	0.00015
Pokrovskoe	slag	1313	>3	0.3	<0.001	<0.0005	0.0002	0.03	0.002	0.0015	0.00015
Pokrovskoe	slag	1314	>3	0.3	<0.001	<0.0005	0.0002	0.015	0.002	0.002	0.00015
Pokrovskoe	slag	1316	>3	0.3	<0.001	<0.0005	0.0002	0.015	0.002	0.002	0.00015

Site	Material	№	Ba	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Pokrovskoe	slag	1317	1.5	0.15	<0.001	<0.0005	0.0001	0.01	0.002	<0.001	0.00015
Pokrovskoe	slag	1318	2	0.2	<0.001	<0.0005	0.0002	0.02	0.002	0.0015	0.00015
Pokrovskoe	slag	1319	0.2	0.1	<0.001	0.0003	0.0002	0.02	0.003	0.003	0.0002
Pokrovskoe	slag	1320	>3	0.2	<0.001	<0.0005	0.0002	0.015	0.0015	0.0015	0.00015
Pokrovskoe	slag	1321	>3	0.3	<0.001	<0.0005	0.0003	0.02	0.0015	0.002	0.0001
Pokrovskoe	slag	1322	0.2	0.03	<0.001	0.0007	0.0001	0.01	0.001	0.001	<0.0001
Pokrovskoe	slag	1323	>3	0.2	<0.001	<0.0005	0.0002	0.02	0.002	0.0015	0.0001
Pokrovskoe	slag	1324	>3	0.2	<0.001	<0.0005	0.0002	0.02	0.0015	0.002	0.0001
Pokrovskoe	slag	1325	>3	0.2	<0.001	<0.0005	0.0003	0.02	0.0015	0.002	0.0001
Pokrovskoe	slag	1326	>3	0.2	0.001	<0.0005	0.0002	0.02	0.001	0.0015	0.0001
Pokrovskoe	slag	1327	0.015	0.015	<0.001	0.0003	0.00003	0.003	0.001	<0.001	<0.0001
Pokrovskoe	slag	1328	0.1	0.03	0.001	<0.0005	0.00015	0.015	0.0015	0.0015	0.0001
Pokrovskoe	slag	1329	0.1	0.03	0.001	<0.0005	0.0001	0.01	0.0015	0.0015	0.0001
Pokrovskoe	slag	1330	0.1	0.03	<0.001	<0.0005	0.0002	0.02	0.001	0.002	0.00015
Rodnikovskoye	slag	1331	3	0.2	<0.001	<0.0005	0.0002	0.015	0.0015	0.002	0.00015
Rodnikovskoye	slag	1332	2	0.2	<0.001	<0.0005	0.00015	0.01	0.001	0.0015	0.0001
Rodnikovskoye	slag	1333	1.5	0.2	<0.001	<0.0005	0.0001	0.01	0.0015	0.001	0.0001
Rodnikovskoye	slag	1334	0.05	0.01	<0.001	<0.0005	0.00005	0.005	0.0005	0.001	0.0001
Rodnikovskoye	lining	1335	1	0.1	0.001	<0.0005	0.0002	0.01	0.0015	0.001	0.0001
Rodnikovskoye	ore	1336	0.7	0.15	0.001	<0.0005	0.0002	0.015	0.0015	0.0015	0.00015
Rodnikovskoye	ore	1337	>3	0.5	0.001	<0.0005	0.0002	0.01	0.0015	0.001	0.0001
Rodnikovskoye	ore	1338	>3	0.3	0.001	<0.0005	0.0001	0.01	0.0015	0.001	0.0001
Rodnikovskoye	flux	1339	0.02	0.01	<0.001	<0.0005	0.00015	0.007	0.0005	0.001	0.0001
Rodnikovskoye	flux	1340	0.02	0.01	<0.001	<0.0005	0.00015	0.007	0.0005	0.0015	0.0001
Rodnikovskoye	flux	1341	0.015	0.01	<0.001	<0.0005	0.00007	0.007	<0.0005	0.001	0.0001
Rodnikovskoye	ore	1342	0.03	0.01	<0.001	<0.0005	0.0002	0.005	<0.0005	<0.001	<0.0001
Rodnikovskoye	copper	1343	>3	0.2	<0.001	<0.0005	0.0001	0.007	0.001	<0.001	<0.0001
Rodnikovskoye	slag	1344	>3	0.2	<0.001	<0.0005	0.00015	0.015	0.0015	0.001	0.0001
Rodnikovskoye	slag	1345	2	0.15	<0.001	<0.0005	0.0003	0.02	0.001	0.002	0.00015
Rodnikovskoye	slag	1346	2	0.15	<0.001	<0.0005	0.0003	0.03	0.0015	0.002	0.00015
Rodnikovskoye	slag	1347	0.015	0.01	<0.001	<0.0005	0.00015	0.007	0	0.001	0.00015
Rodnikovskoye	slag	1348	0.2	0.02	<0.001	0.0005	0.00015	0.015	0.001	0.001	<0.0001
Rodnikovskoye	slag	1349	1	0.1	<0.001	<0.0005	0.00015	0.015	0.001	0.001	<0.0001

Site	Material	№	Ba	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Rodnikovskoye	slag	1350	>3	0.2	<0.001	<0.0005	0.0002	0.03	0.0015	0.002	0.0001
Rodnikovskoye	slag	1351	0.5	0.1	0.001	<0.0005	0.0002	0.02	0.001	0.002	0.0001
Rodnikovskoye	slag	1352	2	0.15	0.001	<0.0005	0.0002	0.015	0.0015	0.002	0.0001
Rodnikovskoye	slag	1353	0.3	0.05	0.001	<0.0005	0.00015	0.015	0.0015	0.001	0.0001
Rodnikovskoye	slag	1354	0.3	0.05	0.001	<0.0005	0.00015	0.015	0.0015	0.002	0.0001
Rodnikovskoye	slag	1355	0.07	0.03	0.001	<0.0005	0.00015	0.015	0.0015	0.002	0.0001
Rodnikovskoye	slag	1356	0.07	0.05	0.001	<0.0005	0.00015	0.02	0.001	0.0015	0.00015
Sensitivity of the analysis			Ba	Sr	W	Sn	Be	Zr	Ga	Y	Yb
			0.01	0.01	0.001	0.0005	0.00003	0.001	0.0005	0.001	0.0001

Tab. 9-14. Chemical clusters of slag from settlements in the Volga and Orenburg regions.

Clusters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Ivanovskoye			2		2		2	
Kuzminkovskoye	1		2	1	1	1		
Lipovii Ovrag		1						
Nizhnyaya Pavlovka	4					1		
Pokrovskoe	9	1	8	1		1	1	
Popovo Ozero	4	4						
Rodnikovskoye	4		2	3		8		
Sergeevka	2		3	13		1		
Syezh'ye	1		1					2
Tokskoye	1		1			1	2	
Shigonskoye	1	8						

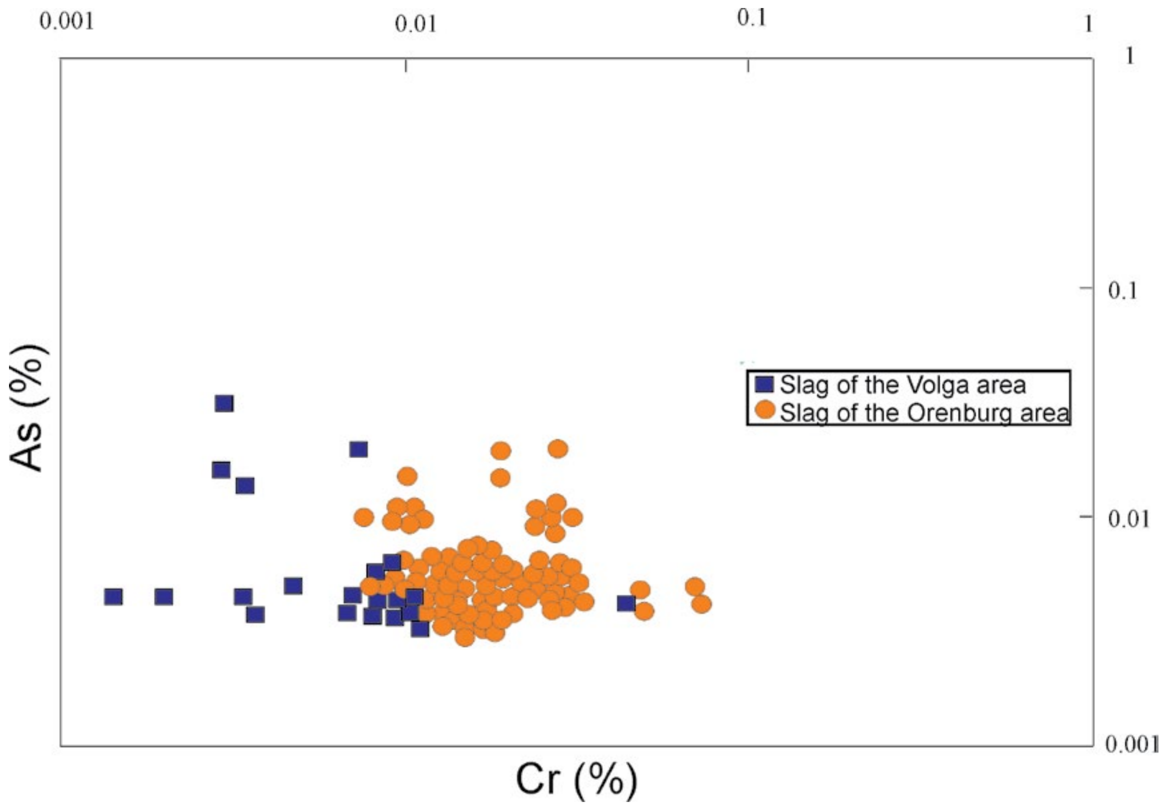


FIG. 9-15. CORRELATION OF CONCENTRATIONS OF AS AND CR (%) IN SLAG OF THE VOLGA AND ORENBURG REGIONS.

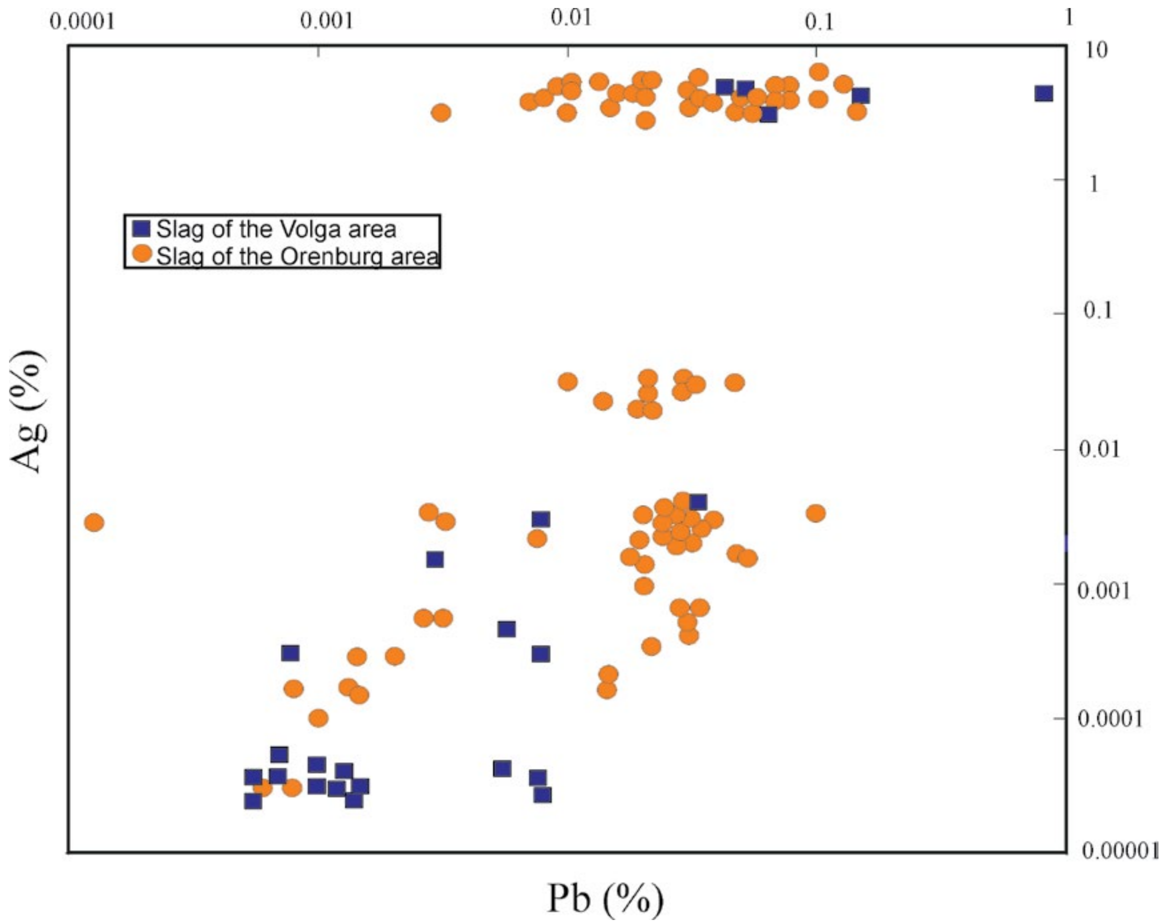


FIG. 9-16. CORRELATION OF CONCENTRATIONS OF AG AND PB (%) IN SLAG OF THE VOLGA AND ORENBURG REGIONS.

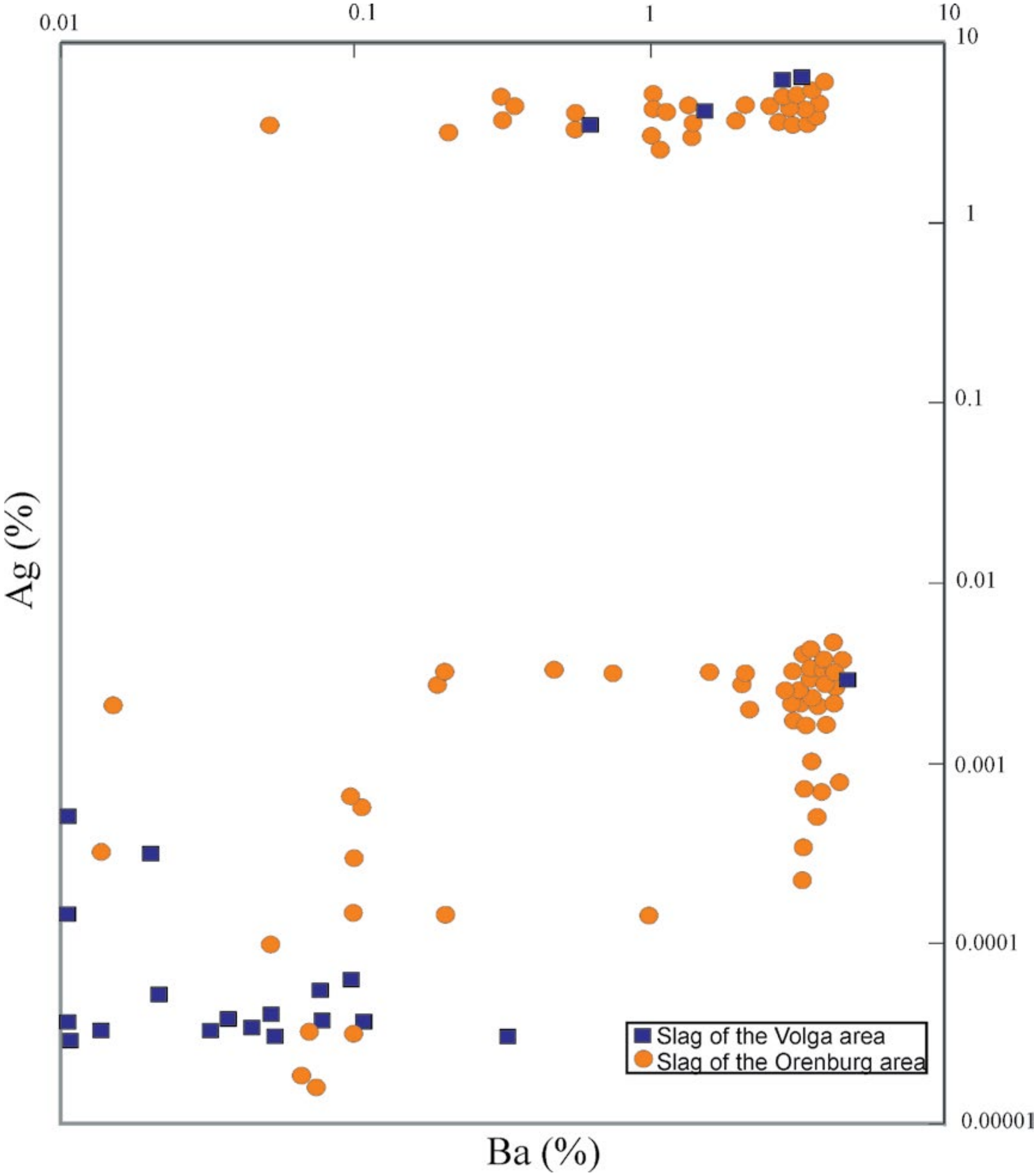


FIG. 9-17. CORRELATION OF CONCENTRATIONS OF AG AND BA (%) IN SLAG OF THE VOLGA AND ORENBURG REGIONS.

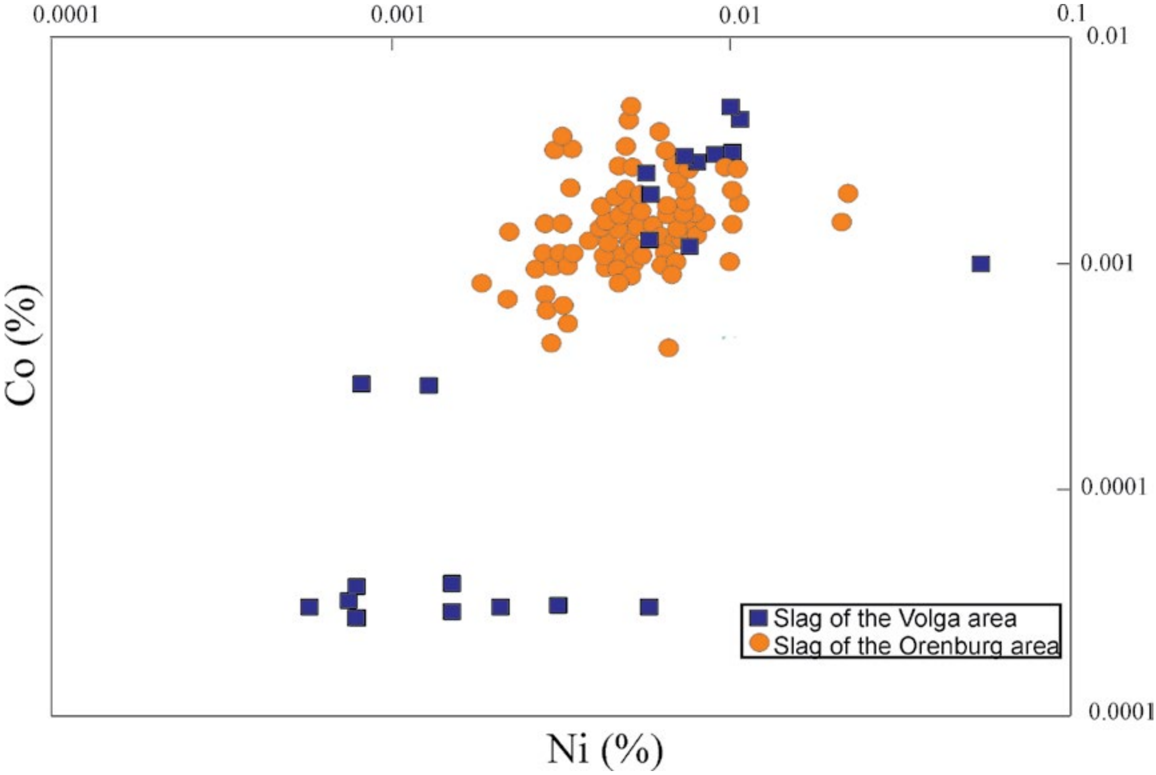


FIG. 9-18. CORRELATION OF CONCENTRATIONS OF NI AND CO (%) IN SLAG OF THE VOLGA AND ORENBURG REGIONS.

Chapter 10.
Mining and Metallurgical Production in the Don and Donets Areas

From the previous chapters we have seen that in the Timber-Grave period metallurgical production was well presented not only in the Orenburg region, but also in Bashkiria and, to a lesser extent, in the Volga region. Therefore sometimes it provokes an impression that from the east metal was distributed to western areas of the Timber-Grave culture. However, as the latest works in Don and Donets areas show, this impression is deceptive.

Ore base of the region

In the Donets-Voronezh region there are a significant number of copper sandstones on the surface. Territorially they can be divided into two parts: Voronezh and Donets (Fig. 10-1.).

In the Voronezh area the deposits are presented by the sandstones consisting of quartz, rarer feldspar, with carbonate and sulfide copper minerals. The main ore mineral is chalcopyrite. There are also malachite crusts on the grey sandstones. The deposits are localized in the east of the Pavlovsk projection of the Voronezh crystal massif (Narkelyun *et al.* 1983, p. 29, 30). Ancient mines of this zone are not known. In the area of the Pavlovsk projection there are some ore deposits on the surface. Therefore researchers believe that for the Mosolovka settlement located in this area it is necessary to look for local ore sources as ore transportation on large distances was unreal (Molotkov, Albekov 2004, p. 116, 127, 129). And an opinion that in the Voronezh region copper deposits on the surface are unknown and metallurgists of the Mosolovka settlement delivered ore from the Donets Basin (Shubin 2010, p. 199) is probably false.

In the Donets region 34 small ore deposits are recorded in the Bakhmut and Kalmius-Torets depressions; and on boards of these depressions the ore deposits are on the surface (Narkelyun *et al.* 1983, p. 31; Tatarinov 1978, p. 251). The ore is presented by greenish-gray quartz sandstone impregnated with copper. The main ore mineral is chalcocite, accompanied by bornite and chalcopyrite. In the oxidation zone the mineralization of malachite, azurite, cuprite, rarer covellite, is found. Often they replace the charred vegetable remains. Limonite is present in the oxidized zone rather seldom (Satpaeva 1958, p. 147-150). The ore forms lenses. On the average it contains 1-2% copper, but individual pieces do up to 10%. The depth of the oxidized zone reaches 30m (Yagovkin 1932, p. 51, 52; Lurie, Krasnopevtseva 1969, p. 72). Almost all these deposits on the surface have ancient mines (Tatarinov 1978, p. 251-255; Fedorovskii 1921, p. 5, 6; Lurie, Krasnopevtseva 1969, p. 61-66). But the deposit Sukhodolskoye whose mineralization is presented by chalcocite and bornite and the ore contains 13.84% copper, although it is on the surface, has no ancient mines (Lurie, Krasnopevtseva 1969, p. 71). This provokes an impression that the sulfide ore was not interesting to ancient miners. However the last studies show that it was not so, and just the sulfide ore or its mix with the oxidized ore was extracted.

S.I. Tatarinov has supposed that in the area of the Bakhmut depression an important mining and metallurgical center existed, about 1000 sq.km, with a plenty of mines and traces of ore smelting. The ores were extracted from open pits and mines. It is also interesting that in this area ancient mines for extraction of a mercury mineral cinnabar are recorded, and in the same place there is mineralization of arsenopyrite containing high concentration of antimony that could be used for production of arsenic-antimony bronzes (Tatarinov 1989, 2001, 2003).

Metallurgical sites

Some researchers do not exclude that the extraction of local ores was started by the post-Mariupol population in the Eneolithic and Kemi-Oba people in the EBA (Chernykh L. Nikolova 2003).

The mentioned above places of mining of arsenopyrite, which could be used for production of the Catacomb arsenic bronzes, as though point to a possibility of mining in the Middle Bronze Age, but it is only an assumption. A stratigraphically earlier position of mine relative to the Timber-Grave settlement of the LBA is recorded in Vyskrivka (Kravets, Tatarinov 1996). But this mine can be dated to earlier time within the Timber-Grave period. S.I.Tatarinov also believes that on the base of the presence of Catacomb barrows around the mines (where arsenopyrite with high concentration of antimony is recorded) a statement of E.N. Chernykh about the North Caucasian origins of arsenic-antimony bronzes in the Catacomb cultures demands a revision (Tatarinov 2003, p. 200). But the concentrations of antimony in the Catacomb arsenic bronzes are insignificant (Chernykh 1966, fig. 20). The mining of arsenopyrite with high content of antimony is more probable in the Timber-Grave time especially as we have discussed such technology above in relation to the LBA of Bashkiria.

All this can be also applied the Multi-Cordoned Ware culture (another names of the culture is KMK and Babino) where it is possible to speak about a specific metalworking, but evidences about ore smelting are absent (Litvinenko 2003). Therefore, we have no documentary base for statements that metallurgical production in the region could be based on local traditions. Despite the existence of assumptions on this subject, reliable traces of mining operations of the Middle Bronze Age populations (both Catacomb and Multi-Cordoned Ware) are absent (Tatarinov 2003, p. 197).

Such traces are connected only with the Timber-Grave and late Timber-Grave time, and many mines and settlements with traces of metallurgical production in the Donets Basin are dated to this period (Fig. 10-1.). The earliest of them are Pilipchatino and Vyskrivka which can be dated within the 17-15th centuries BC. Klinovoye-1 is some later, and the latest are the settlement of Klinovoye-2 and a complex at Mednaya Ruda ('Copper Ore') with dates within the 13-11 centuries BC (Tatarinov 2001). Thus, the last sites belong already to the period of the Final Bronze Age. At last, settlements and mines of the Chervone Ozero are an important complex. The settlement of Chervone Ozero 3 belongs to the first phase of the Berezhnovka-Mayevka Timber-Grave culture (Brovender 2008, 2009-2010).

In the Voronezh zone one of the most important metallurgical site in the territory of Northern Eurasia is localized: the Mosolovka settlement. Facts indicating the metalworking production, enormous quantity of fragments of casting molds (about 700), are especially impressive (Pryakhin 1996, p. 18), which has no analogs on other objects of the Bronze Age. It has created an impression of a mighty center focused, above all, on the metalworking production. However there are also on the settlement some finds which are unambiguously testify a local copper smelting: slags and ore pieces. Earlier three samples of slag from the settlement were analyzed that has allowed to excavator to conclude that the analyzed material is the slag smelted from ore (Pryakhin 1996, p. 55). The ore smelting was assumed also earlier on the base of excavation of the settlement at the Vogres dam (Podgaetskii 1941). However Pryakhin notes that today accurate criteria for determination of volumes of this production on the settlement are absent (Pryakhin 1996, p. 77).

Form of slag

Unfortunately, from all slags found in the region, I have managed to take for analyzes only several samples from the Mosolovka collection. The most part of the analyzed slags (12 samples, No 105, 767-772, 775) is presented by heavy shapeless slag of gray color. Surfaces are rough and tuberous. One of them is more flat. A part of slag (3 samples: 106, 776, 777) was more fluid. As a result the flat cakes formed with one surface smooth and tuberous and another smooth and very even with metal luster. Probably, this surface contacted to a metal ingot. One of samples had a diameter about 20cm. Thus, the difference in the form of slag was caused only by degree of its viscosity, and the more viscous samples sharply prevail in the collection (Tab. 10-2.).

At last, the studies have shown that two samples are heated ore (No 773, 774), and one is a copper ingot (No 778).

Mineralogy of slag

A small number of samples from the Mosolovka settlement have been analyzed under microscope in reflected light (12 slag and 2 ores samples). In addition, one sample was investigated by means of the scanning electron microscope (6 analyses) at the Mining Academy of Freiberg (Germany). 10 spectral analyses of slag of this settlement and one analysis of slag and one of furnace lining from Pilipchatino have been done too. Analyses of materials of the Donets sites were also considered, but their number is also insignificant (Shubin 2010).

Two samples of ore were subjected to heat in different degree. The first of them (No 773) is presented by covellite, partly replaced by isotropic sulfide, cuprite and copper. In some instances magnetite skeletons grow.

In the second sample the gangue is presented better: small pieces of quartz with magnetite ‘cement’. Such ore did not require iron fluxes. The ore is presented by malachite and chrysocolla, but large grains, prills and molten inclusions of copper sulfide are more typical. It is replaced by cuprite and copper. Nuclei and needles of fayalite crystallization are present. Besides, chalcopyrite was used in the smelting, and it supplied slag with iron oxides too. As the analyzed ore was strongly roasted, it is not excluded that a part of copper sulfides was formed from chalcopyrite.

Such optimum composition of ore is reflected in slag microstructure. In the majority of samples fayalite crystallized well; it is presented by elongated prismatic, polygonal and extended skeletal crystals, between which smaller needle structures grew. And in this case the size of crystals depends not on slag composition, it depends on sample size. Large slags cooled down more slowly that resulted in formation of larger fayalite crystals. The SEM analysis has shown that it is rather pure fayalite, the most iron-rich mineral among olivines, therefore it could be formed at relatively low temperatures (Tab. 10-3., an. 1, Fig. 10-4.). The fayalite is presented relatively better in more flat slags that is quite explainable: just the fayalite composition had impact on the slag viscosity.

There are many magnetite inclusions presented by accumulations of small octahedra with prills of copper and copper sulfide among them. In some instances the magnetite crystallized from slag in the form of small dendrites. In some samples the content of magnetite is small. It was turned into fayalite.

Grains and very large wüstite dendrites with fused surface are present (additional diagnostics of this mineral has been confirmed by SEM analyses (Tab. 10-3., an. 4, 5, Fig. 10-4., Fig. 10-5.), but a lot of very fine chalcopyrite grains are present among them. Possibly, similar structures were formed when copper sulfide melted from chalcopyrite and then sulfur burnt out from the sulfide.

Quartz grains are revealed. Fayalite was formed from quartz and wüstite. There are inclusions of copper, sulfide and cuprite in quartz. The ore minerals in slag are presented by malachite, chrysocolla, in some instances by prills of covellite, but prills and molten inclusions of copper sulfide (probably chalcocite) are more typical. The latter can be very large. Inside them copper can be reduced, and in some cases cuprite formed on their external surface. The cuprite also replaces malachite pieces at the edges, sometimes copper prills, having replaced probably a sulfide border. The latter sometimes surrounds copper prills. But in this case the cuprite can be secondary. In some cases copper is covered with a thin border consisting of tenorite (Tab. 10-3., an. a, Fig. 10-6.). It is obvious not a metallurgical mineral, its formation occurred already as a result of oxidation in a settlement layer as at high temperatures this mineral is unstable.

There are also cuprite prills, but it does not mean that temperature of its melting was reached. They were formed replacing prills of copper and sulfide. Sometimes round the prills of copper or cuprite the magnetite border formed. Probably, in these cases chalcopyrite turned into copper or cuprite. Copper is present usually in the form of prills, but sometimes in the form of reduced grains.

There are bornite grains, but chalcopyrite is more often. Possibly, the main ore were nevertheless covellite and chalcocite, but at loss of a part of sulfur another sulfide was formed, with smaller sulfur contents than in the covellite. This sulfide can be formed also from chalcopyrite. Therefore it is difficult to determine a proportion of various sulfides.

In one samples particles of reduced iron are found.

But in general, the quantity of the particles of ore, copper and cuprite in slag is small, they were well smelted. And, the temperature was, probably, within 1200-1350 ºC, as the melting point of cuprite had been reached not always, fayalite crystallized very well, and wüstite formed the fused dendrites, but its fusion and formation of large globules is not found.

It has been checked by means of the phase diagram of FeO-Al_2O_3+SiO_2-CaO system for the fayalite, glass and wüstite in slag sample 775 (Tab. 10-3., Fig. 10-7.). On the diagram it is well visible that these samples of wüstite have to melt at the temperature about 1350-1370 ºC, and those of fayalite about 1250 ºC. After the fayalite crystallization the slag lost iron components, and solidified in a temperature interval of 1100-1200 ºC. Taking into account these data it is possible to conclude that the suggested temperature interval is quite correct.

The smelting proceeded probably a long time. All materials are well processed. The atmosphere was reducing or moderately oxidizing that promoted the formation of fayalite, wüstite and sometimes even to reduction of iron from wüstite. The temperature decreased gradually. From this it is possible to draw a conclusion that the slag had not been tapped, and was formed directly in a furnace or crucible. It is confirmed also by that the wüstite dendrites and fayalite crystals are large.

Two samples in this series are slightly different. In sample 772 the silicate component prevails that prevented the formation of good fayalite slag, but did not affect the increase in copper losses. On the contrary, in sample 770 the fayalite grew worse because of prevalence of the iron component caused by smelting of chalcopyrite in this case. As a result a significant amount of magnetite promoted the increase of copper contents in slag.

However, in general, smelting of this type was very economic and almost perfect. Copper losses in the form of metal and ore were absolutely insignificant: only in two samples of the roasted ore and in slag sample No 770 mentioned above the contents of copper components in slag is more than 1%. In all others it fluctuates within 0.1-1% (Tab. 10-8.) that is not higher than in Sintashta metallurgy.

As a result of smelting the rough copper was produced requiring the following refinement. Investigation of one ingot (sample 778) has revealed inclusions of prills of cuprite and copper sulfide in copper. It is not also excluded that as a result of many smelting operations metallurgists obtained a mix consisting of copper sulfide and copper which required repeated melting too. But often the produced copper was rather pure (Tab. 10-3. an. 3, Fig. 10-6.). Unlike the Sintashta technology of arsenic alloying at the stage of ore smelting, here it was absent (Tab. 10-8.), which is confirmed also by metal analyses (Ryndina, Degtyaryova 1989). There is no base to assume also the use of fluxes, although small crushed bones of animals as a flux are not excluded because glass in slag contains 7.86% calcium (Tab. 10-3., an. 2, Fig. 10-4.). The only chemical anomaly is noted for sample 773 which is the roasted ore. Spectral analysis has revealed in it the high contents of silver and barium that reminds the Orenburg situation where the increased concentrations of these elements are noted in slags. But in this case we absolutely definitely deal with copper ore having these impurities; they were not resulted from a fluxing component. And, in the smelted slags these impurities are absent.

Studies of slags from the Timber-Grave sites of the Donets Basin took place too. It was shown that sulfide ores were actively used in smelting, mainly, chalcocite and also covellite, but the main mineral of the Kartamysh ore field was djurleite. These minerals differ in a copper and sulfur ratio. In ore malachite, azurite, and very rare chalcopyrite are also presented. Sulfides in slag are molten; there are also magnetite and α-quartz. Fluxes were not used as calcium and quartz are present in ore. Slags and mattes there contain neither tin nor arsenic, and bronzes were manufactured already by addition of an alloying component with rough copper. This preference of secondary sulfides like chalcocite is confirmed by traces of its crushing found on the settlement of Chervone Ozero 3, and also by the slag analysis. The oxidized ores were used in the smelting too, but their use was widespread to a lesser extent (Shubin 2010; Brovender 2009-2010, p. 217).

Thus, we see the parameters of smelting close to that reconstructed for the Mosolovka settlement.

Furnaces

As well as everywhere, the most difficult question is reconstruction of furnaces used for ore smelting. In the Donets Basin a solution of this problem can be outlined. On the settlement of Chervone Ozero I an accumulation of round pieces of copper sandstone is found, with an empty space in the center, probably a furnaces about 1m in diameter (Fig. 10-9.). This is confirmed by slag and stone tools found nearby. One more accumulation of slag and stones is found, but the design has not been understood. Stone boxes from vertical slabs serving for ore storage are found here (Brovender 2008, p. 189-193).

Remains of hearths are found on the settlement of Chervone Ozero 3 in construction 2 near the well, although there is no evidence that any of them was connected to the well as in the Sintashta culture (Fig. 10-10.). These are slightly deep in the surface hearths of small diameter (near 30 cm). In one of them a vessel is found with a small amount of ore and slag, but it has been supposed that it was used for ore storage and washing. A round furnace (its size is 0.6×0.45m) with the bottom size about 0.3 m is also found, and the remains of slagged walls from sandstone with slag lumps in some places (Brovender 2009-2010, p. 207-211). The last as though, allows us to claim surely that the smelting was conducted directly in the furnace. However the discussed above vessel contained not only the ore bits which stuck to the bottom, but also slag. The oxidized slag with cuprite could also be prepared for additional smelting, but for some cases we can assume also smelting in a crucible, although it was not so typical for this site. In addition to the slagged walls the smelting in the furnace is testified by pieces of strongly slagged clay, probably, furnace lining (Brovender 2009-2010, p. 214).

In the analyzed fragment of the furnace lining from the Pilipchatino settlement 0.5% copper has been detected (Tab. 10-8.) that demonstrates that the smelting was carried out directly in the furnace.

Metallurgical furnaces have been investigated also on the Pilipchatino settlement (Tatarinov 1977). The ore was smelted directly in the furnace although the author of excavation assumes that together with the ore and charcoal charged layer-by-layer into the furnace, a crucible with ore was placed there too. However the detection in the slagged pieces of furnace lining of copper prills, slag and roasted conglomerates confirms the smelting directly in the furnace. The found furnace fillings (charcoal, slag, copper oxides, and pieces of roasted ore) weighed 10 and 15 kg. The furnaces consisted of a smelting pit and a slightly deep section for ore charging (Fig. 10-11.). It is supposed that the ore was also charged through a top opening in the clay cupola covering the furnace. Air moved into the furnace through a tuyere which was inserted in the upper part of the smelting pit. But the ore charging through the deep section is doubtful especially as it, apparently, as well as the furnace, was covered by the clay cupola. The sizes of this part in both studied furnaces differ too. The sizes of the smelting pits are small: 35×40cm and 50×50cm (with deeper small part). Therefore, in the first furnace there was a possibility of generation of carbon monoxide only thanks to that it was deep, and air from above passed through a considerable charcoal layer. Besides, sulfide ores were, mostly, smelted. In the second furnace the additional section was much more, and finally the sense of this design is not clear. It is not excluded that this design is close to that revealed on the Mikhaylo-Ovsyanka settlement in the Volga region.

Thus, in the Donets zone furnaces of two types have been found: dome-shaped furnaces on the surface with diameter of less than 1m, and pit furnaces. In general, both these types could go back to the standards of Sintashta-Petrovka metallurgy. Mainly small sizes of furnaces complicated the generation of carbon monoxide, but it was compensated by abundance of sulfides in ore, and allowed easily to achieve high temperatures.

Excavations of the Mosolovka settlement, practically, have not revealed metallurgical furnaces. An exception is a pit furnace damaged by a later pit and relating only to the late stage of the settlement existence, and an accumulation of burned clay lining in another place that has not allowed a construction to be reconstructed (Pryakhin 1996, p. 123). Therefore the existence of the same types of design as in the Donets zone is not excluded.

In addition to this, a huge number of crucibles are revealed on the settlement, many of which are very large (Fig. 10-12.; Fig. 10-13.). A careful study of these crucibles allowed a conclusion to be drawn that their use in the metalworking production is doubtful. In case of a crucible copper melting the copper was placed into crucible, and charcoal burned beyond it, and air supply was carried out from the outside to the crucible wall (Pryakhin, Savrasov 1993; Savrasov 1996, p. 147). In this case air was blown directly into a crucible. Therefore, A.D. Pryakhin and A.S. Savrasov assumed that by such a way the ore could be smelted too (Pryakhin, Savrasov 1993, p. 70). Against the lack of metallurgical furnaces on the settlement, numerous finds of metallurgical slag and obviously large-scale production a similar assumption can be quite true. Its indirect confirmation is the conglomerates from slag and ore found on the settlement, which repeat the form of the crucibles, and pieces of burned sandstone. It is supposed that it was result of deliberate roasting of ore before smelting (Kileinikov 1984, Pryakhin 1996, p. 123).

The carried-out analysis of the slag remains shows that the smelting had not been done in two phases, and as a result of sulfide ores smelting metallurgists could produce copper, or in other cases the copper mixed with copper sulfides. Therefore it is more probable that these conglomerates are a result of rejected smelting operations. In this case existence in the region of two types of smelting is not excluded: in the furnace and crucible, but the last assumption should be checked additionally while the smelting in the furnace can be considered as proved. However, the form of crucibles is rather flat; most likely, they served for prevention of the furnace bottom destruction and its continuous repair. Therefore in reality this type of smelting does not differ from the smelting in furnace. Most likely, these crucibles indicate the aspiration to increase the frequency of smelting operations, that the production was aimed at large volumes, and metallurgists did not want to wait when the furnace cooled down, then to separate slag from the lining, to repair the lining, to wait when it dry, and to warm the furnace again.

Smelting volumes

If to consider the hypothetical possibility stated above about the smelting in crucibles, it is possible to calculate the volume of production. Large volumes of the crucibles and the way of blowing into them allow us to consider these crucibles as portable furnaces of small volume. Their working volume fluctuated in limits of 600-1350cm^3 (Pryakhin 1996, p. 60). Possibly, for ore smelting crucibles of larger diameter (about 1000 cm^3) were used. As the specific weight of carbonate ores varies within 2.8-3.5 g/cm^3, and that of chalcopyrite is 4.1-4.3 g/cm^3, we take an average 3 g/cm^3. Therefore, in principle, it is possible to charge into such a crucible up to 3 kg ores. However, charcoal had to be placed into the crucible for the smelting too. Experimental studies have shown that the ratio of ore volume to the charcoal volume has to be about 2:1 (Bamberger 1992, p. 157; Bamberger, Wincierz 1990, p. 123). However, these data have been obtained in the experiments with furnaces and it is not excluded that in the case of crucible smelting a smaller amount of charcoal is required. Besides, in the case of use of sulfides the exothermic reaction of sulfur combustion takes place and the sulfur also works as a reducing agent. Therefore, basing on the experimental data with the furnaces and oxidized ores, smelting of similar amount of ore would demand 1.5 kg of charcoal and as the density of birch charcoal is 380 kg/m^3, it would demand additional volume of about 4000 cm^3. Thus, the amount of ore in a crucible has to be reduced by 5 times that is about 600 g. As there was also the rock in the ore, the exit of copper could fluctuate between 60 and 200 g. In principle, it is close to that we have seen on the Sintashta sites and Mikhaylo-Ovsyanka.

Certainly, we do not know very much about the smelting parameters on the Mosolovka settlement, character of ore, and how fully the crucible was filled. Therefore the suggested figures have a primary estimated character. As casting of one axe required near 2-3kg of copper that is confirmed also by the existence of casting moulds of the corresponding size on the settlement (Pryakhin 1996, p. 49), it was required to do 15-25 smelting operations to produce this metal, if the assumed way of ore smelting in crucibles took place really. Therefore additional studies of crucibles are required for clarification of a question: whether they could be used not only in the metalworking, but also for ore smelting. A.D. Pryakhin was skeptical about the possibility of similar research, more precisely he expressed a regret concerning the absence of this possibility (Pryakhin 1996, p. 77), however some successful examples are known when crucible smelting was reconstructed thanks to analyses of crucible walls and identification in their slagged surface of delafossite which could not be formed at metalworking (Hauptmann *et al.* 1993, p. 566). But in a case of reducing atmosphere in a crucible, this mineral could not be formed, and searches for other criteria are necessary.

In the case of smelting in furnace, it is more difficult to calculate the smelting volumes. But they could be more significant. For example, above it has been already mentioned that the charging of furnaces in Pilipchatino could be 10-15kg. The copper exit at such charging was large – up to 3 kg. But is it true? Whether it was the standard charging of the furnace or the waste lying nearby was dumped into the furnace whose functioning was stopped? Therefore these data cannot be considered as completely reliable.

Problem of ore base

A special problem is determination of ore sources for metallurgical production. It is supposed that for the Mosolovka settlement these sources could be rather remote as in the region ancient mines are unknown. Therefore at discussion of probable sources the preference is given to the Donets Basin where mines of the Bronze Age are known, or even to very remote eastern centers, like the copper sandstones of the Cisural area, for example, Kargaly mines (Pryakhin 1996, p. 124) that seems to be doubtful. It is necessary to remind that S.I. Tatarinov objected to supply of copper to the Donets Basin from Kargaly too (Tatarinov 2003, p. 197).

The MP group of copper cannot be connected with some concrete ore field, for example Kargaly, and reflects, at best, the exploitation of deposits in the copper sandstones in general.

In this chapter we have almost not used chemical methods, in view of insignificance of the sampling that would not allow to do correct statistics of results of the analysis. Only 10 slag samples from the Mosolovka settlement and also one sample of slag and one of lining from Pilipchatino have been analyzed by the spectral method (Tab. 10-8.). Probably, a study of a larger sampling would do possible to outline some distinctions in the composition of trace-elements, but now it does not work. Therefore the mineral composition of slag was the base of this study. It, as well as insignificance of the studied series, does not allow us to consider the conclusions below as something final.

Besides, as we can judge from the slag analysis, mainly, sulfide ore was used for the smelting in the region. Some scholars believe that the preference to the sulfide ores was given for the reason that they are much richer than the oxidized ores (Brovender, Shubin 2008, p. 3). Probably, it was so, but there was also another reason: it was easier to smelt this ore as we have seen by the example of imperfect smelting of the oxidized ore from sandstones on the Kargaly mines. Besides, as it follows from the above-stated description of ore base of the region, the sulfide ores are widespread here; however, they are often mixed with the oxidized ores. And in the Kargaly copper sandstones the oxidized minerals are most typical, such as malachite and cuprite, although chalcocite is present too. A single similarity that should be noted is the presence of silver and barium impurities in one sample of the roasted copper ore from the Mosolovka settlement. But even it does not allow us to assume the ore export from the Orenburg zone, although a chemical solution of the problem does not exist. The base for this statement is the following. The ore smelted on the Mosolovka settlement was optimal, as by a ratio of acid and basic oxides, as by the presence of sulfides. Therefore it was smelted easily, providing the creation of fluid slag and separation of metal. In the Orenburg zone we see an absolutely different situation. Therefore here it was senseless to transport less qualitative raw materials from far away. It is quite applicable also to the Donets region with its own ancient mines.

But for the Mosolovka settlement it is already more difficult to make a choice between ore fields of the Voronezh crystal massif and the Donets mines. In principle, sulfide minerals prevailed in ore of both areas, but in the smelting operations of the Mosolovka settlement the use of chalcopyrite is more noticeable, than it is noted for the Donets settlements and mines. And for the Pavlovsk part of the Voronezh crystal massif this mineral is very characteristic. Therefore it is not excluded that the source of ore of the settlement of Mosolovka was situated somewhere in this area. It was, nevertheless, rather far to deliver the ore for 350km from the Donets mines.

These conclusions confirm the opinion of S.I. Tatarinov and A.D. Pryakhin about the existence of a special Don-Donets center of metallurgy and metalworking during the Late Bronze Age (Tatarinov 1989, 2003; Pryakhin 1996, p. 132, 133). It is necessary to remember, of course, that on the base of spectral analysis of the metal from Mosolovka E.N. Chernykh and S.V. Kuzminykh drew a conclusion about the Cisural and Donets sources for copper of the MP (copper sandstones) group and on more eastern Transural sources for metal of the VU (Volga-Ural), VK (Volga-Kama) and EU (Elenovka-Ushkatty) groups (Chernykh, Kuzminykh 1989a).

Earlier we repeatedly discussed the impossibility of this problem solution being based on the spectral analysis. But, anyway, the distinguished groups have an objective character and therefore demand to be analyzed concerning this situation. We have seen that the higher silver content can really serve as a sign of copper connected with the copper sandstones. But it is the single sign and therefore it cannot be considered as the reliable. The presence of silver in the roasted ore of the Mosolovka settlement indicates a local source of this copper, although connected, probably, with some sandstones of this area. It is impossible to say something certain about the VU and EU groups. It is only doubtful that they were of the eastern origin. It is more probable that these groups are united with the corresponding groups in the east by similar types of deposit and smelting technology. It is only possible to claim unambiguously that the copper of EU group was not delivered from the Andronovo mines of the Elenovka-Ushkatty area. The transportations of metal from one mining and metallurgical center to another (besides, manufactured, probably, a surplus mass of production (see below) was an absolutely senseless operation if this metal did not have any special characteristics, for example, it was alloyed with tin. The last could quite explain the transportation of metal from the Andronovo area. But we see that on the Mosolovka settlement only 23% of the EU metal belongs to the tin bronzes (Chernykh, Kuzminykh 1989a, p. 11). But also for this small part it is lawful to ask: whether the tin was delivered instead?

As for the VK group, as we have discussed it for the Timber-Grave culture of Bashkiria it was partly a result of smelting of sulfide ores with the higher content of arsenic and antimony, and partly a result of alloying with arsenic-antimony minerals at the stage of ore smelting. In our small collection of slag such alloying is noted, but even on the Mosolovka settlement the part of this copper is low (12.7%), while for the Don region its part is 25.7% (Chernykh, Kuzminykh 1989a, p. 11). Therefore, taking into account the given by S.I. Tatarinov data on mining of arsenopyrite with high content of arsenic, it is possible to assume the production of this metal in the Donets zone. And, in this zone this copper was connected with the alloying at the stage of ore smelting, instead of with the initial presence of arsenic in ore, as far as it is possible to judge it from the analyses of raw materials of this area where arsenic in copper ores has not been detected (Shubin 2010, tab. 1, 2).

But why in this case the alloying component could not been brought to the Voronezh settlements if such technology in the region existed? The transportation of a ligature is not so burdensome operation, as the transportation of ore. The answer is hided itself in the same ore base and technological features reconstructed for the Mosolovka settlement. Here probably the local ores were really used which contained more chalcopyrite than in the Donets zone. It required longer smelting operations at high-temperature that resulted in the removal of arsenic. This means that this alloying was inapplicable for this ore. But some quantity of metal of this type was delivered here from the Donets zone. The local alloying is not also excluded in cases of smelting ores containing no chalcopyrite. Such ores for certain existed here, but our analyses, owing to insignificance of the sampling, have not revealed such smelting operations.

Social organization and operation of the Donets-Voronezh mining and metallurgical center

Determination of volumes of copper production in this or that area is an extremely difficult task. Calculations of possible volumes of the extracted ore and the smelted copper based on the volume of dumps have been carried out only for the Kartamysh deposits of Donets Basin. As a result a conclusion has been drawn that 160 tons of copper were extracted and smelted here, and to produce one ton of copper it was required to extract 506 tons of rock and 16.9 tons of ore (Brovender *et al.* 2009, p. 217). As always at similar estimates this figures are very rough, but the described method of calculations is quite correct, therefore the figure is rather realistic. Its realness is also confirmed by that it is nearly three orders lower than the figures suggested for the Kargaly mines. But taking into account that it was not the single ore deposit of the Donets and Don regions, we can assume that in this region 300-800 tons of copper were smelted. This means that the region was very important for supply by metal of Eastern Europe, and for certain it was important not only for the closest district, but also for the neighboring areas. Judging from traces of ore smelting on the Mosolovka settlement, some ore sources of the Voronezh region were exploited too, but the volumes of production, apparently, were incomparably lower here.

It is supposed that from the Kartamysh area the prepared for smelting ore was transported to the territories rich in forests (Seversky Donets) where settlements of metallurgists like Usovo Ozero functioned (Brovender 2008a, p. 13). Studying of the remains of metallurgical production of the Subotov fortified settlement of the 12-9th centuries BC in the Cherkassk area on the Dnepr allowed to assume that ore was delivered there from the Donets Basin as its chemical composition is closer to ore of this region than to the ore from the Carpathian and Dniester areas (Demchenko *et al.* 2001). It is impossible to exclude this possibility, of course, but the provided analytical data are absolutely unconvincing. Therefore, the ore transportation from the region of its mining remains questionable.

The idea about two mining and metallurgical centers of Timber-Grave culture, Pokrovka-Mosolovka and Berezhnovka-Mayevka is also problematic. It is supposed that the first supplied with metal the populations of Prikazanskaya and Pozdnyakovo cultures of the Volga-Kama region, and the second was the copper source for the Trzciniec–Komarov and Sosnicja cultures in the Dnieper area (Otroshenko, 2003). The valid data on such supply of metal are absent, although they are much more probable than supply of ore, and for certain took place, as far as it is possible to judge from the production volumes. The question is only in reliable documenting of the directions of these deliveries that is unsolved task today.

It is also supposed that the production was carried out by clan communities of miners-metallurgists. One such community could consist of 80-100 persons: 30-40 miners, 10-20 workers crushing the extracted ore, and 20-30 transporters of the ore (Tatarinov 1989, p. 43). It is needless to say that the popular variant of the clan production communities could quite take place, but it has no strong proofs yet. As for the number of one community, these figures can hardly be discussed. Possibly, at this time there were really settlements located in the areas of mines and specializing on the mining and metallurgical production. It does not mean, of course, that this production was the only occupation of the population of these settlements. For certain there was also the cattle in their economic complex. But the volumes of production unambiguously indicate the manufacturing of metal for exchange operations.

However there is a question of the property of mines. And this question almost cannot be resolved. In the areas of Donets mines both seasonal and long-term settlements are known (Tatarinov 1987). It is obvious that the population of the long-term settlements developed these mines. But whether are the seasonal settlements an evidence of that people came here for ore from some area (within the radius 100km, for example) and extracted ore for their needs?

More definitely it is possible to say that inside such settlements all operations took place, beginning from the ore mining and to the metalworking. On the settlement of Chervone Ozero 3 tools of all cycles of metallurgical production are found, serving for ore mining and crushing and for metalworking. Many such tools have been also found on other sites of this mining and metallurgical center (Brovender 2008, p. 193-199; 2009-2010, p. 207, 214; Brovender, Zagorodnyaya 2009; Zagorodnyaya 2011). On the Mosolovka settlement many tools connected not only with the metalworking, but also with the ore mining[1] and crushing have been revealed too (Kileinikov 1984). It indicates the lack of distinct specialization inside one settlement.

Origins of the Timber-Grave metallurgy of the Donets-Voronezh region

As we have seen from the above-stated text, the Timber-Grave production of the region was based on its own ore sources. And we have no evidence that these sources were exploited before. Therefore the autochthonic development of the Timber-Grave production here on the basis of local Middle Bronze Age traditions is doubtful, at the undoubted existence of local metalworking. On the other hand, in the production we see clearly the features which are present on the eastern sites, including the Timber-Grave sites. Of course, above all it is smelting of sulfide ores noted for the Western Orenburg and Volga regions and Bashkiria. This sign, of course, cannot be absolutized as it could be caused by specifics of the local ore base. But, nevertheless, it is necessary to take into account it as smelting of any type of ore means a complexity: not only the choice of ore, but also design of furnaces, modes of smelting, types of ligatures. All this should be placed in the united system.

Earlier we have seen similar types of furnaces, types of smelting and ways of alloying with arsenic-antimony minerals in the east. It is possible to relate to this also the alloying with tin that was certainly an eastern technology connected with the Andronovo world. And, in the Don region the share of this metal was 25.7%

[1] It is one more sign of exploitation of the local ore base, respectively, from the Donets zone the raw materials were not brought to the Voronezh zone.

(Chernykh, Kuzminykh 1989a, p. 11). And metallographic studies of bronze objects have shown that metallurgists badly knew how to work with this type of alloys which points to the borrowing of this tradition (Ryndina, Degtyaryova 1989, p. 38). In this case, the mediate borrowing through the massif of the Timber-Grave tribes of the Volga and Cisural areas is only possible.

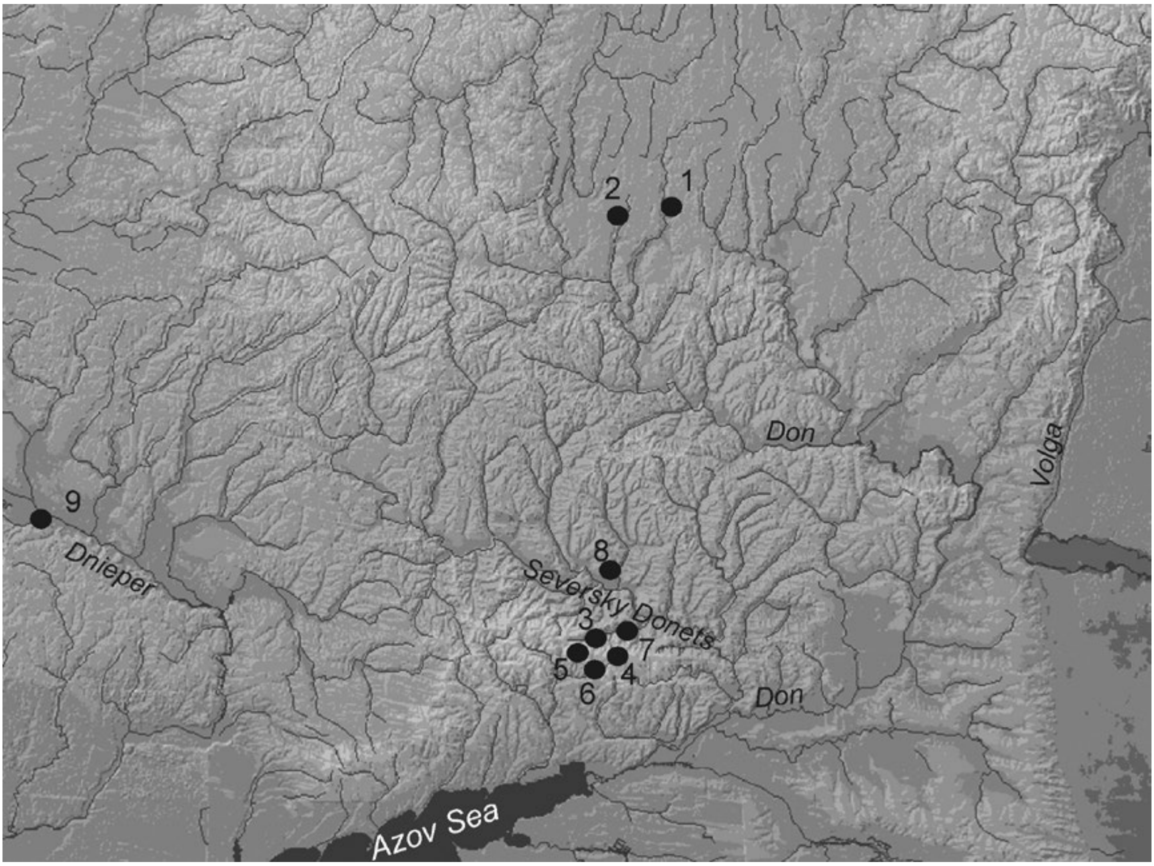


FIG. 10-1. MAP OF SITES IN THE DON AND DONETS AREAS. SITES OF THE VORONEZH ZONE – 1, 2, THOSE OF THE DONETS ZONE – 3-8: 1 – MOSOLOVKA; 2 – VOGRES DAM; 3 – PILIPCHATINO; 4 – VYSKRIVKA; 5 – KLINOVOYE; 6 – MEDNAYA RUDA; 7 – CHERVONE OZERO; 8 – USOVO OZERO; 9 – SUBOTOV.

Tab. 10-2. Form of slag from the Mosolovka settlement.

Shapeless slag	Flat slag
12 80%	3 20%

Tab. 10-3. Mosolovka settlement, SEM analysis of sample 775.

Weight %	Analysis	Material	O	Si	Cu	Fe	Mg	Al	K	Ca
	1	olivine	30.94	22		43.93	1.83	0.69		0.61
	2	glass	34.18	28.78		24.13		1.99	0.6	12.34
	3	copper			100					
	a	border around copper	X		X					
	4	wüstite	22.21			77.79				
	5	wüstite	21.95			78.05				
Atomic %										
	1	olivine	53.42	21.64		21.73	2.06	0.71		0.42
	2	glass	54.52	24.32		11.03		1.88	0.39	7.86
	3	copper			100					
	4	wüstite	49.92			50.08				
	5	wüstite	49.44			50.46				

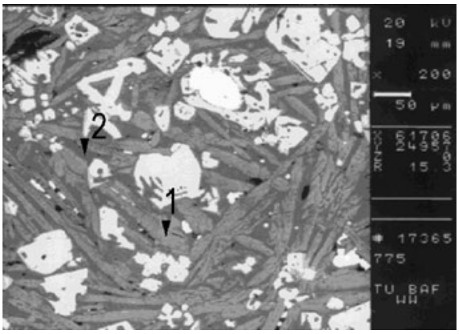


Fig. 10-4. Mosolovka settlement, microstructure of slag (sample 775). Long prismatic prisms of fayalite (grey) in the glass matrix (dark grey), inclusions of magnetite and wüstite (light grey), deformed globule of sulfide (white) surrounded with wüstite.

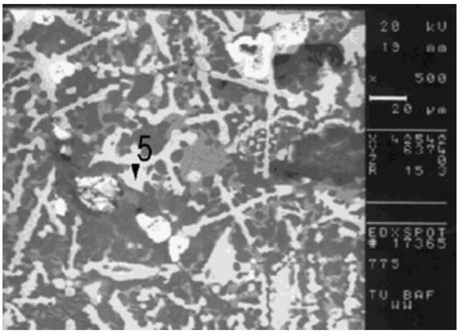


Fig. 10-5. Mosolovka settlement, microstructure of slag (sample 775). Lattice and dendritic structures of wüstite (light grey) and prills of sulfide (white) in the glass matrix.

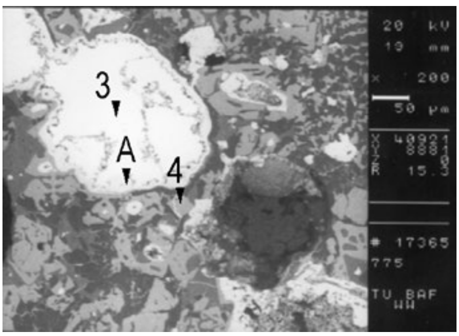


Fig. 10-6. Mosolovka settlement, microstructure of slag (sample 775). Copper prills (white) within the border of cuprite. Crystals of wüstite (grey) in the glass matrix.

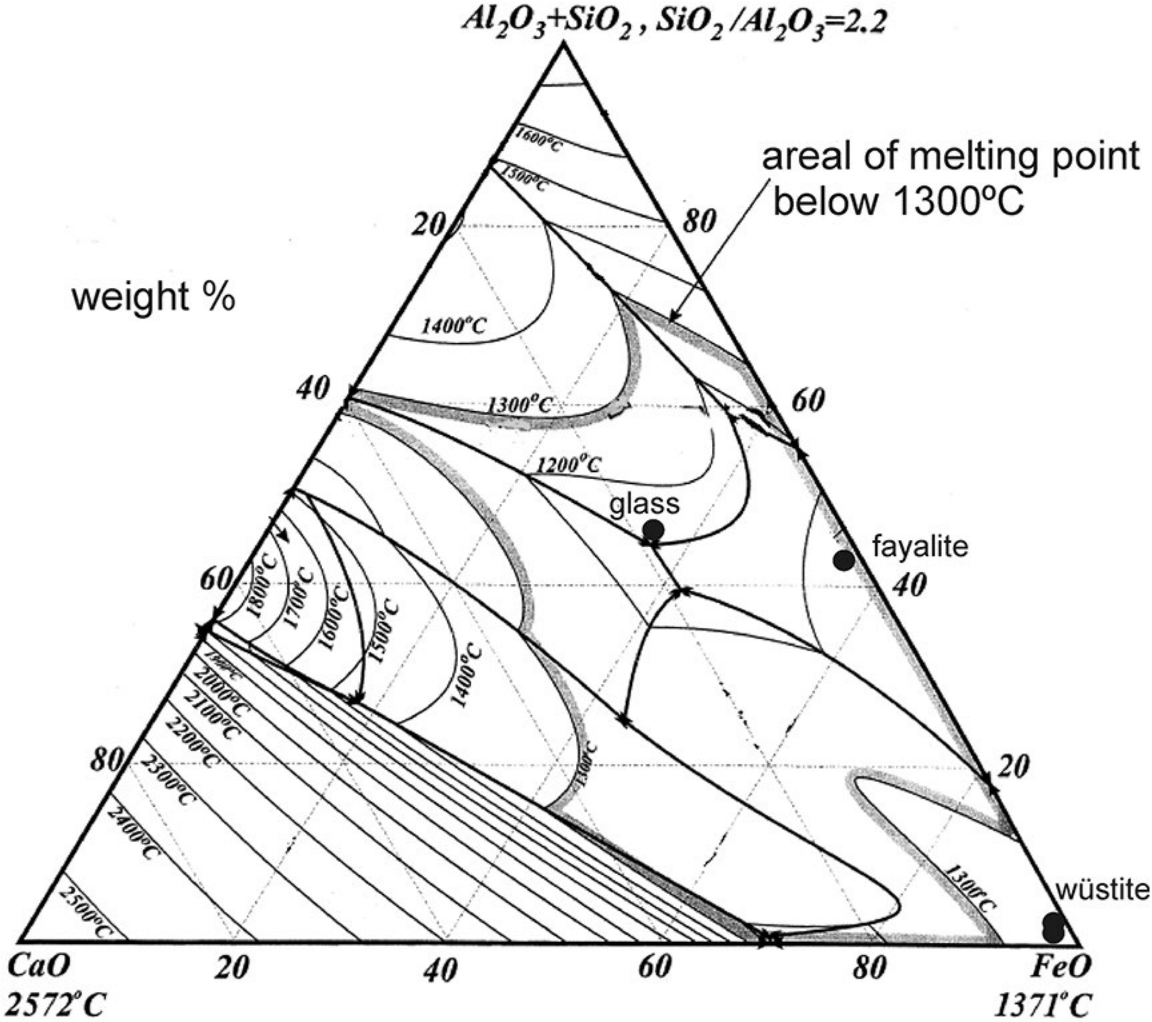


Fig. 10-7. Phase plot of FeO-Al2O3+SiO2-CaO for fayalite, glass and wüstite in slag, sample 775.

Tab. 10-8. Emission spectral analyses of slag ore and lining from the settlements of Mosolovka and Pilipchatino (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).

Site	Material	Sample	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Pilipchatino	slag	758	0.003	0.0015	0.015	0.3	0.01	0.3	0.001	0.0003	1
Pilipchatino	lining	759	0.02	0.002	0.03	0.1	0.015	0.7	0.002	<0.0003	0.5
Mosolovka	slag	767	0.001	0.0015	0.007	0.15	0.003	0.2	0.0005	0.00015	0.1
Mosolovka	slag	768	0.003	0.002	0.007	0.15	0.0015	0.3	0.0005	0.0003	0.7
Mosolovka	slag	770	0.015	0.005	0.007	0.15	0.0015	0.2	<0.0005	0.005	>>1
Mosolovka	slag	771	0.005	0.007	0.005	0.3	0.0015	0.2	0.0005	0.0003	0.7
Mosolovka	slag	772	0.005	0.002	0.01	0.3	0.0015	0.3	0.0005	0.00015	0.3
Mosolovka	ore	773	0.002	0.001	0.005	0.1	0.007	0.1	0.0005	0.003	>>1
Mosolovka	ore	774	0.03	0.01	0.007	0.1	0.005	0.2	0.0005	0.0003	>>1
Mosolovka	slag	775	0.007	0.01	0.0015	0.1	0.0015	0.07	0.0005	0.0002	1
Mosolovka	slag	776	0.001	0.0003	0.005	0.3	0.003	0.2	0.0005	<0.0003	0.03
Mosolovka	slag	777	0.005	0.015	0.001	0.15	0.003	0.07	0.0005	0.0005	>>1
Sensitivity of the analysis			Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
			0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.0003	0.001

Tab. 10-8. Emission spectral analyses of slag ore and lining from the settlements of Mosolovka and Pilipchatino (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30)(contd.).

Site	Material	Sample	Zn	Pb	Ag	As	Mo	Ba	Sr	W	Sn
Pilipchatino	slag	758	0.7	0.007	0.001	0.005	0.0015	0.2	0.05	<0.001	0.0003
Pilipchatino	lining	759	0.015	0.003	0.002	0.005	0.0002	0.07	0.015	0.001	0.0003
Mosolovka	slag	767	0.015	0.002	0.0005	0.005	0.0002	0.05	0.01	<0.001	<0.0005
Mosolovka	slag	768	0.01	0.002	0.001	0.005	0.0003	0.07	0.01	<0.001	0.0015
Mosolovka	slag	770	0.015	0.03	0.003	0.005	0.00015	0.07	0.01	<0.001	0.05
Mosolovka	slag	771	0.5	0.02	0.0007	0.005	0.0003	0.2	0.03	<0.001	0.01
Mosolovka	slag	772	0.01	0.002	0.0005	0.005	0.0007	0.15	0.015	<0.001	0.005
Mosolovka	ore	773	nd	0.02	>10	0.005	0.003	1	0.03	<0.001	<0.0005
Mosolovka	ore	774	0.01	0.03	0.002	0.005	0.0005	0.07	0.02	<0.001	0.03
Mosolovka	slag	775	0.07	0.005	0.0005	0.005	0.01	0.03	0.01	<0.001	0.0015
Mosolovka	slag	776	0.007	0.001	0.00005	0.005	0.0003	0.15	0.02	<0.001	0.0003
Mosolovka	slag	777	0.15	0.015	0.002	0.005	0.01	0.02	0.01	0.0015	0.007
Sensitivity of the analysis			Zn	Pb	Ag	As	Mo	Ba	Sr	W	Sn
			0.003	0.0003	0.00003	0.01	0.0001	0.01	0.01	0.001	0.0005

Tab. 10-8. Emission spectral analyses of slag ore and lining from the settlements of Mosolovka and Pilipchatino (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30)(contd.).

Site	Material	Sample	Be	Zr	Ga	Y	Yb
Pilipchatino	slag	758	0.0002	0.015	0.001	0.002	0.00015
Pilipchatino	lining	759	0.0003	0.015	0.0015	0.002	0.00015
Mosolovka	slag	767	0.00015	0.015	0.0005	0.002	0.00015
Mosolovka	slag	768	0.0002	0.015	0.001	0.002	0.00015
Mosolovka	slag	770	0.0001	0.015	0.001	0.0015	0.00015
Mosolovka	slag	771	0.00015	0.015	0.001	0.002	0.00015
Mosolovka	slag	772	0.0002	0.015	0.001	0.0015	0.00015
Mosolovka	ore	773	0.00015	0.01	0.001	0.001	<0.0001
Mosolovka	ore	774	0.00015	0.01	0.001	0.002	0.00015
Mosolovka	slag	775	0.00007	0.0015	0.001	<0.001	0.0001
Mosolovka	slag	776	0.00015	0.01	0.0005	0.0015	0.0001
Mosolovka	slag	777	0.00007	0.001	0.001	<0.001	0.0001
Sensitivity of the analysis			Be	Zr	Ga	Y	Yb
			0.00003	0.001	0.0005	0.001	0.0001

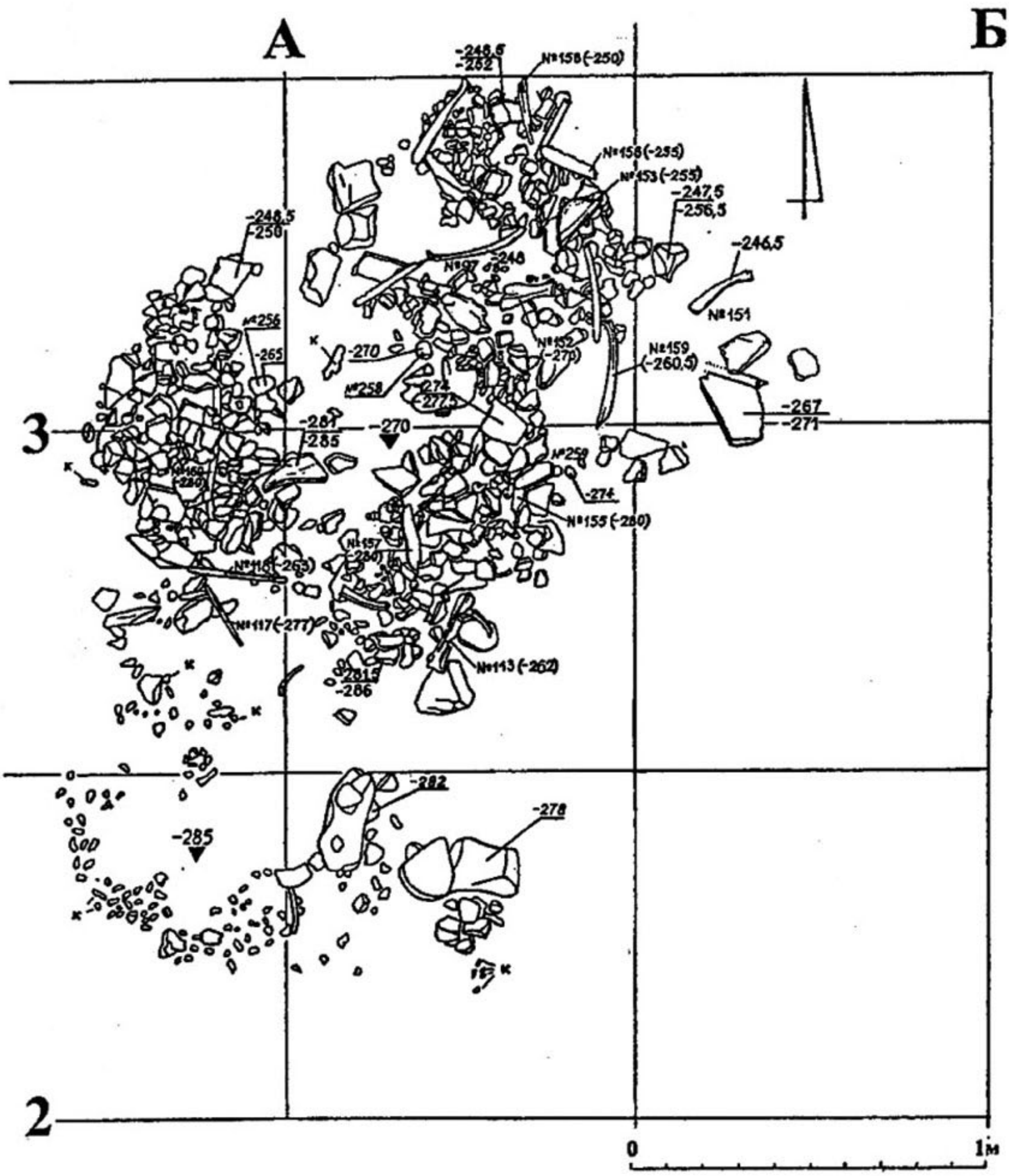


Fig. 10-9. Metallurgical complex of the settlement of Chervone Ozero 1 (Brovender 2008).

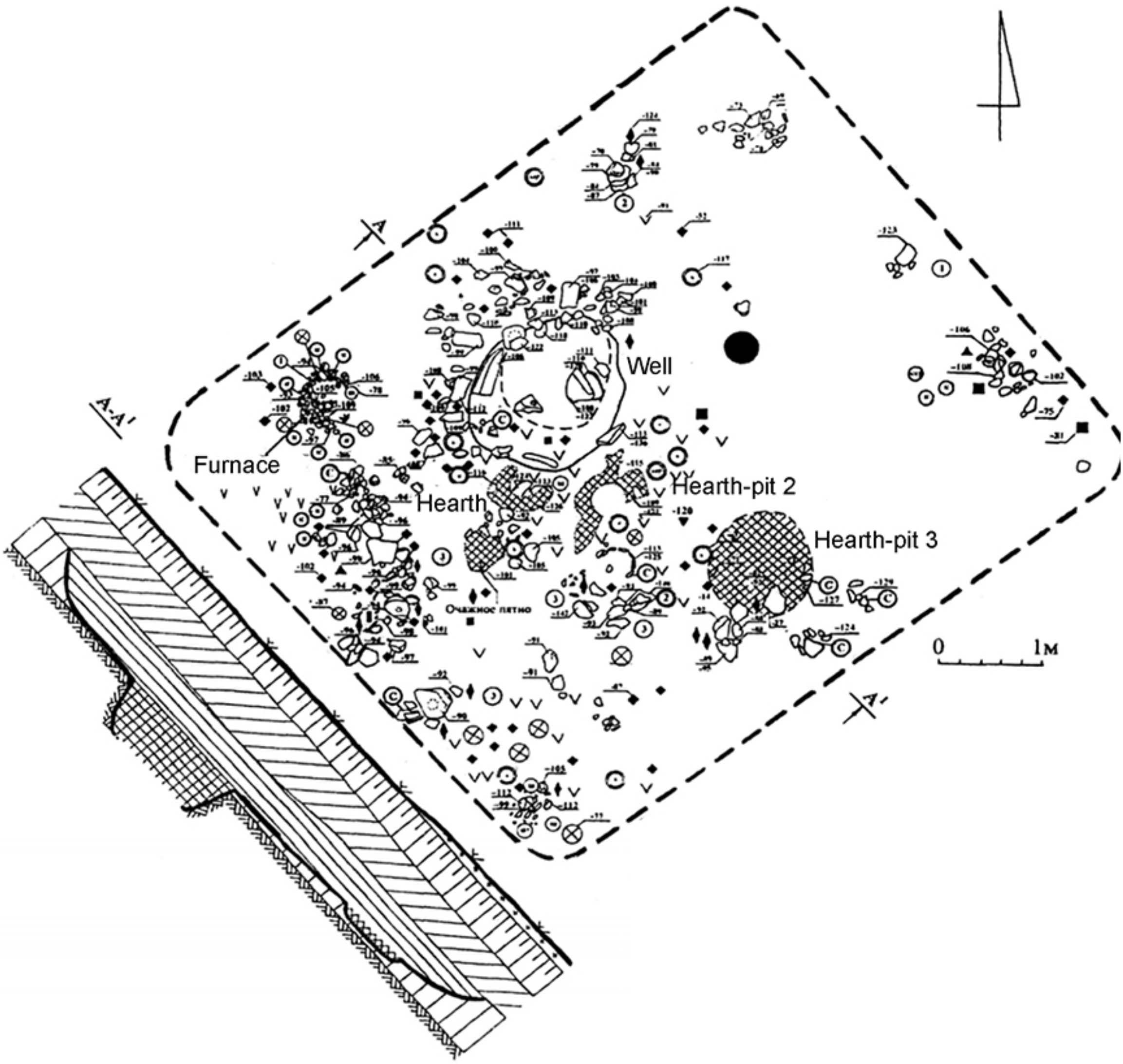


Fig. 10-10. Metallurgical complex of the settlement of Chervone Ozero 3 (Brovender 2010).

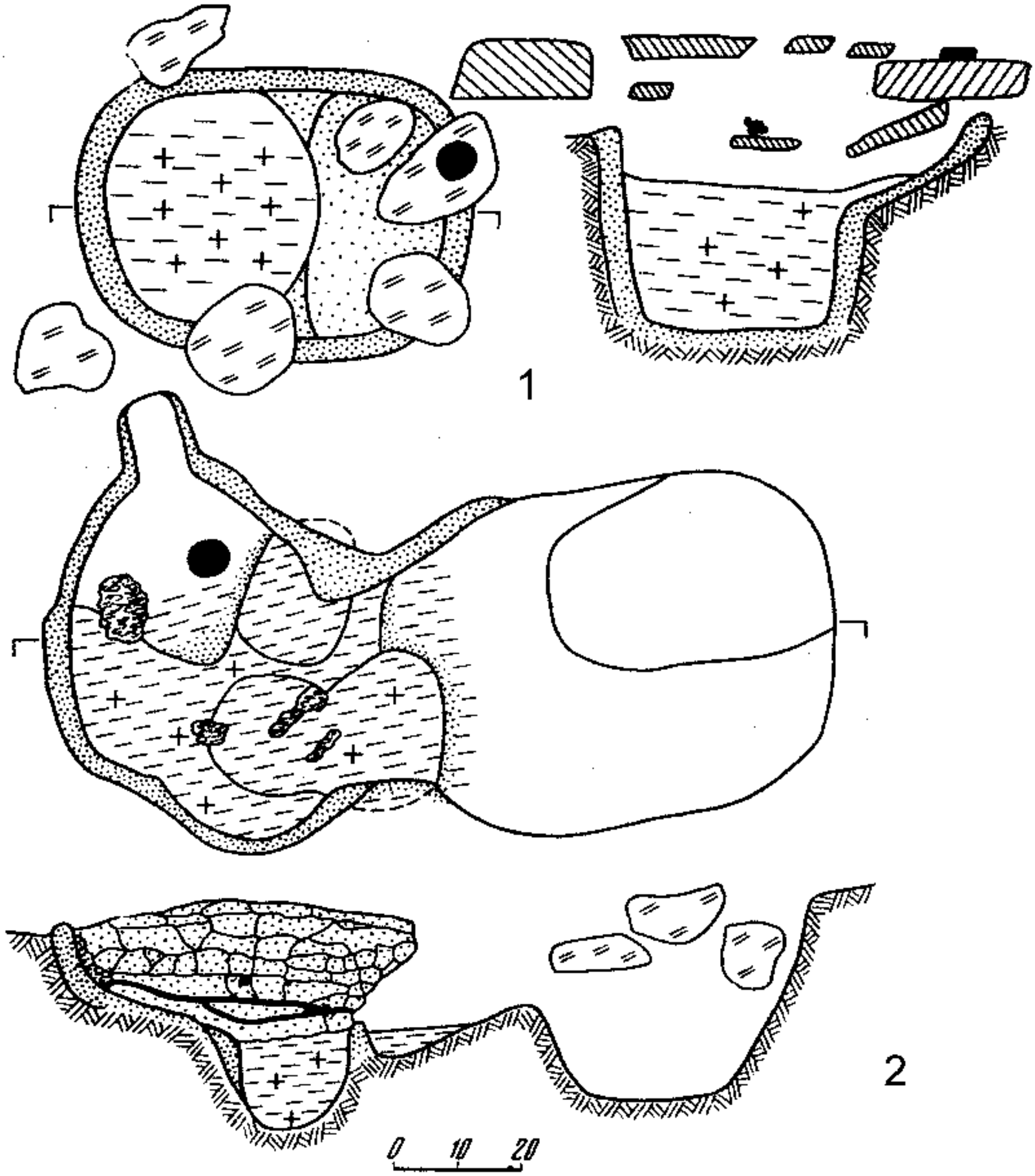


Fig. 10-11. Furnaces of the settlement of Pilipchatino (Tatarinov 1977).

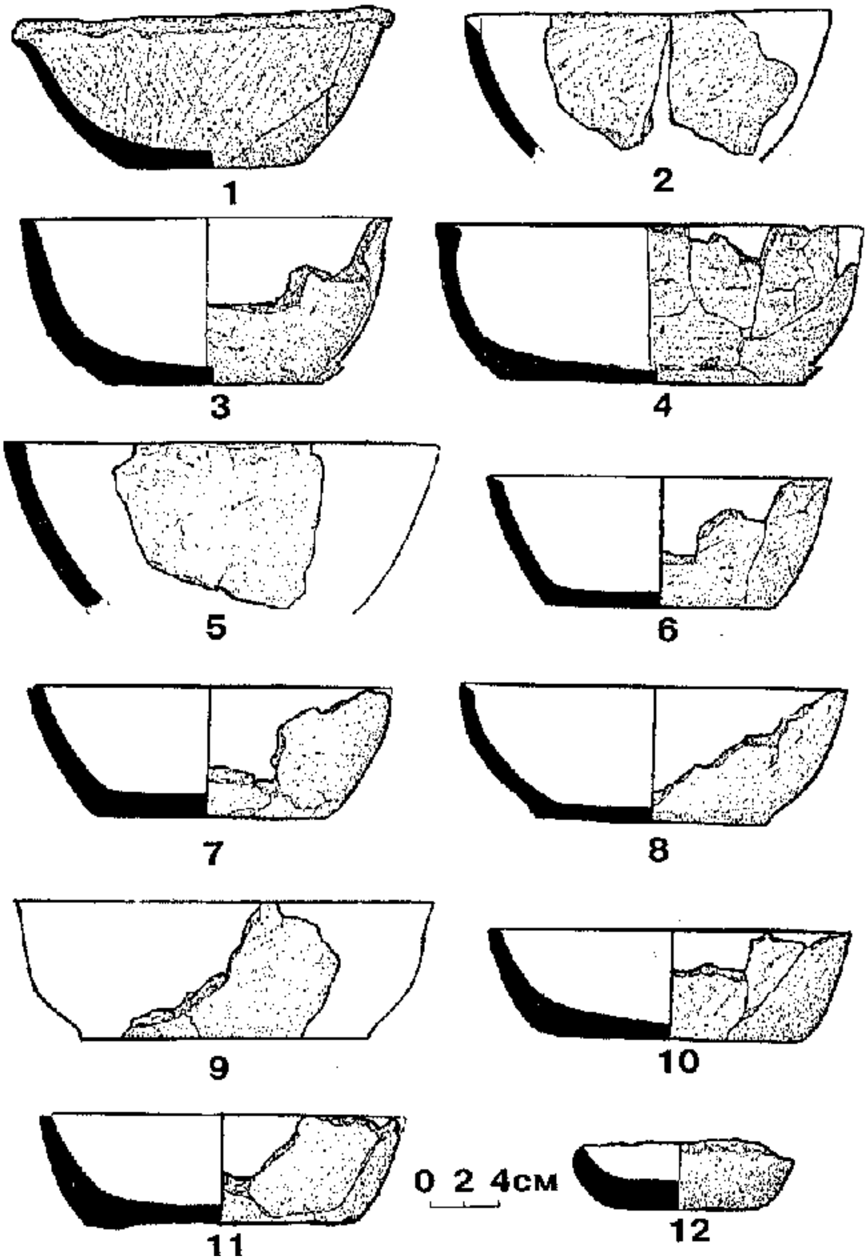


FIG. 10-12. CRUCIBLES OF THE SETTLEMENT OF MOSOLOVKA (PRYAKHIN, SAVRASOV 1993).

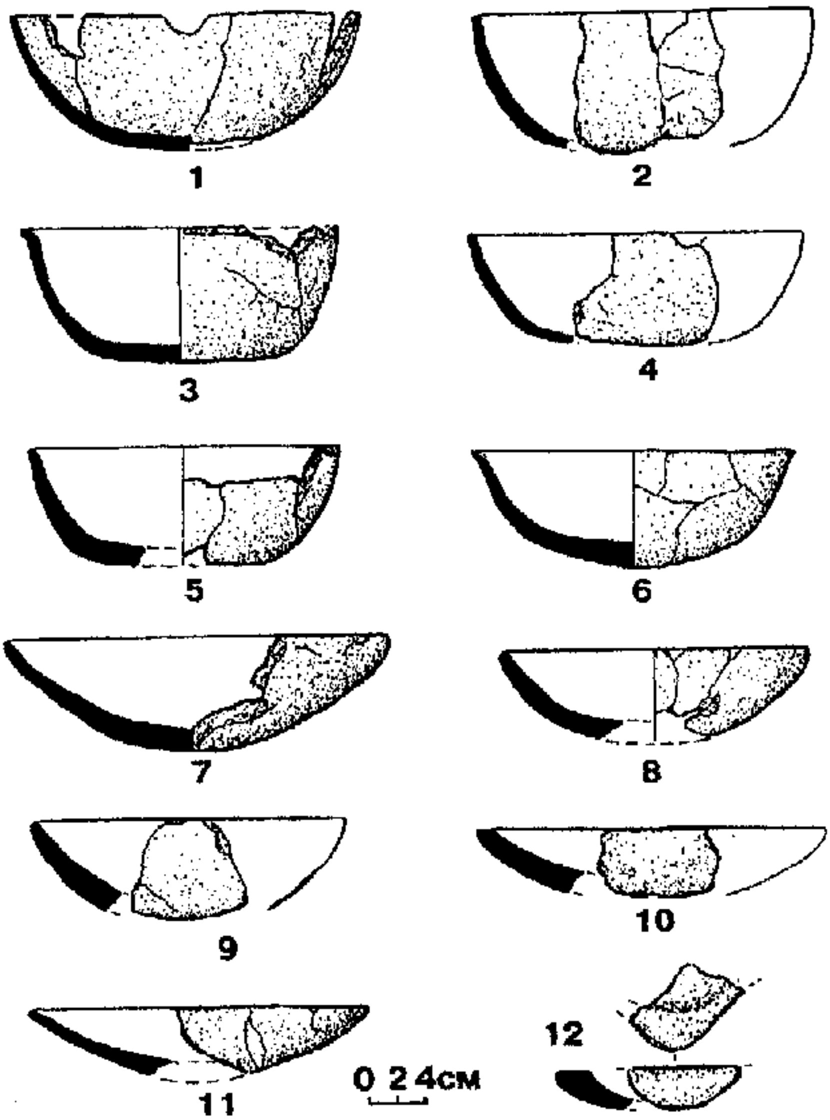


FIG. 10-13. CRUCIBLES OF THE SETTLEMENT OF MOSOLOVKA (PRYAKHIN, SAVRASOV 1993).

Chapter 11.
Metallurgical Production in the Asian Part of the Eurasian Metallurgical Province in the Bronze Age

The Altai and Sayan in the system of metallurgical provinces

The easternmost part of the Euroasian Metallurgical Province (EAMP) is limited by the Altai Mountains forming together with the Sayan Mountains a huge mining system. During the most Bronze Age the Altai was included into this metallurgical province, however in the final period of this epoch, with formation of the Central Asian Metallurgical Province, many new features occurred, that influenced not only on typology of objects, but also on characteristics of smelting process here. The Sayan are interesting to our research to a lesser extent because any reliable data on metallurgical production here appeared only since the time when this region was not included into the system of the Euroasian Province. But the significance of the Altai for understanding of history of the production within the EAMP is extremely great. It was not restricted only to that this area on the province periphery has a plenty of ore deposits. It was the single source of tin, the main alloying component of the whole system of the EAMP. Besides, just from this area the majority of innovations leading to changes in the EAMP system since its second phase spread.

Ore base of the Altai Mountains

Now about 730 polymetallic deposits are known in the Altai. Genetically they are connected with intrusions of quartz porphyries originated from granite magma (Grigoriev, Glebov 1934, p. 53, 58, 59; Grigoriev I. 1934, p. 41). Copper in the Altai deposits is usually connected with lead and zinc although there are pure copper deposits too (Khismutdinov 1961, p. 5; Grigoriev, Glebov 1934, p. 62).

Altai has a well developed oxidized zone up to the depth of 30-60m, and in some cases up to 80m (Grigoriev I. 1934, p. 50; Roslyakov 1970, p. 59-66); the zone of cementation is expressed slightly (Grigoriev, Glebov 1934, p. 98). Many deposits are covered by “iron caps” (Roslyakov 1970, p. 6; Grigoriev, Glebov 1934, p. 98). All Altai ores are fine-grained and need a complicated enrichment.

The Altai deposits may be divided into several groups.

Zmeinogorsk group

The majority of deposits here are polymetallic with prevalence of silver and lead. Quartz is the vein mineral. In the oxidation zone the main minerals are malachite, azurite, iron and lead ochres. On the Lazurskoye deposit the copper content in the oxidized zone is 7%, the content of lead is 5% (Grigoriev, Glebov 1934, p. 63-77).

Kolyvanovskaya group

The deposits belong to mesothermal type and are presented by quartz veins. The content of copper is 5.5% (Grigoriev, Glebov 1934, p. 77; Grigoriev I. 1934, p. 46).

Charysh-Anuy group

On the majority of deposits the ore is poor. Ore is holded by quartz rocks. In the oxidized zone the high content of iron, lead and zinc are typical that sometimes in the 19th century forced to stop smelting of these ores (Grigoriev, Glebov 1934, p. 78-80).

Irtysh group

The group is presented by a significant quantity of copper and copper-zinc deposits. The first prevail in the northern part of the group, the second are in the southern. The contents of zinc and lead in the ores of copper deposits are rather great. The ores are situated in the quartz rocks. The oxidized zone contains a significant quantity of iron and lead oxides. Some deposits are blocked by the "iron caps". The copper content in the ore is high. The copper mineralization is presented by malachite, azurite, and cuprite (Grigoriev, Glebov 1934, p. 81-101).

Zyryanovsk group

The most part of deposits is polymetallic, with prevalence of lead and zinc. Vein minerals are quartz and barite. In the oxidized zone the content of iron is high.

Bukhtarma is the main copper deposit of the group. Here traces of ancient works remained. Ores is presented by copper and iron hydrooxides in quartz. The thickness of quartz veins is 17-35cm, reaching in some cases 1.5 m. The copper content in the ore is 11% (Grigoriev, Glebov 1934, p. 102-118).

Ridder group

It is presented by polymetallic ores with insignificant contents of copper. Probably, it was not exploited.

South-Narym group

Deposits are found by large ancient pits. The ore is holded by the amphibolic slates impregnated with malachite. The gangue is hematite with quartz inclusions. Veins of malachite reach sometimes 1 cm. There are lead and zinc traces (Zhelubovskii 1937, p. 6-10).

Thus, the Altai deposits were an important raw source in antiquity. And, all of them have a number of similar features: existence of the rich oxidized copper mineralization on the surface and extending on the considerable depth; the ore is holded, mainly, by quartz rocks; often it contains impurities of other metals (lead and zinc), and, ores of these metals are often available on the same deposits. Many of these fields were probably exploited in antiquity, but subsequently traces of ancient works were erased by the latest mining (Chernikov 1949; Rozen 1983). Almost all considerable deposits here are discovered by the remains of ancient mines. And, during the Russian works on these mines many evidences on ancient mining production have been obtained. The ore was mined in open pits and adits reaching 10-20m in depth. Thus, the adits were limited to the oxidized zone of ore deposits. According to some researchers, in the Altai in antiquity, mainly, oxidized ore was used (Chernikov 1949, p. 51; Rozen 1983, p. 26). The most important result of the former works is a conclusion that in view of the lack of cassiterite deposits in a huge area from Bohemia to the Altai, the deposits on the ridges of Kalba and Narym in the Altai were the main source of tin for the large region of Northern Eurasia (Chernikov 1949, p. 73).

Early and Middle Bronze Age of Southern Siberia

In the Early Bronze Age this territory was occupied by the Afanasievo tribes (Fig. 11-1.). Within the calibrated radio-carbon system this culture is dated to the first half of the 3rd millennium BC (Görsdorf *et al.* 1998). In my opinion, the most justified is the traditional concept of origins of Afanasievo culture as a result of migration of the Pit-Grave tribes (Alekseev 1961, p. 380; Semenov 1987, p. 18). Unfortunately, data about the ore smelting of this period are, practically, absent that is identical to the situation in Eastern Europe. And, the data on chemical compositions of metal are present, mainly, in the eastern (Sayan) part of the area. In the Afanasievo time the pure copper dominates in the metal, although copper alloys with arsenic are already known too (Sunchugashev 1975, p. 146; Bobrov *et al.* 1997, p. 68).

There is, however, an opinion that the Afanasievo metalworkers did not know artificial alloys, and the assessment based on the old analyses is not absolutely true as at that time the Okunev culture was not discovered yet, and the Okunev objects got to the sampling. On this basis the conclusion has been drawn that by its parameters it is more correct to relate the Afanasievo culture not to the Early Bronze Age, but to the Eneolithic. However in the tables published by the same authors, arsenic is present in many objects in quality of 1-3% that, probably, was a result of alloying, and in other objects its concentration is 0.2-0.5% that can be considered as ore impurity. Additional analyses of some Afanasievo objects have yielded the same result, and in one site of the Minusinsk Depression having already Okunev features the tin impurity is revealed (Grushin *et al.* 2006, p. 24, 30; Khavrin 2008, p. 210-212).

The rare objects from meteoric iron occured, for example, a bracelet in the form of a leather strap with the sewed iron plates from the Afanasieva Gora cemetery. In the cemetery of Pokrovka IV a gold ring is found (Grushin *et al.* 2006, p. 19). The use of these metals was more likely an exception, and all this together corresponds to the key parameters of the Pit-Grave metallurgy. And, this situation is also accompanied by morphological similarity of the Pit-Grave and Afanasievo objects (see Grishin 1971, tab. 1.2-4,6-10; 12.3). Therefore the conclusion that the impulse to the emergence of Afanasievo metallurgical center came from the west, from the territory of the Circumpontic Metallurgical Province seems to be indisputable (Grushin *et al.* 2006, p. 21).

A question of possibility to relate the Afanasievo culture to the Eneolithic is more debatable. Neither existence nor lack of this or that ligature can be the basis for consideration of a culture within this or that archaeological period as it can be explained by local phenomena, manifestation of local traditions, absence or existence of a certain ligature. So, being guided by a similar argument, we also have to refer the Pit-Grave culture of the Cisural area to the Eneolithic, as well as some later cultural formations. Comparability of the parameters of Afanasievo metallurgy with those of the Pit-Grave culture allows us unconditionally to refer the Afanasievo culture to the Early Bronze Age, taking into account the conditional character of such procedures which we have specified in the introduction. However in this case there is no conviction even that the conclusion about the lack of alloys is true. Arsenic impurities in such concentration hardly can be a result of smelting of oxidized ores, and during this period we have no bases for assumptions about smelting of sulfides. Therefore similar dispersion in the contents of arsenic impurity can be explained by alloying with arsenic minerals at the stage of ore smelting that did not allow to provide exact desirable concentrations of arsenic. Irrespective of the solution of the matter, metallurgists of a region, where the impulse to the formation of Afanasievo metallurgy came from, should know similar ways of alloying, probably, rather typical for this epoch; in any case, it was necessary to know, or to develop independently the ways of production and forging such metal. And the Pit-Grave culture of the Cisural area with its orientation to the production of pure copper does not corresponds to these conditions.

An intersting feature is the presence in Afanasievo complexes of the Minusinsk Depression of rare silver ornaments, and also one earring made of lead (Grushin *et al.* 2006, p. 23). The matter is that the problem of silver is also topical for the later periods of Southern Siberia. Many years ago de Genin wrote about the possible ancient silver smelting in the Altai when he described five copper-smelting furnaces, slag and probably silver ore at the river Shulba. However M.F. Rozen has doubted the possibilities of silver smelting in antiquity, believing that ancient people gathered native silver as it took place subsequently in the Russian period on the Zmeinogorsk mine (Rozen 1983, p. 26, 28). It is necessary to take into account the fact that during various epochs silver in Southern Siberia was accompanied by lead. The lead earring of the Afanasievo time has been mentioned above. Lead smelting in antiquity did not make any sense. On the other hand, silver was produced from lead ore, and lead could be a by-product in this case. And, this process is complicated and had to be introduced from a region with the developed metallurgical tradition (Grigoriev 2003).

There are polymetallic deposits with higher contents of silver in the Altai. However extraction of silver from copper ore was impossible in this period. Therefore for the whole Bronze Age of the Altai, probably, the technology of silver production which we have described for Sintashta culture is applicable.

Unfortunately, small number of works, analyses, the lack of slags and furnaces hinders to understanding of characteristics of metallurgical production of Afanasievo culture. The published analyses are not divided into Early and Late Afanasievo. Therefore it remains unclear with what the introduction of use of meteoric iron, silver and lead, and also arsenic as an alloy was connected. All this, undoubtedly, were western or southern phenomena, but a question remains: at what stage they occurred – at the very beginning of the Afanasievo culture, or at its end when the formation Okunev culture in the Sayan and late complexes of the Afanasievo culture in the Altai occured. These evidences can reflect different processes. In the second half of the 3rd millennium BC in the Altai Afanasievo culture was reformed, and a ware with bellied body and brushed ornament on the surface appeared, which has affinity with the Late Pit-Grave site of the South-Western Urals and the Northern Caucasus (see Soenov 1995, fig. 5,2,3, fig. 9,1; Posrednikov, Tsyb 1992, fig. 3,1,2,6; Morgunova 1992, fig. 5,2; Vasiliev *et al*. 1986, fig. 11; Kiryushin, Klyukin 1985, fig. 5,18-2; Grigoriev 1999, p. 188).

Thus, it is indisputable that the impulse to the formation of the Afanasievo metallurgical center came from the CMP, but we do not know whether there was the single impulse.

Our data on the later Okunev metallurgy of the Minusinsk Depression (Fig. 11-1.) are also poor. This culture is dated to the last third of the 3rd millennium BC – the early 2nd millennium BC (Görsdorf *et al.* 1998). The main types of alloys were pure copper and arsenic bronze, but there are in the Okunev time single objects (a knife from Verkhnii Askiz I and an earring from Tas-Hazaa) alloyed with tin. Three silver rings (Uybat V, Bateni, Moiseikha) are also known (Bobrov *et al.* 1997, p. 68; Khavrin 1997, p. 162, 163). Some chronological difference is traceable: in metal of the early Uybat period of Okunev culture there are only two objects with low tin content, and in metal of the later Chernovaya period already a half of metal contains tin, while another half is made of pure copper (Khavrin 2008, p. 213).

There are also the first evidences of copper smelting. On the bank of the Uzun-Zhul stream fragments of ceramics of the Okunev time[1] and slag are found. A fragment of a bottom of a thick-walled vessel is covered with the slag crust. It has been considered as the sign of crucible smelting (Sunchugashev 1975, p. 20). The analysis of a copper prill from this slag crust revealed 5% arsenic (Khavrin 1997, p. 162). Such abnormally high impurity is not typical for Okunev metal in which the arsenic concentrations fluctuate in a wide range between 0.02 and 2.8% (see tab. Khavrin 1997, p. 163). The low-arsenical part of the Okunev metal reflects, probably, the ore smelting without the use of special alloys, but in the cases when arsenic concentrations exceed 0.5-1% we deal probably with some way of alloying. It is impossible to clear this question without a

[1] In other place of the same work the ceramics is called ‘late Afanasievo’ that chronologically reflects the same stage of metallurgy of the region (Sunchugashev 1975, p. 79), however S.V. Khavrin considers this vessel as belonging to Okunev culture (Khavrin 1997, p. 161).

good series of slag analyses, but the way of alloying "metal into metal" can be excluded. Ya.I. Sunchugashev belived that in the Minusinsk Depression the alloying with sulphurous arsenic minerals into metal took place, citing as an example experiments of V.A. Pazukhin who worked, however, with powder copper (Sunchugashev 1975, p. 126). Besides, other components are also present in the arsenical minerals, as wel as inclusions of gangue which should be removed from metal. In these minerals metals are presented not in a pure form, but in compounds, i.e. it was needed to do metallurgical reactions for which conditions and time were necessary. Therefore the alloying into ore is more probable.

Arsenic minerals are well presented in Khakassia. But often copper ores contain the arsenic impurity. In the Haradzhul and Butrakhty deposits with the mixed copper-arsenic ores the content of arsenic reaches 30% (Sunchugashev 1975, p. 52, 128). Therefore it is possible to consider three variant of the alloying: 1) mix of copper and copper-arsenic ore, 2) alloy of the metals smelted from ores of these types, 3) addition of arsenic minerals to copper ore. In all cases we will have rather fuzzy picture of arsenic concentrations that is characteristic of the Okunev metal, and all of them are technologically quite reliable. There is a question what does reflect the analysis of this copper prill from the slag crust. It is unlikely it was a result of smelting of high-arsenic copper ore. Uzun-Zhul is remote from Haradzhul and Butrakhy deposits on a distance about 100 km, and it was more reasonably to smelt such ore near the mines and then to transport the copper-arsenic alloy to use it for the following alloying. Therefore the third technological scheme seems to be more probable: it assumes the addition of arsenic minerals to copper ores. But without a good analytical series this conclusion is also a possible assumption only. The new fact is the data on the ore smelting in crucibles, although it is not excluded (and even it is the most probable variant) that by such a way metallurgists smelted also in the Afanasievo time, but evidences for this are absent.

Thus, in general, Okunev metallurgy can be considered as a continuation and development of the Afanasievo tradition, but it can be considered also as a new impulse from the Circumpontic zone. But such possibility can be testified only by the emergence of the first objects alloyed with tin, a fact obviously insufficient for such a conclusion.

The question of connection of Okunev metallurgy with the Afanasievo tradition cannot be solved in a separation from a question of connection between these cultures. The answer to the last question differs. As a whole, the Okunev material culture differs from the Afanasievo. It is especially visible in distinctions in technologies of ware manufacturing (Ivanova, 1968). Some authors have assumed that the Okunev culture originated on the basis of development of forest Neolithic tribes (Vadetskaya *et al.* 1980). Others hold an opinion about West Asian sources of Okunev art (Savinov 1997; Devlet 1998, p. 154-159). I.P. Lazaretov gave a series of parallels with steppe complexes of Eastern Europe (Lazaretov 1997, p. 39-40). The author of this work suggested a hypothesis about a migration of the West Asian people through Eastern Europe (Grigoriev 2002, p. 186-192). Within problems of this research it is impossible to answer this question. It is possible to exclude safely the variant of the local Neolithic roots of Okunev metallurgy and to claim that its roots are migratory Circumpontic. However it is impossible to tell whether it was a result of development of the Afanasievo production or result of a new impulse from the same region, although, considering a sharp cultural break between the Afanasievo and Okunev cultures, and also the emergence of tin bronzes, we may, nevertheless, assume a new impulse. But in this case there is no guarantee that the emergence of tin bronze is not dated to the beginning of the late Okunev time.

Seima-Turbino time

Seima-Turbino bronzes

At the beginning of the Late Bronze Age in Southern Siberia there were essential cultural transformations connected with the formation of Seima-Turbino (Fig. 11-1.), Krotovo and Elunino sites in the Irtysh and

Upper Ob regions. Vishnyovka and Tashkovo complexes of the Ishim and Tobol regions were also in some connection with this process. Just the rapid distribution of this cultural tradition to the west led to reformation of the Euroasian Metallurgical Province at the beginning of its second phase (Chernykh, Kuzminykh 1989). Basing on it, the relation of these complexes to the Late Bronze Age seems to be indisputable if to be guided by the Euroasian periodizational scheme. However the quite reliable synchronization of the Seima-Turbino sites with Abashevo and Sintashta, if even not with their early phase (Chernykh, Kuzminykh 1989, p. 262, 263; Grigoriev 1999, p. 104), related to the Middle Bronze Age, raises a vital terminological problem. In principle, this synchronization does not also contradict the calibrated radio-carbon dates for the Seima-Turbino sites which fall into the interval since the late 3rd millennium BC to the 18th century BC (Soloviev 2009, p. 94, 95). But, as the main parameters of the discussed metallurgical and metalworking traditions were the traditions of the Late Bronze Age, and they were closely connected with the following metallurgical traditions of the EAMP, it is more lawful to relate them to the Late Bronze Age.

Diffusion of new principles of metalworking became the brightest manifestation of these cardinal changes: thin-walled casting in the closed moulds and new types of tools and weapons: spearheads with a cast socket and wide blade, celts, knives without a tang and with straight or semi-triangular blade, daggers with a cast handle. Many objects are decorated with ornament or figures, either animal or human, using the lost wax technique. The complex includes also chisels, punches, and fishing hooks (Fig. 11-2., Fig. 11-3.). The appearance of new types of objects became possible in connection with the transition to new technologies of alloying with tin, i.e. in this case it is a question of a complex transformation. As it is convincingly shown in the work of E.N. Chernykh and S.V. Kuzminykh (1989) this complex was formed in the Sayan-Altai region and spreaded through the south of the forest zone to Eastern Europe that is reliably marked by finds of these metal objects (Fig. 11-1.). And in the Altai the Elunino culture is known which preceded the distribution of Seima-Turbino bronzes, included a number of types characteristic also of these bronzes.

Metallurgy of Elunino culture

The largest sampling of slag of this time has been found on the Elunino settlement of Berezovaya Luka (Fig. 11-4.). In general, according to a series of radiocarbon analyses the Elunino culture is dated to the 20-17th centuries BC, although the most compactly the radiocarbon dates fall within the 18-17th centuries BC. And the early phase of the culture is the Berezovaya Luka (Grushin 2002, p. 18, 19, 23, 24; Kiryushin *et al.* 2004, p. 141). Already the materials of excavation give us some grounds for conclusions about these or those features of metallurgical production of this time. On the settlement of Berezovaya Luka both oxidized and sulfide ores have been found, and, the last are presented by chalcopyrite. The made analyses have shown that there are lead impurities in the ore, and the lead got to copper from the ore. It allowed some authors to assume that the ore was mined in the Zmeinogorsk zone (Kiryushin *et al.* 2004, p. 120-123, 128; Tishkin 2002, p. 185). The analyses of some samples from the same settlement have detected phosphorus, which corresponds to many burned bones with a bluish-violet surface found here. As a result, a conclusion has been drawn that the bones were used as fuel in the metallurgical production (Kiryushin *et al.* 2004, p. 126, 127). This conclusion demands only a small correction. Bones, certainly, evolve heat at their combustion, but hardly were they used for the purpose of a partial replacement of charcoal. Their use as a flux is more probable. On the Eluno settlement of Kolyvanskoye I crucibles are found (Grushin 2005, p. 147, 148). It provokes an idea about the crucible smelting of ore. Additional results have been received in the analysis of a large series of slag.

From the materials of the Berezovaya Luka settlement 67 samples have been studied. In addition to slag, the samling contains some other materials: small pieces of gangue (No. 2097, 2100), malachite (No. 2079, 2083), pieces of quartz rock with malachite inclusions (No. 2075), malachite with iron oxides (No. 2078, 2085), pieces of rock (No. 2076, 2077, 2084, 2086, 2088), one of which is slagged, pieces of iron hydrooxides (No. 2080), including those containing the oxidized copper ore (No. 2087, 2092).

Besides, a fragment of burned bone (No. 2090), small prill of oxidized copper (No. 2096), fragment of ceramics (2082), clay brick with the size of 2×1.5cm (No. 2089) got to the sampling.

Seven samples (No. 2036, 2039, 2043, 2045, 2054, 2061, 2064) are presented by small (2.6-5cm) fragments of heavy shapeless flat slag. The thickness of samples varies from 1 to 1.8 cm. One sample (No. 2054) is very thin, up to 6mm at the edges and even thinner in the central part. It differs from other slags by deeper black color and density. Slags of this group have many small pores. In many of them one surface is rough and sometimes has a ceramic crust or small traces of charcoal and branches. Therefore it is not excluded that this slag could be formed on the furnace bottom. The second surface is rough, but it is usually covered with a smooth slag crust having sometimes metal luster. One of such samples has an evident zonal structure. One its surface (probably, bottom) is flat, with the stuck ceramic crust about 0.5 mm thick. The second is rough, with charcoal imprints. Occasionally the surface under the ceramic crust has green and red color from oxidized copper and cuprite.

The second group of samples is similar to the first, but differs by that they are much easier (No. 2034, 2038).

The third group is the largest in the sampling and consists of 34 samples (No. 2035, 2037, 2040-2042, 2044, 2046-2053, 2055-2059, 2062, 2063, 2065, 2066, 2069-2074, 2091, 2093-2095, 2098). These are shapeless pieces of heavy slag with the fused rough surfaces. Sample No. 2050 differs from the others due to the larger looseness and lack of the fused slag crust. In some cases malachite impregnations are visible on the surface, brown manifestations of iron hydrooxides and brown or reddish thin cuprite crust. Sizes of the samples are about 2-3cm. Only one sample reaches 6cm (No. 2035). A part of surfaces is crushed in the course of copper extraction, but the majority of samples had such small sizes initially. This means that the slag usually was not crushed for copper extraction.

Four samples differ from the others. It is very light slag of the same small size, as well as other samples. Sample 2060 looks like coal slag. It is not excluded that it was formed as a result of smelting of pure malachite because it is close to the group of similar slag found in the Southern Cisural area.

Sample 2067 is a small (2.5×2.1cm) fragment of light slag or slagged crucible (the last is more probable). Sample 2068 is close to it. It is a small (3.5×2×1.4cm) fragment of very light, probably, ceramic slag. One its surface is fine-grained and rough. The second is equal.

Sample 2099 owing to its very small size cannot be related to any group.

Thus, the most number of samples (Tab. 11-5.) is presented by heavy shapeless slag.

In total from the settlement of Berezovaya Luka the following materials have been analized: 59 samples by means of spectral analysis (1 – copper, 1 – slagged bone, 1 – goethite, 2 – ore, 3 – slagged ceramics, 51 – slag), 4 samples of slag by means of chemical analysis, 44 mineralogical analyses of slag under microscope and 11 visual mineralogical determinations.

Chemical composition of slag

The number of chemical analyses is very small, but they are rather indicative. Four samples have been analysed by means of the bulk chemical analysis in the Complex laboratory of “Chelyabinskgeosjemka” (Tab. 11-6.). Copper losses in the slag revealed by this analysis were not too high, although in one sample they reach 3.34%. But as a whole the separation of metal from slag occurred rather fully. There is not much sulfur, although some quantity of sulfur is present in all slags that allows us to say that some quantity of sulfides was used in the smelting. The large contents of silicon dioxide demonstrate acid composition of gangue that corresponds to the character of the Altai deposits.

It is also visible at calculations of coefficient of basicity made on the base of this analysis according to the formula:

$$O = (CaO + MgO + FeO + MnO) / (SiO_2 + P_2O_5 + TiO_2 + B_2O_3)$$

(Perepelitsin 1987, p. 211-214).

All slags from Berezovaya Luka belong to ultra-acid and acid groups (Tab. 11-7.). This composition of slag reflected also in its microstructures. Crystallization in it had to take place poorly.

Calculations of viscosity have been also done for the temperature of 1400 °C (Tab. 11-8.). The viscosity was between 8.23 and 31.09 Pa·s. For comparison it is necessary to note that for slags of the Sintashta culture the calculated viscosity varies in the range of 1.46-6.2 Pa·s. Respectively, the slags from Berezovaya Luka were very viscous that was caused by their ultra-acid composition and absence, most likely, the traditions of use of iron fluxes. In all these data some paradox is concluded: at the high slag viscosity the content of copper in it is insignificant. It was extremely difficult to smelt the ore of such composition. For this purpose rather high temperatures and a long time allowing particles of metal to separate were needed.

Mineralogy of slag

The main information has been received from slag investigation under microscope. Two samples are iron-containing rock (No. 2036, 2051). One is presented by a piece of goethite (No. 2051), the second is a roasted piece of goethite, therefore, magnetite partly formed here. Some pieces of magnetite disintegrated into smaller particles.

Other samples are presented by slag which can be united in different mineralogical groups.

2nd mineralogical group

The main group of slag (26 samples) is very porous. These pores are small and large. And, along with the pores of correct roundish form, there are a lot of pores which does not have a definite form that points to the viscosity of slag. Besides, in many samples cracks in glass are present.

Crystallization took place in the slags poorly. There are crystals of olivine (possibly, of fayalite composition), but the olivine crystallization did not happened in all areas of slag and it is presented by small nuclei of crystallization, small skeletal forms, long thin needles, rarer by small prismatic crystals (Fig. 11-I.3-6). All this indicates the high rate of slag crystallization. The weak crystallization could be caused by the lack of needed components or the oxidizing atmosphere of smelting. The last is improbable as cuprite in slags of this group is presented poorly. More plausible explanation is the acid and ultra-acid composition of slag detected by chemical analyses.

The extended olivine crystals have different orientation; therefore, the cooling was rather equal in different directions. Only in one sample (2039) it is noted that the olivine crystallization is present near one slag surface which has many small copper prills. From this it is possible to assume that this part of slag contacted with molten copper, and the second with the furnace wall where ceramic and silicate inclusions crystallized worse. There are individual slags in which the olivine crystallization did not happen at all. In one sample (2042) rare larger prisms are found that specifies that this slag solidified slightly more slowly than the others.

The second noticeable component in slag is magnetite. It is presented by small octahedra formed by disintegration of larger grains of iron oxide. But also skeletal forms crystallizing from slag are quite often. In rare instances (2057) magnetite particles are fused on the surface. However it does not indicate, apparently, the smelting temperatures close to the melting point of magnetite as the melting of the crystal surfaces could occur due to reaction with the melt. In some samples (2042, 2045, 2048, 2053, 2059, 2066) magnetite has not been detected. Identification of magnetite in sample 2071 raises also doubts because the form of the crystal is similar to magnetite, but it is brighter, like wüstite.

Copper losses in slags of this group are very small. These are rare small prills and small accumulations of prills. Sometimes these accumulations are significant, but the sizes of prills in these cases are very small. In one case (2059) the prills of copper are found inside the olivene. Rare large prills are surrounded in some instances by a cuprite border. A large grain of copper with cuprite (2052), copper alloy with cuprite and a large inclusion of molten copper surrounded cuprite filling the cracks (2042) have been identified too. The last specifies that the cuprite was formed in the course of smelting; it is not a product of secondary oxidation. In some instances the prills of cuprite are also present in other samples, however their number is small, besides the part of these prills can be a result of secondary oxidation of copper prills. But the part of cuprite prills, certainly, was formed in the course of smelting. Sample No. 2070 is indicative as it is recorded here that from an accumulation of such prills the cuprite flew into cracks filling them. Therefore, it was formed in liquid slag, instead of after its solidification. Besides, glass solidified before cuprite. The glass was obviously of silicate compound, and solidified at the temperatures not less than 1250-1300 ºC. The small quantity of cuprite and the presence of olivine indicate also the reducing smelting atmosphere, although, judging from magnetite, sometimes the atmosphere was moderately oxidizing.

In some samples (No. 2039, 2041, 2044, 2045, 2046, 2049, 2053, 2056, 2071, 2073) all ore components were molten in the course of smelting that does not allow us to do conclusions about character of initial ore. There are not so many ore inclusions in slag. In a number of slags small grains of malachite (No. 2040, 2052, 2055, 2066, 2091) have been identified. In one of these samples (No. 2052) malachite is found in association with quartz that can point to the ore origin from quartz veins. In the same sample the malachite edged by melting cuprite and malachite in filling of pores is revealed, but this is obviously a secondary formation, as well as in samples 2070, 2093 and 2094. In one sample (No. 2050) a lot of malachite among iron hydrooxides is revealed. In the same sample there are small inclusions of chalcopyrite in quartz. However in this case just malachite was used in smelting as the content of chalcopyrite is very small and secondary sulfides are absent. In several samples malachite is found together with secondary sulfides (No. 2037, 2042, 2070, 2093, 2094). In sample 2042 grains of copper sulfide with copper reduced inside and roundish grains of bornite in one case with malachite are found. In other samples copper sulfide (chalcocite?) and covellite are found. Occasionally the sulfides are presented by grains, but more often by molten prills. Their associations with malachite are present. In sample 2070 covellite filling a crack has been detected. Therefore, glass started to solidify at a higher temperature, than the melting temperature of covellite. Here a round grain of malachite surrounded with a covellite border, and the large globules of copper surrounded with a thin sulphidic border are revealed.

All this demonstrates that in the smelting a mix from oxidized and sulfide ores was used, and the sulfide ores were presented, mainly, by secondary sulfides. The last could be used also independently, without malachite.

In sample 2070 also a large copper globule with numerous inclusions of sulfide has been found. Therefore the produced copper probably demanded the following refinement.

Some samples allow an assumption to be done about the use of a primary sulfide, chalcopyrite. Very small inclusions of this mineral are found in samples 2048, 2048-1, 2057. During the smelting of chalcopyrite the molten secondary sulfide formed (No. 2048). In sample 2057 together with chalcopyrite the small prills of covellite and a grain of malachite edged by cuprite are found. In the same sample a small chalcopyrite inclusion in round malachite grain is noted. But we have no bases for statements about an intensive use of chalcopyrite. It got there together with the oxidized ore and in a small quantity. The presence of sulfides had salutary effect in the smelting and caused, apparently, the preservation of the reducing atmosphere in the furnace.

In some samples reliable signs indicating ore bearing rock have not been identified (No. 2045, 2046, 2048, 2048-1, 2055, 2057, 2059, 2071, 2073). In the majority of other samples the quartz grains which cracked often as a result of heat influence (No. 2037, 2040 - 2042, 2050, 2052, 2053, 2056, 2066, 2069, 2070, 2091, 2093, 2094, 2095) are recorded. In individual quartz grains the small particles and prills of copper and cuprite (No. 2066, 2094), malachite inclusion in quartz (No. 2052) and small inclusions of chalcopyrite (No. 2050) are found. All this specifies, as though, that the ore was connected with quartz.

At the same time, in the same samples (No. 2095) there can be single grains of chromite and association of quartz and magnetite (No. 2094). The grains of chromite of small sizes have been found also in some other samples (No. 2039, 2044). In slags of Sintashta culture the inclusion of chromites point to the ore origins from deposits in the ultrabasic serpentinized rocks. In this case the base for such conclusions is absent as the chromite grains are very small and found in rare cases. They got to the smelting probably together with pieces of some iron hydrooxides dissociated in the course of smelting to magnetite. This iron component could be introduced together with the ore from quartz veins, could either occur from another deposits and intentionally be added to ore from quartz veins or be a flux needed in case of smelting ores from quartz veins. However we have no base for certain judgments on this subject basing on slag investigations under microscope. The spectral analysis has been conducted for only one sample of geothite (No. 2051) in which copper impurity about 0.4% has been found. It specifies that iron oxides got to the charge together with the ore from silicate rock, and were not fluxes. Bone was used as a fluxing component, its slagged samples were repeatedly found on the settlement. The analysis of the slaged part of one bone has revealed 0.2% copper (No. 2090).

Three samples of this slag group (No. 2037, 2049, 2094) demonstrate the presence in some areas of accumulations of delafossite needles. This mineral formes in the oxidizing conditions only. Its presence is low, and, as a whole, the slag belongs to the same group. However it specifies that in some smelting operations or in some zones of furnace the atmosphere was more oxidized. In one sample (No. 2037) cuprite dendrites grew between the delafossite needles. Probably, it is explained by that in this case the sulfide ores were used to a lesser extent.

Conclusions:

Thus, the specifics of slag of this group were caused by use of both oxidized and sulfide ores. Apparently, secondary sulfides were the main ore. A quantity of chalcopyrite got to smelting too, but it did not play a large role in this process. The smelting was carried out in the reducing conditions that was promoted by the use of mix of the sulfide and oxidized ores. As a result, sulfur of the sulfide ore combined with a part of oxygen of the oxidized ore that prevented the excessive oxidization of slag. The ore was mined, mainly, in quartz rock. The iron component got probably in the smelting on occasion, and it was connected with peculiar properties of the ore.

Most likely, the olivine is presented by fayalite. Therefore its crystallization could happen at a temperature not below 1205 ºC. Judging from the molten cuprite, the temperature could reach 1250-1300 ºC. The slag solidification happened very quickly. And, we, practically, have no bases for statements that any part of slag cooled down more slowly as crystals grew in various directions. Therefore the conditions of cooling of this slag are not quite clear. Earlier I assumed that it could occur in a crucible, but strict data in favor of it are absent. The uniform cooling from different directions is more characteristic, nevertheless, for the furnace, and the high speed of solidification was caused by the acid composition of slag. The tapping of slag in this case is excluded, by both its viscous composition and uniform cooling from different directions.

Existence of a large quantity of ceramic slag (that we will touch upon below) was one of arguments in favour of the crucible smelting. In principle, such slag could be received also from the furnace lining. But in other large studied collections, such as Sintashta, ceramic slag is presented by single samples although the lining of the furnace had to be present in the Sintashta production too.

The separation of metal from slag occurred rather fully, the number of copper inclusions in slag is very insignificant. To reach it the slag had to be not too viscous. But the viscosity coefficient at the temperature of 1400 ºC calculated for four slags from the settlement of Berezovaya Luka varies between 8.23 and 31.09 Pa·s that, in general, is higher than indicators of other slags of the Bronze Age. Therefore it is not excluded that the full separation of metal from slag was achieved by a long smelting at high temperature. Metallurgists of the Sintashta culture, as we have seen, carried out the smelting in the high-temperature area during a short time. In this case, it was probably differently, although there is no analytical data confirming it. For some time the temperatures above 1300 ºC are not excluded that was possible thanks to sulfides, but a strong confirmation to it is absent too. Fluxes were almost not used to decrease the viscosity too, as there few iron components, and archaeologically fixed additions of bones were insignificant judging from the chemical analyses. Therefore, in a certain degree, such separation of metal from slag is a paradox. The only explanation is that there were many secondary sulfides in the ore originally, and their fusion promoted the decrease in viscosity.

4th mineralogical group

Against the background of the above described slags four samples (2054, 2060, 2064, 2069) containing cuprite and delafossite (Fig. 11-II.) differ sharply. In samples 2060 and 2069 relatevely few needles of delafossite are present. Their quantity in sample 2054 is much more, but the sizes of needles are small. The delafossite needles are oriented in different directions. In sample 2064 there are more needles and they are larger. Round them cuprite dendrites, its individual prills, small inclusions and prills of copper are formed. The copper solidified after delafossite as it takes sometimes any form, filling the space between the needles of this mineral. It is in some cases noticeable that the cuprite dendrites were formed from copper: from its prills the cuprite particles separated which formed the dendrites (No. 2069). Olivine in slags of this group has not been almost found. The exception is the samples 2060 and 2069 in which olivine needles are occasionally noted.

In the nature delafossite forms racemose crusts. The presence of needle crystals indicates the high rate of slag solidification.

The ore minerals in these slags are presented by many malachite grains. It can sometimes be present in the pores and cracks in glass that reflects, apparently, already the secondary formation of malachite. There are associations of malachite with cuprite and even almost full replacement of malachite with cuprite (No. 2064). In the center of such formations copper with large cuprite inclusions can be reduced. This means that in this case we obviously deal with metallurgical minerals, instead of those formed subsequently in cultural layers.

On the edge of one malachite grain a particle of magnetite is noted, and along it there is formation of delafossite (No. 2064). Against the absence of quartz in these slags (except for sample No. 2069) it is not excluded that malachite was taken from iron-containing rock. The same can be indicated by numerous particles of magnetite between the delafossite needles in sample 2064, disintegrating from larger grains. Their edges are lighter, probably, it is wüstite which reacted with copper minerals and formed the delafossite. In sample 2069 the contents of magnetite is especially high.

Magnetite is formed due to disintegration of larger grains. Partly it has skeletal forms grown from liquid slag. Most likely, mainly, pure malachite was used in the smelting. Ores in the Altai are connected with quartz rocks, but ancient miners tried to remove quartz during the ore crushing and enrichment. Some part of iron oxides got to the charge. However it is hard to say how purposefully it was.

There is a lot of copper and copper minerals in samples of this group. But in sample 2060 especially many such inclusions have been detected: large and small deformed copper prills, molten shapeless (often extended) particles of cuprite (some seated densely, uniting in an oval body), and cuprite dendrites. Sometimes large copper globules are surrounded with very thin cuprite border or there is crystallization of cuprite dendrites round them. Molten copper can be also inside the molten cuprite. It is sometimes noticeable that cuprite is formed on copper, and its extended prills separated from copper prills. This means, it was often a repeated oxidation of copper caused by the oxidizing atmosphere. There is a lot of cuprite in this sample too. Sometimes the cuprite forms large globules connected with cracks filled by cuprite (No. 2069). Therefore, the cuprite was molten. In sample 2069 round the large copper globules a border from cuprite and malachite was formed, surrounded with a shrinkage crack in glass.

Conclusions:

Summarizing the evidences on samples of this group, it is possible to claim with confidence that only malachite was smelted. It is impossible to judge so surely about the ore bearing rock. Possibly, it was quartz as the formation of delafossite happens in cases of some deficiency of iron in the Cu-Fe-O system (Trofimov, Mikhailov 2002, p. 8). Nevertheless, there was also an iron component, possibly hydrooxides in the rock. Probably, malachite was connected with oxidizing processes in cracks in the rock of silicate compound where iron oxides were formed too. But inclusions of the gangue are rare, probably, the miners tried to take very pure malachite.

The slags were smelted in the sharply expressed oxidizing conditions. As a result, we see the formation of delafossite and cuprite, copper losses are great, and slag was very viscous. As the growth of delafossite crystals occurred in different directions, it is possible to say that the cooling of slag was carried out evenly from different directions. After the solidification of cuprite and delafossite the rate of cooling was very high. The solidification of delafossite takes pace at the temperatures of 1175-1200 ºC (Trofimov, Mikhailov 2002, fig. 2). And, judging from the well molten cuprite, the temperature reached 1300 ºC.

Thus, the temperature parameters of smelting of this group were rather close to the parameters of slags of the previous group. The radical differences in microstructure were caused by the extremely oxidizing smelting atmosphere that was caused by the use of exclusively oxidized ore. At first sight, the insignificance of this group of slag specifies that it was not a purposeful process, it was rather a result of that the Elunino metallurgy was based, mainly, on the ore mix consisting of oxidized ore and secondary sulfides. In case the first component in the furnace charge sharply dominated, slags of this 4th group formed. However it is necessary to pay attention to one coincidence. In this slag group the ore bearing quartz rock is presented worse as the pure malachite was selected. In principle, it is the same type of smelting which we have fixed as archaic crucible smelting of the Ural Abashevo. Therefore it is not excluded that the found crucibles were connected with this type of smelting. Respectively, taking into account the rare evidences of crucible smelting in the Afanasievo-Okunev time, it is not excluded that it was a local tradition of production. Another type of smelting of mixed sulfide and oxide ores in the furnace was an innovation.

This combination of smelting of both sulfide and oxide ores in Elunino culture is supported also by data of metalgraphic analysis. Judging from investigations of microstructure of metal objects, both oxidized and sulfide ores were used for metal production. In structure of single objects a significant quantity of sulphidic inclusions is revealed that testifies to an insufficient refinment (Degtyareva *et al.* 2010, p. 27).

Ceramic slags

Some samples have shown structures characteristic of ceramic masses (12 samples) (Fig. 11-I.1,2). In reflected light their studying is difficult; however some inclusions come to light. These slags are not uniform as could be formed in different conditions (slagged either crucible or furnace lining, and, in different places, in contacts with various other reagents of the smelting). Almost all these slags are easy, and saturated with small pores. In some slags distinguishable in the reflected light inclusions are almost absent. In one sample (2034) small carbonaceous inclusions are fixed in ceramic mass. In the others small inclusions of copper occur, there is formation of malachite or cuprite in pores (No. 2044, 2065, 2095). Only one sample (No. 2058) differs in this series: there are single very small inclusions of white metal.

In some samples of this group the formation of slag glasses is noted, although not in all parts of the slag (7 samples). Glass is saturated with pores, and the pores are very rough that points to the viscosity of slag. In some places of glass there are individual small needles, thin extended skeletons and nuclei of olivine crystallization. Sometimes accumulations of small magnetite particles are present, a result of disintegration of larger grains of iron oxide. Possibly, in some cases the ore was from ultrabasic rock. It is detected also by the rare presence of small chromite grains in slags of this group (Fig. 11-I.2). Some grains have a lighter edge or magnetite border. In one sample (2038) small grains of quartz are found. Copper components (copper and ore) in slags of this group are absent. The exception is a sample 2038 in which a small chalcopyrite grain is found. In sample 2062 inclusions of two small prills of copper and a fragment of malachite are recorded. This sample is heavier, than the others, and can include the ore and slag mass, and not only the furnace lining.

Analysis of inclusions by means of SEM has not been carried out, but, most likely, the olivines belong to fayalite as they are rather light and only silicate component and iron oxides could take part in their formation. The analysis did not detected magnesian minerals. Therefore it is possible to assume that the temperature reached 1200 ºC. At the same time, solidification of these slags occured quickly enough, therefore olivine crystallization did not happen. It is not excluded that the explanation is in the lack of any components.

There is one more important circumstance. At a large quantity of ceramic slags on the whole (12 samples against 30 samples of normal metallurgical slags investigated mineralogically), no sample got to the sampling which could be identified surely as a part of crucible. All these are rather shapeless formations. The exceptions are samples 2067 and 2068 which were initially identified as ceramics. In principle, it is not excluded that the slags formed as a result of fusion of the furnace lining and fragments of crucibles (both for ore smelting and metal melting) also got to the analysed series.

But in general, the part of the ceramic slag in the sampling is 28.5%, what we have not seen in other collections (except for the later Mezhovka collection), while the parts of slag of the 2nd and 4th II mineralogical groups are 62 and 9.5% respectively (Tab. 11-9.). To make more accurate the ratio of these two smelting types a calculation without ceramic slags was carried out. In this case the part of slag of the 2nd group is 86.5%, and that of the 4th group is 13.5%. Thus, the smelting with use of sulfide ores sharply dominated. But it is necessary to take into consideration that the slags smelted from pure malachite remain badly, therefore the true part of this type of smelting was for certain slightly higher.

Smelting volumes

Ii is very difficult to calculate the smelting volumes. For slags of the 2nd group smelted in the furnace, it is absolutely impossible. But, for the crucible smelting it is real to do it. On the settlement of Kolyvanskoye I related to Elunino culture, it was established that ore was smelted in crucibles of 500 ml (Alekhin, Demin 1988, p. 85-86). At the average specific weight of malachite about 4 g/cm^3, such crucible could contain about 2 kg ores, however for the smelting process it is necessary to charge charcoal in the ratio to ore 1:2

(Bamberger 1992. 157; Bamberger, Wincierz, 1990, p. 123). It is not excluded that for the crucible smelting it was needed less charcoal, probably, 1 kg. As the density of birch coal is 380 kg/m^3, its total volume should be about 2630 cm^3. Therefore, the crucible can contain no more than 300 g ore. It is very difficult to tell, how much copper could be smelted by such a way in one operation taking into account the losses of metal which has been established in slags of the 4th group (30-50%), but the figure of 50-100g seems to be realistic.

Emission spectral analysis

59 spectral analyses of samples from the settlement of Berezovaya Luka have been done (Tab. 11-10.). One analysed sample (No. 2051) was the iron oxide geothite. Nevertheless, it contains 0.4% copper that shows that the geothite was a part of ore rock, instead of it was used as a fluxing component. Three samples of oxidized ore (No. 2092, 2097, 2100) have been analysed. In all of them the higher concentrations of lead and zinc have been detected. In one sample (No. 2100) higher contents of arsenic and antimony have been found, but in general the ore samples demonstrate low concentrations of these elements.

A fragment of slagged bone covered with metallurgical slag (No. 2090) has been also analysed. In this sample the higher concentration of beryllium (0.3%) and strontium (0.1%) are recorded. However often they are also present in ore, therefore cannot be a reliable sign of use of the bone as a flux. In general, many burned bones with bluish-violet surface have been found on the settlement, which has provoked an idea about their use in the furnace charge (Kiryushin *et al.* p. 126-127). Certainly, it is a correct conclusion, and bone was used as the flux. It is hardly to say what will be a sign of it in slag, besides the bone inclusions. Chemical analysis has revealed in two slags higher concentration of potassium and calcium which are present in bone, but they can be caused also by character of ore or could pass into slag from ashes. But, despite the absence of strict analytical data (they have a probabilistic character), it is not necessary to doubt the use of bone as a fluxing agent.

Other samples analysed by these method were slag. In the frequency diagrams of trace-elements distribution (Fig. 11-11.) the bimodal and threemodal diagrams have been received for lead and zinc. The correlation diagrams really show the distinction of these elements in slag, but they do not allow us to distinguish accurate chemical groups of slag (Fig. 11-12., Fig. 11-13., Fig. 11-14.) on this basis. The comparison of frequency diagrams made for different mineralogical groups of slag (Fig. 11-15.) demonstrates that, mainly, the ceramic slag (group K) shows the low values of these elements. In the group with average values of these elements the presence of furnace lining can affect too irrespective of whether pure malachite or mix of the sulfide and oxidized ores was used. Attempts to distinguish groups by other elements have not been crowned with success. Therefore, most likely, the ore came from one or several chemically similar ore sources with the higher contents of lead and zinc. Samples of both mineralogical groups of the slag smelted from ore show the same picture. Therefore, probably, their mineralogical distinctions are caused, mainly, by a larger oxidization of ore of the second group.

On the basis of this work it is impossible to claim unambiguously that the lead and zinc reflect presence of sulfide ores because the quantity of samples of the 4th mineralogical group is too small, and it does not allow us to draw any statistically valid conclusions. Although, basing on the reason that impurity of these metals is characteristic of the sulfide Altai deposits, we may assume it at the level of a tendency, but not as a reliable sign. Another difficulty is that metallurgists used not pure sulfide ores, but their mix. The assumption of possibility to use cadmium as a marker of sulfide ores (Kiryushin *et al.* 2004, p. 126) is not confirmed as in the studied sampling the cadmium is present in the oxidized ore and in slags smelted from it, but it is usually absent in the slag smelted from the mix of oxides and sulfides.

Lack of the high concentration of such element as arsenic attracts attention. It means that the technology of alloying with arsenic minerals recorded for Sintashta metallurgy was not used here as in these smelting conditions (long influence of high temperatures) the arsenic would not remain in slag and metal. It is necessary to pay attention that the concentrations of arsenic and antimony in slag are not so high that it would be possible to raise a question of use of fahlores which could give the antimony-arsenic copper that is present in the Seima-Turbino complexes. Respectively, the metallurgy of this settlement was hardly its source. In several samples with the small antimony content its growth is proportional to the growth of arsenic (Fig. 11-16.), but it is difficult to tell what was the reason, an alloying or ore impurity.

It is necessary to remember that this settlement is rather early among the Elunino sites, and materials of a single settlement do not allow the problem to be solved of relations between Elunino and Seima-Turbino metallurgy. The only sample of the analysed copper prill (No. 2096) has not revealed essential impurities of arsenic and antimony although there is a noticeable impurity of lead (0.3%) that is peculiar to the Altai deposits.

In three samples of slag (2039, 2043, 2099) the content of tin between 0.1 and 0.3% is noted, shown also in the frequency diagram that can point to a rare use of the archaic way of alloying ore with tin. However this assumption is groundless as in one of ore samples (No. 2100) high concentration of tin is noted too. On the other hand, in another sample, a drop of copper (No. 2096), traces of ligatures have not been revealed. Thereupon, the former spectral analyses of ore, slag and metal of this settlement are very indicative (Kiryushin *et al.* 2004, p. 127-129). In metal high concentrations of tin are, almost, an obligatory component, and in ore and slag the tin is completely absent. It demonstrates that the alloying with tin was carried out into metal, instead of in the furnace charge as it took place with arsenic alloys of Sintashta metallurgy. Lack of tin in sample 2096 does not disprove, but confirms it as this sample was not metal scrap or an object, it was the copper drop received in the course of ore smelting.

The minimal content of copper is present in slags of the ceramic group: in 9 samples from 0.0015 to 0.7%, and in 5 samples 1% and more. In slags of the 2nd group the copper content varies in 9 samples between 0.0015 and 0.7%, and in 21 samples 1% and more. In all slags of the 4th group the content of copper exceeds 1%. It, in general, confirms a possibility of formation of slags of ceramic group mainly from the furnace lining or slagged edge of the crucible, and shows large losses of copper in case of smelting malachite in comparison with smelting of a mix of oxidized and sulfide ores.

The same situation is reflected also by concentrations of lead which are insignificant in the ceramic group (the average value is 0.02%), and are higher in the 2nd and 4th groups (the average value is respectively 0.1 and 0.6%).

Metallworking and types of objects

Metalworking of the Elunino culture in the Altai is extremely important for understanding the following metalworking of Northern Eurasia as this complex includes a part of Seima-Turbino types, and it was probably one of components forming the Seima-Turbino bronzes with their developed casting technologies. The quantity of objects of Elunino culture is not too great, about 70 artefacts (Fig. 11-17.). Nevertheless, they are interesting because there are those features which are present at later metallurgy of the EAMP, including characteristic of the Seima-Turbino complexes: knives, awls, a punch, fragments of socket (that points to the appearance of socketed objects), daggers, spearheads, including those with casted socket, arrowheads, trapeze-shaped celts-shovels, single-edged knifes with a massive tang, single-edged knifes with a tang fastened to the handle at an angle of 60-80°, single-edged daggers with a curved back and rectangular handle with sculptural or ring-shaped end (Degtyareva *et al.* 2010, p. 27).

The metalworking of this culture was based on the casting into bi-fold moulds. Some handles of daggers are decorated with animal figures using the lost wax technique. “The cast objects were further finished by forging with small or average degree of reduction with use of various thermal modes of metalworking. Preliminary annealing of homogenization was sometimes used, probably for the purpose of metal softening, and giving a larger plasticity to it. The final operations directed to stretching and thinning of the working part of tools were carried out in the mode of premelting temperatures, of either red heating of metal or cold forging with intermediate annealings. Hot deformation of tools was mainly carried out at temperatures of the red heating of metal of 600-800 °C". At the same time, technological deficiencies in the form of small casting defects are also sometimes present that points to an experimental nature of this technology (Degtyareva *et al.* 2010, p. 27-34).

Tin alloys

Distribution of tin alloys was the main feature of Seima-Turbino metallurgy. From table Tab. 11-18. it is visible that in the whole collection a half metal contains impurity of tin. The noticeable role is played also by alloys with arsenic (24.1%), and also complex alloys with arsenic and antimony (11.3%). In addition to this, there is an essential difference in territorial distribution of these groups. Alloys with tin dominate in the east, and alloys Cu+As, Cu+As+Sb and Cu+Ag do in the west. Besides, presence of single objects with arsenic in the east, morphologically relating to Sintashta-Abashevo metallurgy, is evidence of the western origin of this type of alloys, and also the eastern origin of alloys with tin (Chernykh, Kuzminykh 1989, tab. 9, p. 166-173, 186-192).

Discussing the LBA metallurgy of the Cisural area, we have noted that complex alloys Cu+As+Sb had probably a double origin: metal with lower contents of As+Sb could be smelted from the fahlores, and metal with the high contents was a result of alloying, and, the alloying succeeding the Sintashta tradition of alloying with arsenic at the ore smelting stage, but minerals containing antimony were also used as an alloying component. Lack of this metal in the Asian zone of the Seima-Turbino sites distribution probably confirms this idea. It is also indicative that in the Elunino sites such alloys are unknown too. Tin-lead and tin bronze prevailed there, but in isolated cases there are both alloys: with lead and with tin and lead.

The use of lead as a ligature is remarkable. It is supposed that the found on the Elunino sites rings and bars made of lead-tin-copper and lead-copper bronzes could serve as raw materials for alloying. And, in objects with higher content of lead the effects of red brittleness are noted that points to the insufficient experience in work with this material, and it resulted in breakage of the objects (Degtyareva *et al.* 2010, p. 28-30, 33). From this, probably, follows that lead was not a well familiar ligature. Usually it got to metal together with tin, and sometimes was used separately.

Thus, in the Elunino complexes tin bronzes are aso well presented. Therefore, the already mentioned conclusion of E.N. Chernykh and S.V. Kuzminykh that in Northern Eurasia the tin ligatures had eastern origins is unconditional. But the tradition of lead-tin alloying in the Seima-Turbino complexes is unknown.

The absence of alloys with silver in the Seima-Turbino complexes in the east is also interesting. Actually, in the Elunino complexes lead is also known, but silver is not presented. Therefore it is not excluded that the invention of silver production in Northern Eurasia had exclusively the Sintashta roots. The presence of lead in the Altai complexes, probably, was not connected with attempts to produce silver, and can be explained by complexity of the Altai ores, the presence of lead ores on copper fields, and attempts to use the lead as alloying component. This problem is not studied yet.

Metallurgical production of Seima-Turbino time in the Tobol-Ishim region

One of the least studied problems in the researches of ancient metallurgy of Northern Eurasia is production of copper by populations which left Odino-Krokhalevka, Vishnyovka, Krotovo and Tashkovo ceramics in the south of Western Siberia. Archaeological sites of the Odino-Krokhalevka type are dated to the first third of the 2nd millennium BC in the system of traditional chronology and considered as earlier comparing to all other Bronze Age cultural types in Western Siberia (Potyomkina 1985, p. 158-161). V.T. Kovaleva supposes that Tashkovo, Odino, Loginovo and Vishnyovka sites belong to the pre-Andronovo and partly pre-Sintashta time (1997, p. 75). According to G.B. Zdanovich, the Vishnyovka cultural type preceded the Petrovka type which was formed on its basis (1988, p. 139). It corresponds to the opinion of M.T. Abdulganeev who believes that chronologically Krokhalevka and Elunino complexes coincided (Abdulganeev 1987, p. 73). Other authors believe that the sites of Elunino, Odino-Krokhalevka, Krotovo and Tashkovo types belong to the period of distribution of Seima-Turbino and Samus-Kizhirovo bronzes (Grigoriev 1999, p. 191-204; Stefanov, Korochkova 2000, p. 84-92). Thus, they could exist in the post-Seima time, in the 16th century BC, although their earliest materials correspond to Seima-Turbino and partly Sintashta, but the Sintashta culture had started earlier. At the same time, analogies of a part of ceramic complex of the Verkhnyaya Alabuga settlement which will be discussed below can be found in later Fyodorovka culture (see Grigoriev 2000b, fig. 35; Molodin 1985, fig. 48-50). The last, on the contrary, has to be dated earlier, than it is considered to be (Grigoriev 2000b, p. 354).

Unfortunately, there are practically no metal artefacts on the Vishnyovka, Odino and Tashkovo sites. The only exception from the settlement of Verkhnyaya Alabuga is a bronze fishing hook related to the chemico-metallurgical group VU (Potyomkina, 1985, p. 162; Kuzminykh, Chernykh 1985, p. 356-357). On the settlement of Tashkovo II the analysis of copper prills has revealed the presence of tin and the studied sample has been related to the VK group (Kovaleva 1988, p. 39-40). Both these groups are characteristic of sites of the Late Bronze Age.

Proceeding from the stated above, the considered cultural groups of the Tobol-Irtysh region belong to the Seima-Turbino time, and their metallurgical production has to reflect the spread of metallurgical technologies at the beginning of the Late Bronze Age. Possible impulses to this could come either from the Transurals (metallurgy of Sintashta culture), or from the Altai (metallurgy of Elunino culture). Unfortunately, until recently the evidence of ore smelting of these tribes was absent. Studying of many collections of Western Siberia, publications, consultations with experts gave a ground for a conclusion that on sites of this region metallurgical slag was practically absent and, therefore, smelting of ore did not almost take place here. In the seen collections it was managed to find only seven slag samples from three settlements: Vishnyovka, Korshunovo and Verkhnyaya Alabuga.

In the territory of the Kurgan region and Northern Kazakhstan they are almost only settlements with clearly expressed cultural layers in which materials of this epoch are found. Individual pieces of ceramics are found also on other settlements, but the cultural layers are present only on these three.

Dating of the slag from Verkhnyaya Alabuga and Korshunovo is quite problematic. On the last sites the slag has been found in the area with ceramics which can be interpreted as belonging to either the Bronze Age or Early Iron Age. Therefore the connection of this sample with the Bronze Age is not reliable; nevertheless its technical characteristics are rather close with other slags of the studied series. In the cemetery of Verkhnyaya Alabuga, mainly Alakul materials of the Late Bronze Age are presented, although there are some Eneolithic burials too. At the same time in its western and southern parts "a settlement of the Early Bronze Age" (see above about the reference of these materials to the Late Bronze Age) is investigated where the analysed slags have been collected. The ceramic complex of the settlement is recognized as the westernmost site of the Odino-Krokhalevka type (Potyomkina 1985, p. 158-161). Other materials have not been revealed there. Therefore the relation of the slag to this period is the most probable; especially as such finds are absolutely uncharacteristic of funeral monuments. Connection of slag from the Vishnyovka settlement with Vishnyovka cultural complex is most faultless as it is a single-layer settlement with well expressed cultural layer.

Information about sites ond form of the slag

The settlement of Verkhnyaya Alabuga located on the Tobol, in the Kurgan region, within the territory of a cemetery of Alakul culture of the same name, has been studied by T.M. Potemkina (1985). From materials of this settlement five slag samples have been investigated. Four of them (73-75, 77) are pieces of light, very porous flat slag, the fifth (66) is a flat, shapeless, very rich in iron flat slag cake with inclusions of copper.

Korshunovo I is located in the Kurgan region too, but not on the Tobol, but on the Iset river. The site is very large, and contains ceramics of the Eneolithic, "Early Bronze Age", Early Iron Age and the Middle Ages. The settlement has been partly excavated by M.P. Vokhmintsev, and together with the "Early Bronze Age" and "Early Iron Age" ceramics a piece of slag has been found and analyzed (67); it is a gray, porous and shapeless piece of slag with inclusions of oxidized copper.

The single slag sample is received on the settlement of Vishnyovka I in Northern Kazakhstan which has been excavated by G.B. Zdanovich and is considered as the earliest site of the Bronze Age in this region (Zdanovich 1973). The slag sample (54) is presented by fragment of a large porous flat cake.

All samples have been investigated by means of mineralogical microscope in reflected light. In addition to this, two samples from the settlements of Verkhnyaya Alabuga and Vishnyovka have been subjected to chemical analyses, and one of them (from the settlement of Verkhnyaya Alabuga) was so interesting that demanded additional studies which has been done by means of SEM.

Chemical analysis

Chemical analysis (Tab. 11-19.) of two samples has shown a very high iron content. And, if in the sample from Vishnyovka silicon dioxide is presented, in the sample from Verkhnyaya Alabuga it has not been identified by the analysis, iron simply dominates in it. Copper in both samples is present, but its quantity is very small. In the sample from Vishnyovka it is possible to note the presence of calcium oxide (7.36%), but it is difficult to tell whether it passed into slag from ore, whether was connected with deliberate fluxing or ashes. Naturally, such composition of slag led to that the slags belong to the basic and ultrabasic groups (Tab. 11-20.). Slag of such composition was very fluid and had low viscosity (Tab. 11-21.). For the slag from Verkhnyaya Alabuga the calculated viscosity is 0.31 Pa·s, and for the slag from Vishnyovka – 1.59 Pa·s.

Mineralogy of slag

The main group of samples from Verkhnyaya Alabuga and slag from Korshunovo I are presented by porous glass with weak fayalite crystallization (needles and small prisms). Many cracked and melting quartz grains are found. Magnetite is rare; it is presented by fine grains, skeletons and dendrites. Small prills of copper and particle of reduced iron are very rare. In some instances iron is found inside small grains of magnetite that points to its reduction from oxide. Occasionally there are small prills having intermediate color characteristics between iron and copper, probably an alloy of these metals. Ore minerals are presented by small particles of cuprite, malachite (but there is no confidence that the malachite is not secondary, formed already in the settlement deposits) and very small particles of chalcopyrite. Prills of copper sulfide are occasionally seen.

Slag of the settlement of Vishnyovka I (No. 54) slightly differs. The main inclusion in it is large dendrites and particles of wüstite with fused surface forming often large lattice structures. There are many fayalite crystals in the form of long needles. Just fayalite and wüstite gave such high FeO content revealed by the chemical analysis (Tab. 11-19.). The molten particles of copper sulfide replaced in some cases with copper are present. Small copper prills are occasionally fixed. A single ore minerals, chalcopyrite, is revealed only.

This process makes possible to smelt a small quantity of iron as a bi-product. It is confirmed by the result of analysis of sample No. 66 from the settlement of Verkhnyaya Alabuga by means of mineralogical and scanning electron microscopes (Fig. 11-22., Tab. 11-23.).

The main inclusion in the slag is iron that has been demonstrated by both mineralogical and chemical analysis. It has a set of small and large cavities. The metal surface is also non-uniform. There are darker and lighter parts. They form layered, in some instances even dendritic pattern. The last, however, does not testify that the iron melted. There is a stripe of wüstite alomg the iron edge, and on the other side of the wüstite, on the edge of the sample, copper is reduced. In the contact zone with wüstite the iron forms the extended cellular and dendritic structures. The cavities were formed after removal of cupriferous components from chalcopyrite. Then the stripes of wüstite conglomerated with iron and became unevenly denser, therefore the cavities remained in metal. In the iron the smallest copper particles are recorded, but very rare. Copper sulfide on the sample edge turned partly into cuprite. Dendrites in iron are slightly darker, and there are carbon impurities in them. Investigation of this sample by R. Schwab at the Institute of archaeometallurgy in Freiberg has shown that a part of the iron is carbonized, and it is steel.

Conclusions:

Characteristics of slags from these sites are close to slag of the 6th mineralogical group in the Cisural area, but here these slags are dated to earlier time. The smelted ore was mined from the quartz rocks, and, chalcopyrite was the main ore. The chalcopyrite desintagrated into iron and copper sulfides. The copper sulfide melted owing to the low melting point with burning out of sulfur and was reduced in copper. The iron sulfide was oxidized to wüstite which in case of preservation of redusing conditions could pass into iron. The presence of iron prills indicates this process, however the molten prills of this metal does not testify at all that the melting temperature of iron was reached. It was molten wüstite whose prills were further reduced. Formation of the lattice and dendritic structures of molten wüstite also marks this process. They were formed after fusion of copper sulfide from the crystal lattice of chalcopyrite.

As in the sample from Verkhnyaya Alabuga steel is noted, one more cause of cast iron can be that in case of its carburizing the melting point falls to 1147 °C while pure iron melts at 1534 °C. However, it is possible in the case of reducing atmosphere and superfluous quantity of charcoal (Amborn 1976, S. 15; Tylecote 1980a, p. 209; Childs 1996, p. 299).

The use of sulfide ore promoted high temperatures of smelting. It could quite reach 1400 °C (1360 °C is the melting point of wüstite). However, it is not excluded that it was higher, as the carried-out X-ray diffraction analysis of the sample from Vishnyovka (Tab. 11-24.) has revealed a high-temperature modification of quartz – cristoballite, and absence of tridymite and quartz. This modification forms at cooling from the temperature above 1470 ºC. For small volumes the achievement of such temperatures was quite possible.

Thanks to the smelting of sulfide ore, despite the very high temperatures and for certain intensive blasting, the oxidation of slag did not occur. The smelting was carried out in reducing conditions that is most reliably marked by the particles of reduced iron.

The separation of copper and smelting of ore occurred almost completely. The last is rather characteristic of smelting with use of sulfides as at an initial stage matte is quite easily formed which melts the ore much better than slag. Copper losses in slag of this group are very insignificant. As it is possible to judge from the mineralogical analysis, they do not exceed 1%. Chemical analysis of sample 66 has shown about 2% (Tab. 11-19.), but it is a rather specific sample. All this is well explainable by low viscosity of this slag.

In this case it is problematic to explain this low viscosity by use of fluxes. Iron fluxes were hardly applied as chalcopyrite contains a lot of iron. The use of calcite is not excluded as in the Vishnyovka slag the content of CaO exceeds 7% (Tab. 11-19.), however it could be also connected with specifics of ore.

On the other hand, the basic composition of slag was not led to formation of large polygonal fayalite crystals, although there were, as though, enough components for its formation. Nevertheless, fayalite crystallized very poorly, and in slag from Vishnyovka, where it is well presented, it crystallized in the form of long needles that point to the high speed of slag cooling. It is unlikely that it was connected with slag tapping. Besides, we have no information on metallurgical furnaces of these settlements. Furnaces have not been also found on other sites of this period. On the Novokuskovo site with ceramics of Igrekovo type fragments of a melting bowl with slagged surface have been found (Kosarev 1981, p. 73), and on the settlement of Markovo-2 with Odino ceramics – a rectangular crucible (Molodin 1985, p. 31). However, most likely, it is evidence of metalworking production, especially as the crucible from Markovo-2 has a small size, as well as Krotovo crucibles, whose volume did not exceed 100 cm^3 (ibid, p. 60). In the Altai on the settlement of Novenkoe-6, with the materials close to Krokhalevo, Odino and Vishnyovka, a fragment of slagged rim of crucible has been found (Grushin 2005, p. 147, 148; Abdulganeev 1988, p. 125). Therefore we can assume the ore smelting in crucible, but strict proofs are absent. Smelting in furnace is more preferable. Oxygen inflow is necessary for smelting sulfides. Blasting, of course, could be carried out into crucible from above, but smelting of chalcopyrite is a long process during which there would be a continuous combustion of charcoal. And, judging from the reduction of steel, there was surplus of charcoal and reducing atmosphere in the furnace charge until the end of the smelting.

Taking into account this reservation and discussed above Elunino complexes (where occasionally chalcopyrite has been detected), we can note that here, in the east of the Euroasian province, the earliest smelting of chalcopyrite in furnaces occurred, irrespective of the solution of question about the materials of here described sites. As the accurate dating of concrete complexes with slags is not always clear, and the volume of the materials is extremely insignificant, we can state that this tradition is present here at the beginning of the Seima period. Certainly, it is impossible to connect origins of this tradition with Sintashta culture. There are also some essential distinctions. If metallurgists of Elunino culture smelted a mix of oxidized ores and secondary sulfides, on the sites of Odino-Vishnyovka type we see the active use of chalcopyrite. It is difficult to tell what the reason of this distinction was, as well as to answer a question of relationship of these traditions with Seima-Turbino. But these materials are united by one important feature connected with Seima-Turbino metallurgy. In both cases smelting was carried out at rather high temperatures and during a long time. In these conditions the alloying with arsenic at the stage of ore smelting was impossible as arsenic would not remain in metal. Therefore the choice at metallurgists was limited: either to be based on pure copper or to start to alloy directly into metal. And tin was an optimal decision for this alloying, and it occurred during this period. And if, discussing the Seima-Turbino bronze, we have mentioned that there was a complex transformation: new types of objects, new technologies of metalworking, new principles of alloying, now we see that it was connected also with new types of raw materials and another technology of ore smelting.

The second question is relationship of Vishnyovka metallurgy with Petrovka production because as it has been already discussed, earlier the participation of the Vishnyovka people in formation of Petrovka culture was supposed. However today in the Petrovka complexes comparable slags are unknown. In these complexes originally the smelting succeeded to Sintashta traditions, with gradual shift from the use of ultrabasic ores to the use of oxidized ores in quartz rocks that led to growth of number of the oxidized slags with many cuprite inclusions. In some places (for example, in Northern Kazakhstan) this problem was solved, but because of scarcity of these materials it is hard to say how strong this tendency was.

Problem of rise of metallurgy of the Seima time

Formation of metallurgy of the Seima time is a serious problem. Concerning the problem of origins of the Seima-Turbino sites, E.N. Chernykh and S.V. Kuzminykh have assumed a synthesis of some traditions of the Neolithic Glazkovskaya culture in the lake Baikal area and metallurgical traditions of the Sayan and Altai (Chernykh, Kuzminykh 1989, p. 251-253). The last in context of this work is especially essential as if to concretize this thought, we have to discuss Okunev or Afanasievo traditions. Many scholars pointed to local roots of Krotovo and Elunino cultures. So, V.I. Molodin, publishing materials from the cemetery of Sopka-2, has suggested for the Krotovo culture some undoubted parallels with the culture of combed-pitted ceramics and Ust-Tartas culture of the south of Western Siberia dated of the 4th – 3rd millennia BC (Molodin 2001). Scholars also note a succession of Elunino culture with the Eneolithic Bolshoi Mys culture that can be especially visually shown on ceramics (Kiryushin 2002, p. 52). The aforesaid does not allow us to doubt that local components took part in the rise of these cultures. However radical changes in metalworking force also to look for some other components. And in this regard many scholars point to the remote southern direction of connections. V.I. Molodin wrote about mighty ethnocultural influence from the population of the south of Central Asia (Molodin 1988, p. 36, 37; 2001, p. 93, 96, 116). Yu.F. Kiryushin suggested searching the initial region of this component in the south of Central Asia and Eastern Mediterranean, noting its contacts with local populations (Kiryushin 2002, p. 52; Kiryushin *et al*. 2002, p. 58). According to Grushin, the alien component has parallels in Okunev and Sintashta cultures and it was connected with steppe cultures of Eurasia (Grushin 2002, p. 21). The author of this work suggested the Near East as the initial region because in the Near East and in Transcaucasia there are parallels to this metal, although there are no absolutely accurate correspondences (Grigoriev 1999, p. 205-211). Nevertheless, these parallels indicate the similar principles of metalworking that is confirmed also by parallels in the types of alloy.

As it has been already said, the alloying with tin started spreading in the Euroasian Province exactly from this time. In the proper Seima-Turbino complexes a part of tin bronzes (together with tin-arsenic alloys) is about a half in metal collections. About a quarter of metal is presented by arsenic copper and bronze, identical to the TK group of the Volga-Ural metal. As a matter of fact, this group marks contact of the Seima-Turbino people with local Cisural populations that is confirmed also by that this metal is characteristic of the European zone of distribution of the Seima-Turbino sites. Arsenic-antimony alloys amount 11.3% of metal, and they are localized also in the European zone. At last, 8.5% of metal are presented by pure copper. An important conclusion is that the Altai deposits were the source of the tin ligature (Chernykh, Kuzminykh 1989, p. 166-168, 174). It is necessary to say that the arsenic-antimony alloys are considered as artificial bronzes only conventionally as some their part could have a natural origin from fahlores, but another part was a result of alloying. In the Asian zone unalloyed metal is almost absent. This situation in the European zone, apparently, is explained not by technological preferences but the remoteness from sources of raw materials for the alloying. But the main new phenomenon introduced in the EAMP by the Seima-Turbino metallurgists is the alloying with tin.

Tin and tin alloys

As we discussed earlier, single objects alloyed with tin are present in Okunev culture. And, it is not excluded that these objects are dated to the beginning of the Seima period. Anyway, not only the morphology of objects changed, but there was also a sharp change of the technological tradition. It is senseless to search for roots of this tradition in the west, in the Sintashta and Abashevo cultures. Similar tradition was absent there, as well as tin deposits. In the south of Central Asia arsenic alloys dominated during the Late Bronze Age since the transition from Namazga V to Namazga VI (Shetenko 2002, p. 188). However there are exceptions to this rule. About a half metal artifacts of the Tulkhar cemetery is casted from tin bronzes (Bogdanova-Berezovskaya 1968). These alloys are also well presented in metal of the Sumbar cemetery in South-Western Turkmenistan (Galibin 1983). However in Iran a high part of tin bronzes is absent, although tin was known since the late 3rd millennium BC (Pigott 1988, p. 4-6; 2009, p. 371). In Harappan time in India artefacts with both high and low contents of tin are known. There are also arsenic bronzes. And, in the area of the Harappan civilization there are no ores with the high concentrations of tin or arsenic, therefore, alloying components were brought from the neighboring areas (Babu 2003, p. 175, 176). It is to us also interesting that tin here had been used earlier, in the pre-Seima time.

Tin bronzes were well known in Anatolia, above all, in the Troad, and in Transcaucasia, but, except for the Troad, anywhere they do not make up the majority of metal (Avilova, Chernykh 1989, p. 70; Černykh *et al.* 1991, p. 601; Teneishvili 1993, p. 7; Treyster 1996, p. 206). However in Anatolia the use of these bronzes was a long and steady tradition. Their wide use began here already in the Middle Bronze Age. But the employment of tin ligatures commenced in the Near East at the beginning of the Early Bronze Age (Cudeyde, Ikiztepe, Alişar, Troy I, Thermi I, Tepe Giyan, Tepe Yahya) (Moorey 1975, p. 43; Coghlan 1975, p. 47; Yalcin 2000, p. 27). Early Dynastic I period texts from Ur quite clearly distinguish copper and tin bronzes (Potts 1994, p. 153).

In Western Iran tin bronzes appeared also early, in the late 4th millennium BC, but their essential distribution happened after the mid-3rd millennium BC (Oudbashi *et al.* 2012, p. 159). There are attempts to challenge the existence of tin bronzes before the EB 3 period (Hall, Steadman 1991, p. 225-228) that caused a retaliatory discussion (Yener, Goodway 1992, p. 84, 85). In this case it is possible to state doubts on dating of this or that artefact, but the presence of tin bronzes in Anatolia since the beginning of the EBA seems to be proved, although their part in metal in the beginning and at the end of this period was, of course, different. For example, in Armenia, in the EBA, a noticeable quantity of tin objects is known. Some artefacts have its high contents. For example, a spiral ring from the Talim cemetery with the tin content about 11%. Growth of a part of tin bronzes took place in the MBA and especially in the LBA. And, isotope compositions of the EBA tin bronzes are comparable with Trojan and other bronzes in the Near East. In the MBA only two such objects are known. In the MBA and LBA the isotope ratios correspond to ores of Armenia that point to the local production. But in the EBA this metal was brought (Meliksetian *et al.* 2003, p. 597; Meliksetian *et al.* 2011, p. 203, 204). And it is more probable that these bronzes were brought from Anatolia.

Tin is relatively late metal. In Latin there was no word for its designation. The used for this purpose an expression *plumbum album* means '*white lead'*. There is no also common Indo-European basis for this metal, unlike copper. Greeks used the word κασσιτερος, from which the name of tin ore cassiterite originated (Muhly 1973, p. 242).

Near Eastern texts report about supply of tin to Mesopotamia from the east (Muhly 1976, p. 90). In the 20th – 19th centuries BC enormous deliveries of tin took place in areas of South-Eastern Anatolia. The weight of individual ingots reached 65 kg. It is calculated that over a 50-year period about 80 tons of this metal could have been transported. From this quantity it was possible to obtain about 800 tons of bronze (Muhly 1980, p. 33).

The matter is that in the Near Eastern texts contains information about a ratio of copper to tin in the bronzes: 6:1 and 9:1, although some texts mention a lower proportion (Hall, Steadman 1991, p. 225)[2].

Where these deliveries were carried out from? Now it is one of the most difficult problems of the archaeometallurgical studies in the Middle East. Earlier traditionally it was considered that as tin deposits

[2] With this it is connected one more problem of definition of a threshold from which it is possible to consider that intended tin additions took place. The matter is that at low tin concentrations the bronze does not become much harder. Therefore some authors believe that the threshold of artificial alloys is about 5% tin, and 3% can go into metal from ore (Hall, Steadman 1991, p. 225). However even in the LBA more often we see much lower concentrations. This is explained by the fact that the problem is not reduced to the hardness of metal. Even at low concentration any alloying component acts as deoxidant improving properties of metal (Yener, Goodway 1992, p. 82).

are well presented in Europe (Britain, Brittany, Iberia, Tuscany, Sardinia, the Erzgebirge), and the eastern deposits (in Afghanistan and Egypt) are insignificant, the tin was transported to the Near East from the west (Tylecote 1987, p. 21). There was also another point of view that tin to Mesopotamia arrived from Iran, and already from Mesopotamia trade caravans delivered it to Syria and from there to Cyprus (Muhly 1973, p. 191, 257-260). The last years the idea of the western sources of tin has been refused, and interest of researchers is turned to different areas of the Near East. But there is some strangeness. If to look for some sources of tin in the east, in Afghanistan or Uzbekistan, it becomes unclear how these deliveries could be realized through Iran where before the beginning of the 2nd millennium BC this ligature was unknown, but even then the arsenic alloying continued to play a very important role up to the wide spread of so-called Luristan bronzes at the end of this millennium (Pigott 2004a, p. 29, 34; Thornton *et al.* 2005, p. 395). According to V. Pigott, although ancient tin mines are known in the Near East (in Turkey, Afghanistan, Uzbekistan, Tajikistan, Kazakhstan, and the Indus valley), most of them are located very far, and the Luristan sources of Western Iran are more preferable (Pigott 2009, p. 371-374).

This idea has really some ground. Investigations of the Deh Hossein copper-tin field in the west of Central Iran have revealed oxides and sulfides of tin. Besides, the ores contain arsenic, and the combination of tin with arsenic is characteristic of the Mesopotamian metal[3]. As though, isotope analyses do not contradict to it too. At last, "the Greek word for tin, κασσιτεροζ (*kassiteros*), can be interpreted as metal 'coming from the country of the Kassites' (Ghirshman 1954), and the Kassites lived in central and west central Iran." This means it is quite probable source, although, for certain, not a single (Nezafati *et al.* 2009).

There are small tin deposits in Anatolia and Transcaucasia, in Adzharia (Yener, Goodway 1992, p. 80; Yener 2003; Kuparadze *et al*. 2008, p. 250). Anatolian fields, in this case, are most important as could be an important source of tin for Mesopotamia since the EBA. Discussing the technology of tin mining, we have touched upon the Kestel mine in South-Eastern Anatolia. Publications of these materials caused mistrust and criticism (Hall, Steadman 1991; Sharp, Mittwede 1994). However the authors of this discovery have given rather developed and reasoned answers to this criticism (Yener, Goodway 1992; Yener, Vandiver 1993). Therefore in the EBA it was obviously important source of tin for the region. It is difficult to specify this problem. Lately some works have appeared, which as though, outline a way of identification of tin sources in metal on the basis of isotope analyses of tin (Haustein *et al.* 2010). But even with development of this technique the eternal problem of re-melting of metal scrap remains.

Thus, basing on the tin alloys, we are not able to define precisely the area of formation of this metallurgical tradition: it is too wide, and includes Anatolia, Mesopotamia and, probably, the western part of Iran. As the emergence of any complicated metallurgical tradition is a complex phenomenon, we can narrow considerably this region, leaning only on logical grounds. It seems to be unlikely to consider any region of Mesopotamia as the source of this tradition as tin was delivered there already in the finished form. A group of metallurgists that came to Siberia had to know properties of this alloy, how to look for, mine and melt tin ore and to make the alloying.

All this are not idle questions. The problem of need of emergence of this tradition is closely connected with it. Lately in literature an opinion has appeared that the alloying with tin did not arise from technological priorities or availability of raw material resources, but did from purely esthetic and ethnic preferences. And this position can seem to be strange only at first sight. But on the settlement of Tepe Yahya in Eastern Iran in layers dated about 1900-1700 BC two cultural complexes localized in different areas of the settlement are recorded. One of them had local roots, the second, Bactro-Margianan archaeological complex, was alien. In the area of the local complex ones continued to use arsenic bronzes, and in the area of BMAC of the same settlement the tin was used, but its part for time about 1700 BC was only 20%. As the same processes took

[3] It can have also another explanation. Mesopotamia imported a lot of metal, and degree of its utilization was very high here. Therefore alloys of different metals here could be more widespread, and this caused a considerable part of composite alloys.

place in Turkmenistan where at the transition to Namazga VI the tin bronzes started spreading, it is supposed that penetration to the south of the Andronovo tribes introduced this type of alloying to Turkmenistan, and BMAC people migrating to Iran (Namazga VI is a part of this complex) became the cause of emergence of tin in Tepe Yahya (Thornton *et al.* 2005, p. 395-398). However this approach has an essential contradiction. In the early 2nd millennium BC neither Andronovo complexes nor tin aloys existed in the north. In this period there were arsenic alloys of Sintashta culture which formed synchronously with BMAC. Taking into account that the formation of BMAC is considered as a result of migrations from the Syro-Anatolia area (Sarianidi 1989, 1993) it is more perspective to look for Anatolian roots of this alloying. But the noted connection of BMAC with tin alloys causes an undoubted interest. One more fact is interesting: with the formation of BMAC the use of tin increased in the southwest of Iran, in Susa (Thornton, Lamberg-Karlovsky 2004, p. 269). It could be caused by that the BMAC people kept connections in the west, providing further deliveries of tin from Afghanistan and Uzbekistan there, but it can simply coincide with the intensification of mining on the discussed above mines in the west of Central Iran.

There is one more worthy of notice fact. Above, discussing the Elunino metalworking, we have mentioned existence of Cu+Sn+Pb alloys. Such type of alloys has been found also on Tepe Yahya, in the area with materials of BMAC (Thornton, Ehlers 2003, p. 5), although, in general, in Iran and Mesopotamia it was not typical. Occasionally such artefacts are present in the MBA of Anatolia and Levant where in the EBA compexes they are absent (Avilova 2008, tab. 9, 23). This peculiar alloy is well present in Armenia, making up 6.2% in the MBA and 7.4% in the LBA (Meliksetian *et al.* 2011, p. 204, 205).

Technological benefits of transition to the tin alloys are obvious. After the beginning of smelting of sulfide ores, at using of mix from copper sulfides with arsenides, losses of arsenic were rather high because of its oxidation and removal. Besides it was difficult to control this process. Additions of cassiterite to copper ore or copper have no such problems (Charles 1980, p. 176, 177), but the question of ways of the tin alloying is not as simple as it seems. According to experimental data, it is easy to produce the tin bronze at joint smelting of copper and tin ores (Rovira *et al.* 2009, p. 413). But by such a way it is difficult to control desirable composition of metal, and such production has no reflection in our slags. Our studies almost did not reveal tin in slags (in a rather large analysed series), therefore the additions of tin ore to copper ore are doubtful. It could take place at early stages of the production and mark a stage of transition to the tin alloying, but in Northern Eurasia this stage is noted only for the Eneolithic sites of the Urals. Evidences on alloying of copper with tin are almost absent, and additions of cassiterite into copper are considered as debatable (Rehren 2003, p. 209). Some authors have believed that the tin alloying was carried out by the additions of cassiterite into the molten copper under a charcoal layer. An argument in favor of it is the extremely rare finds of tin, large its losses in slag when smelting cassiterite, simplicity and efficiency of the addition of ore into metal because under the charcoal layer oxygen of cassiterite (SnO_2) easily combines with carbon, and tin remains in copper, practically, without formation of slag. In such a way it is possible do an alloy with the content of tin in bronze up to 6-7%, keeping the temperature about 1100 ˚C within an hour (Charles 1980, p. 174, 175; Yener, Goodway 1992, p. 8). But other authors suppose that, judging from analyses of artifacts, in the Bronze Age metallurgists strictly controlled the content of tin; therefore they added metal tin, and did not use the cementation of metal with tin oxide in conditions of the reducing atmosphere. Tin is easily oxidized back. Therefore identification of cassiterite in cast objects sometimes led to a conclusion about the cementation. Studies of a bronze sample from Sardinia with this inclusion have shown that it was oxidized tin (Tylecote 1987, p. 143). Metal tin (an ornament from Lchashen) is known in the LBA of Armenia (Meliksetian *et al.* 2011, p. 205). In the LBA additions of metal into metal were, of course, an optimal way, but at early stages and in different areas, various ways could be used, including cementation.

Thus, the technology of tin alloys could not have its source from technology of alloys ore with arsenic minerals. Except the transition to a new type of alloy, new minerals, the principle of alloying changed radically. Besides, it was necessary not only to find these minerals, but also to learn how to produce the metal tin. Theoretically, it is not difficult. Tin can be simply smelted, having mixed cassiterite with charcoal in a crucible and having carried out the smelting at a temperature of 1000 °C. In the crucible tin particles should be reduced which can be chosen and alloyed in another crucible (Tylecote 1987, p. 140). But how ancient smelters could come to it? For Britain a variant of the first tin production has been suggested: a casual attempt of smelting cassiterite which was put on a piece of charcoal in the furnace (Craddock, Craddock 1996, p. 53). But such chance is improbable if it regularly repeated in different areas, and approximately at the same time. It is possible to discuss a trial and error method during a long time. But it is doubtful that in different regions of the world approximately during one epoch metallurgists tried to smelt different stones and if occasionally it was possible to produce the metal, they tried to alloy it with copper. But, if to take an incidentally found piece of cassiterite in hand, nobody takes into his head that it is possible to receive a ligature from it. Thus, this chance can be excluded. Discussing the tin impurity in metal and slag of the Eneolithic period, we said that, most likely, originally tin ores was smelted together with copper ore. Chronologically it coincides with the beginning of smelting of chalcopyrite which could be confused with a sulfide of copper, iron, and tin, stannite (Cu_2FeSnS_4). As the oxidation of this mineral leads to formation of cassiterite, it coud be crowned with the use of the latter. Respectively, this gradual technological transformation could happen in an area where, besides the tin deposits, the steady use of chalcopyrite took place. Therefore Anatolia is the optimal area. It is not excluded that the principle of the alloying "metal into metal" was prepared by that there was in the Near East a way of producing arsenic bronzes by alloy of copper with speiss (Thornton 2009, p. 320) that we have discussed in the chapter devoted to Sintashta slag.

But, at the transition to the smelting of cassiterite, it is worth to discuss also a technological aspect of the problem. Until recently it did not resist solution too. In the Altai and Sayan such evidences are absent. In principle, the evidences about the tin manufacturing are rather limited even in those areas where it is well fixed and investigated. There are slags and small furnaces of the 15th century BC from Cornwall and the Roman furnaces in Portugal (Tylecote 1987, p. 140). In Anatolia a series of tin deposits are known, and information on the early smelting of cassiterite is lately received there. Results of the works near the Kestel mine in South-Eastern Anatolia which was mined since the beginning of the EBA, shows that this technology demanded a long preliminary development of skills of enrichment of this ore. The rock here is presented by hematite containing tin inclusions in quantity up to 1.5-2%. Naturally, such ore could not be directly used in smelting. Therefore it was taken out to the settlement of Göltepe where it was pounded and roasted; therefore hematite turned into magnetite. Then this mass was stirred and washed in a special bath, and during this procedure particles of this magnetic mineral gathered, and cassiterite was extracted. It was smelted then without furnaces, in a crucible, the remains of slag were pounded, and tin drops were molten then in another crucible. Temperature in the crucible at smelting of cassiterite had to be within 700-1000 °C. Therefore to reduce temperature the unburnt crucibles were put in soil. The crucibles were burned already in the course of smelting. Naturally, this process gives dust-like slags which are difficult for finding at excavation. The process of cassiterite smelting as experimental works have shown, is quite simple, it is enough to blast into the crucible through a charcoal layer within 20 minutes. The scales of production of the 3rd millennium BC strike: on this settlement about a ton of fragments of crucibles is found (Yener 2000, p. 88, 100-123; Yener *et al.* 2003, p. 181-186). Therefore, the development of all these skills was necessary.

In a case of availability of pure cassiterite from placers, the technological problems of enrichment did not arise. For example, in India small tin fields are found, although traces of its mining in antiquity are absent. Therefore it is supposed that cassiterite was extracted from placers in rivers, and ethnographic data from Central India are an example. The presence of cassiterite here was determined by color of leaves of plants on the bank. In a perspective place workers washed out bottom sediments by wooden bolters or dug pits on the bank, and also washed out the soil. Cassiterite was smelted in small shaft furnaces; crashed cassiterite was mixed with charcoal and smelted about an hour. The reduced metal tapped from the furnace (Babu 2003, p. 176, 179). But this stage was possible only when there was already knowledge about properties of this mineral and ways of its following smelting and use. Possibly, in the Altai we face already with this stage, instead of the initial stages of development of this new way of alloying as here the alloying was carried out from the very beginning by metal into metal. Therefore its roots should be looked for in the Near East (by this time this technological tradition already went beyond Anatolia where it arose for the first time). It does not exclude a possibility of existence of incidental more archaic smelting of chalcopyrite with copper ores anywhere.

Silver and lead

Seima-Turbino artefacts containing high concentrations of silver in copper are of special interest: Cu+Ag and Ag+Cu alloys have been found. From 353 analysed Seima-Turbino objects, only 22 with such a composition are known. It is supposed that the source of the metal was the Nikolskoe field, which is situated near the Tash-Kazgan mine in the Urals (Chernykh, Kuzminykh 1989, p. 166, 172-175). However, it is impossible to be certain of the metal's provenance, based on emission spectral analysis. Besides, the content of silver in the ore from Nikolskoye does not exceed 1% (Chernykh 1970, fig. 33). It is most likely that these are artificial alloys. Similar objects are known in the Near East, although quite rare (Hauptmann, Palmieri 2000, p. 77). Above, in the chapter about the Sintashta metallurgy, I have already written that metallurgy of silver could be created only in a region where during a long time before it the lead metallurgy was known, because silver was smelted from the lead ore. And in this case it is very indicative that lead earrings are found in a burial on the Elunino settlement of Berezovaya Luka. Similar earrings are also present in the Krotovo culture of Baraba area. In the Uglovsky area of the Altai a stone vessel with a lead patch is found, dated to the first third or first half of the 2nd millennium BC (Kiryushin *et al.* 2004, p. 126). The connection of these metals is therefore obvious. However, as it has been discussed above, the metallurgy of silver and lead was also known in the region in the Okunev period. Therefore this argument cannot be very reliable; nevertheless it is more probable that various metallurgical traditions were formed within one or some related cultural traditions, instead of be composed from traditions of regions removed from each other, especially as silver during this epoch was used as impurity to copper, and proper silver artifacts were absent. And such billons in Okunev culture are not known. It is not excluded that a found on the Kazanchuruk mine on the left bank of Irtysh lead ingot with a high content of sulfur (Rozen 1983, p. 23) marks the production of Elunino time as this area had not been occupied by the Afanasievo people, and especially by the Okunev people. However it is impossible to date this object. Pieces of pure lead and bronze with its high contents are found in the Altai in the area of Bystryi Istok on the Andronovo settlement of Olginka (Kiryushin *et al.* 2004, p. 126).

Thus, as well as in the situation with metal artifacts types, the search of roots for used ligatures leads us nevertheless to the Near East, while without a possibility of more exact localization.

Sources of the metallurgical technology

There is one more aspect of this problem. These essential transformations in the metalworking were connected with changes in smelting technologies. As we have seen, in Elunino culture a tradition of smelting of oxidized ores existed, probably in crucibles. Most likely it was a derivative of early local traditions of crucible smelting of the oxidized ore. At the same time, the smelting of sulfide minerals from quartz rocks in furnaces took place. In this period smelting of chalcopyrite appeared in the region. All this led to the increase of smelting temperatures. They always reached 1300 °C, and in some instances considerably exceeded this threshold. And, the duration of smelting operations was probably long. In these conditions the alloying with arsenic at the stage of ore smelting was impossible, and the alloying of copper with metal tin is an optimal way. Besides, the alloying with arsenic would lead to its loss at overheat of metal (at filling in cast moulds and hot forging). In this case we see also a wide use of casting and hot deformation of metal at forge operations. This means that there was a complex transformation in the region: the transition to new types of ore and technology of its smelting, to new type of alloying, the emergence of new technologies of metalworking and new types of metal artifacts.

The earliest smelting of chalcopyrite is recorded in Anatolia where in the EBA slags from Murgul and Norşun Tepe sulfides have been identified: variations of small inclusions of chalcopyrite, bornite, pyrrhotine, and copper sulfides (Hauptmann *et al*. 1993, p. 559). Finds of chalcopyrite on the settlement of Arslantepe are dated to the same period (Caneva, Giardino 1994, p. 452, 453). This tradition gradually increases in the Eastern Mediterranean, and on the Cyprus in the LBA metallurgy is based, mainly, on chalcopyrite (Muhly, Wheeler 1976, p. 256, 257). Outside the Eastern Mediterranean and the Near East it is not so typical.

So, in this region since the EBA we see the beginning of steady smelting of chalcopyrite and the use of tin alloys connected with it. In the same place there are parallels to new for Northern Eurasia types of metal artifacts.

Near Eastern analogies to Seima-Tirbino metal artifacts

Double-edged daggers with a cast hilt and single-edged daggers with a curved back have been known in Anatolia since the Middle Bronze Age. There, as in Seima-Turbino cemeteries, double-edged daggers usually have a simple hilt, and single-edged daggers a flat hilt with a border along the sides. The single-edged dagger from Tell el-Ajjul has such a hilt, although its blade does not have a bent back. Also known in the Near East are socketed spearheads with a wide blade, but the socket was forged – a different technology (see. Avilova, Chernykh 1989, p. 51-53; Chernykh, Kuzminykh 1989, p. 108-124; Müller-Karpe 1974, Taf. 166.25). Similar spearheads occur from the second half of the 3rd millennium BC onward throughout the Near East (Gorelik 1993, p. 62). The leather binding of the socket was indispensable in preventing the spearhead detaching itself from the shaft. There is a cast imitation of similar bindings on some Seima-Turbino spearheads, which begs us to connect their genesis with regions where spearheads with disconnected sockets were known. In Anatolia and Syria some spearheads with forged disconnected socket had a small bronze ring or mount – in place of the leather binding (Erkanal 1977, Taf. 15, 16; Müller-Karpe 1974, Taf. 253.10,11). This detail was subsequently reflected on cast Seima-Turbino spearheads. They have no function and were derivative of the rings and mounts known on Near Eastern spearheads.

The spearheads with a cast socket appeared in the Near East in the 17th century[4]. A socketed spearhead with a mount on the socket, lancet-shaped blade and similar in proportions to examples from Seima-Turbino cemeteries, though with a narrower blade is found in Egypt (Berlev, Khodzhakh 1979). Cast-socket spearheads are rather typical finds in Syria (Ras-Shamra I), in the Trialeti barrows of Transcaucasia (Trialeti, Arich etc.) and in Mycenaean shaft-tombs. They are dated by Syrian parallels to the 17th – 15th centuries BC (Dzhaparidze 1994, tab. 26,22, tab. 26,5, p. 89; Kushnaryova 1994, p. 104). A distinctive feature of them is the presence of either a ring or mount on the socket. Its likely original use was for attaching spearheads with a disconnected socket to the shaft, but on the cast spearheads from Trialeti these rings and mounts are often made of silver and gold and had a purely decorative function.

As mentioned above, single-edged knives and daggers with a cast hilt and border along the sides occur also in the Near East. Unlike in Anatolia, frame-shaped hilts become typical also of double-edged daggers. Their mass distribution occurred in the 17th century BC (Gorelik 1993, p. 17). Seima-Turbino double-edged daggers with a cast hilt and arc-shaped edges are practically identical to those from Kish and Sachkhere of the middle and second half of the 3rd millennium BC (Chernykh, Kuzminykh 1989, p. 116, fig. 65; Gorelik 1993, p. 222, tab. III,22,56). The decoration of the hilts of daggers and backs of axes or battle-picks with cast figurines of animals was widespread in Western Asia (Gorelik 1993, p. 222, tab. III,23,33,34, p. 226, tab. V,6,11,21, p. 258, tab. XXI,42,43,47,53,57,67,71,80, p. 270, tab. XXVII,8). They were casted with the use of lost wax process. The earliest instance of lost wax casting is in the Nahal Mishmar hoard in Palestine, dated

[4] The dates are given according to accepted for the Near East traditional chronology.

to the late 4th millennium BC (Moorey 1975, p. 42; Muhly 1980, p. 30-32; Müller-Karpe A. 1994, S. 155). In Anatolia the lost wax casting appeared also very early, in the 3rd millennium BC (Yener 2000, p. 67).

Casted celts are very close to forged mattock-shaped tools manufactured in the Near East. Similar object are known in the Hama J level in Syria and in Susa (Müller-Karpe 1974, Taf. 247D; Talion, 1987, p. 226). Two such celts are present in Seima-Turbino complexes (Chernykh, Kuzminykh 1989, fig. 3,1,2).

The appropriateness of seeking Near Eastern connections for Seima-Turbino celts may be indicated by their relief decoration. It is unnecessary to consider widespread ornaments, such as hatched triangles, but on Seima-Turbino celts there are ornaments known in the Transcaucasian Middle Bronze Age, without prototypes in the Sayan-Altai area (see. Chernykh, Kuzminykh 1989, fig. 12-23; Kushnaryova 1994, tab. 28; 1994b, tab. 42; 1994a, tab. 40; Dzhaparidze 1994, tab. 18, 21). It is possible to relate them to chains of lozenges hung from border belts, sometimes terminating in an isosceles triangle, with the acute triangles inserted into each other. Sometimes chains of lozenges hang either from the apex of a triangle or from the space between the triangles. Occasionally, there are rows of vertical lines cutting space between triangles.

Known in Seima-Turbino complexes, fishing hooks and stemmed chisels occur earlier in Northern Eurasia only in Sintashta culture. Discussing such Sintashta artefacts, I have adduced parallels in the Near East.

Conclusions:

Taking into account the emergence of new smelting technologies, tin alloys, new principles of metalworking, and also new types of objects, we may speak about a complex transformation and about connection of this transformation with an uncertain yet area of the Middle East.

Andronovo metallurgy

Andronovo metallurgy became a new stage in development of metallurgical production in the Asian zone of the Euroasian Province. It is difficult to overestimate its volumes. In this period the production spreads over huge spaces from the Transurals to Eastern Kazakhstan. Obviously the enormous supply of tin in the whole province was connected with the Andronovo metallurgists. Therefore it should necessary to expect existence of bright metallurgical complexes. Unfortunately, for so huge territory the quantity of such complexes is not enough. Partly it is connected with that several decades ago when settlements in Kazakhstan were actively investigated, archaeologists not always took metallurgical slag in the collections, selecting sometimes only individual samples. But partly it is caused by that, unlike the Sintashta period, the LBA production was really presented not everywhere. And it is necessary to recognize this factor as the main.

Above all, it is necessary to discuss the terms ‘Andronovo culture’ and, respectively, ‘Andronovo metallurgy’ as they are seem rather clear only at first sight. The main components described by this term, are Alakul and Fyodorovka cultures. Some scholars add Petrovka culture here. And a number of connected cultures (Cherkaskul, Elovka and so on) are included in the circle of ‘Andronovo-like’. There are two main approaches to the relationship of the main Andronovo cultures. The first assumes a genetic continuity in the line ‘Petrovka – Alakul – Fyodorovka – Sargar’. And, the last component belongs already to the Final Bronze Age, and is not considered as Andronovo (Zdanovich 1983, 1988). The second approach assumes independent roots for both Fyodorovka and Alakul cultures (Kuzmina 1986, 1988, 1994; Grigoriev 1999). The author of this work believes (Grigoriev 1999, 2000b, 2002) that the Petrovka culture was formed on the Sintashta basis. The Sintashta culture was also a basis of formation of the early Alakul complexes though in further development of the Alakul tradition the role of the related Petrovka culture was great.

Fyodorovka culture was not connected with this tradition. In my opinion, its initial roots were in the Middle East although the final formation happened in the areas of Eastern Kazakhstan and Altai, from where the Fyodorovka tradition spreaded to the west and this distribution resulted in the final formation of Alakul culture and emergence of a series of syncretic types. E.E. Kuzmina distinguishes among these types those in which the Alakul tradition dominated and those with the prevalence of Fyodorovka features (Kuzmina 1986). Here we will not touch upon this problem in details, having limited only to a mention of one type, Atasu, as materials of these sites will be discussed in this work. Traditionally earlier in the Kazakhstan archeology the Atasu and Nura types were distinguished which were considered as identical to Alakul and Fyodorovka materials of other areas. Contrary to this, E.E Kuzmina considers Atasu type as syncretic, although relating to the Alakul tradition. But in a context of this work this different interpretation can be ignored. Similarly, if to be terminologically exact[5], the Fyodorovka culture is a trans-Ural phenomenon as it has been suggested basing on the trans-Ural materials. In the Minusinsk Depression it is more correct to call the sites of this tradition 'Andronovo' (excluding from this term Alakul materials), and in Eastern and Central Kazakhstan the 'Nura' type. But it is not so essential for this work too, and further we will call all these materials 'Fyodorovka'.

There is also a difference in spatial placement of these sites. The Alakul culture covers the Transurals, Western, Northern and Central Kazakhstan. Its eastern frontier is between the rivers of Ishim and Irtysh. To the east it is possible sometimes to meet impurity of the Alakul material, but, in general, it is not the Alakul territory. Areas on the Irtysh and up to the Yenisei are a distribution area of the Fyodorovka sites. However they are presented also in the west. But in the steppe in the west their presence is quite limited. Contrary to this, in the forest-steppe zone (at least, in the Transurals) there is a lot of Fyodorovka sites (Grigoriev 2008). Here, in the forest-steppe, later cultures formed on the Fyodorovka basis, Cherkaskul and Mezhovka, are also localized. It also reflects the distribution of Fyodorovka culture from the east to the west and its contact with Alakul culture.

Proceeding from everything told above, the term 'Andronovo family of cultures' is correct only in sense of fixing the contact of these two different (by origin and, in a certain degree, on the spatial placement) cultural formations. Partly this term can be considered as a tribute to tradition, partly it really reflects diverse processes of interactions and relationships. Therefore at studying of cultural processes it is incorrect, as it demands to adhere to exact definitions and to avoid false meanings. But in some general works it can be used. In this case, we may speak about the 'Andronovo area' extending from the Urals to the Yenisei.

Ore base of the Andronovo area

Within the territory of the Euroasian Metallurgical Province it is perhaps, the richest area with a lot of ore deposits. In the east it is limited by the Sayan-Altai deposits described above, in the west by the Ural deposits. The quantity of copper-ore fields in the Urals is enormous, they belong to the most various types, and some of them have been discussed in the previous chapters. In the territory which is interesting to us now, there are many deposits too, although on this territory they are distributed irregularly.

A group of large-scale deposits is situated in the west of the area, in eastern part of the Orenburg region, near Orsk. There are the largest chalcopyrite deposits, such as Gai and Blyava, but their ore layers have no occurrence on the surface. Oxidation zone and its 'iron cap' are blocked by later deposits, and in the antiquity these fields could not be exploited. Except them there are small ore deposits in quartz veins (Zavaritskii 1929, p. 133; Chernykh 1970, p. 44; Pshenichnyi 1975, p. 4, 8, 14, 15, 26). In the antiquity large works were

[5] These distinctions in more detail and a question of historiography see Grigoriev, 2003c. Justification of dates is given in another publication (Grigoriev 2002, p. 146, 248): Petrovka, Alakul and Fyodorovka cultures since the 16th century BC, Cherkaskul culture since the 16th /15th centuries BC, Mezhovka since the 15th /14th centuries BC.

carried out to the west, but these deposits belong already to the copper sandstones of the Cisural area which were exploited by the Timber-Grave people.

To the northeast from Orsk there are a number of deposits in diabases, serpentines and a massive sulfide deposit in porphyries (Polyakov 1925). In the Dombarovsky area near the Mugodzhar Hills, two ancient mines, Elenovka and Ushkatty (Fig. 11-4., Fig. 11-VI., Fig. 11-VII.) are known. Peculiarity of these deposits is the absence of 'iron cap' and a leaching zone, and the high content of sulfur in sulphidic ores.

The open pit on Elenovka has the depth of 6m. The deposit is situated in the contact of quartz keratophyres covering the pyroxen porphyrites. The rock is rich in iron; the ore is quartz-tourmaline with copper oxides and low iron content. The content of copper is very high.

In Ushkatty the ore zone in the form of small lenses 0.5-4m thick extends for 1km. There are two large open pits: 20×15m and 130×20m. 1.3 km to the west from the pits, near the Ushkatty River traces of ore smelting are recorded. The type of the deposit is similar to Elenovka (Malyutin, 1940, p. 89, 95-98). E.N. Chernykh gives a bit different data about the sizes of these mines (45×30×3m on Elenovka and 8×4×2m on Ushkatty) and specifies that geochemically they are very similar. Mineralization on the mines is presented by oxidized copper minerals and secondary sulfides. Just these mines are suggested as a source of copper of the EU group of the Volga-Ural region (Chernykh 1970, p. 38-40).

Copper mineralization to the east, in Kazakhstan, is presented extremely widely. It is impossible to describe all fields of this huge region; therefore we will touch upon some largest regions of the copper mineralization: Atbasar-Tersakkan, Kokshetau heights, Dzhezkazgan-Ulytau, Northern Betpak-Dala, Balkhash, Uspensk-Spassk, Karkaraly and Ekibastuz-Bayanaul. In the east of Kazakhstan the Altai deposits are localized which have been discussed bedore.

Atbasar-Tersakkan area

In northern part of Kazakhstan, from Dzhezkazgan to the north, a belt of copper sandstones 200 km wide extends (Fig. 11-4.XIV). In the north its border is 100 km to the south from Petropavlovsk (Sapozhnikov, 1948, p. 3, 154). The ore is presented here on the wide area, but by individual small sites. It is situated in quartz sandstones and presented by different types of ores. Primary ores are the poorest. In the zone of cementation the main ores are bornite, chalcocite and cuprite, in the oxidized zone – malachite, azurite and chrysocolla. The zone of oxidation reaches 10-15m in depth, and the cementation zone – 60 m. The copper content in the oxidized ores of the Atbasar area is 4-17%, but usually 0.7-2% (Satpaev 1929, p. 33; Narkelyun *et al.* 1983, p. 111-215; Satpaeva 1958, p. 154-156). Minerals replace cement of sandstone and penetrate cracks. Limonite and goethite are present here in addition to the copper minerals; however they are widespread extremely irregularly. The vein mineralization in the area is absent. On the Atbasar group of deposits down the river Zhabay traces of ancient works are recorded. They are found also in the Ishim area and in areas of the lakes of Imantau and Yakshi-Yangiztau. To the south, on the Tersakkan deposits, ancient mines are not revealed yet, but possibly it is connected with a weak study of the area.

Kokshetau heights

Deposits (both contact and in quartz veins) are localised here in eastern part of the Kokchetav height (Fig. 11-4.VIII) (Yagovkin 1931, p. 27). The Borovoe group situated to the north from Shchuchinsk is presented mainly by inclusions of copper sulfides in gold-bearing quartz veins. And though ancient mines are found here, there is no confidence that they were made for copper. Another situation is near the lake Atan-Sor. The ore here is presented by quartz veins with oxidized zones in which malachite and azurite prevail, and hematite and limonite are also present, and halcosine in the zone of cementation. Ancient mines are found on all deposits of this zone.

Dzhezkazgan-Ulytau area

Dzhezkazgan is the most famous ancient deposit of Kazakhstan (Fig. 11-4.IX). The ore mineralization is connected here with gray sandstones and quartz veins. The thickness of the latters do not exceed usually 1-2cm (Satpaeva 1958, p. 8-29; Narkelyun *et al.* 1983, p. 122). The formation of ore deposits was caused by ascending hydrothermal solutions enriched with sulfur and iron. The last element, however, does not play an essential role in the general ore composition. Red sandstones, rich in iron oxides, are, as a rule, barren (Satpaeva 1958, p. 8-14, 38-41; Yagovkin 1932, p. 44). It caused the higher SiO_2 content in the Dzhezkazgan ores that is visible from the generalized chemical composition of the Dzhezkazgan sandstones (Satpaeva 1958, p. 15) (Tab. 11-25.).

The most important ores are replacement in sedimentary rocks, fillings of pores and interstices. In some places there are massive layers of ore about 3-4m thick. Near surface the accumulations of oxidized ores 5-6m thick are present with a visible length of 10 m (Satpaev 1935, p. 211, 219; Sapozhnikov p. 84). The content of copper in the ore reaches 5-35%. The main minerals of the sulphidic zone are bornite, chalcocite and chalcopyrite. In the zone of the secondary sulphidic enrichment (reaching in depth up to 60-70m) chalcocite is the main mineral. The thickness of the zone of oxidation varies from 3-4 to 12-15m. Near Zlatoust it reaches 45 m. The main mineral of the oxidized zone is malachite, azurite, chalcocite, cuprite, native copper and chrysocolla are present too. Specifics of the zone is that the process of oxidation proceeded in sharply expressed sulfuric acid conditions that caused preservation of sulfides here (Satpaev 1935, p. 224-225; Satpaeva 1961, p. 166, 173, 174; Narkelyun *et al.* 1983, p. 124). There is a lot of ancient mines near Dzhezkazgan dated to the Bronze Age.

Betpak-Dala

In Betpak-Dala desert several copper deposits are known. Usually they are small and poor (Fig. 11-4.X). It would be desirable to emphasize two of them. The Taskura deposit has insignificant ore resources, but good oxidized ores presented by malachite with the average copper content of 1-4% (Yagovkin 1931, p. 30; 1932, p. 49). More essential in the Bronze Age were the mines of Kenkazgan and Efimovskoye in northern Betpak-Dala. The ore occurres on contact of sandstone-clay and calcareous deposits, in sandy-argillaceous siliceous and iron oxide rocks. Minerals of the oxidized zone are presented by malachite, cuprite, chrysocolla and azurite. The content of copper in the oxidized ore reaches 20-50%.

Uspensk-Spassk area

Exploitation of ores in the Uspensk-Spassk area (Fig. 11-4.XI) was widely carried out in the 19th century AD. It probably erased traces of ancient mines. On the most part of fields the ore is holded by quartz veins and quartz rocks (Satpaeva 1958, p. 52; Chukhrov 1950, p. 28, 29, 40-42; Rusakov *et al.* 1933). However in some instances there are ores in sandstones and limestones (Altyn-Tyube, Kairakty). The zone of oxidation is developed up to the depth of 20-40m, reaching 60 m on the Uspenskoe field (Satpaeva 1958, p. 65). In the latter case quartz in the zone of oxidation is partially leached, and its contents fall. In general, iron minerals are not characteristic of the oxidation zone, the sulfur content in ore is low (Satpaeva 1958, p. 53). Ore of the Uspenskoe mine has an optinal ratio of acid and basic oxides and is a ready furnace charge which does not need additional fluxing. Limonite is present in the oxidized zone of the deposits of Samombet, Berkara and around Spasskoye (Chukhrov 1950, p. 41, 42). The main copper mineral of the zone of oxidation is malachite. The subordinated position is held by azurite, cuprite, native copper and chrysocolla. Chalcocite and covellite are presented in the zone of secondary sulphidic enrichment. The copper content in the oxidized zone varies between 0.1 and 14%.

The Koktasdzhartas group of deposits located nearby, to the north from Karkaralinsk, (Fig. 11-4.XV) belongs to the copper-porphyritic type. The ore is deposited in the form of masses of scattered sulfides in secondary quartzites (Yagovkin 1931, p. 26; Chukhrov 1950, p. 30, 31), but deposits of other types are also present.

Balkhash area

Copper ores in the Balkhash area are situated in vein deposits and inclusions in the igneous or sedimentary rocks (Fig. 11-4.XII). But not all deposits of this area could be used in antiquity. Some were certainly not mined: Kyzyl-Espe, Sayak, Ak-Chogyl, Gulshad, Kounrad and a number of smaller. They could not be exploited because they are either covered by the 'iron cap' or copper minerals of the oxidized zone are extremly poor. Ancient mines on all these deposits have not been found (Yagovkin 1931, p. 31). Deposits in quartz veins: Kara-Tyubek and Uch-Kara were more interesting. There are traces of ancient works. Minerals of the zone of oxidation are azurite, brochantite, cuprite, malachite and limonite (Yagovkin 1931, p. 38). Old mines are found also on some impregnation fields. The Kok-Zobay deposit belongs to them. It is presented by veins of rich cuprite and chalcocite in plagioclase granite. There is one large open pit and some smaller. Ancient pits 1-3m in depth are found also on the deposit of Shurabek where minerals of the oxidized zone are presented by thin veins of malachite and limonite in the silicified granites, with the average copper content of 2%.

A large ancient open pit 700m long is found on the deposit of Miy-Kaynar (Munglu) where ore is holded by limestones, with malachite, cuprite and azurite in cracks.

Ekibastuz-Bayanaul area

Deposits of the area fall territorially into two groups (Fig. 11-4.XIII): Ekibastuz and Bayanaul. In the Ekibastuz group copper ores are presented by small inclusions in porphyritic tufas and tufa sandstones. The impregnation ores in antiquity, apparently, were not exploited. Use of the ores lying in the form of a dense network of veins of malachite, azurite, cuprite, chalcocite and chrysocolla accompanied by iron hydrooxides is more probable (Yagovkin 1931, p. 36, Chukhrov 1950, p. 33). Use of the porphyry copper deposits of Boshchekul is improbable. Because of the developed 'iron cap' the deposit of Moykain was not used too. The same can be also said with confidence about chalcopyrite deposits of the Bayanaul area (Yagovkin 1931, p. 31; Chukhrov 1950, p. 43). The 'iron cap' is present also on the skarn deposit of Chokpak (Yagovkin 1931, p. 35; Chukhrov 1950, p. 32). Ancient works could be carried out on the vein deposit of the Bayanaul group. The ore is holded here by quartz veins. The sulfide ores are presented by bornite and chalcocite, the oxidized ones by malachite, azurite, and in some instances by chrysocolla. Sometimes hydrohematite is present in the zone of oxidation (Yagovkin 1931, p. 33, 34; Chukhrov 1950, p. 32, 33).

Ancient mines

Thus, as we see, in Kazakhstan, in its different parts there are many copper deposits appearing on the surface. With rare exception the gangue is presented by quartz and sandstones with high quartz content. And, the oxidized zone extending on the large depth is very well developed everywhere. Therefore the majority of deposits could be mined, but their ores were not too convenient for smelting in antiquity: they are oxidized ores in quartz rocks.

However this abundance of ore deposits on the surface made here possible a large-scale production in the Bronze Age. Information on ancient mines of Central and North-Eastern Kazakhstan has been collected by

A.H. Margulan (2001[6]). And, it is necessary to emphasize that he has included in his summary of mining and smelting places not only results of archaeological inspections. It is mostly based on early reports of geologists. Therefore some questions in these reports were reflected authentically: the presence of mines, what exactly was mined, types or ore bearing rock. But the dating is correct only for individual objects, and the description of metallurgical furnaces are questionable. But the main thing in this work is description of enormous scales of mining production which are fixed in this region. Judging from archaeological materials, they are dated to the Bronze Age and the Middle Ages. It is hard to say how great this production during the Bronze Age was, but, apparently, it was enormous. In the Urals, Eastern Europe and the Altai there is nothing comparable with this vim of mining works.

It is enough to give only some examples to show this vim: On the deposits of Shuruk individual mines are 200-400m long and 40-50m wide. "On the southwestern slopes of the Altynsu hill "an enormous ancient pit" with grandiose dumps reaching to 3m in height is located. The length of the pit is about 800 m, the width is 30-40m. Traces of fire in the form of soot and heated stones are present on the pit sides, testifying to use of fire at ore extraction". On the mine of Sayak III a chain of ancient mines "has the extent of more than a kilometer. The length of individual pits reaches 500 m, the width is 12-30m, the depth to 25 m and more. … Chains of ancient mines of Dzhezkazgan relating to the Begazi-Dandibay period are grandiose. For this time huge pits up to 1 km long are characteristic. They are concentrated by large groups on the site of Kresto-Center which is a core of Dzhezkazgan, with the richest ores and the most mighty (18 m) ore horizon. Individual mines on this site reach 750-800m long, 50m wide and 8m deep. One of the mines has the form of a huge arch; the distance between its ends is 460 m. … Kengazgan is an enormous oval pit comparable with modern mines. The total length of the pit is 530 m, the width in the middle is 170 m; the length of individual extensions is 20-50m. Prospecting holes made in the central part on the depth of 15 m did not reach the bottom, it forces to assume that the initial depth of the mine was no less then 25-30m". In Dzhezkazgan near the ancient settlement of Milykuduk total area "with dumps and traces of ancient metallurgical production is about 10 hectars. A vertical section of the area of the ancient settlement revealed three layers of crushed ore, relating correspondently to the Bronze Age, early and late Middle Ages. Between the ore layers there is a layer of sandy loam 8-15cm thick. Character of the crushed ore in each layer is different. So, in the upper layer pieces of ore are of rather large sizes, approximately about 1-2cm^3. The bottom layer consisted of more crushed ore, the sizes of pieces are 0.5-1cm. A huge number of large storage pits for ore. From there 2000 tons of ore was extracted with the copper content of 8-10%". (Margulan 2001, p. 50, 52, 54, 60).

From this one more interesting to our research aspect follows: the ore intended for smelting had the content of copper about 8-10%. Dumps found near the smelting centers contain the ore with 2-5% copper, and this ore did not use in smelting any more (Margulan 2001, p. 59).

It is remarkable that, in addition to the copper mines there are many mines for extraction of cassiterite which was smelted to produce tin, the main alloying component of the Late Bronze Age; and, in some cases it was mined on the same fields as the copper ore. Mining and smelting of lead-silver ores has been also detected. Chemical analyses have revealed high lead contents in ore from ancient dumps of Kyzylespe (78.49%), Alabuga (61-57%), and Kenshoky (51.02%) (Margulan 2001, p. 22-31, 36, 37, 73). As we have already repeatedly discussed, there was no special sense in lead extraction at that time; most likely, this ore was extracted to produce silver by a method of cupellation recorded in Sintashta metallurgy. Judging from the analyses, rather pure ore was used for this purpose, as at this stage there was no aspiration to smelt metal. It was necessary to oxidize the ore and then to evaporate the oxide. The use of pure ore was more convenient for this operation.

[6] The reference is given to the collected works of A.H. Margulan which has been published in many years after his death. This collection includes the results of works of many years, including the early.

Metallurgical furnaces

Unfortunately, data on metallurgical furnaces of the Andronovo period are rare. Studying of reports on excavations of sites in Northern Kazakhstan has not revealed reliable constructions which can be connected with metallurgical production although small hearthes to 1m in diameter are present everywhere. It is not excluded that a part of them could be used for ore smelting especially as volumes of the production in the north of Kazakhstan are incomparable with the volumes in the southern areas. Nevertheless, there are no evidences about such use of these hearthes.

In the Tobol area on settlements small surface and round hearthes 0.5-1m in diameter have been found. Some have a covering of the bottom with stones or clay bricks. But their connection with the metallurgical production has not been established (Potyomkina 1985, p. 323).

The furnaces attached to wells have been found in the Alakul dwellings on the settlement of Mochishche (Fig. 11-26.1,3) (Grigoriev *et al.* 2007). Similar installations are noted also on the Korkino settlement (I am thankful to Yu.P. Chemyakin for the provided information). As a matter of fact, this localization of furnaces near the wells is the Sintashta tradition saved in the Alakul culture. These furnaces were deep in the surface, and had the sizes to 60-70cm. On Mochishche ordinary round furnaces have been found too. One of such furnaces has been found in the Alakul-Fyodorovka layer on the floor plastering made over a filling of an earlier well (Fig. 11-26.2, furnace 1).

In the Transurals, a series of furnaces has been recorded on the settlement of Atamanovka V, where are Timber-Grave-Alakul, Fyodorovka-Cherkaskul layers and a layer of the Final Bronze Age with the materials related to Bersuat type (Malyutina, Petrova 2009).

In the Timber-Grave-Alakul dwellings a round furnace is revealed (dwelling 4) with the size of 1.25×1.1m, and also a long construction faced with stones (the dwelling 3) in the form of a trench about 5m long, 0.5-1m wide, and 0.25-0.35m deep. The form of the trench is irregular: it has three expansions and three narrowings. It is attached to a pit, probably, a well. As a mater of fact, both of these structures are known on the Sintashta sites, and the long construction is similar to the furnace of the settlement of Semiozerki (Fig. 3-2.5).

In dwelling 1 of the Final Bronze Age two furnaces attached to wells (they are connected to wells with small cuts) and having flues in the form of long trenches are revealed. The furnaces themselves are deep, have the oval form and sizes of 1.7×1.2m and 0.9×0.55m (Fig. 11-27., Fig. 11-28.). Stratigraphical observations allow excavators to assume that in this dwelling one of these systems of the furnace attached to the well started functioning in the Timber-Grave-Alakul time. This means that we see a certain succession of furnace designs within the settlement. In this dwelling one more hearth is found (its size is 0.5×1.2m).

Metallurgical production is marked by a series of slags and a roundish copper ingot 12-13cm in diameter. Unfortunately, its weight is not specified in the publication, but taking into account that the density of copper is 8.9 g/cm^3, it is possible to assume that its weight was in limits of 1.5-3kg.

On the settlement of Bersuat XVIII with the same set of cultural types the small round hearthes and long constructions, in some instances with facing stones, are revealed. But in this case there is also no possibility to determine which of them were used in the metallurgical production (Malyutina *et al.* 2006). On the settlement of Arkhangelskii Priisk II a lot of slag (Fig. 11-29.5,7), fragments of slagged furnace lining (Fig. 11-29.3,4) and crucibles (L.Yu. Petrova's excavation) have been revealed. There are on the settlement also materials of Alakul culture and the Final Bronze Age, but the metallurgical remains, according to the author of excavation, belong to Mezhovka culture. Studying of the slagged lining has shown that slag flew down from them, i.e., usually it were remains of slagged furnace walls, instead of slagged bottom, that specifies that the furnace charge contacted directly to the furnace walls. Slags and slagged lining are often crushed; therefore, when slag accumulated on the walls, it was knocked off, and a new lining was done.

A significant number of fragments of crucibles found here (Fig. 11-29.1,2,6) is interesting. Diameters of the crucibles is about 20 cm, but there are allocated a group of crucibles with higher sides and internal volume of 270-600cm^3 and the more flat crucibles, with the volume of 70-300cm^3. All the crucibles are slagged only inside, traces of blasting on external lower surface are absent. Accordingly, the blasting was directed from top to down, to a crucible. Despite the small degree of slagged surfaces of the smaller crucibles, it is impossible to assume the metal melting in them. Because of the shallow internal volume and their width it would be inconvenient to melt and then pour metal in them. Therefore, most likely, all crucibles were used for ore smelting.

The blasting was carried out by means of the blowing tuyeres. Two fragments of tuyeres, and one slagged tuyere replaced by accumulated ore slag (Fig. 11-29.8) have been found. The external surface of fragments is partly slagged, and the internal one is burnt as the tuyere was inserted into the furnace, and air enriched with oxygen passed through it. Internal diameter was about 4cm, and the tuyeres were inserted into the furnace approximately on 5 cm. Studying of the completely slagged tuyere has shown that it was inserted at the height of 2.7 cm above the bottom (at the internal wall of the furnace). It was inserted into the furnace on 4 cm. The lower part of the end was about 1 cm above the bottom level, and the middle was 1.8 cm above. The angle of the blasting tilt was about 45˚.

Judging from the height of the tuyere and the angle of blasting, the furnace was built on the surface, with small shallow depression for a crucible, and blasting had to be directed to its center, but at some distance. Furnace charge (ore with charcoal) should fill the whole furnace, otherwise walls would not be slagged and the slag would not flow down on the tuyere. The furnace had an internal diameter of 40 cm and the height superstructure was at least 20 cm, and the diameter of the bottom was 30 cm and its depth of 5 cm. But in this case it was impossible to tap slag that has been supposed for the Mezhovka slags in Bashkiria.

Data on ancient metallurgical furnaces in Central Kazakhstan are more extensive. Unfortunately, most often the furnaces have been studied by geologists studied the mining sites. These furnaces can be dated to both The Bronze Age and the Middle Ages. Information on these furnaces is published in the same work of A.H. Margulan (2001, p. 60-68). Because of chronological uncertainty of these objects we will not describe them in detail. The details can be found in the cited work. Here the description of these furnaces is given in general.

It should be kept in mind that all described furnaces are very large. It is not excluded that small furnaces simply dropped out of sight. In general, it is possible to speak about three types of constructions. On the fortified settlement of Milykuduk near Dzhezkazgan 25 furnaces have been revealed. One of them (No. 3) was a square construction with the size 4×4m and the height of walls to 2 m. Because of such huge size it has been supposed that it served for ore roasting. But ores of this area are oxidized, though contain some sulfur impurity. Nevertheless, they did not required the roasting. Probably, it is a medieval construction, but in any case the question remains, especially as its square form did not promote improvement of the temperature mode of smelting. This is a single such construction, therefore it can be ignored.

The second type is presented by long furnaces 1 and 2 in Milykuduk (Fig. 11-30.). They are 1 m wide, and 2 and 4 m long, but the longer furnace is divided by a partition into two chambers, and an individual tuyere was inserted into each chamber. Thus, as a mater of fact, it is two attached furnaces. There is no ground to speak about dating of these furnaces, but their connection with the medieval layer of the settlement is most probable.

Round furnaces of large diameter (from 1.5 to 3 m) deep in soil are more widespread (in Balatersakkan, Milykuduk, and Besoba). Their walls are faced with stone or clay layer, sometimes the walls have traces of fire. The bottom is deep to 0.4-1m. Pieces of charcoal, ore and slag are found on the bottom. They are also too large constructions which would not allow to reach rather high temperature. This type of constructions is very important as it has generated the interpretation of well known furnaces of the settlement of Atasu. Besides, it is not excluded that they are dated to the Bronze Age. In any case, near one of these furnaces (Balatersakkan) a lot of ceramics of "the transition period from the Middle Bronze Age[7] to the Begazi-Dandybay period" is found. Thus, it was, at least, the late Andronovo time. Possibly, in this case we deal with not absolutely correct interpretation. The situation in Besoba is remarkable where six such furnaces have been found "from which one of enough large sizes is connected with a small furnace by means of a channel". It reminds the Sintashta furnaces attached to wells[8]. Discussing the sites around Atasu, we will return to this question.

The greatest number of furnaces has been found on sites of the Atasu area: Atasu, Myrzhik, Ak-Moustapha, Ak-Maya (Kadyrbaev, Kurmankulov 1992). On all these settlement there are rather small round or pit furnaces with a diameter from 0.5 to 1.5 m. Nearby some of them accumulations of slag are found that points to their use in metallurgical production. These are rather simple and widespread cinstructions. It is supposed that they were used for the metal melting, some for crucible smelting.

It is considered that the basic constructions for ore smelting were the huge furnaces with 1.8 to 3 m in diameter found on all above-mentioned settlements (Fig. 11-31.). The part of their walls has traces of fire. On the settlement of Atasu 14 furnaces of this type are investigated. The depth of these furnaces varies from 0.6 to 1.7 m. On the settlement of Myrzhik the depth of these constructions is 2-2.9m. The horizontal long flues covered with stone plates are attached to many furnaces. In some instances the flues were arranged along the dwelling walls warming the room. Small furnaces made of stone plates are attached to some wells (in some cases they are situated at the distance of 0.3-1m). It is supposed that they served for crucible smelting of ore. Nearby sometimes clay platforms are situated. It is not excluded that metal casting was carried out on them.

Large pits were interpreted by the excavators as metallurgical furnaces to which small furnaces for melting metal in crucibles and horizontal flues were attached. This conclusion was caused by that near these installations metallurgical slags were found, copper prills and burnt bones (used probably as a flux), and in some cases the walls of these pits were burned. However it is difficult to agree with such their interpretation. Our experience with similar constructions on the settlement of Sintashta (where it was rather accurately proved that they were wells) has demonstrated that it is a very difficult task to determine their real outlines and depth in conditions when the walls of virgin clay were destroyed. On Atasa this task became more difficult, because the high level of subsoil waters. Therefore these pits have been ecavated only in their upper parts. As a result, their true depth has been reconstructed proceeding from the idea that they are metallurgical furnaces. It is also necessary to remember that by the time of excavation on Atasa in Northern Eurasia only single furnaces of the Bronze Age were investigated, and in most cases their fixing and identification were very uncertain. Ideas of technology of ancient metallurgical production, actually, were absent. Therefore, the researchers had simply nothing to use as a base for their understanding.

As with the Sintashta furnaces it is possible to claim rather surely that we deal with wells. These wells could have the diameter in the upper part about 1.5-2m and the diameter in the lower part a little more than 1m. The roasting of walls could be deliberate, for their strengthening. But in a case of erosion of the lower part of walls their subsidence took place, therefore the bottom of attached furnaces subsided and looks like the burnt wall of a well. We have seen a similar situation on the Mochishche settlement.

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[7] In the early tradition of Kazakhstan archaeology the Middle Bronze Age corresponds to the Late Bronze Age in Eastern Europe.

[8] The fact that they were not enough deep to be a well surprises too. Almost all Sintashta wells are filled with clay. When we started excavating them, it was necessary to get used during a long time to this thought and to dig the layer that seemed to be virgin clay.

Use of these constructions as smelting chambers would not allow to reach high temperatures and even to support fire. The studied small openings located at the edges and in walls of some constructions, and interpreted as pressure-blowing channels, were obviously insufficient for this purpose. Bamberger's experimental studies have demonstrated that a small diameter of the furnace (20-40cm) is necessary for creation of a high temperature in smelting operations and a simultaneous use of six pressure-blowing tuyeres (Bamberger 1992, p. 152, 157). Our studies (see the chapter about experimental works) allow me to claim that it is overestimated, especially for the furnaces attached to wells. Nevertheless, so large volumes of furnaces as it is reconstructed for Atasu are absolutely unreal. Besides, the supposed pressure-blowing channels (1-3 in each furnace, with a small diameter about 10 cm) would be insufficient even for smaller constructions.

Similar constructions on the settlement of Myrzhik (and also interpreted as smelting chambers!) reached 2-3m in depth.

Therefore it is more lawful to consider the studied constructions within that reconstruction which has been suggested for the Sintashta furnaces. So-called smelting chambers were the wells used for creation of additional blasting into the furnaces attached to them. Just the ectangular or round constructions from vertical slabs (situated nearby many wells) interpreted as furnaces for crucible melting were the basic smelting furnaces. In some instances they could be fixed as accumulation of stone slabs near a well. In total, on the settlements 11 similar constructions have been revealed. Their sizes vary from 0.6 to 1.5 m.

Besides, there are constructions which were not connected with the wells that also repeat the Sintashta situation. It is a hearth with the diameter of 1m on the settlement of Ak-Moustapha, a pit 0.48 m in diameter and 0.2 m deep in dwelling 1 of the Atasu settlement, and hearth in dwelling 2 of the Atasu settlement. The latter had a diameter of 1.5 m that is fixed by distribution of burnt soil (marking probably the destroyed construction), but in it the remains of a round clay furnace with the diameter of 0.5 m and the height of 0.3 m are recorded.

At last the third type of metallurgical constructions on Atasu is the two-chambered figure-of-eight and oval furnaces found in dwellings 1 and 2. Their sizes are within limits of 0.6×0.4 – 1.7×1.2 m. It is supposed that they were used for copper melting that is confirmed by found drops of the oxidized metal in the filling of one of such constructions. It is not excluded that it was realy so, although strong evidences for this are nevertheless absent. Similar constructions have been investigated on the Semiozerki II settlement of Petrovka culture.

Thus, the rectangular and square constructions attached to wells were the leading type of metallurgical furnaces on the Atasu sites. As a rule, they are slightly larger than those of Sintashta therefore it is not excluded that the charging of these furnaces was slightly larger. But there are also the small furnaces which were not connected to wells that repeat the Sintashta situation too. At last, there are a small number of the long furnaces known on the Petrovka settlements. Thus, the Atasu furnaces were direct heirs of Sintashta-Petrovka metallurgy, and, now, considering the small number of evidences on Petrovka constructions, it is possible to raise carefully a question that Sintashta metallurgy played more important role in formation of Atasu, than Petrovka.

On the Sargari-Alexeevka settlements of the Final Bronze Age of this region (Enthusiast II, Ikpen I) the heaths of open type are typical. We can assume that some of them were covered and were furnaces, but strong data on their connections with metallurgical production are not present. On the settlement of Enthusiast II an oval hearth with the size of 2.2×1.1 m and the depth of 0.3m is investigated, with the walls faced with stone. A furnace consisting of long attached chambers has been also excavated (Tkachev 2002, p. 129, 130). But its design is not absolutely clear. It is not excluded that its recorded form is a result of re-building. The furnace design on the settlement of Ikpen I is clearer (Tkachev 2002, p. 36). It was the deep round dome furnace with a diameter a little more than 1m with the attached flue faced and covered with stone plates which is terminated in the north with a stone ring, probably remains of a vertical part made of lighter material (Fig. 11-32.). It is a typical design for the Sintashta sites.

A furnace is found on the settlement of Rublevo VI in the Altai (Panin *et al.* 2006, p. 108). In the same region, on the settlement of Novoshulbinskoye of the Sargari culture, a pit furnace close to the Atasu constructions discussed above has been investigated (Sitnikov 2006, p. 150). Most likely, in this case it is also not a pit furnace, but a well with a furnace attached to it.

Therefore the Sargari furnaces, probably, succeeded to the Alakul tradition which was going back, in turn, to the Sintashta one.

Evidences about the Fyodorovka furnaces are more than poor. On the settlement of Ust-Kenetay round constructions with the diameter of 0.7 m (that is rather universal design in many cultures) and the long cut in the floor rectangular constructions with the size of 2.2×0.5m are revealed (Evdokimov 1982).

Thus, everywhere in this region, and up to the Final Bronze Age the furnaces reflect those traditions which were created in the Sintashta time. They are presented by simple round furnaces and hearths, long trench-shaped furnaces, the furnaces attached to wells of various forms. Horizontal flues were very often used. There are also simpler constructions which could succeed to the Sintashta tradition, but coul be invented independently.

Ore and slag

Description of samples

For so vast spaces the sampling of materials of the Late Bronze Age is insignificant. This insignificance is aggravated also with that many sites of the Bronze Age are multilayered, and slag could be replaced in them. Slag does not bear an expressed cultural sign. Therefore at the material analysis only those samples have received an accurate cultural definition whose cultural affiliation was confident. The others were considered as ‘Andronovo’ (if on a settlement only Alakul and Fyodorovka materials have been noted) or ‘Late Bronze’ (if to them materials of the Final Bronze Age were added).

There are few materials of Alakul culture from the Transurals. It is a fragment of slagged ore from the settlement of Bersuat XVIII on the river with the same name (No. 165) and two slag samples from the settlement of Ubagan II in the Tobol area. The former (No. 82) is presented by a shapeless heavy piece of slag with small copper inclusions; the latter (No. 76) is a fragment of thin, small, dense and heavy flat cake with copper inclusions on the edge. Its form is similar to the Sintashta slags. The settlement of Bersuat XVIII has been investigated G.B. Zdanovich and M.K. Habdullina (Malyutina *et al.* 2006), the settlement of II Ubagan by T.M. Potemkina (1985).

Slightly more samples originated from the most southern part of the Transurals, the settlements of the Dombarovsky district of the Orenburg region where the Elenovka and Ushkatty mines of the Bronze Age are known. These are three heavy shapeless pieces of slag from the Shandasha settlement. From the Kupukhta settlement four slag samples are included in the research: a fragment of badly shaped large flat cake (No. 1846), a small fragment of very dense slag, whose initial form it is difficultly to determine as the slag was crushed in antiquity (No. 2021), an oval (4cm long) piece of heavy shapeless slag with the fused surfaces (No. 2022), and a small fragment of light porous, probably, ceramic slag (No. 2023). From the collection of the settlement of Baytu four samples of ore (No. 2028-2031) and three of slag are investigated. It is a fragment of dense slag of black color (No. 2024), its surfaces have glass lustre. One undamaged surface is smooth, without pores. The initial form is unclear. The second sample (No. 2025) is a small fragment of thin (5 mm) black vitreous slag plate with smooth surfaces. The last sample (No. 2026) is presented by a small fragment of dense shapeless heavy slag. In general, all these are Alakul settlements, though there is also the Kozhumberdi ceramics reflecting contacts with the Fyodorovka people.

In total, for the Transural Alakul sites only 16 mineralogical analyses under microscope are done.

Materials from only three Alakul (Atasu) settlements of Central Kazakhstan are investigated. Two samples of slag from the settlement of Ak-Moustapha have been analysed: one of them (No. 53) is light, porous, shapeless slag of red color; the second (No. 25) is a thin fragment with a smooth surface and large pores. From the settlement of Atasu a piece of roasted furnace charge and four samples of friable heavy shapeless slag are analysed. At last, from the settlement of Myrzhik two fragments of flat slag cakes of dark gray color have been included in the research, with tuberous surface and small rare pores; and one sample of ore. In total 9 mineralogical, 8 spectral, 2 X-ray diffraction, 6 bulk chemical and 7 SEM analyses have been done.

Thus, the whole Alakul sampling is limited to only 25 mineralogical analyses.

The situation with Fyodorovka slags is not better. One piece of shapeless slag (No. 218) from the Graurtly settlement (S.G. Botalov's excavation) in the Transurals and two samples of shapeless slag from the Pavlovka settlement in Northern Kazakhstan (T.S. Malyutina's excavation) are investigated. The largest collection (19 samples of slag) occurs from the settlement of Ust-Kenetay in Central Kazakhstan: five of them (No. 228, 229, 233-235) are heavy shapeless pieces of slag, the others (No. 230-232, 236-246) are lighter, shapeless, porous slag. On this settlement also the material of the Final Bronze Age is present (Evdokimov 1982), but the slag is connected with the Fyodorovka (Nura) layer. From the settlement of Ikpen I (Tkachev 2002) 5 small pieces of slag have been analysed (No. 672-676). From the settlement of Ilyaska in the Southern Transurals the spectral analyses of 21 sample of ore (No. 1240-1252) and 28 large shapeless pieces of slag (No. 1253-1279) and 7 mineralogical analyses (No. 2217-2222) (Fig. 11-33.) have been done. These remains are connected probably with the Fyodorovka-Cherkaskul complex of the settlement. Two samples (No. 2231, 2232) occur from the settlement of Novo Bayramgulovo (excavations of Ya.V.Rafikova) where various LBA cultures are presented, but the slag is dated probably to the Mezhovka time. A large collection of slag is studied from the mentioned above settlement of Arkhangelskii Priisk II of the same time. These are 17 slag pieces of the furnace lining, 16 ceramic slags, 19 dense shapeless heavy slags, some slags of uncertain type, and also a large number of slagged pieces of crucibles. 58 mineralogical analyses under microscope, 99 spectral and 7 bulk chemical analyses have been in total done.

These poor materials are supplemented with materials of the Transural sites which can be called 'Andronovo', with both Alakul and Fyodorovka materials. Above all it is a flat dense slag cake (No. 32) from the excavated by K.V. Salnikov (1957) settlement of Kipel: with its thicker edge it is similar to Sintashta slags. One sample of ore and one shapeless slag with visible iron oxides (No. 81) occur from the settlement of Yazyovo III where the most part of ceramics is presented by ware of Alakul culture, but there are also Fyodorovka and Cherkaskul ceramics (Potyomkina, 1985). Several samples have been analysed from the Korkino settlement with two layers, Alakul and Cherkaskul (Chemyakin 1976, 1978). It is a piece of slagged rock (No. 269), a thin flat slag cake (No. 815), a piece of shapeless dense slag (No. 268) and some pieces of the shapeless porous slag similar to ceramic slags (No. 270, 816, 818, 820). Reference of the slag from these settlements to the Alakul time is most probable, but it is impossible to conclude it surely. At last, from the settlement of Ak-Maya in Central Kazakhstan (Kadyrbaev, Kurmankulov 1992, p. 66, 67) two samples have been analysed: the first (No. 265) is presented by a flat fragment of dense heavy slag of black color with quartz inclusions; the second (No. 266) is a small fragment of shapeless slag. Slag of this group of sites have been analysed by 11 mineralogical analyses and 10 spectral analyses.

As a result the general Andronovo series is 95 mineralogical analyses under microscope that allows us, at least, to outline some tendencies in development of the production.

The sampling from the sites of the Final Bronze Age is the smallest. Rare samples occur from Central Kazakhstan. It is a large piece consisting of particles of quartz in slag (No. 219) from the settlement of Kafarka of Sargari culture (V.V. Varfolomeyev's excavation in 1986). From the Kent settlement it is a piece of heavy porous slag of gray color (No. 757) with one flat surface and the second rough, and both surfaces are porous. This settlement has been excavated by the same author and belongs to the Dongal type finishing the Bronze Age in Central Kazakhstan. On the settlement of Sargari (excavations of S.Ya. Zdanovich) a large friable and porous flat slag cake (No. 44) is found. At last, on the settlement of Telmana XVI a porous heavy fragment of slag flat cake (No. 49) is found.

A sampling from the Altai sites is insignificant too. These are samples from settlement Burla-3 where along with Sargari ceramics both Begazi and wheel-made ceramics are present. The settlement is dated probably to the late 2nd millennium BC. It has been excavated by V.S. Udodov (1991, 1994). In the analysed collection there is a slagged piece of copper (No. 782), slagged ceramics of yellow-green color, probably, burnt clay used to fasten a tuyere (No. 783) and a piece of azurite (No. 1114). Three samples of the oxidized ore, azurite and malachite (No. 1115-1117) occur from a similar settlement of Kaygorodka-3 which has been excavated by the same author. On the settlement of Kalinovka II (G.E. Ivanov's excavation, 1987-1988) Cherkaskul, Sargari and Dongal materials are revealed (Fedoruk 2008, p. 204, 205). In my opinion, it is not quite justified to define the Altai materials as Cherkaskul. However they certainly belong to the Fyodorovka-Cherkaskul tradition of production of the EAMP which is interesting to us. Samples from the settlement (No. 793-795) are presented by shapeless molten lumps of porous slag. At last, from the Chernaya Kurya VI settlement 9 samples of the oxidized ore (No. 1118-1126) are taken for the analysis. The settlement has been excavated in 1982 by G.E. Ivanov; it belongs to the Final Bronze Age.

Thus, in total 6 mineralogical analyses and 16 spectral analyses have been made from the sites of the Final Bronze Age.

At last, some samples can be related only to the Late Bronze Age as a whole. It is a sample from the settlement of Atamanovka V in the Southern Transurals (No. 706): a piece of partly roasted ore. On the settlement the Timber-Grave-Alakul, Fyodorovka-Cherkaskul and Final Bronze Age ceramics are revealed. Small samples of slag and ore occur from the settlements of Nikolaevka (slag No. 31) and Novoburino (ore, No. 30). On the last settlement the Alakul and Mezhovka ceramics have been revealed. Two pieces of the oxidized ore are found on the Malookunevskoye settlement (No. 71, 72). From the settlement of Kamyshnoye II with the Petrovka, Cherkaskul, Mezhovka and Sargari ceramics and some fragments of Fyodorovka ware (Potyomkina 1985, p. 76-103) there is one sample of the shapeless flat slag with inclusions of ochre and copper (No. 70) and one sample of roasted ore (No. 80). On the Novonikolskoye settlement in Northern Kazakhstan a large slag flat cake of dark color with small pores, similar to Sintashta slags (No. 46) is found, as well as a small piece of copper ore (No. 11). A piece of the oxidized ore is found on the Kuropatkino settlement in Northern Kazakhstan (No. 41).

From the mining center of Kara-Tyube in Central Kazakhstan comes a fragment of shapeless slag (No. 267). In the same region, in the area of the mining center of Stepnyak, a thin flat shapeless slag cake is found with quartz inclusions. Small samples of slag are taken from the mining center of Altyn-Tyube in Central Kazakhstan (No. 250, 251), and two small fragments of flat shapeless slag from the settlement of Akimbek in Central Kazakhstan.

From the tin mine of Eastern Koinda in South-Eastern Kazakhstan on which the LBA ceramics is found, seven samples of slag have been investigated: two of them (No. 1006, 1007) are shapeless, light and porous slags; the others (No. 1001-1005) are heavier shapeless slags. From the area of Chisty Yar on the Irtysh two samples have been studied: one (No. 315) is presented by a piece of porous rough slag with one smooth surface; the second (No. 316) is a fragment of dense edge of a slag flat cake, the thickness is a little more than 1cm, in the form it is similar to Sintashta slags.

Thus, slags and ores of this group of sites are investigated by 17 mineralogical analyses and 8 spectral analyses.

As a whole the analysed base for the Late Bronze Age from the Urals to Altai is 109 mineralogical, 141 spectral, 2 X-ray diffraction, 13 bulk chemical analyses and 7 SEM analyses.

In addition to this 166 spectral analyses of ore from the Kazakhstan mines of Southern Bulattau, Efimovskoye, Aydygarli, Kenkazgan, Talapty, Verkhnee Umgurlu, East Kurday, Chatyrkul, Altyn-Tyube are made (Tab. 11-34.).

Form of slags

The comparison of the form of slags of different cultural groups of the Late Bronze Age (Tab. 11-35.) demonstrates that the flat slag cakes typical for the Sintashta collection, are considerably present here (28.6%) only on the Alakul and Sargari sites. Possibly, their presence on the Alakul-Fyodorovka settlements (Kipel and Korkino) can be explained by that they belong to the Alakul time. Nevertheless, the heavy shapeless slags dominate in the Alakul and Sargari collections (52.4 and 71.4%) that may be explained by more acid and viscous composition of the ore bearing rocks of this period. For the Fyodorovka-Mezhovka collection the heavy shapeless slags are characteristic (54.6%), and the lighter ones are on the second place. These distinctions indicate the existence of some raw and technological difference between Alakul and Fyodorovka metallurgy, and also the proximity of Alakul and Sargari metallurgy.

However these distinctions can be also explained by the available ore base. If to compare the forms of slag from different regions we see the presence of less viscous slag (flat cakes and the flattened slag) in Kazakhstan and, to a lesser extent, in the Transurals. For Eastern Kazakhstan and the Altai this slag is less characteristic (Tab. 11-36.). But, as we remember from the description of ore base of the region, ore in quartz rocks was equally characteristic both for Central Kazakhstan and for the Altai. In the second region there was no Alakul culture. Therefore it is probably a question of distinction in cultural traditions.

Chemical compositions of slag

The carried-out chemical analysis of some LBA slag samples from Kazakhstan an essential difference from the Sintashta slag is revealed (Tab. 11-37.). First of all, the highest content of copper in slag of the Atasu-type settlements of Atasu and Myrzhik (from 29 to 60%)[9] in Central Kazakhstan is evident. We have mentioned above that the storage pits in Milykuduk in this area were filled with ore prepared for smelting, and the ore contained 8-10% copper. In the furnace charge from the settlement of Atasu the content of copper is about 18%. This means we may speak about the content of copper within 10-20% as about a standard. All these are rather paradoxical figures as in the slag which has been analysed the copper content is almost the same as its content in malachite and exceeds its contents in the ore prepared for smelting and in the furnace charge. In old spectral semi-quantitative analyses (Margulan 2001, tab. 4) the contents of copper in slag usually do not exceed 5%. Therefore it is impossible to exclude that results of rejected smelting operations from the settlements of Atasu and Myrzhik got to our sampling (it is too small), but it is not confirmed assumption too. Our analysis of slag from Novonikolskoye and Ak-Moustapha has shown the copper losses less than 1%.

[9] It is necessary to pay attention that the analysis have not revealed all components as the total contents are below 100%. It does not allow us to do any exact calculations on the basis of these analyses. They have only a ratable character.

The incomplete character of the chemical analysis deprives of sense the calculations of slag basicity and viscosity. But the insignificant number of iron oxides is evident. This means that the slag was, most likely, acid. It is well visible from the table of ratio of $SiO_2/FeO+Fe_3O_4$ in the slag and furnace charge (Tab. 11-38.). At such slag composition the high content of copper is quite explainable. The ore of this region is characteristised by the silicate component, but iron oxides are not characteristic (Tab. 11-25.). In slag they, though in a small amount, nevertheless, are present. For settlements of Central Kazakhstan (Atasu, Myrzhik, Sargari) the total amount of iron oxides varies within 5.48-17.15%. Only on the North Kazakhstan settlement of Novonikolskoye their contents reaches 42.27%, but it is absolutely another zone. Therefore deliberate additions of some amount of iron oxides are not excluded, but they were insignificant as in comparison with ore the content of iron in slag has to grow even without special additions.

Besides, in the furnace charge of the settlement of Atasu calcium oxide has not been detected while in slag of this settlement it is present in the amount of 1.76 and 3.27%. As we remember, near the furnaces the burnt bones have been found, nevertheless the content of calcium oxide in slag is not so great that it would possible to speak about essential fluxing. A part of this component could pass into slag from ashes.

Chemical analyses of the Mezhovka slags from the Southern Transurals have been also carried out (Tab. 11-39.). The high part of silicate components in all these samples attracts attention. One of the analysed samples (2358), probably, was the ore bearing rock. The content of silicon dioxide in it reaches 63.46%, and the content of iron oxide is very low. And, the contents of all components in the slags do not too differ from their contents in this rock. Thus, despite the territorial and cultural distinctions, we see here also the obvious preference of ores from acid rocks. But in this case it was necessary to clear up whether the crucibles of the settlement of Arkhangelskii Priisk II were used for ore smelting or they are remains of metalworking. It is a rather difficult task. Similar studies have been carried out on the Eneolithic settlements in South-Eastern Spain. This work has shown that in the slag smelted from ore in a crucible, in comparison with the slagged walls of the crucible the content of iron and magnesium grows, there are in some cases ore inclusions (Müller *et al.* 2006, p. 212-214).

Therefore calculations of average chemical compositions of the ore bearing rock, heavy slag and slagged parts of the crucibles have been carried out (Tab. 11-40.). These calculations have not revealed a basic difference between the dense heavy and crucible slag. Visually the dense slag seems to be more balanced and fluid. In chemical composition it is shown in the form of some decrease in a part of silicon dioxide and increase of classical slag components: oxides of iron, calcium and aluminum. And, we have no bases to assume that additions of fluxes containing calcium and potassium (for example, calcite or bones of animals) took place as the content of potassium oxide did not grow, and some growth of the calcium content can be explained by its transition from ashes, and for the slag from Novo Bayramgulovo by its presence in the ore bearing rock. But, irrespective of the fact how these components got to slag, from ashes or from fluxes, in relation to the slagged parts of crucibles it is possible to say that it is improbable that such concentration were formed as a result of copper melting. It is more characteristic, nevertheless, for smelted ore slag.

The common losses of copper and its oxides in slag are 2-6%. They are relatively high, but within the standards of the Bronze Age.

Calculations of the coefficient of basicity for the Mezhovka slag have been carried out. Both ore bearing rock and slags on the basis of these coefficients have been related to the ultra-acid group (Tab. 11-41.). There is no considerable difference of these coefficients between the usual metallurgical slags and slagged parts of crucibles. Respectively, slag of this compound cannot crystallize well and has to solidify quickly after decrease of temperature. It is almost distinctly that the ore was extracted from a field in acid rocks, probably in quartz veins. And iron fluxes were not used.

All analysed Mezhovka slags were very viscous, from 13.92 to 28.84 Pa·s (Tab. 11-42.). Such slag could not be fluid and solidified quickly enough. Therefore there was no possibility to tap this slag from the furnace or to pour it from a crucible. In this case the viscosity of this slag is much higher than the viscosity of Sintashta slag, and it is close (and if to compare with some sites is even above) to viscosity of the Orenburg slags where it resulted in very high losses of copper remained in the slag.

X-ray diffraction analysis

The carried-out X-ray diffraction analysis (Tab. 5-17.; Tab. 11-43.) shows that from the beginning of the Late Bronze Age, unlike the Sintashta time, a high-temperature regeneration of quartz, cristobalite, is present in slag. As it is formed when cooling from temperature of 1470 °C, it is possible to suppose that during this period the high smelting temperatures were reached, although it is, probably, not true for all sites as the number of the analyses is limited. Thus, at a further discussion of this problem, it is necessary to assume a possibility of so high temperatures.

Mineralogy of slag

Alakul metallurgy

Slags which can be reliably connected with Alakul culture are found, mainly, in two regions: on settlements of the Dombarovsky area of Orenburg region and in Central Kazakhstan.

4th mineralogical group

Oxidized slags are most typical for the Alakul culture (Fig. 11-III.; Fig. 11-IV.; Fig. 11-V.1-4). In them the gangue is well presented: usually it is quartz pieces (Kupukhta, samples 1846, 2022, Shandasha, samples 90, 91, Baytu, samples 2024, 2024-1, 2026, 2028, Bersuat XVIII, sample 165). Sample 2028 (Baytu) is presented by quartz rock with malachite veins (Fig. 11-III.1). Some samples have fragments of quartz sandstone consisting of small granules (Kupukhta, sample 2023, 2023-2, Fig. 11-V.3). Therefore, in Western Kazakhstan some part of the Alakul ore was mined from the copper sandstones. And, when these typical structures have not been identified, the ore could come from the sandstones too. It is not possible to distinguish reliably it at the statistical level. The conclusion about the preference of ores from quartz rocks and the quartz-containing sandstones is fundamental that is confirmed by ore inclusions in quartz or sandstone, and sandstone inclusions in malachite grains (Kupukhta, sample 2023).

Some fine chromite grains (Kupukhta, sample 2023) obviously do not point to smelting of ore from the basic rocks. Probably, they got to the smelting together with iron oxides. Therefore sometimes in glass accumulations of small magnetite particles in the form of octahedra or thin skeletons crystallizng from slag (Fig. 11-III.4) are fixed. The octahedra in this sample are slightly darker, but on their edges a lighter border is present in some instances, demonstrating probably the beginning of reduction into wüstite. In samples 2024 and 2026 (Baytu) small skeletons and dendrites of magnetite crystallizing from slag are also noted. Their quantity is not really great.

Crystallization of fayalite is not characteristic of this slag. Only in sample 2024 a small accumulation of its nuclei is found.

A lot of copper prills is present in glass matrix. A part of them is very small and was dissolved in the liquid slag. In these cases the glass has the red coloring noticeable in crossed nicols. A border of cuprite and in samples 2023 and 2023-2 (Kupukhta) also of copper sulfide can be formed around large copper globules. In the same samples prills or molten inclusions of chalcocite and covellite, and also grains of malachite and chrysocolla with fused surface have been identified. In some cases the molten sulfide fill also small cracks in slag. Therefore, solidification of the slag happened before the fall of temperature to the point of the covellite solidification. The sulfide border in one case is recorded around a globule of cuprite. The melting sulfide turns often into cuprite. Many molten prills of covellite and sulfide are deformed. Therefore, by the time of their solidification the slag was already very viscous. In sample 1846 (Shandasha) sulfides are not revealed. The ore is presented by malachite in it.

Cuprite grains are also recorded. Along with them there are prills and molten inclusions of this mineral that fill cracks in slag. The oxidizing atmosphere in the furnace is testified also in some cases by the presence of small needles of delafossite, however their quantity in slags from the Transurals is insignificant. Some delafossite needles are bent. Probably, by the moment of their crystallization the slag was very viscous. The high viscosity is also well demonstrated by that in samples 2024 and 2024-1 from Baytu the glass in some places is painted by red strips, the glass is saturated with small particles of copper and cuprite.

The quantity of cuprite depends on the ratio of oxidized and sulfide ores in the furnace charge. Therefore in samples from Shandasha where only malachite is revealed, the quantity of cuprite inclusions is much more, often it is presented by well developed dendrites, and not only the prills. The dendrites of this mineral are noted also in sample 2026 from Byatu. A sample from Bersuat does not contain delafossite and cuprite dendrites, but there is a lot of its prills and grains. Here the smelting was also carried out in the oxidizing conditions, although together with malachite and azurite there are noticeably present sulfides, but for some reason the process was not normally completed, and many ore inclusions, cuprite and copper left in the slag.

Slags from the Atasu settlements of Central Kazakhstan (Ak-Moustapha, Atasu, Myrzhik) entirely correspond to these characteristics. They were also connected with the quartz rocks, and in slag from the Myrzhik settlement sandstone structures are recorded. Ore is presented too, mainly, by malachite, chrysocolla and azurite, and the part of secondary sulfides was obviously less than on the Transural sites. Possibly, it caused the more intensive oxidization of slag and higher loss of copper here. For this slag crystallization of delafossite needles[10] and cuprite dendrites are more characteristic. The latters formed both due to the crystallization from slag, and due to association of small prills of cuprite into dendrites. In some cases the cuprite formed round copper prills due to their oxidation. The red coloring of glass is more often here, thanks to a large amount of the small dissolved copper and cuprite[11]. In these samples it is well visible that copper was reduced directly from cuprite.

It is not excluded that a part of cuprite prills has a secondary character, and they were formed already in the settlement layers, as a result of filling of the pores. In particular it concerns the prills having the regular form or containing inclusions of chloride which is unstable at high temperatures (Tab. 11-44., an. 262.1, Fig. 11-45.). Copper has no noticeable impurity (Tab. 11-44., an. 262.a, c, Fig. 11-45.) and, judging from that the copper fills often cracks in slag, glass started solodifting at higher temperature than the melting point of copper.

Conclusions:

Thus, the mix of oxidized and sulfide ores from quartz rocks was used in the smelting. But the content of the oxidized ore was much higher than that of sulfide. The need to melt quartz rock led to rather intensive blasting and oxidizing smelting atmosphere, therefore we see the intensive oxidization and accompanying it high losses of copper in slag.

[10] They are also detected here by the SEM analysis (Tab. 11-44., an. 262, e, Fig. 11-45.).

[11] The content of the copper dissolved in glass is in some cases very high. So the analysis of glass by means of the SEM has revealed 18.15% copper, its impurity is even in magnetite crystallizing from slag (Tab. 11-44., an. d, 2, Fig. 11-45.).

To some extent on settlements of Central Kazakhstan it was possible to solve this problem, partly thanks to the construction of furnaces attached to wells where the blasting from the well resulted in more intensive formation of reducing gas, carbon monoxide, which was characteristic of Sintashta metallurgy. In the Southern Transurals the problem slightly decreased thanks to the more active use of secondary sulfides. But the problem remained everywhere.

It is difficult to tell how the high temperatures were reached. Solidification of delafossite occurs at the temperature of 1175-1200 ºC (Trofimov, Mikhailov 2002, fig. 2). Covellite melts at the temperature of 1127 °C, copper at 1084 °C, the melting point of cuprite is higher – 1232 °C. All these components are molten, therefore, the smelting was carried out at temperatures at least 1200-1300 ºC. But temperatures were obviously higher as the glass in some places started solodify before cuprite. The phase diagram of the system FeO-Al_2O_3+SiO_2-CaO for glass in slag of sample 262 from the settlements of Atasu constructed on the basis of SEM analyses (Tab. 11-44., An. 262.2) shows that the glass of this composition melts at the temperature about 1300 °C (Fig. 11-46.). It is possible to assume that because of the silicate composition a long time was necessary to complete the smelting. But then, in process of decrease in blasting intensity and smelting of components, copper sedimentation, the slag became very viscous, and the glass solidified quickly enough. X-ray diffraction analysis of slag from the Myrzhik settlement has revealed cristobalite; therefore the temperature of 1470 °C is not excluded. On the other hand, the molten magnetite has not been detected, and the temperatures were below 1530 °C. Proceeding from all this, the most probable temperature range for the majority of smelting operations is 1200-1400 ºC.

Here it is necessary to return to that problem which we have discussed on the basis of bulk chemical analyses of slag. It is the question of the highest losses of copper remained in the slag, comparable to the content of copper in malachite. Visually, on the basis of analysis under microscope, for all this series it is possible to speak about the losses within 7-50%. Therefore slag with high losses, in principle, can be considered as the raw materials which could be re-melted. However there is no slag demonstrating this re-melting in these series. Although below we will discuss other mineralogical groups, they are not typical for these sites. On the other hand, as we have seen, such intermediate smelting to produce cuprite was senseless: cuprite is a heat-resistant material; besides, silicate glass was formed whose melting required a temperature more than 1300 °C. Therefore the smelting was one-step process. The only possible explanation is that the amount of the barren rock turned into slag was insignificant. And the aspiration to form liquid slag was absent. The main components of the smelted malachite ($CuCO_3 \cdot Cu(OH)_2$), except for copper, were sublimated. Similar smelting is possible only in case of exploitation of very rich ores. These features are also reflected in slags of 2nd mineralogical group.

2nd mineralogical group

In the Alakul series only two samples of slag relate to the 2nd mineralogical group, which is characterized by smelting of ore from quartz rocks in the reducing conditions. These are samples 82 from the settlement of Ubagan II in the Tobol area and 89 from the settlement of Shandasha in the Dobarovsky area to the east of Orenburg. The reducing atmosphere in this case was provided, mainly, by smelting of secondary sulfides like covellite and chalcocite. There are many quartz grains and molten sulfide inclusions in the slag, and it is visible that copper was formed directly from this sulfide. The quantity of the molten sulfide is rather great, and the quantity of gangue is low. In slag from the Shandasha settlement small nuclei of olivine crystallization are also noted. The smelters also obviously did not aspire to form normal fayalite slag. The smelting was conducted with the molten sulfide. Copper losses in the form of the sulfide remained in slag, to a lesser extent in the form of copper and cuprite, are slightly lower here, but rather high too. This means, in principle, that key smelting parameters were close to above described, but, thanks to the smelting of sulfides, oxidization and such unreasonably high losses of metal were absent. Therefore it is not excluded that these slags reflect not a certain individual technological type, but a casual smelting of ore with another chemical composition.

1st mineralogical group

Typical for Sintashta slags of the 1st mineralogical group connected with smelting of ores from basic rocks are also rare in the Alakul series (Fig. 11-V.5,6; Fig. 11-VI..1-3): only sample 2021 from the Kupukhta settlement and sample 2025 from the settlement of Baytu. The microstructures of these slags differ.

In sample 2021 main inclusions are crystals of olivine. Many olivine crystals have a zonal structure. Their external part is lighter. Therefore it is not excluded that the center of crystals is more magnesian. This is possible at the use of ultrabasic serpentinized rock in the furnace charge as it took place in Sintashta metallurgy, however the analysis have not revealed the typical for these rocks chromite grains. Besides, most part of olivines has, nevertheless, one lighter color, it is probably fayaite. Magnetite is presented very well in the form of octahedra of rather large sizes. Particles of magnetite are formed, disintegrating from larger grains. Occasionally very small dendric skeletons of magnetite crystallizing from slag are present. Ore minerals in the sample are presented by grains of malachite, covellite and cuprite. In some instances a covellite border is fixed on edges of malachite. Thus, the mixing of ores of various sources did not take place, all ore types come from one source.

Thus, the ore mix from oxidized ore and secondary sulfides was used in the smelting. The nature of ore bearing rocks is unclear, however is not excluded that it were iron oxides. In any case, quartz inclusions in the slag have not been found. The smelting temperature was about 1200 ºC or some higher. It allowed to fayalite to be formed. However even covellite is not always molten. Cooling of the slag was rather slow, probably directly in the furnace, therefore the crystals of fayalite have polygonal forms.

Magnetite is better presented in sample 2025 where are, along with the small crystallizing skeletons, fine grains and accumulations of particles disintagrating from larger grain. It is remarkable that small and very rare chromite grains of are found in this sample. In some cases magnetite has a zonal structure: a lighter border. It is not excluded that the border is a rather pure magnetite, and inside the compound is more chromic. It is also remarkable there are no quartz grains in this sample. At the same time, cuprite is absent. A large copper globule surrounded with a sulfide border is found. Therefore it is not excluded that the ore here was from another source, mainly, from iron hydrooxides. Losses of copper are minimal, about 2-3%.

Thus, in both cases the mix of sulfide and oxidized ores from the rich in iron rocks was used in the smelting. It promoted the creation of reducing atmosphere and low viscosity of the slag. But in the sample from Kupukhta the atmosphere was a little more oxidized, and the rate of cooling was higher. As these samples occur from sites where the slags were smelted from ore in quartz rocks in the conditions of oxidizing atmosphere, it is hard to say, how purposefully this ore was selected for smelting and whether is it a continuation of the Sintashta tradition. It is impossible to say here about the purposeful smelting of typical for Sintashta ores from deposits in the ultrabasic serpentinized rocks. It is more probable that similar ore could get to the smelting casually, because of its limited presence on a deposit in quartz.

6th mineralogical group

One sample of slag from the settlement of Ubagan II in the Tobol area (No. 76) differs from all described samples. In its microstructure very porous light glass prevails in which several small prills of iron and in some places a small quantity of fayalite crystalls are present. Thus, the slag was formed in the reducing conditions and solidified very quickly. The smelting temperature was slightly higher than in the other Alakul slags as the iron prills of (possibly, formed from molten wüstite) have been found. It allows us to assume that the basic temperature limit was about 1300-1400 °C. The fast solodification of the slag happened probably because of its very acid composition, but low copper losses and the reducing atmosphere are unclear at such high temperatures. The slag is very close to the slag from Verkhnyaya Alabuga and Korshunovo I. Therefore it is more probable, the ore was mined in quartz rock, but the part of sulfides was high in it, which provided the reducing conditions. Therefore carefully (considering singularity of the sample and small quantity of components in the slag) it is possible to relate the slag to the intermediate mineralogical group 2-6. As we will see further, similar slag is characteristic also of Mezhovka culture.

Thus, the 6th mineralogical group is present in slag of the Alakul sites of the Transurals and Kazakhstan (Tab. 11-47.). Slags of the 1st and 2nd mineralogical groups, probably, are the sign of heritage of the Sintashta-Petrovka metallurgy, but most likely, their presence was caused by a chance. One sample related to the mineralogical group 2-6, probably, is the evidence of contacts with the Odino-Krokhalevka and Vishnyovka populations or with metallurgists of Mezhovka culture.

Smelting volumes

Unfortunately, unlike the Sintashta situation, it is impossible to calculate the volumes of charge by slag from sites around Atasu. However it is not excluded that a complex investigated on the Myrzhik settlement can clear this question. Here near the hearth with a diameter of 1.6 m two small pits with diameters of 0.3 and 0.4 m, and 0.15 and 0.2 m in depth have been found. One was filled with the fine-crushed ore. Probably, it is also the volume of one charging. The volume of these pits is respectively 3375 and 8000 cm^3. As the specific weight of carbonate ores (namely such were used on Atasu) can vary within 2.8-3.5 g/cm^3, volumes of charging could fluctuate in the limits of 10-24kg. It is much more than the case of the Sintashta sites. However, from the description it is not clearly, how fully these pits were filled. Besides, this calculation is made for a monolithic piece. Therefore we may reduce these volumes twice, to 5-12kg. As it has been already spoken, the ratio of volumes of ore to charcoal has to be 2:1 (Bamberger 1992, p. 157; Bamberger, Wincierz 1990, p. 123). Respectively, each smelting on the Atasu sites required 2.5-6kg charcoal. It approximately corresponds to the volume of 8400-20000 cm^3.[12] Therefore, the volume of furnaces had to fluctuate within 7375-28000 cm^3. If the height of the furnaces was 30-40cm, their minimal area fluctuated in the limits of 245-700cm^2, which corresponds to the diameter of 16-27cm. However it is necessary to take into account that a furnace cannot be filled densely. In this case air will not pass through it, and the furnace will not get warm. Therefore an admissible in this case diameter of the furnace is about 30-60cm. It, in general, corresponds to these constructions on the Atasu sites as in some instances their outlines are fixed by the external contour and do not take into consideration the thickness of walls and lining.

To produce this quantity of charcoal it is required 0.01-0.03 m^3 of wood, in condition of good technology (Agapov *et al.* 1989, p. 101, 102). It corresponds to 5-20kg wood[13].

It is hard to say, how many copper was produced as a result of one smelting on Atasu. Malachite contains 57.4% copper. Therefore purely theoretically it could be 2.5-6kg metal produced in one smelting. But the Atasu slags contain a lot of copper and cuprite, about 30-40%. Besides, the malachite used in the smelting was not ideally pure. There were also fragments of rock. Judging from dumps and ore storeges on the metallurgical complexes, the ore selected for the smelting contained 8-10% of copper. Therefore it seems to be quite probable that the final product weghted 0.2-1kg.

[12] Density of birch charcoal is 380 kg/m^3, of pine charcoal is 300 kg/m^3.
[13] Density of birch is 630 kg/m^3, of pines is 500 kg/m^3.

Fyodorovka metallurgy

Fyodorovka slags have been found only on four settlements: Ust-Kenetay in Central Kazakhstan, Pavlovka in Northern Kazakhstan, Ilyaska I and Graurtly in the Transurals. This situation does not surprise as single-layer Fyodorovka settlements almost do not known. Mezhovka materials from the settlements of Arkhangelskii Priisk II and Novo Bayramgulovo are close to this cultural group, although they take relatevely later chronological position, reflecting, more likely, the development of Fyodorovka tradition.

6th mineralogical group

The largest collection occurs from the settlement of Ust-Kenetay (19 samples: No. 228-246). The majority of the studied samples are characterized by rather weak olivine crystallization. As a rule, olivine is presented by either nuclei of crystallization, or small prisms and skeletons. Only in some samples larger, including, polygonal forms of olivine are revealed which as shows the SEM analysis is fayalite (Tab. 11-44.; Fig. 11-48.a). However in many cases the olivine crystallization took place poorly, and is visible only at large magnification (Fig. 11-48.b). It can be caused both by high speed of smelt cooling and absence of necessary for formation of fayalite components. The same situation is present in slag from Graurtly (No. 218) where olivine crystals are, practically, absent in the porous glass matrix of silicate composition.

The ore was connected with quartz rock. Quartz is presented by crushed grains of various sizes; only in one sample the structures in the form of the soldered granules are recorded that can point to the ore origin from copper sandstones. However, as a whole, it is not typical for the studied series.

Inclusions of iron oxides are present in the quartz. Possibly, the iron oxides were mostly connected with borders of quartz veins. Therefore a part of iron was introduced into the furnace charge together with the ore bearing quartz rock. At the same time, there is a ground to assume that in some cases when quantity of iron in rock was too little iron fluxes were applied which were taken from another place than the ore. It is demonstrated by rare inclusions of chromites, but these inclusions are absent in the samples with very high content of iron oxides and their addition to the charge was sensless.

Copper ore was the third source of iron in the furnace charge. The ore from the cementation zone was used in the smelting, which is specified by its very mixed compound: oxidized ores (malachite and cuprite), secondary sulfides (covellite and chalcocite), primary sulfides (chalcopyrite, occasionally bornite). And, the role of primary sulfides was rather great. The smelting conditions were reducing that was promoted by the presence of sulfur which captured a part of oxygen from the oxidized ore. It is impossible to exclude also a purposeful preparation of the furnace charge from both oxidized, and sulfide ores that considerably facilitated the smelting process, but strong proofs to it are absent.

As a result of chalcopyrite smelting, copper sulfides separated from iron sulfide. The last quickly enough oxidized into wüstite that lead to formation of prills of wüstite and its fused dendritic structures. In slag from Ust-Kenetay the wüstite contains small Si and Al impurities (Tab. 11-44.; Fig. 11-48.a). Especially many dendrites and particles of wüstite are present in slag from Pavlovka (No. 216), but it is extremely rare in slag from Graurtly (No. 218). Subsequently wüstite was reduced to iron which is present in some cases in the slag. However, a part of iron formed directly from magnetite particles. The last are presented by unmelted particles. The copper sulfides (including covellite and chalcocite) lost a part of sulfur and formed the isotropic copper sulfide replaced further by copper and cuprite. The following reactions of cuprite with carbon monoxide and sulfur resulted in the reduction of copper. This process completed rather fully as the content of cuprite in the slag is very insignificant. The reducing atmosphere is demonstrated also by the iron particles. In the slag from Graurtly there are prills having intermediate optical characteristics between copper and iron, probably an alloy of these metals.

The smelting temperature was in the interval of 1300-1400 °C, sometimes rising above. It can be concluded on the basis of the overheated cuprite forming rather regular prills, and on the basis of presence of prills and particles of iron with fused surface. Their formation from wüstite is most probable; therefore we cannot assume higher temperatures reached the melting points of iron. Especially as magnetite formed, as a rule, normal crystals or grains, and its partly fused dendrites are found in one sample only. The last can be explained by the formation from wüstite too. One more possible reason of the emergence of the molten iron is its carbonization.

The smelting was carried out, apparently, during a long time. In any case, all components are well smelted, and almost all copper separated from slag. The slag usually does not seem to be viscous that is confirmed by the separation of copper. At the same time, it is not quite clearly, why olivine crystallized badly. A similar situation is possible only in case of fast cooling or lack of necessary iron components.

4th mineralogical group

One slag sample from Pavlovka (No. 217) was smelted from the oxidized ore, mainly, malachite in quartz rocks. Quartz melted, forming silicate glass. The iron component was poorly presented, therefore fayalte was not formed. The glass is saturated with molten copper and cuprite particles.

Copper can be formed directly from malachite. Often the copper prills are surrounded with a cuprite border from which numerous deformed prills separate. Probably, temperatures only slightly exceeded the melting point of cuprite. In some instances the cuprite is partly dissolved, therefore more its small prills and copper prills formed around that strongly paints the glass. Larger prills of copper are rare. Probably, it separated from the slag. The part of these small prills was formed from molten malachite. Dissolved in the glass copper (seldom) and cuprite (more often) form a dense net of small dendrites. In some places the needles of delafossite are found. The large deformed molten grains of cuprite were formed from grains of some oxidized ore are revealed too.

Thus, the slag was very much oxidized and formed in the oxidizing conditions, at the temperature about 1200-1300 °C. The solidification of the slag happened quickly, owing to its silicate composition. Thus, the slag corresponds to the 4th mineralogical group, characteristic of the Alakul sites. But it is the only sample. In general, the 6th mineralogical group certainly dominates in the Fyodorovka series (Tab. 11-49.).

Mezhovka metallurgy

In spite of the fact that the Mezhovka culture of the Urals was a continuation of the Fyodorovka line of development, slag materials of the Mezhovka culture are described separately to show possible developments or change of the tradition.

In slag from Ilyaska I (No. 2217-2221, 2218-1, sample 2222 is limonite) and Novo Bayramgulovo (No. 2231) the components crystallized very badly: relatevely porous silicate glass dominates, in some places the crystallization did not take place at all (Fig. 11-VI.4). Sometimes very small nuclei of fayalite crystallization in the form of needles are present. In slag from Novo Bayramgulovo fayalite is slightly better presented, there are some small prismatic forms, but the general contents does not exceed 25% (Fig. 11-VII.1,2). Small magnetite rash is occasionally noted. In the slag of Ilyaska only rare inclusions are present: quartz grains and very small rare prills of copper and in rare cases iron. Some copper prills are much lighter, probably, they contain iron impurity. In slag from Novo Bayramgulovo the copper prills are completely absent, and the smelting of copper ore is demonstrated only by a small accumulation of delafossite needles ($CuFe_3O_2$) on the slag periphery (Fig. 11-VII.2). This mineral forms in the oxidizing conditions at low concentration of iron, at the temperature about 1200 ºC (Trofimov, Mikhailov 2002). But in general, the smelting atmosphere was obviously reducing. In this case, as well as with Fyodorovka metallurgy, the high speed of slag solidification against the background of insignificant copper losses is not fully clear too.

It has been cleared up by studies of a large series of slag from the settlement of Arkhangelskii Priisk II where the bulk chemical analyses have determined the ultra-acid composition providing the high viscosity (see above). As it has been already discussed, the combination of dense heavy slag with slag on the furnace lining is an interesting feature of the site. The last samples (No. 2352-2354, 2357, 2358) have an expressed zonal structure, and they partly consist of the ceramic mass. It is replaced by the slagged porous ceramic mass with rare inclusions: small nuclei of fayalite crystallization, small needle crystals of fayalite and small magnetite rash. Thus, it is ceramics subjected to thermal impact.

The proper slag mass of these slagged crucibles (Fig. 11-VII.5,6) does not essentially differ from the dense metallurgical slags (Fig. 11-VII.3,4) (No. 2420-2422, 2424-2431, 2436, 2440, 2442). It is presented, mainly, by porous slag glass in which fayalite crystallization in the form of small nuclei, needles and small long prisms took place only in some places. In some cases there are groups of needle crystals oriented in different directions that specify the different directions of cooling. Occasionally there is magnetite in the form of thin rash, small skeletons, dendrites and octahedra crystallized from the liquid slag. Sometimes on edge of magnetite crystals there is a border from wüstite that is an indication of the reducing atmosphere. It is very indicative that the wüstite was not molten, and even its surface is not fused. Therefore, from the moment of its formation the temperature did not rise above 1360 °C.

In both groups of slag one sample is present (No. 2431, 2354), in which the fayalite crystallized well (50-60%), it is presented by long prismatic, needle and skeletal forms, but there are also polygonal crystals (Fig. 11-VII.3,6). In sample 2354 zonal olivine crystals with lighter external part have been detected. Most likely, this part has the fayalite composition, and the internal part is more magnesian as we have seen it in similar Sintashta microstructures. Correspondently, it is not excluded that these samples were smelted from the ore in the ultrabasic or basic rocks.

All this indicates two things: there was obviously deficiency in iron component in the furnace charge, the slag soidified quickly enough, and was cooled from different directions, i.e., most likely, in the furnace, this slag was not tapped. In the last cases the fayalite would hardly crystallize and if small needles were formed, they would be oriented in a single direction: from top to down.

There are some prills of copper, but they are very small, and their general contents usually vary from 0.1 to 1%, though the chemical analyses show also higher contents. In three samples (2422, 2424, 2436) accumulations of copper prills have been found which kept a shape of a molten ore body. As molten malachite at first turns into cuprite that reduces then into copper, thus this form hardly would remain. It is more probable that some secondary sulfide was molten.

In general, cuprite in this slag is not, practically, presented. Single cuprite borders around the copper prills could be formed later. It also indicates the reducing smelting atmosphere. The same is confirmed also by single iron prills in some samples which were reduced either from the molten particles of wüstite or melted after their carburizing.

In some samples quartz grains are recorded. Ore inclusions in them are not found, but the connection of ore with quartz rocks is rather reliably demonstrated by the chemical composition (Tab. 11-39.). Ore minerals, in general, are not almost revealed, except for sulfides like the chalcocite forming occasionally small prills, a border round copper and filling a crack in glass in one case.

Thus, the limits of smelting temperature were between the melting points of fayalite and wüstite. The phase diagram of the system FeO-Al_2O_3+SiO_2-CaO (Fig. 11-50.) for wustite from slag of the Ust-Kenetay settlements made on the basis of SEM analysis, and for three slags and three slagged crucibles of the discussed Mezhovka settlements, made on the basis of the bulk chemical analysis (Tab. 11-39., Tab. 11-44.) demonstrates the temperature at which the substance of this compositions melts. In principle, similar calculations for the bulk chemical composition are not quite correct as there are many unfused inclusions in slags. However the mineralogical analysis has shown their sufficient homogeneity and lack of large particles of quartz or other refractory inclusions.

It is necessary to make one more reservation here. Judging from the chemical composition, two samples of slagged crucible (2467, 2477) contain less proper metallurgical slag (the lowest contents of oxides of iron and copper), and one sample (2451) is presented by just the slag mass. As a result, all the slags lie in the field of melting temperatures about 1200-1300 ˚C (samples 2231, 2422, 2429) while the melting temperature of the crucible mass is within 1400-1500 ˚C. This means that the crucibles could stand very high temperatures, and their slagging occurred already due to contacts with proper metallurgical slag and molten metal or when the temperature was about 1400 ˚C. The molten wüstite of the sample from Ust-Kenetay (236) melts at a temperature about 1360-1370 ˚C.

As, despite the ultra-acid composition of the Mezhovka slag, the all copper separated from it, its viscosity during almost whole smelting was insignificant; therefore the temperature of the melt was higher. But the wüstite present in this slag is not molten; therefore, the temperature did not exceed its melting point. Respectively, the most probable temperature range of the smelting was 1200-1360 ˚C. The high temperatures were promoted not by the small volumes of the furnace only, but also by the exothermic reaction of combustion of sulfur. After the fusion and reduction of ore, the sulfur and considerable part of charcoal burned out, that lead to decrease in temperature and fast solidification of slag at the temperature about 1100-1200 ˚C, that is specified also by the fayalite crystallization.

Conclusions on chemism and microstructure of the slag

The described slag is rather paradoxical. Having the acid composition it shows absolutely insignificant losses of copper. All ore components of the furnace charge were smelted completely, and all reduced copper separated successfully. It was possible only at the high temperatures reducing the viscosity. But for this purpose it was needed to intensify blasting that had to result in formation of the oxidizing conditions, but they did not occur. Therefore, either it can be explained by some specific design of the furnace, but it is more probable, by the use of secondary sulfides in the smelting that allowed creating the reducing atmosphere at the high temperature. Besides, their presence reduced the slag viscosity. But after they melted and reduced into copper, slag solidified almost promptly.

The most part of the slag was smelted from ore in quartz rocks in the reducing conditions. For Northern Eurasia it is the 2nd mineralogical group, but the active use of sulfide ores brings together this slag with the 6th mineralogical group. Nevertheless, the secondary sulfides dominated in this smelting. Therefore it is more correct to speak about the intermediate group 2-6. At the same time, in both groups distinguished by the form, there is slag (No. 2431, 2354) in which the part of iron component was high and which on formal signs can be related to slag of the 1st mineralogical group. Probably slags from Ilyaska I and Novo Bayramgulovo belong to the same group 2-6 (Tab. 11-51.). In principle, also the Mezhovka slags from Yukalekulevo and Novokizganovo in Bashkiria are close to them, but there chalcopyrite was more actively used in the smelting that has made it possible to relate all these samples to the 6th mineralogical group. Thus, it is possible to speak about the smelting of sulfide ores from quartz rocks, as about the Mezhovka technological standard which was going back to Fyodorovka metallurgy. Distinctions are seen only in the extent of use of the primary sulfides like chalcopyrite or bornite, but now it is impossible to judge about the value of these distinctions because of the limitated analzysed series. The presence in both Fyodorovka and Mezhovka series of single samples of other groups is extremely limited, and is not out framework of normal deviations.

Just the smelting of sulfides made possible to keep the redusing atmosphere at higher temperatures than it was practiced in the Sintashta time. It had a consequence in the slagging of the furnace lining, not characteristic of Sintashta. It brings us to one more problem, namely, the use of crucibles found on the Mezhovka sites. The majority of these crucibles are very shallow that would by unfunctional for copper melting. But it was also impossible to place ore with charcoal into them. Therefore the studies of slagged parts of the crucibles were carried out too.

As it follows from the chemical analysis, a basic difference in the compositions of the slagged crucibles and the proper slag is absent (Tab. 11-39., Tab. 11-40.). The analysis under microscope have revealed the quite expected zonal structure, with ceramic mass, in whose black upper part the rare copper inclusions are present, and the proper slagged part in which there are areas with crystallization of small fayalite, dendrites and octahedral of magnetite though in general the crystallization is extremely poor here. In the slagged part of one sample (No. 2455) there are slightly fused disintegrating grains of some iron oxide from which fused octahedra of magnetite. Therefore, in the crucible there was an iron oxide which was hardly connected with slagged part of the crucible and furthermore, with the molten copper. Probably, the crucibles were used for ore smelting. In the same sample very small needles of delafossite, copper and iron oxide, are found which forms in the oxidizing conditions. This mineral usually appears in slags smelted from ore. At last, there are very small prills of copper in all these slags, usually in the extremely small quantity, sometimes they form small accumulations. Only in sample 2455 theit quantity is slightly more, some parts of glass have slightly red color that points to abundance of very small copper prills painting the glass here but not distinguishable. Thus, the slagged parts of crucibles contain as same set of minerals as the usual metallurgical slags that allows us to assume that, at least, a part of these crucibles was used for ore smelting.

This assumption has been checked by means of the spectral analysis (Tab. 11-52.). At the processing of data of spectral analysis at the first stage an attempt to see chemical distinctions between slags of different type was done. The average value of each chemical element for each group of slag was calculated (Tab. 11-53.). And, it is necessary to remember about a conditional character of this procedure as if any element was >1, for example, I was accepted to use the value 1. This procedure for comparison of slags of different groups is senseless as in case of presence in any of slag groups (for example, in slagged lining) of two slag groups of different either origins or technologies with the polar contents of individual elements, their average value can correspond to the average value of elements in other slag group. Analysing the slagged lining and slagged crucible we tried to select the slag mass, instead of the ceramic component. But it is badly controlled process as the ceramic component could get to the slag mass in the smelting. But the same is also true in case of the usual dense slag because the molten furnace lining could get into it, and it could affect the trace-element composition. Therefore this procedure was necessary for an assessment of possibility of changing trace-element composition influenced by this factor.

The analysis of this table shows that in slag in comparison with ceramic masses there are no basic changes in the following elements: Ni, Cr, Mn, V, Ti, As, Sn, Sb. The contents of Co in slag are slightly higher. The contents of Cu, Zn, Pb, Ag, and Ba increase more considerably (on a half-order or much). If to compare the groups of slag among themselves it is well visible that in the dense slags the contents of Cu, Zn, Pb, and Ag are higher than in the slags from crucibles and furnace lining. Therefore it is not excluded that the decrease in the part of these elements was caused the material of lining. In slags from crucibles the contents of Ti is slightly higher, but within the normal deviations. However the content of Sb decreases, being closer to its content in the ceramic slags. But there are no significant deviations in this group of slag, and it is impossible to say that the furnace lining took very active part in their formation. In slags on the lining the contents of Ni, Co, and As decrease (approximately two times less). But there are no basic deviations too that allows to apply statistical procedures to all these slags as if the lining even made impact on the chemical composition of slags, it was rather evenly concerning each separately taken group.

Then these regularities have been confirmed by the frequency diagrams and diagrams of the ratio of trace-elements couples. The majority of trace-elements of the crucible slags is in the same fields, as those of the slag formed on the lining. Therefore it was not a slagged crucible for metal melting; this slag was smelted from ore too. Here this result is illustrated only by the diagram Pb-Zn as these elements reflect above all the ore slag, instead of compositions of the clay mass (Fig. 11-54.). We see that all samples are situated along one straight line. In the ore slag the contents of these trace-elements is higher, and in the ceramic slag they are minimal. The contents of these trace elements increase in the crucible slag, but in slagged lining their contents are average, between the contents in the ceramic slag and metallurgical slag. It is a quite expected picture which shows a drift of chemical compositions of the crucible slag from compositions of ceramic masses to compositions of ore slag. Respectively, at least, a part of these crucibles was used for ore smelting, in spite of the seeming senselessness of this. The aspiration to protect the furnace bottom from impact of copper and slag was the most probable cause of the placing crucibles into the furnace. In these smeltings we fix high temperatures and probably a rather long duration of smelting (well separated copper and completely smelted components of the furnace charge) that led to intensive slagging of the furnace walls. But if the furnace lining should to be removed only sometimes, the slagging of the furnace bottom was more negative as at the extraction of copper it was necessary to chop off the slag from the bottom that would lead to destruction of the furnace bottom.

Slag of Andronovo sites

A part of the slag occurs from the sites having Alakul, Fyodorovka or Cherkaskul layers. On these sites several mineralogical groups of slag have been distinguished.

1st mineralogical group

Three samples from the Korkino settlement (No. 815, 818, 820) belong to the 1st mineralogical group connected with smelting ore from the ultrabasic rocks. In the slag the olivine crystallized very well in the form of large polygonal crystals between which small long prismatic and needle crystals grow. Often the external border of crystals is lighter. Possibly, this part contains more iron oxide, and the internal part is more magnesian. An exception is sample 815 in which fayalite is presented by small needle crystals.

There are chromite grains of the average sizes, in one case with a thick magnetite border. In some instances they together with small copper particles are concluded in grains of serpentine. Often around such melting grains the olivine crystals grow. Magnetite is presented by small rare rash.

Ore minerals are presented by small prills or molten inclusions of copper sulfide (the latter fill also the cracks in glass matrix), rare fine grains of cuprite, occasionally by malachite. Copper losses in the slag (in the form of small rare prills) are extremely insignificant and do not exceed 1%.

In this case ore (secondary sulfides with impurity of oxidized minerals) from the ultrabasic serpentinized rocks was smelted. The smelting temperature was in the interval of 1200-1300 °C. The sulfides promoted the reducing smelting atmosphere. It is not excluded that the use of furnaces attached to wells was another reason of this atmosphere. The slags cooled slowly, in the furnace. The smelting parameters are identical to those in Sintashta.

2nd mineralogical group

Only several samples belong to this mineralogical group: sample 81 from Yazyovo III, sample 32 from Kipel, samples 268 and 816 from Korkino in the Transurals and sample 266 from Ak-Maya in Central Kasakhstan.

Ore minerals (malachite, grains of chalcocite, chrysocolla, occasionally small inclusions of chalcopyrite) in slag of this group are obviously connected with quartz which is presented by small, in some cases fused grains. There are small inclusions of copper and ore pieces in quartz.

Secondary sulfide (chalcocite) is more often presented by prills or fused filling of cracks. In many cases this molten inclusions are replaced with molten cuprite. The latter also replaces the malachite grains, forms the molten prills or fills the cracks in glass matrix. But the quantity of cuprite is insignificant. Prills of copper are slightly better presented, but they are usualy small and their quantity is insignificant. The largest have in some cases a sulphidic border replaced by cuprite. In some places the accumulations of small copper prills are present which unite in larger copper globules (probably these large inclusions then settle down). Occasionally some parts of the glass matrix are tinted with red by many small dissolved copper and cuprite prills. Some particles of cuprite are not molten, but not so often.

The number of copper inclusions is higher than the number of cuprite inclusions. The smelting atmosphere was, mainly, moderately oxidizing and reducing. The last is emphasized by that occasionally there are in the slag also rare small particles of reduced iron. Iron is also recorded in some grains of magnetite.

The quantity of magnetite is usually insignificant; slag is saturated with small skeletons of magnetite in sample 268 from Korkino only. In the others magnetite is presented by small octahedra, rash and very small skeletons and dendrites crystallizing from the liquid slag.

Fayalite crystallized very poorly and not in all samples, probably it was caused by the lack of both iron components and the steady reducing atmosphere. The most part of slag is presented by silicate glass with fayalite crystalls in the form of small nuclei, needles, and only in slag from the Kipel settlement fayalite is present in the form of long skeletal prisms, both large and small, between which its needle structures grow.

Thus, ore from quartz rocks was smeled, and the slag has rather acid composition. Possibly, attempts to change this situation by fluxes were not practiced. Both oxidized and secondary sulfide ores were used. The part of sulfides was not too great, but, thanks to them, it was possible to reach the reducing atmosphere and to avoid high losses of copper in the form of cuprite. But after the weakening of blasting the slag solidified very quickly. The most probable temperature range is 1200-1300 ºC.

6th mineralogical group

A small group of the slag marking the active use of chalcopyrite in the smelting is also revealed. In this case there is no sample that would mark the smelting of pure chalcopyrite without impurity of the oxidized ore, the part of the chalcopyrite in individual slags differs, but basing on formal signs this slag belongs nevertheless to this group. These are the samples 269 and 270 from the Korkino settlement in the Transurals and sample 265 from the Ak-Maya settlement in Central Kazakhstan.

As it has been already told, these slags demonstrate that the pure chalcopyrite was not used in the smelting. The ore originated from the zone of cementation where chalcopyrite was presented together with the oxidized minerals. It is well visible from the analysis of a piece of slagged ore bearing rock (sample 270) where rare particles of copper, cuprite, chrysocolla, chalcopyrite, pyrite, iron and magnetite are present in the silicate rock. In slag samples individual grains of quartz have been identified; therefore it is not excluded that quartz was the gangue. In slag from Korkino one small chromite grain in the magnetite border is noted, but it is not a ground to relate this slag to the 1st mineralogical group because of its singularity.

The ore minerals in slag of Korkino (in slag from Ak-Maya ore inclusions are absent) are presented by small grains of chrysocolla, malachite, cuprite, association of malachite and covellite and small grains of chalcopyrite. The secondary sulfides are present in the form of molten inclusions; chrysocolla is also molten on the edges of grains. There is molten cuprite that was formed due to oxidation of molten copper sulfide. Cuprite was formed also from the molten chrysocolla, but in some cases it has been found that copper formed directly from the ore. The presence of the sulfide minerals provided the reducing atmosphere. This reducing atmosphere is confirmed also by the presence of some particles of the reduced iron.

There are many fused grains, prills and dendrites of wüstite of the large sizes. Often they form lattice structures. Probably they were formed at smelting of the primary sulfide, chalcopyrite. At the same time it is often noticeable that these dendrites are formed also at separation of prills from large fused grains of wustite.

Fayalite in the slag from Ak-Maya crystallized well. It is presented by large crystals and prisms between which needles, small skeletons and other structures grow.

Viscosity of the slag was low as it was obviously of the basic composition; as a result, the metal losses were absolutely insignificant: some very small particles of copper have been revealed.

Thus, a natural mix of the sulfide (including chalcopyrite) and oxidized ores from deposits in quartz rocks was used in the smelting. Temperatures reached in the course of smelting, thanks to exothermic reaction of combustion of sulfur, were rather high. Judging from the molten wüstite, they varied in the interval of 1200-1400 °C. The good presence of sulfides provided more reducing atmosphere, than that in the slag of 2nd mineralogical group. Some features of microstructures were caused also by the smelting of chalcopyrite. Therefore in this case the relation of this slag to 2nd mineralogical group is possible. Its inclusion into the 6th mineralogical group has been based on the formal signs only.

As we see, slag of the 2nd mineralogical group prevails in this group of sites (Tab. 11-55.). Its part is 46%, but as this mineralogical group was formed due to the reducing smelting atmosphere cause by impurity of secondary sulfides, and also taking into account the above stipulated possibility of its association with slag of the 6th group, the total part of this slag in the sampling is 73%. Other slag is presented by the 1st mineralogical group, characteristic of the Sintashta sites.

In principle, for the Transural sites (Korkino, Yazyovo) slag the relation of this slag to the Alakul time is most probable.

Final Bronze Age

Within this time the earliest culture is Sargari, being formed in the 14th century BC, and afterwards (since 14th /13th century BC) related cultures arose, coexisting with it: Begazi-Dandybay, Karasuk and Irmen (Grigoriev 2002, p. 283, 287, 288). The Final Bronze Age differs by a significant number of massive metal artifacts pointing to large volumes of production.

Taking into account the scarcity of used slag sources, it is very difficult to tell something certain about the following development of metallurgical production during this period, especially as historical and cultural processes of this time are not quite obvious for the Altai region too. In the steppe zone during this period there was a certain cultural leveling connected with the formation of Cordoned Ware cultures (Mogilnikov 1976; Chernykh 1983). But if for Kazakhstan the steppe Transurals the problem of these cultures formation is rather simple, they were connected, above all, with Alakul culture (Grigoriev 2000b, p. 399) in the east, where the Alakul sites are presented extremely poorly, there are problems. It is not obvious that the contemporary sites in the Altai should be considered as Sargari, instead of the Trushnikovo type suggested by S.S. Chernikov (1960). The part of the Fyodorovka component in their formation was obviously higher. Unfortunately, the presence of Fyodorovka cordoned ceramics often confuses researchers. So, excavations of the settlement of Sovietsky Put'-1 have revealed Fyodorovka and Sargari ware which were not divided stratigraphically and planigraphically (Sitnikov 1998, p. 71). But, as a rule, Sargari layers on multilayered setlements can be distinguished extremely clearly. In our opinion, the 5th group of Sargari ceramics of this settlement belongs, apparently, to Fyodorovka culture. Just the presence of cordoned ware in this complex made the impression that the layers are not stratigraphically divided. Nevertheless, all these cultural types are important components of the EAMP, and may be considered in this framework.

However the situation becomes complicated with the appearance of Begazi-Dandybay and Irmen ceramics on these sites, and their ratio with Sargari is also a serious problem. Therefore many components could have impact on specifics of production during the Final Bronze Age: Alakul, Fyodorovka, Sargari, Irmen and Begazi-Dandybay. In addition to this, there could be the technological traditions caused by interaction of these components. Taking into account possible local specifics connected with specifics of ore base, the problem becomes simply unsoluble at this stage that extremely annoyingly against the background hat the east of the Euroasian Metallurgical Province, apparently, had huge impact on the subsequent development of metallurgical production.

Unfortunately, slags of this time occur only from rare sites. In Central Kazakhstan it is the Sargari settlements of Kafarka, Telmana XVI and Sargari, and also the Kent settlement of the Dongal type, in the Altai it is the settlement of Kalinovka II.

However this scarcity of sources reflects only the limied character of the sampling, instead of a true state of metallurgical production. On many settlements of the Altai with Sargari layer (Sovietsky Put'-1, Chekanovsky Log-I, Gilevo-II, Novoshulbinskoye, Rublevo VI) metallurgical slags have been found that specifies that during this period the Altai was an important mining and metallurgical center. On the Novoshulbinskoye settlement 115 kg slag, 4.5 kg ore and ingots have been revealed, and on the settlement of Sovietsky Put'-1 there was 100 kg slag, ore, and bronze prills and small ingots (Sitnikov 2006, p. 150; Panin *et al.* 2006, p. 107-109). It indicates quite large volumes of production.

Researchers suppose that the oxidized ores were smelted. On the settlement of Sovietsky Put'-1 the ore is presented by oxidized samples: malachite and azurite, and in one case covellite.The gangue includes many iron oxides: limonite, goethite, and hematite (Sitnikov 2006, p. 151, 152). Slag from the settlement of Rublevo VI is presented by vitreous flat cakes with metal inclusions, with flat top and the convex lower part on which impressions of structure either furnace bottom or melting bowl are fixed (Panin *et al.* 2006, p. 109). It follows from this that the ore was smelted directly in the furnace without tapping of slag. Charcoal was used, but also bones, which is reconstructed on presence of phosphorus in bronze objects and fragments of burnt bones found on all settlements (Sitnikov 2006, p. 153).

Analyses of other slags of this epoch do not contradict to this.

Form of slag

From the settlement of Kalinovka II two samples (No. 793,794) have been analyzed, presented by shapeless molten and porous slag. A sample from the Kafarka settlement (No. 219) is presented by the large shapeless piece consisting of quartz in slag. Slag from the settlement of Kent is gray heavy shapeless and porous (sample 757); one its surface is flat, the second s tuberous; pores are present on all surfaces. On the settlements of

Telmana XVI (sample 49) and Sargari (sample 44) large heavy and porous slag flat cakes have been found that points to smaller viscosity of this slag. Thus, during this period the both main types of slag are presented (Tab. 11-56.); it is possible to raise a question of prevalence of heavy shapeless slags, but the quantity of materials is not enough.

Chemical and X-ray diffraction analysis

Chemical analysis of slag has been done only for the settlement of Sargari (Tab. 11-37.). In the slag the silicate component sharply prevails over iron oxides, there is 6.12% calcium oxide; therefore additions of bones as a flux are not excluded, but iron oxide was hardly used as a flux. All this caused the viscosity of the slag that resulted in the high content of copper in slag (14.4%). Smelting temperatures were, probably, very high as cristobalite is noted in the slag (Tab. 11-43.).

Mineralogy of slag

1st mineralogical group

A single Final Bronze Age sample from the settlement of Telmana XVI (No. 49) related to the 1st mineralogical group was connected with smelting ore from basic rocks. Slag is oversaturated with octahedra of magnetite of various sizes which were formed from the larger magnetite grains. In some places there are accumulations of very large skeletons and unfused dendrites of magnetite.

It caused large losses of metal in the form of copper prills, very large in some cases. Often these prills are deformed by magnetite. A lot of copper is dissolved in the glass, tinting it practically everywhere. Copper was directly reduced from secondary sulfides. Some sulfide inclusions are large and surrounded with copper. There are also sulfide inclusions in the copper prills. Occasionally cuprite is present in the same prills as the copper. There are also unfused particles of cuprite, but it is rare.

Conclusions:

Thus, secondary sulfides in the basic rocks were used. Temperature of smelting was within 1200-1300 ºC. The atmosphere was moderately oxidizing and reducing, the slag was viscous because of a large quantity of magnetite.

2nd mineralogical group

The 2nd group is connected with smelting of ore from quartz rocks. The sample from the Kafarka settlement (No. 219) is saturated with quartz. Often its melting cracked grains are almost indistinguishable in the glass matrix. Small crystallization of nuclei of magnetite and fayalite is occasionally noticeable. Ore inclusions are absent, only one small grain of copper is revealed.

A sample from the settlement of Sargari (No. 44) differs slightly by the better crystallization of components. The silicate glass is very porous. On its background the cracked grains of quartz are poorly distinguishable. There are many fayalite crystalls, but they are very small needles, which are present not everywhere. Accumulations of small octahedra of magnetite have been occasionally identified.

Melted inclusions of covellite, chalcocite and copper are present, sometimes malachite and chrysocolla are replaced with copper and cuprite, and the cuprite is partly fused. There are numerous associations of sulfide, cuprite, malachite, and covellite. It reflects a range of the ore arriving in melting, and, these ores are present on a field together, their presence at furnace charge isn't result of purposeful mixing. Copper from this structure is restored at once.

Conclusions:

Thus, chrysocolla and malachite with impurity of covellite and chalcocite in quartz rocks were the main ores. Judging from the fused cuprite, the temperature was about 1300 ºC, but it is not excluded that it could be higher as the surface of quartz grains is strongly fused. Solidification after reduction of blasting happened quickly because of the silicate composition. Copper losses are large, up to 14%. As it is follows from the chemical analysis, iron fluxes were not used, but the use of bones is not excluded. Therefore, the reducing atmosphere was provided, mainly, by the use of mix of sulfide and oxidized ores.

4th mineralogical group

Samples of the 4th group are revealed on the settlements of Kent (No. 757) and Kalinovka II (No. 793, Fig. 11-VI..5,6). The gangue was quartz in which inclusions of malachite (occasionally accompanied in the slag from Kalinovka by chalcocite) or iron oxide (magnetite) are present. The latter in the slag from Kalinovka is present not often, but it is very typical for the slag from Kent. And, magnetite is presented by octahedra, more rare by dendrites and skeletons crystallized from the molten slag. Grains of melting malachite have been found, which is dissolved in the glass and turns into copper and cuprite. Small prills of copper and cuprite tint the glass. Needles of delafossite have been also identified. Only in some places of the slag from Kalinovka there are needle crystals of olivine.

Conclusions:

Oxidized ore in quartz rocks was smelted, to a lesser extent the secondary sulfides. The smelting temperature was, at least, 1200-1300 ºC, which is demonstrated by molten chalcocite and cuprite, and crystallization of delafossite. The smelting atmosphere was oxidizing. It is difficult to judge about the rate of cooling as the weak crystallization could be caused also by the acid composition of slag.

Thus, although the number of the analyzed slag of the Final Bronze Age is small, the slags have the common features: they were smelted from ores in quartz rocks. It was usually the oxidized ore, but sometimes secondary sulfides were used together with it, and due to this the slag was not oxidized so intensively, and it caused the difference in mineralogical groups (Tab. 11-57.). As a whole, it was the preservation of Alakul tendencies in the metallurgical production which can be confirmed also by the preservation of Alakul types of smelting furnaces.

Bronze Age slags without clear cultural affiliation

A part of samples was found either on the surface or on settlements where layers of the all periods of the Bronze Age are present. Despite this vagueness, some samples were interesting.

1st mineralogical group

Two samples (No. 315, 316) from Chisty Yar in the Irtysh Basin, Semipalatinsk area, found by V. Kamenskogii in 1910 are especially remarkable. They are visually similar to Sintashta slags. It has been confirmed also by study of their microstructure.

The ore was from the ultrabasic rock that is marked by inclusions in the slag of chromites and serpentines although there are quartz grains too. Grains of chromite are sometimes edged with the magnetite border.

More often magnetite is presented by small nuclei of crystallization and dendrites. The basic ores were malachite and secondary sulfides whose prills have been found in the glass matrix. The most frequent inclusion is olivine, forming polygonal, prismatic and needle crystals. Occasionally prills of copper are present. Parameters of these slags are identical to those of Sintashta; therefore it is possible to speak also about identical technology.

2nd mineralogical group

Some samples have been related to the 2nd mineralogical group. These are pieces of the roasted sulfide ore (chalcocite and bornite) with quartz inclusions (Atamanovka V, sample 706, Kamyshnoye II, sample 80, Stepnyak). There is also a sample of slag smelted from this ore (Kamyshnoye II, sample 70). The slag is presented, mainly, by a piece of secondary sulfide (grains and molten inclusions in cracks) replaced with copper. Small inclusions of this sulfide are present in copper. Three fine grains of malachite have been identified. But ones smelted, mainly, covellite and chalcocite. In one small area of the sample olivine in the form of small long prismatic crystals is found. Iron oxides are present in rock, but can be formed also from bornite. Temperatures were insignificant, and could reach 1100-1200 ºC. Cooling of the slag happened quickly enough. Partly it was caused by rather low temperatures.

In principle, two samples from the Akimbek settlement belong to this group although they show some differences caused by smelting of malachite from quartz rock. Fayalite practically did not crystallized; there is a lot of magnetite presented by large not melted crystals (octahedra, skeletons, more rare dendrites). Between them very small, hardly noticeable crystallization of magnetite dendrites is fixed. Occasionally there are larger disinagrating grains consisting of separate octahedra. In addition to this, quartz grains with ore inclusions are fixed. Many malachite and cuprite inclusions are also found in slag glass. Fusion of cuprite grains is well fixed, as a result it started filling cracks. There are a lot of copper prills. In some instances copper also fills the cracks. Fluxes were not used at least the iron fluxes. Temperature could reach 1300 ºC. The slag solidified quickly that did not allow fayalite crystals to be formed. The smelting was not too long as the ore inclusions were badly smelted, and there is a lot of copper, cuprite and ore in the slag. Losses of metal are rather great.

6th mineralogical group

Some samples were smelted from chalcopyrite in quartz rocks: slag from Novonikolskoye (No. 46) in Northern Kazakhstan, Kara-Tyube (No. 267) in Central Kazakhstan and from the tin-ore mine Eastern Koinda (No. 1001-1007) in Eastern Kazakhstan. The last samples are remarkable because they testify the ore smelting near mines, but, in this case, the smelting of tin ores.

The chemical analysis of a sample from Novonikolskoye (Tab. 11-37.) shows insignificant presence of copper, 10.39% of calcium oxide that may be a sign of the use of fluxes, and a sharp prevalence of iron oxide over silicon oxide. As a result, the coefficient of basicity calculated for this slag is 1.78, i.e., the slag belongs to the basic group that allows to all components to crystallize well.

Nevertheless, fayalite crystallized in different samples very unevenly. The fayalite is presented by needles of various sizes, short prisms, rarer by large prismatic and polygonal crystals. Therefore it is possible to assume a rather fast cooling of the slag because of some reason.

Quartz was the gangue. There is a lot of it in slag and it associates with ore minerals. Chromite is revealed in one sample. But its quantity is small.

Magnetite is a rare inclusion. It is presented by octahedra and small dendrites and skeletons crystallizing from the slag. Transition of magnetite into wüstite has been found, and in these cases its surface is fused. There are many wüstite inclusions. It forms the large fused dendrites or fused lattice structures. Sometimes molten copper sulfide is observed round such structures. Such structures could not crystallize from slag or be formed from grains of an iron mineral. Their combination in some cases with sulfides indicates the smelting of chalcopyrite when it disintagrates into copper and iron sulfides; the copper sulfide runs out, and the iron sulfide oxidizes, turning into wüstite and forming the lattice and then the dendritic structures. The formation of similar dendrites of wüstite took place before the crystallization of fayalite. Sometimes the copper sulfide turns into cuprite which is presented by grains, molten inclusions and prills. However the presence of the molten cuprite is not so much an evidence of high temperatures, as the evidence of oxidation of the molten copper sulfide.

Similarly, the present small iron prills were for certain formed from wüstite prills. There are also small copper prills. Prills of yellowish metal are more typical, possibly a copper and iron alloy that is characteristic of the chalcopyrite smelting. Individual grains of malachite, cuprite and chrysocolla have been found, but the smelting was based, nevertheless, on the sulfide ores.

Metal losses in the slag were very insignificant. This is explained by that the calculated for the temperature of 1400 ºC viscosity of this slag (Novonikolskoye) is only 2.29 Pa·s.

Thus, ones smelted, mainly, the chalcopyrite from quartz rocks. As a result, there was a good balance of acid and basic oxides in the furnace charge, and the smelting atmosphere was reducing. The temperature of smelting was probably within 1300-1400 ºC. At some stage even higher temperatures (up to 1500 ºC) could be reached as cristobalite has been identified in the slag from Novonikolskoye (Tab. 11-43.).

It is not quite clear, why fayalite crystallized irregularly in all samples on this background. It is not excluded that the slag was partly tapped.

Conclusions:

In principle, this group of slag from multilayered settlements and casual finds can be hypothetically connected to certain cultural groups as some regularity in distribution of this slag have been found (Tab. 11-58., Tab. 11-59.). The presence of the 1st mineralogical group in this collection surprises as these samples have been found in the Irtysh Basin, and this mineralogical group is characteristic of Sintashta culture and, to a lesser extent, of the western Alakul complexes formed on the Sintashta base. The presence of this slag far in the east where both Sintashta and Alakul sites are absent is inexplicable. Distribution of slag of the 2nd mineralogical group, characteristic of the Alakul and Sargari sites, in the collections of settlements in the Transurals and Central Kazakhstan allows us to assume that metallurgical complexes of these settlements were connected with one of these traditions. Slag of the 6th mineralogical group is typical, above all, for the Fyodorovka sites. It is, practically, absent in the Alakul and Sargari complexes. The presence of this slag on the mine of Eastern Koinda in Eastern Kazakhstan is quite explainable: Alakul culture did not extend up to this eastern area, and the slag (and, probably, the tin mining here) belongs to Fyodorovka culture. Limited penetration of this tradition into Northern and Central Kazakhstan (Novonikolskoye, Kara-Tyube) is also fixed.

But in general this region is characterized by new features of the production. The part of smelting of ore in the basic rocks was insignificant (Tab. 11-59.). The preference was given to the ore from quartz rocks. And, the part of oxidized slags smelted from the oxidized ore is very small (17.3%). Secondary sulfides were actively used in the smelting. But the main innovation was the use of primary sulfides (usually mixed with the secondary sulfides), whose part in this sampling is 42.3%. But the territorial distribution of these features is remarkable.

A map of distribution of the mineralogical groups (Fig. 11-60.) shows some regularity which, however, demands a careful approach and discussion. In the previous Sintashta-Petrovka period the main slag group in the steppe Transurals was the 1st group that reflects the preference of ore from ultrabasic rocks. A gradual decrease in the part of this tradition from Sintashta to Petrovka is observed. Bisides, it is fixed in those Petrovka complexes which, apparently, coexisted with the late Sintashta. This tendency remains also during the Late Bronze Age. Single samples of slag of this group are present in the Orenburg region, Central and Eastern Kazakhstan. The rarity of these samples does not allow us to speak with confidence about the coming of this tradition from the steppe Transurals. But surely this tradition was accepted by the Alakul culture of the forest-steppe Transurals.

Besides, Sintashta metallurgists used the ore from quartz rocks which was smelted in the reducing conditions that gave slag of the 2nd mineralogical group. By the Petrovka time the part of this group decreases to 4.4% as the part of the 4th mineralogical group grows. The latter reflects smelting of oxidized ore in the oxidizing conditions. At the same time the 2nd mineralogical group is well presented in the Altai, in the Elunino complexes. For the Late Bronze Age, in general, the balance of these groups depended on preference of smelting either the oxidized ores or their mix with the sulfides. In this period in the Orenburg region and Kazakhstan there are only single samples of the 2nd mineralogical group. The most part of samples is found in the Andronovo complexes of the Tobol area. As it is accompanied also by the distribution of traditions of smelting ores from the ultrabasic rocks, we can raise a question of penetration of the Sintashta smelting tradition here, and just the proper Sintashta, not mediated by the Petrovka tradition.

Contrary to it, slags of the 4th mineralogical group are present as single samples everywhere, but they are noticeably presented in the Orenburg region and Central Kazakhstan. This group is not characteristic of the Sintashta sites. It is known only on the Petrovka sites or on the sites having both Sintashta and Petrovka layers. Therefore, it is possible to assume that either late Sintashta or Petrovka traditions of metallurgical production came to the Orenburg region and Central Kazakhstan.

The situation with the distribution of slag of the 6th mineralogical group reflecting the smelting of chalcopyrite and its mix with secondary sulfides and the group 2-6 close to it (they are not divided into separate groups on the map) is the most interesting. For the steppe Transurals in the Sintashta time this group is not typical. It is also absent in Elunino culture. But this type of smelting sharply dominates in the Vishnyovka-Odino-Krokhalevka and Fyodorovka complexes. This means that the roots of this type were in the east; and it spreaded in the western direction. Slags of this type do not known in the steppe Transurals. An exception is the Mezhovka settlements of Ilyaska and Novo Bayramgulovo located near the Ural foothills, and also the Arkhangelskii Priisk II on the steppe and forest-steppe border. This type is presented in Eastern and Central Kazakhstan and along the forest-steppe belt from the Transurals to Northern Kazakhstan that, in general, corresponds to the areas of localization of all above-mentioned cultural complexes. Therefore, it is most likely, if this slag comes from multilayered settlements, it belongs to these, above all, Fyodorovka complexes.

Thus, judging from the character of distribution of mineralogical groups of slag, both over the territory and over cultural groups, it is possible to assume the following dynamics of development of metallurgical production between the Transurals and Altai. Already at the Sintashta stage the Sintashta technological impulses spread to the north, to the forest-steppe Transurals. At the end of this stage and in the Petrovka period there was transformation of this tradition which is expressed in the refusal of smelting ores from the ultrabasic rocks and transition to smelting ore from quartz rocks in the oxidizing conditions. In this time we see expansion of the tradition to the south, to the Mugodzhar Hills, and to the east, to Central Kazakhstan. In parallel we see another concurrent process: the tradition of smelting chalcopyrite occurred in the east. It spread to the west, first of all, on the south of the forest zone and in the forest-steppe zone up to the Urals, and also to Central Kazakhstan. However in the Sargari time this tradition is not presented, domination of the former Alakul tradition of production here remains: mainly oxidized ores from quartz rocks are used in the smelting.

Slags and ores of the Karasuk-Irmen time

Possibly, with some delay relatively to the formation of Sargari culture the Karasuk, Irmen, Lugavskaya and Begazi-Dandybay cultures arose. It was a new phenomenon in the region, only partly connected with the former cultural traditions, influenced by migrations from some remote area of the Near East, or adjacent to the Near East (Chlenova 1972, p. 131-135; Grigoriev 1999, p. 284, 285; Grigoriev 2002, p. 291-294). Researchers see two components in the Begazi-Dandybay complex of the Altai: Near Eastern and Andronovo (Bobrov 2002, p. 12). The analysis of ceramics of the Irmen culture in the Kuznetsk Depression has also demonstrated two components: Korchazhka (Andronovo tradition) and an alien presented by ware with the round or flat bottom and the poor ornamentation (Kovalevskii 2002, p. 67). A.A. Kovalev has supposed that many of the West Iranian parallels to Karasuk metal suggested by N.L. Chlenova are dated to the late 3rd millennium BC. Therefore the migration happened earlier, during this period (Kovalev 2004). But it does not correspond to the late emergence of this complex of metal in Siberia.

The analysed materials connected with these complexes are absolutely insignificant. First of all, it is eight samples of the oxidized ore from the settlement of Chernaya Kurya VI which have been analyzed by means of spectral analysis. Excavators have revealed two layers on the settlement. The first of them is dated to the 8th century BC and contains late Irmen ceramics. The second belongs to the Early Iron Age and is dated to the 3rd -2nd centuries BC. The ore is connected, most likely, with the layer of the Final Bronze Age. Judging from the high concentration of lead and zinc, the ore was mined on polymetallic fields typical for the Altai.

At last, limited materials got to the collection from the settlements of Burla-3 and Kaygorodka-3 where the Cherkaskul, Begazi and the Central Asian wheel-made ware are found (Udodov 1991, 1994; Fedoruk 2008, p. 204). From the settlement of Kaygorodka-3 three samples of ore defined as pieces of azurite, one with malachite impurity have been taken. Two samples have been analysed by the spectral method, one of them has shown higher concentrations of polymetallic impurities. Probably, typical for the Altai ores from a polymetallic field was used, and relative purity of one of the studied samples is explained by its larger oxidation. From the settlement Burla-3 a slagged piece of copper, slagged yellow-green ceramics, and a piece of azurite have been analyzed.

These data are absolutely insufficient for conclusions about the nature of metallurgical production of the Final Bronze Age in the Altai, however there is a feeling that the oxidized minerals like malachite and azurite were actively used in the metallurgical production. Also the use of secondary sulfides, for example, fahl ores is not excluded, because they oxidize rather easily on the surface. In general, it is comparable with the tradition of the EAMP of the region which we have discussed above, but sharply differs from the Fyodorovka tradition with its active smelting of primary sulfide ores. A similar situation was apparently characteristic also for the Minusinsk Depression where on the ancient copper-smelting sites the oxidized ores have been found only (Sunchugashev 1975, p. 114). Many of these sites belong, of course, to the Early Iron Age, but a part do to the considered period. It is confirmed, for example, by finds near two metallurgical furnaces on the Poselshchik Mountain: drops of copper, fragments of casting moulds and tuyeres, slag, oxidized ore and ceramics of the Kamenny Log phase of Karasuk culture. The furnaces investigated here are very large: 2.35×0.58×0.35m and 2.85×1.25×0.9м. They are covered by massive granite plates. It has been supposed that the smelting in them was carried out in crucibles, and slag was poured out from a crucible into a small pit (Sunchugashev 1975, p. 85-89). If it was actually so, against the previous smelting of the Late Bronze Age directly in the furnaces, it is one more sign of a gap with the former technological tradition.

One more important aspect is connected with these mineralogical groups. We perfectly see that in comparison with the MBA complexes where impurity of secondary sulfides in the furnace charge is felt, but it was obviously no more than a third of the furnace charge, in the LBA the situation changes: the secondary sulfides are used, but the active use of chalcopyrite begins. It is difficult to estimate the part of secondary sulfides in the LBA too. In the oxidized slags of the 4th mineralogical group they are not almost presented. It is possible to assume that in the 2nd group of slag they made in total a half providing the reducing atmosphere of smelting. Therefore if to illustrate this situation with the conditional diagram (Fig. 11-61.), we will see even decrease in the part of the secondary sulfides in the LBA in comparison with the MBA. But this part decreases partly due to the noticeable use of chalcopyrite (possibly, also bornite), partly due to the irregular distribution of the use of secondary sulfides in different areas: in the Orenburg region and Central Kazakhstan, mainly, oxidized ores were smelted. It raises the part of the secondary sulfides in other areas.

But at the more active use of sulfides the duration of smelting operation and temperature grows. It is paradoxical that it occurs also where the sulfides are not smelted and the more refractory ores from quartz rocks are used, above all. A part of the slag smelted from ore in the basic rocks in the Sintashta time was 81.6% (1st and 3rd mineralogical groups), and in the LBA (1st mineralogical group) its part is only 5.9%. As a result of all this we see that in the Sintashta time the smelting temperatures were in the interval 1200-1300 ºC, and now the interval is usually 1200-1400 ºC, and in many cases it is possible to assume the temperatures about 1500 ºC.

In these conditions the former tradition of alloying of ore with arsenical minerals could not remain: arsenic would be sublimated. Therefore the situation with the alloying changes too.

But there is also while poorly shown in the material specifics of complexes of the Final Bronze Age: if on the Sargari settlements we see the smelting of secondary sulfides and oxidized ores (that is remains of former traditions), on the later sites we see the use of oxidized ore (the finds of ore mentioned above and slag of the settlements of Kent and Kalinovka II if this slag belongs to the Dongal layer too). And the smelting temperatures are not as high as in the earlier LBA complexes: they come back to the interval 1200-1300 ºC. Certainly, it is impossible to be based on this limited number of analyses, but they are confirmed by new changes of traditions of alloying.

Spectral analysis

A series of slags from the Late Bronze Age sites of Andronovo area has been analysed by means of the spectral analysis. In total 49 analyses of ore, 102 analyses of slag and 10 analyses of crucible fragments have been made (Tab. 11-52., Tab. 11-62.). Taking into account the huge spatial and chronological dispersion of these samples, the number of the analyses is very limited that deprives of sense to do any statistical procedures.

Besides, analyses of ore from some deposits of Central Kazakhstan on which ancient mines are known have been carried out. The particular interest is caused by results of the analysis of ore from Kenkazgan where unprecedentedly large-scale works were performed in the antiquity.

A usual instrument at data processing of the spectral analysis is frequency diagrams of distribution of trace-elements. In case the diagrams are double-peak or asymmetric it can indicate different origins of ore or metal. However, sometimes such picture is shown also by the diagrams constructed for ore from a single deposit (Tab. 11-34.; Fig. 11-63.). As we see from the diagrams, in Kazakhstan individual deposits also demonstrate slightly higher concentrations of lead and zinc, although it is not so expressed as in the Altai deposits (Fig. 11-63.).

Some deposits of Central Kazakhstan contain ores with the high content of barium, but the quantity of such ore is insignificant (Fig. 11-63.). At last, presence on mines of Kenkazgan and Altyn-Tyube of ore with the high content of manganese is evident. Further we will see that slags with manganese are present in the collections of Central Kazakhstan.

The analysis of the collection shows that there is no tin in the LBA slag. It is quite expected result as the tin was alloyed at the stage of copper melting. In fact, an exception is only one sample from the settlement of Sargari (No. 44) in which the content of tin exceeds 1%. It is doubtful that the alloying with cassiterite at the ore smelting stage was made here though the spectral analysis of ores from the Kazakhstan deposits have not found this impurity (tab. 11- 34). But it is a single sample.

There is, practically, no ore with the higher arsenic content on the settlements. Only 5 samples from the settlements of Malookunevo, Ilyaska, Yazyovo, Kuropatkino and Chernaya Kurya and 2 samples from the settlement of Arkhangelskii Priisk are known where the content of arsenic varies in the range of 0.1-0.5%. It is obviously too low to produce the arsenic bronze. Taking into account that as we have seen, the smelting temperatures during this period increased, and arsenic in these conditions had to be sublimated, it is possible to say that there was no ore that could give notable concentrations of arsenic in metal.

At the discussion of Sintashta-Abashevo metallurgy it has been noted that for the Middle Bronze Age slags the border marking the manufacture of arsenic alloys is 0.01% of the arsenic content. Only 12 samples of slag from the settlements of Verkhnyaya Alabuga, Nikolaevka, Graurtly, Myrzhik, Baytu, Sargari, Altyn-Tyube and Ikpen I and 42 samples from Arkhangelskii Priisk have got to this range. Possibly, in this period this impurity was caused by the active smelting of sulfide ores in which this impurity is present. Therefore it is possible to speak about lack of the arsenical alloying.

It is confirmed also by that in both ore and slag the higher arsenic content can be also accompanied by higher concentration of antimony. Respectively, impurities of fahlores could get to the smelting.

But a significant quantity of antimony is absent in the slag. Only in one sample from Sargari its contents reaches 0.7% that is accompanied by the high contents of tin (>1%) and arsenic (0.015%). Unfortunately, because of singularity of this sample we cannot discuss a possibility of the complex alloying although the similar alloying is extremely characteristic of the Sargari metal.

In several samples of slag, including several slags of the settlement of Ikpen I, the high content of manganese (to 1%) is noted that is characteristic for the mines of Kenkazgan and Altyn-Tyube. Therefore it is not excluded (although it is not reliable) the ore could be mined there. A variant of additions of the corresponding fluxes is also not excluded. In principle, similar fluxing is known. But a single analogy is on the Cyprus. The majority of slag heaps there is not dated. An exception is slags from the Hala Sultan Tekke of the Late Cypriotic period III (1190-1175 BC). Their analysis has shown that fluxes were not used there and the slag was not tapped. Fluxing with manganese is supposed only for slags of the Late Classical Antiquity, but the reliable datings are absent (Bachmann, 1982, p. 145, 149). In this case a possibility of this fluxing is important.

In 17 samples of ore from the settlements high concentrations of silver (more than 3%) are noted. These are the settlements of Yazyovo, Kaygorodok, Kuropatkino, Chernaya Kurya (3 samples), Ilyaska (9 samples), and Atasu (2 samples). These settlements are situated from the Transurals to the Altai and belong to different periods of the LBA. Therefore in this case the silver impurity cannot indicate not only any deposit (for example, the mine of Nikolskoye), but even a type of deposits. For the slag such high concentrations of silver are not typical. The exception is three samples from Kalinovka II and Sargari.

At last, taking into account the based on the Cisural materials discussion about the possibility of fluxing with barite, the barium content arouses interest. Its high concentrations (more than 3%) are noted in ore from the settlements of Ilyaska (9 samples) and Kuropatkino (1 sample). In slag such concentrations of barium are found only in two samples from Ilyaska. The higher concentrations (0.3-0.7%) are present in the slag from the settlements of Ilyaska, Graurtly and Myrzhik (one sample from each) and Ikpen I (3 samples). Therefore in this case it is possible to speak certainly about the ore origin of barium in the slag and about the absence of tradition of its use as a flux. Respectively, if such type of fluxing will be confirmed further, it was a Cisural innovation.

Conclusions:

Despite the limited sampling, some conclusions can be considered as rather reliable. In the Late Bronze Age, in comparison with the Middle Bronze Age, the tradition of alloying with arsenic minerals at the ore smelting stage disappeared. It is quite natural situation as, as it follows from the mineralogical analysis of slag, in this period in many areas smelters started to use more actively the sulfides and ores from quartz rocks, and temperatures and duration of smelting operations sharply grew everywhere. In these conditions the former arsenic alloying becomes impossible. Restoration of this tradition in the Final Bronze Age is not excluded, because we see that the smelting temperatures slightly decrease, and return to smelting of the oxidized ores, but limitation of the studied samples of this period forces us to be cautious with this conclusion.

Characteristic of metal of the Asian zone of the EAMP

Tin alloys

In comparison with the Seima-Turbino metal, the Andronovo metal is studied much worse. In the former studies it has been shown that 2/3 of the Andronovo metal (without division into Alakul, Fyodorovka and Cherkaskul) are alloyed with tin. And, the higher tin concentrations are accompanied by the higher concentrations of lead. A part of metal of the VK group (Volga-Kama, Cu+As+Sb) is 8% (Chernykh 1970, p. 21, 22). Unfortunately, today there are no generalizing works about chemical compositions of Alakul or Fyodorovka metal. Relatevely detailed information is available only for the Transural and Tobol areas.

In the collection of the Chistolebyazhye cemetery, a rather early complex in the system of Alakul culture, the part of tin bronzes is already very high (44.4%), with the tin content from 1.81 to 6.95%; there are also tin-lead alloys (7.7%). Other metal artifacts are presented by pure copper (Tigeeva 2011, p. 69, 70). In principle, a close composition of metal is shown also by other Alakul sites of the Tobol area, but in them the part of tin-lead alloys is slightly higher (22.7% of tin bronzes) and the part of pure copper is slightly lower (35.7%). The part of the VK copper (Cu+As+Sb) is 8.7% (Kuzminykh, Chernykh 1985, p. 346-366) that is close to the figure for the Andronovo metal as a whole.

To the south, on the settlement of Kulevchi III, the part of tin bronze is lower (16.9%), but in some objects with tin there is the lead too, though it is not so frequent, as in the Tobol area. There are also tin-arsenic alloys in quality of 6.2% (Degtyareva *et al.* 2001). It is necessary to notice that this settlement cannot be considered as the proper Petrovka, it belongs to the, so-called, Kulevchi phase when the Petrovka and early Alakul traditions coexisted. This means, it is rather early site, as well as the Chistolebyazhye cemetery (Vinogradov N. 1984, p. 29-22; Matveev, 1988). Probably just it explains the preservation of arsenic metal, although in addition it is alloyed now with tin. In this regard it is possible to assume that distinction in the tin content had not so much chronological character. The lower tin contents in the more southern steppe complex of Kulevchi was caused probably by that the penetration of tradition of this alloying and subsequently the paths of transportation of either tin or tin bronzes, passed through the forest-steppe.

Thus, the tin alloys in Alakul culture have also unconditional eastern origins. But there is one intriguing detail: the presence in the Alakul metal of the Tobol area of tin-lead alloys which, as we have seen, are absent in the Seima-Turbino metal, but known in the metal of Elunino culture. In materials of the early Chistolebyazhye cemetery, as well as in the Elunino metal with the high lead content, the effects of red brittleness are noted (Tigeeva 2011, p. 77). Therefore it is not excluded that the distribution of alloying with tin in the Alakul culture of the Tobol area happened at the earliest stages of the Seima-Turbino metallworking formation; and the connection of Alakul ore smelting technology in the Tobol area with technology of Sintashta culture does not contradict to this too.

Fyodorovka-Cherkaskul artifacts have been analysed worse, and the series analysed for the Tobol area is insignificant. A part of tin alloys here is larger (72.7%), tin-lead bronzes are also presented (9.1%). The rest of the metal is pure copper (18.2%) (Degtyareva, Kostomarova 2011, p. 35). Larger part of the tin alloys in the Fyodorovka metal in comparison with Alakul is quite explainable by that for the Transurals the Fyodorovka culture was a component came from the east, the sources of tin where also in the east.

For the following stage, the Final Bronze Age, the distribution of metallurgical groups is remarkable (Agapov 1990). In both European and Asian parts of the EAMP the noticeable differences are, mainly, in the different parts of tin bronzes (Fig. 11-64.). In Eastern Europe their part is 12.5%, and in Asia it is higher: in Northern Kazakhstan – 68.7% of metal, in Central Kazakhstan – 80.5%, in Eastern Kazakhstan – 88.5%, in Zhetysu (South-Eastern Kazakhstan), Kyrgyzstan and the Aral region – 90.1%. It is also remarkable that in the Altai where, apparently, the majority of tin was produced, also the sharp prevalence of high-tin bronzes with the tin content of 12-26% has been fixed (Agapov *et al.* 2012, p. 56). Thus, from the east to the west we see the decrease in the part of alloyed metal. It means the preservation of those parhts of deliveries of tin from the Altai and Central Kazakhstan which arose at the beginning of the LBA. But a sharp recession of the part of these alloys in Europe, disproportionate to the distance to the tin sources, is observed that was characteristic also for the previous time. Therefore, the deliveries were somehow connected also with the ethnocultural, and not just the rational context.

A very important problem is the alloying with tin. Many years ago S.S. Chernikov wrote that this alloying was making by additions of cassiterite at the stage of ore smelting (Chernikov 1949, p. 51). This explanation has met absolutely true objections on the ground that by such a way it is impossible to produce metal with a certain percentage of tin. Besides, tin, with its low melting point, should evaporate. Therefore these ores were smelted separately and already metal tin was added to copper. It is confirmed also by the analyses of ores and slags in which tin is absent. Bronze ingots from the settlement of Novoshulbinskoye are alloyed (Sitnikov 2006, p. 153). To these arguments we can add one more. Tin was the leading alloying component in the EAMP, and on the huge spaces of this province the mining and smelting of copper ore were carried out everywhere. It is difficult to imagine transportation and exchange of cassiterite. Among many analyses of slag there are only several samles with the tin content reaching or exceeding 0.3% that quite could be a result of smelting ore with this impurity. According to E.N. Chernykh tin in metallurgical processes behaves neutrally (Chernykh 1970, p. 11), i.e. it should be distributed equally between slag and ore. Respectively, this way of alloying would be unprofitable, and it is not confirmed by our analyses of slag.

Therefore smelting cassiterite took place in the Altai; however places of these smelting operations are not studied yet. Tin smelting from cassiterite have been recorded only in the valley of Kargy River in Tuva (Popov 1999, p. 344, 345), what was, apparently, a typical situation.

Problem of chemico-metallurgical group VK

Another interesting problem is a part of the arsenic-antimony copper VK (Cu+As+Sb). In the European steppe, in comparison with the Timber-Grave period, the situation changed not so essentially. Here this metal makes 17% from which a half is alloyed with tin. But in the Asian zone, i.e. in Sargari culture, in comparison with the Andronovo time we see an essential growth of the VK metal (36.1%), and, the most part is alloyed with tin. Deposits of Central Kazakhstan which probably were the basis for metallurgy of the Sagari time contain not so much arsenic and antimony to give such abundance of the arsenic-antimony bronzes (Fig. 11-63.). Therefore, most likely, this metal in the Final Bronze Age had artificial character. In a certain sense, it can be considered as a kind of alloying with arsenic that is characteristic of cultures of the Final Bronze Age in the east and northeast. Respectively, this form of alloying during the Final Bronze Age became widespread.

In this sense the part of this metal in the different complexes of the LBA is interesting. Tab. 11-65. contains the data already discussed on pages of this book to which the data have been added which were recalculated from the table of alloys in the forest zone of Southern Siberia (Bobrov *et al.* 1997, tab. 2).

Above we have already discussed that in the Seima-Turbino complexes this metal occurs only in the European zone, that it was formed exactly there. And, in the LBA steppe complexes (both Timber-Grave and Alakul) its part is insignificant. In general, its part is insignificant also in the Andronovo complexes. Only in the LBA of the Don area 25.7% of this metal is present, but probably mainly, due to the late complexes. The part of alloys Cu+As+Sb sharply grows in the Final Bronze Age, especially in the forest Cisural area (Prikazanskaya culture) and in the steppe of the Asian zone. Contrary to it, in the latest complexes of this period in the forest zone (Irmen and Lugavskaya cultures) the quantity of this metal is small, and in the Karasuk, Korchazhka and Elovka culture it is absent. But in the entire this forest block of the Final Bronze Age instead it the related arsenic alloys without antimony impurity starts dominating. Thus, in the Final Bronze Age we see in many areas the sharp growth of alloys Cu+As+Sb, and Cu+As in the others, but it is absolutely unclear what caused this situation.

Smelting of sulfide fahlores or artificial alloying at the stage of ore smelting could be a source of this copper. Probably, the problem is in the small collection of studied slag, or smelting of sulfide ore was carried out near mines, but the studied slag collection indicates neither that, nor another.

Arsenic alloys

The arsenic alloys are characteristic neither of Sargari sites in the Altai, nor of Sargari sites as a whole, although tin-arsenic alloys are present in some cases (Sitnikov 2006, p. 157; Agapov 1990, p. 11; Agapov *et al.* 2012, p. 49). However in another complex of the Final Bronze Age in the Sayan-Altai mountainous area the arsenic ligature occurs. It is the already discussed sites of the Karasuk, Lugavskaya, Irmen and Begazi-Dandybay cultures. On the example of their alloys it is possible to speak most definitely about the gap with former traditions of the EAMP. The data of researchers that in the EAMP system equal parts belong to pure copper and copper alloy with tin have been given above (Chernykh 1970, p. 21; Sunchugashev 1975, p. 144; Bobrov *et al.* 1997, p. 58). The part of bronzes can change depending on the territory and availability of alloying components, but other types of alloys are not typical for the EAMP. With the formation of Irmen-Karasuk cultural bloc the Central Asian Metallurgical Province (CAMP) arose there and the situation on the eastern flank of the EAMP changes. Active introduction of arsenic ligatures begins.

In a detailed research of this period it has been perfectly shown that metalworking of the Karasuk and Lugavskaya cultures was based on arsenic alloys, alloys with tin were very rare (Bobrov *et al.* 1997, p. 52-54). In the Minusinsk Depression and Khakassia 84% of the Karasuk metal are presented by alloys with arsenic, and 16% by alloys with arsenic and tin or with tin (Sunchugashev 1975, p. 144). Only in Eastern Transbaikalia in artifacts of the Karasuk time the tin alloy is present more often, that is explained by the presence of copper and tin mines on the Onon River (Grishin 1975, p. 67, 68). The alloying of objects of the Karasuk type with tin was practiced also to the east, in the Amur area and the Russian Pacific coast (Konkova 2006, p. 10). Thus, it was typical of the East.

To the west, in the contact zone between the EAMP and CAMP the part of tin alloys raises too. In Irmen culture of Western Siberia a third of metal is presented by alloys with arsenic, a quarter – with tin and arsenic, slightly less than a quarter – alloys with tin, pure copper and alloys with arsenic and antimony follow them. In Korchazhka culture 50% of metal is presented by alloys with tin, a third – by pure copper, other artifacts are alloys with arsenic. However, the alloys with tin were used, mainly, in ornaments therefore the total weight of objects from pure copper was, apparently, higher. In Elovka culture the alloy with tin dominates. According to these signs the stereotypes of Korchazhka and Elovka metalworking was closer to the EAMP, than to the CAMP, although a certain introduction of new traditions took place, nevertheless, in these northeastern parts of the EAMP. In other centers of the EAMP alloys with tin certainly dominate, except for Maklasheevka center in the Cisural area where the tin ligature is absent in copper of the antimony-arsenic group VK, and chemical compositions of these objects are similar with those of Irmen, Karasuk and Lugavskaya (Bobrov *et al.* 1997, p. 57, 58, 61, 62).

An important problem in this case is the way of production of arsenic bronzes, a question universal for history of metallurgy in the majority of areas, but, unfortunately, having no universal answer. And it is extremely important to develop various approaches for the solution of this problem that has been expressed in division of this metal into two groups: low-arsenic bronzes, close to the VK group, whose relation to artificial alloys is conditional, and high-arsenical bronzes with impurity of antimony or zinc which are a result of alloying (Bobrov *et al.* 1997, p. 50, 51). By the way, in this book we have assumed the same for metal of the Volga-Ural zone.

The first group of metal is a result, apparently, of smelting, both primary sulfide ores, and fahlores. These conclusions are based on that in the Cisural area the VK group is characteristic of those cultures in which on the basis of slag analyses the steady smelting of sulfides is recorded, and also that arsenic in metal has positive correlation with concentrations of antimony and bismuth which are absent in arsenical minerals, but are typical for fahlores (Bobrov *et al.* 1997, p. 37; Grigoriev 2001). Respectively, the disappearance of tin alloys in Maklasheevka culture can not indicate at all connections with eastern traditions of the production, but it can be explained by preservation of tradition of use of the sulfide ores and loss of the connections providing the tin deliveries. But this conclusion cannot be considered as admissible without careful comparison of metal with slag too.

A way of producing the high-arsenical bronzes is no less complex problem. Researchers believe that the alloying of copper with arsenic minerals took place, as analyses of ore and slag from the Poselshchik Mountain have identified no arsenic in them, and in copper its contents exceeds 1% (Sunchugashev 1975, p. 125; Bobrov *et al.* 1997, p. 36). However the alloying of copper with arsenic ore is quite doubtfully (see above the discussion of this problem at the description of Okunev metallurgy). Nevertheless, it is more probable the alloying at the stage of ore smelting, identical to that we have seen in Sintashta metallurgy, or smelting of the copper-arsenic ore known in the Haradzhul and Butrakhty deposits of the Minusinsk Depression (Sunchugashev 1975, p. 52, 128). But it is impossible to exclude a variant of alloying copper with speiss that we have discussed on the Iranian material in the chapter about Sintashta slag.

It is necessary to remember that as we repeatedly saw on pages of this book, the technologies of ore smelting and metalworking are closely interconnected. Very often the appearance of a new technology of ore smelting and a new raw materials causes a change of properties of used metal and a change of technology of its casting and forging. It is a uniform system. But there is also a feedback in such a system: if any certain technology of metalworking and corresponding to it types of tools are widespread, metallurgists tried to choose also the ways of ore smelting corresponding to them. In relation to this case it means the following. The work with arsenic bronzes differs from the work with tin alloys and pure copper, therefore in case of the presence of ore with arsenic metallurgists, certainly, tried to use it. However in case of its absence the alloying with arsenical minerals at the stage of ore smelting could be used.

Thus, in the Final Bronze Age in the Sayan and Altai we see the return to more archaic technological traditions: to arsenic alloys, very probable alloying on the smelting stage, and more active use of oxidized minerals. This feeling of technological return is reinforced by that the types of metal of the CAMP are more comparable not with Andronovo, but with the earlier Seima-Turbino tradition (Kyzlasov 1993, p. 47; Bobrov *et al.* 1997, p. 69; Grigoriev 1999, p. 280). Distribution of these phenomena in the western direction causes a feeling of crisis in tin mining in the Altai, deliveries of arsenic copper and bronze from the Sayan and decay of production in the Urals, Altai and in Kazakhstan (Bobrov *et al.* 1997, p. 58, 59, 69). But the reasons of this crisis lay, apparently, in the sharp change of the ethnocultural situation, formation of a family of cultures of the Karasuk type and formation of the CAMP (Bobrov *et al.* 1997, p. 70).

As a result, on the eastern flank of the EAMP a new metallurgical province formed which starts extending subsequently to the west, endowing some northern areas of the EAMP with its features. Similarity of Karasuk metal with earlier Seima can be explained by that the appearance of metal of both these groups was connected with impulses from one region (Chlenova 1972, p. 131-135; Grigoriev 1999, p. 284, 285). But it is difficult to tell from which region of the Middle East or Transcaucasia. It is impossible to specify this initial region on the basis of technology of ore smelting. The matter is that the high part of arsenic bronzes was peculiar to many cultures of the 2nd millennium BC, both in Transcaucasia, and in Anatolia. In Transcaucasia in the LBA the copper alloys with arsenic dominated (70.3%), alloys with tin were 8.4%, pure copper – 10%, the rest was represented by variations of the main alloys (Teneishvili 1993, p. 6). The late phase of this period is especially interesting, when the part of tin bronzes was higher, but the situation, in any case, is indicative. In Anatolia the part of arsenic alloys in the LBA is 57.6%, and together with binary tin-arsenic alloys they quite make an overwhelming part of metal (Avilova, Chernykh 1989, tab. 13). A similar situation was also in Central Asia where in metal of two settlements (Namazga and Tekkem) in the LBA layers the arsenic alloys dominated. The same situation with the arsenic bronzes at this time was everywhere: in Margiana, Southern Bactria, Susa and Shakhdad. Only in Northern Bactria metallurgists of Sapalli culture prefered to use tin (Shetenko 2002, p. 187). An intriguing fact is detection in one of slag samples from Tepe Tekkem of 4.3% tin. Parallels to it in the form of two pieces of slag with the high tin content are known on the settlement of Uzerliktepe in Azerbaijan (Kushnaryova 1965, p. 79). It was, certainly, a very archaic way of alloying, not characteristic of the EAMP. But the preservation of arsenical alloying in the LBA was most characteristic of Iran where it existed up to the beginning of the Early Iron Age that allowed Pigott to speak about technological conservatism of the Iranian metallurgy (Pigott 2004a, p. 29).

Thus, most likely, the transformations in metallurgical production which involved the eastern zone of the EAMP during the Final Bronze Age were caused by spread here from the southwest of other technological traditions connected with one of the metallurgical centers, formed in the southern zone of the Circumpontic Metallurgical Province; however it is impossible to determine this region more precisely.

Metalworking

In metalworking of the early Alakul cemetery of Chistolebyazhye in the Tobol area two technologies dominated: cold forging with intermediate annealings (46.15%) and hot forging at the temperature of 600-800 °C (46.15%). Casting without the following forging was applied in the manufacturing of only 7.7% of the objects. To some extent it can be considered as development of Sintashta traditions of metalworking where the casting was poorly presented too, but the part of cold forging increases and the part of hot forging slightly decreases. Technological development is also fixed. The part of cast objects increases to 25% in the later Hripunovo cemetery, and sometimes annealing of homogenization, more progressive method of heat treatment was applied (Tigeeva 2011, p. 72, 77). Such dynamics was caused by transition to the new type of alloying with tin. Besides, as we have seen, the annealing of homogenization was applied in metalworking of Elunino culture. Accordingly, the development of the Alakul tradition of metalworking can be considered as the development from Sintashta tradition with the subsequent borrowing of eastern traditions.

In Fyodorovka and Cherkaskul metallurgy the casting technologies play already a dominant role. The casting is carried out either into bi-fold moulds with inserted core, or into one-fold moulds with a cover. Then the artifacts were finished by the forging directed to removal of casting defects, stretching and thinning of the working edges. The level of metal reduction was average; no more than 40-50%. Intermediate annealings were also applied to remove the intercrystal tension (Degtyareva, Kostomarova 2011, p. 35). Thus, this tradition has nothing in common with Sintashta and Alakul metalworking. It is rather close to Seima-Turbino, initially focused on manufacturing of objects with tin. This means that for the Fyodorovka metalworking it is more logical to assume the eastern impulses.

During the Final Bronze Age in the steppes (a family of Cordoned Ware cultures) the development of metallurgy of the EAMP reaches its culmination. It is shown in the perfect metalworking with a wide variety of casting and forging operations, and with domination of casting. The annealing of homogenization, introduced in the region at the very beginning of the LBA, is widely applied (Agapov *et al.* 2012, p. 51-54).

Metal artifacts of the Asian zone of the EAMP

Petrovka, Alakul and Timber-Grave metal objects succeed to the Sintashta-Abashevo traditions. It is very clearly demonstrated by lamellar single-edged knifes, knifes with a small stop, axes with a massive back (more characteristic of Sintashta, than of Abashevo), adzes, and sickles (Fig. 11-66.). But there are also new types which have not been connected with the Sintashta tradition. Above all, it is spearheads with a cast socket and knifes with a cast handle (Fig. 11-66.11) which were connected with Seima-Turbino metalworking. But the most part of types succeed to local traditions of the Middle Bronze Age.

Unfortunately, the quantity of reliable Fyodorovka metal is insignificant as there was no tradition to place metal into burial tombs in this culture, and quantity of single-layer settlements is extremely insignificant. Therefore it is difficult to discuss types the Fyodorovka artifacts (Fig. 11-67.1-7). In principle, it is possible to assume that some of these types were connected with the local Sintashta-Alakul line of development, for example, to assume that Fyodorova bracelets with conical terminals were created from the Alakul bracelets with spiral terminals. But characteristic of Fyodorovka culture funnel-shaped earrings do not succeed to the Alakul tradition. There are also socketed arrowheads, daggers with a stop-guard and midrib.

Some new types have rather remote parallels. Fyodorovka shaft-bushed axes with a massive cordoned back cannot be derived from Alakul metalworking, although the shaft-bushed axes are present in Alakul culture. For this type of axe such a back has no functional use. In the Caucasus and Near East, cordons on the backs of axes are very common (Gorelik 1993, tab. XIX-XX; Mikeladze 1994, tab. 17; Markovin 1994, tab. 70; Erkanal 1977, Taf. 6; Müller-Karpe 1974, Taf. 172, 232). Fedorovka 'knives' with a stop were not knives, but javelins or arrowheads. Many have a rhombic cross-section and thicken at the waist. If used as knives this would reduce the length of the functioning cutting edge and make them less effective, but if used as a thrust weapon, they would carry a larger load. This function may be demonstrated by an original spearhead from the Malokrasnoyarka settlement, to whose blade, standard for this type, a socket had been attached (Chernikov 1960, p. 44). Analogies to such javelins and spearheads are known in Sumbar culture in South-Western Turkmenistan, in Margiana, on sites of the Bactro-Margianan archaeological complex, in South-Eastern Anatolia (Hassek Höyük, Arslantepe, etc.) (Khlopin 1983, fig. 17; Sarianidi 1998, fig. 25.4; Behm-Blancke 1984, Abb. 8.1,2, S. 52; Palmieri 1981, fig. 4; Stronach 1957, p. 113-117). Eventually, they go back to spearheads and javelins with a stop, which were widespread in the Circumpontic zone. Dagers with midribs on blades and socketed arrowheads are known in the Near East (although they are present in both Elunino and Seima-Turbino complexes (Gorelik 1993, tab. III-V; Erkanal, 1977, Taf. 17, 46-48a, p. 50). Single-edged Fyodorovka knives with a curved back might derive from Seima-Turbino knives, but could also have been introduced from the Near East (Avilova, Chernykh 1989, fig. 7). Finally, a hook with a forged socket from the Pavlovka settlement is rather indicative (Zdanovich 1988, tab. 10,15). Similar artefacts are not typical of

Alakul culture but are extremely widespread in most cultures of the Circumpontic Metallurgical Province. In the Late Bronze Age similar objects are known in the North Pontic area in the Loboykovka hoard alone (Chernykh 1976, tab. XXXII). However, its clearly later date does not permit comparisons with the Pavlovka hook; furthermore, the latter has a more 'graceful' shape, which is more typical of Caucasian articles.

Thus, the complex of Fyodorovka metal has some local parallels, Seima-Turbino (i.e., eastern for the described area), but there are parallels in the south and the Near East.

Cherkaskul sites in the Transurals, formed on Fyodorovka base, are poorly furnished with metal artefacts. However, the absence of other Bronze Age cultures in the forest regions of the Transurals enables all the metalwork of this period, including chance finds, to be linked with either the Cherkaskul or Mezhovskaya cultures. These artefacts correspond to metalworking of phases II and III of the Eurasian Metallurgical Province: that of phase II can be regarded as metal of Cherkaskul culture (Fig. 11-67.8-13), that of phase III of Mezhovskaya. This is confirmed by separate finds of bronze objects and casting moulds on settlements (Grigoriev 2000b). Some artefacts of this zone correspond to Fyodorovka traditions of metalworking: double-edged knives with midrib, guard-stop and rectangular tang; tanged knives; pendants of 1.5 revolutions, with notches; a ring with conical spiral terminals (Kosarev 1981, fig. 51; Obydennov, Shorin 1995, p. 33; Kazakov 1978, fig. 22; Petrin *et al.* 1993, fig. 40,8). Another group of metal is connected with the Seima-Turbino tradition. It is worthy of comment that all finds of celts in the Transurals are situated to the north of the Miass river, i.e. in the zone of the basic localisation of both Cherkaskul and Mezhovskaya cultures (Salnikov 1965a). Classic Seima-Turbino types are represented in the Transurals by single finds of celts and a double-edged knife with a short expanded tang. But special attention should be given to the discovery on the Lipovaya Kurya settlement of a mould for casting a socketed gouge, which is typologically close to a similar object from the Rostovka cemetery of the Seima-Turbino type (Chernykh, Kuzminykh 1989, fig. 20, 39, 51; Matyshenko, Sinitsina 1988, fig. 38; Khlobystin 1976, p. 35).

A group of so-called 'Eurasian' metal, which was derivative of Seima-Turbino, is more representative, but it is rather early and has been included in the proper Seima complexes. The group includes a celt, spearheads with a rhombic socket-shank, and double-edged daggers with a cast hilt (Chernykh, Kuzminykh 1989, fig. 40, 45, 65; Kosarev 1981, fig. 51; Obydennov, Shorin 1995, p. 31, 32; Petrin *et al.* 1993, fig. 47,3,4). Articles of the Samus-Kizhirovo types (celts with false eyes) belong to the same line of development (Chernykh, Kuzminykh 1989, fig. 77-80; Obydennov, Shorin 1995, p. 32; Petrin *et al.* 1993, fig. 47,1,2).

Thus, the Cherkaskul complex of metal consists of two components: Fyodorovka and Seima-Turbino. And after this this new tradition develops in the northern forest-steppe and in the south of the forest zone, and we see the spread of this tradition to the west.

Mezhovskaya culture inherited traditions assimilated by Cherkaskul Seima-Turbino metalworking: celts with a rectangular facet, hexahedral celts with an arched facet and frontal eye, daggers of the Sosnovaya Maza type, spearheads with slits on the blade and a round socket, as well as other artefacts (Chernykh 1970, fig. 46, 48, 58; Obydennov, Shorin 1995, p. 78-80). If to simplify, it is possible to say that such components as celts, socketed spearheads, and knifes with a metal handle are heritage of Seima-Turbino metalworking, and stemmed spearheads with a stop and bracelets with conical spital terminals are that of Fyodorovka. This complex of metalwork of a number of cultures (Mezhovskaya, Prikazanskaya, Suskan-Lebyazhinka) is also evident in some hoards to the west of the Urals (Sosnovaya Maza, Karmanovo, Derbedeni) (Chernykh 1970, p. 115, 116; Kuzminykh 1983; Kolev 1991) (Fig. 11-67.13-18). It appears in the Balimskaya-Kartashikhinskaya phase of Prikazanskaya culture, with types of metal artefact that were typical of the whole pre-Ananyino horizon of metalworking in the Volga-Kama region. And a number of morphological features and chemical composition of metal distinguish Prikazanskaya metalworking from that of Mezhovka and makes it comparable with that of Timber-Grave (Kuzminykh, 1983). That is, we see here an interaction with more southern metallurgical traditions.

Dating of formation of this tradition in the Cisural area is a debatable question. For example, metalworking of Suskan-Lebyazhinka culture of the Volga region is almost identical with that of Mezhovka, and Seima-Turbino was the basis of this metalworking (Kolev 1991). It contradicts the earlier opinion that pre-Ananyino metalworking in the Volga-Kama region had been formed under the influence of the Zavadovka-Loboykovka (Timber-Grave) metallurgical centres of the North Pontic area (Kuzminykh 1983, p. 129, 130). Taking into account that this metalworking includes the types ascending to Fyodorovka, remained in Cherkaskul-Mezhovka, and the Seima-Turbino component could be transferred indirectly through the Fyodorovka-Mezhovka tradition, it can also appear a bit later than the time of existence of the Seima-Turbino bronzes. Indeed, the rise of Suskan-Lebyazhinka culture happened rather early, practically at the end of the Pokrovsk phase of the Timber-Grave culture (Kolev 1991, p. 197; 1993; Bochkaryov 1995, p. 121, 122). Besides, the formation of Fyodorovka, Cherkaskul and Mezhovka cultures happened earlier than it is considered to be: the Fyodorovka culture is dated to the 16th century BC, Cherkaskul is to the 15th century BC and dating to the second half of the 16th century BC is not excluded, Suskan-Lebyazhinka culture is dated not later than the early 15th century BC in system of traditional dates (Grigoriev 1999).

Certainly, this problem, as well as the problem of formation of metalcomplex of these cultures, demands special additional studies, but in general the situation looks as follows: this tradition of metalworking spread from the east to the west with some lag from the spread of the Seima-Turbino and proper Fyodorovka traditions. The major role in its formation was played by two traditions: Seima-Turbino and Fyodorovka. And the spread was passed through the forest and forest-steppe zones, i.e. in the northern part of the area. Interaction of this tradition with southern traditions (Alakul and Timber-Grave) is clearly visible.

Formation of metalworking of the Final Bronze Age cultures is the most difficult question. It is possible to start from that the problems connected with these cultures, in general, are studied very poorly. It is enough to say that this period lasted about 700 years. There was some internal dynamics in it, certainly, some sub-periods, multidirectional impulses occurring at different times. But today we continue to believe that there was the monotonous Sargari culture at this time. Only the last years new complexes of the end of this period begin to appear distinguished from Sargari, and also ceramic complexes without cordons, defined in the Transurals, as Bersuat type (Malyutina *et al.* 2006). Therefore in the future an essential reconsideration of this epoch is expected.

Metalworking of this time was based on the local steppe traditions, but the role of northern cultures, for example Mezhovka was very great that introduced elements of Seima traditions in the metalworking (celts, spearheads with a cast socket). Especially brightly the heritage of the Seima traditions is visible in the Altai (Agapov *et al.* 2012, p. 56). Possibly, a significant role (especially in Eastern Europe) was played by impulses from the west. It is shown most clearly in the contact zone of the North Pontic area (between the EAMP and the European Metallurgical Province), where investigation of metal artefacts has determined the priority of the Ingul-Krasnomayatsk center of metalworking of Sabatinovka culture relative to the Zavadovka-Loboykovka centre of metalworking of Timber-Grave culture (Chernykh 1976, p. 153-156). It allows us to place the initial date of the Zavadovka-Loboykovka center within the 14th -13th centuries BC. It is likely, that 'pre-Cordoned' developments occupied part of the 14th century BC, but not a long part.

But some additional impulses influenced the appereance of new types of artifact are not excluded. It is possible to point here to the opinion of Merpert about connection of Sosnovaya Maza-type daggers with Luristan bronzes, and their distribution through the Caucasus (Merpert 1966), but there is one problem with this: the main area of distribution is the Volga-Kama region, and there are rather precise prototypes in Seima-

Turbino complexes (Chernykh, Kuzminykh 1989, fig. 64,1,2; Avanesova 1991, fig. 52). This resemblance might well have been conditioned by the Near Eastern origin of Seima-Turbino bronzes.

Why spearheads occur with slits on the blade, whose stemmed versions are known in Transcaucasia and Anatolia, is not quite clear either (Gorelik 1993, tab. XXXIII; Stronach 1957, p. 107-112). Shaft-hole axes with a ridge on the back occur in the eastern zone in this period. Their form confirms their local roots; however, ridges were characteristic of axes from the Near East (Gorelik 1993, tab. XIX-XXI; Erkanal 1977, Taf. 5, 50-56; Müller-Karpe 1974, Taf. 172.2,18,21). Adzes with a narrow heel and expanded working section are a very revealing type of metal artefact. They have a number of precise analogies in the Circumpontic zone, dating from the Middle Bronze Age (Kuzmina 1994, fig. 43b). The appearance of stemmed spearheads in the steppe is another unclear phenomenon. Some of them have a stop, which means that they can be considered basically as a development of Fyodorovka spearheads, but they differ in the proportions of the blade (Avanesova 1991, p. 49). This opens up the possibility of an additional influence. The presence of a hook on the stems of individual spearheads provokes Circumpontic associations, although direct parallels are not permissible for chronological reasons. It is possible to be more definite about the Near Eastern analogies to such artefacts as bronze tweezers. They are extremely rare, but are spread through the whole of the Eurasian Metallurgical Province (EAMP) of this time. Identical articles are known on Cyprus, where they are dated from the Early Cypriotic time up to the transition from Middle to Late Cypriotic (Vermeule, Wolsky 1990, tab. 106; Müller-Karpe 1974, Taf. 344, 345).

It is possible to add one more paradox. The metalworking of the most easterly Semirechye metallurgical centre is connected more closely with that of the western centres of this time than with the central ones (Agapov 1990, p. 15).

Possibly, in the east it was caused by those impulses which led to formation of such cultures as Karasuk, Irmen, Elovka and Begazi-Dandybay (Fig. 11-68.). Some years ago N.L. Chlenova (1972, p. 131-135; 1974) gave a set of Near Eastern parallels to metal artifacts of Karasuk culture which we have amplified with some new parallels (Grigoriev 1999b; 2002). Therefore, besides the local steppe Alakul basis, at different phases influences of the western, northern and southern traditions of metalworking peneterated the region.

Metallurgy of Prikazanskaya culture in the Kama area

Territorially Prikazanskaya culture of the Kama area is out of the region considered here, but its connection with eastern impulses allows us to consider its rare studied samples in this section. There are two samples of slag (703 and 761) and one fragment of slagged furnace lining (762) from the Prikazanskaya settlement of Akshuben I. From each sample two polished sections and, respectively, two mineralogical analyses have been made.

The most part of the lining is presented by porous ceramic mass in which the crystallization, practically, did not occur (Fig. 11-IX.1). Only some inclusions are present: small olivine needles, quartz grains, rare fine grains of chromite. In the slagged part the larger prismatic fayalite crystals have been identified, between which there is a small rash of magnetite octahedra, rarer its thin dendritic structures crystallizing from liquid slag (Fig. 11-IX.2). The uppernmost part of the sample is the normal slag mass with many prisms of fayalite and accumulations of fused lattice structures of wüstite with contours of a primary ore grain (Fig. 11-IX.3).

One of the slag samples (No. 703) is dense, heavy, and of red color. Its one side is more flat, slightly roundish, with ceramic crust, the second is rough. Possibly, this slag was formed on the furnace bottom. The second sample (No. 761) is presented by the heavy shapeless slag, smooth and fused. Both samples were formed near the furnace lining that affected their microstructure: there are three clearly distinguished zones. The bottom zone is the porous ceramic mass without visible crystallization: only small and rare fayalite needles and quartz grains (Fig. 11-IX.4) have been fixed.

It is impossible to identify reliably the ore bearing rock. The slag includes grains of quartz, but they are rare and usually are situated in the bottom zone of the slag, being connected, probably, with sand additions into the furnace lining. Individual grains of chromites are present too, but they do not testify the origins of ore from the ultrabasic rocks as their quantity is insignificant, and they are very small. Besides, they are present in the slagged lining therefore came probably from the clay.

There was initially a large amount of iron minerals in the smelting that is specified by abundance of wüstite and fayalite. In both proper slag zones the wüstite is presented by fused lattice structures and dendrites occupying large areas. These structures formed from some iron mineral as in some cases they form accumulations keeping the form of primary grains (Fig. 11-X.1,2,5). But a part of the large fused dendrites of wüstite obviously crystallized from liquid slag. They grew from smaller dendrites present in the slag (Fig. 11-X.3,4). In the lower zone of the slag where its cooling was slower, these fused dendrites grew to enough large sizes. In some cases the wüstite is formed from magnetite. And, the magnetite is not melted, but particles separating from it are reduced to wüstite and melted (Fig. 11-X.4).

It is not excluded that chalcopyrite was the initial material which gave such quantity of wustite. After fusion and separation of copper sulfides, wüstite formed with appearance of the fused lattice structures, some of which keep the borders of primary grains. The same is specified by the presence of sulfides and small grains of chalcopyrite in the slag (Fig. 11-X.6), lack of malachite and insignificant quantity of cuprite. The slag contains an insignificant quantity of melted inclusions and prills of copper sulfide, chalcocite.

This abundance of wüstite promoted the formation of fayalite. Possibly, there were in the slag many silicate components (quartz) for its formation, but they did not remain, being turned into the fayalite. In the upper zone of the slag the fayalite is presented by prismatic crystals with different orientation. Usually they are skeletal prisms (Fig. 11-X.2). This part of slag cooled slightly quicker. In the middle part of slag the fayalite forms large polygonal crystals and large prisms which are oriented in one direction, from top to down (Fig. 11-IX.6; Fig. 11-X.1,3-6).

The quantity of cuprite in slag is insignificant. It is presented by small rare prills, in some cases by filling of cracks or a frame of pores. Copper prills of the small sizes are also rare. Small particles or prills of iron have been even rarer revealed.

The small losses of copper in the form of metal and ore inclusions are confirmed also by the results of spectral analysis: they vary within 0.15-0.3% (Tab. 11-69.). And, presence of arsenic, antimony or tin has not been detected. Therefore, the alloying at the stage of ore smelting was not practiced.

Conclusions: Thus, the main ore mineral was chalcopyrite. Smelting temperatures exceeded the melting point of cuprite, but probably were lower than the melting point of magnetite as its grains melt only being turned into wüstite. Respectively, the temperature was about 1300-1400 ºC. The slag cooled down rather slowly, directly in the furnace. Possibly, the smelting lasted for a long time as all ore components are very well smelted and their quantity in slag is insignificant. The slag was fluid, and all copper separated well from it. It is rather typical slag of the 6th mineralogical group, identical to Fyodorovka and Mezhovka slags that points to the Fyodorovka-Mezhovka impulses stimulating the appearance of this type of smelting in the Kama area.

Dynamics of development of metallurgical production in the Andronovo period and during the Final Bronze Age

In the Late Bronze Age in the Asian zone of the EAMP we see very complex interconnected processes of transformations of the metallurgical production. By the beginning of this time the production existed in two areas on the western and eastern flanks of this zone. In the west it is the Sintashta metallurgy based on smelting of oxidized ores and secondary sulfides, and also on the alloying with arsenic at the stage of ore smelting. In the east there is the transition to smelting of sulfide ores, including chalcopyrite from quartz rock, and application of tin alloys. All subsequent development of the production in the region was based on development, transformation and interaction of these two traditions.

In the west and center of the region the Sintashta traditions show themselves in preservation of former types of furnaces attached to wells, and in the transition to smelting of ores from quartz rocks. Actually, some part of such ores was used also in the Sintashta time, but now these ores become dominating. Thus, depending on a region, either the mix of sulfide and oxidized ores, ore exclusively oxidized ores are smelted. The last is especially characteristic of the Alakul sites in Central Kazakhstan and Eastern Orenburg area, and for the Timber-Grave sites in the Orenburg area. The former tradition of smelting of ore from the ultrabasic rocks remains only in some places, in the forest-steppe Transurals. Porobably, the impulse to the appearance of Alakul metallurgy there happened at the end of the Sintashta period, and it was influenced by the direct Sintashta impulse, instead of that of Petrovka. To the south the transformations of production were carried out through the both Sintashta and Petrovka metallurgical traditions.

This transition to the smelting ore from quartz rocks led to increase of smelting temperature and to longer duration of smelting operations. As a result, the traditional in the Middle Bronze Age way of alloying by smelting of arsenic minerals together with ore did not lead to a guaranteed manufacturing of alloyed metal as arsenic sublimated in these conditions.

It is difficult to say: what was the reason of this transformation that led to refusal of smelting ore from the ultrabasic rocks. On the one hand, the ores in quartz rocks are much richer and are presented incomparably wider. Therefore it is not excluded that migrations of descendants of the Sintashta people led to the transition to new sources of raw materials, and borrowing from the east of new types of alloying and appearance of ways of tin trade allowed the problem of alloying to be solve, which rose with the transition to new types of ores.

Together with the technology of alloying some types of artifacts were also borrowed at whose manufacturing the casting was more convenient than the forging (for example, spearheads). Above, discussing the traditions of metalworking, we have seen that just Sintashta was the initial basis of both Petrovka and Alakul metalworking traditions, but then the part of casting technologies grew that is explained by the appearance of eastern technological traditions. As the types of artifacts are very closely connected with technology of their manufacturing, and the latter with the type of alloy, we distinctly see that the essential technological transformation here happened together with the transition to new types of ore caused the necessity of transition to the new type of alloying, and the latter led to appearance of corresponding them casting and forging technologies and allowed other types of artifacts to be manufactured. But the new types of artifacts do not make the basis of the Timber-Grave and Alakul metalcomplex. The most part of artifacts inherits the former local traditions of the MBA II. Moreover, technologies of ore smelting also follow from the Sintashta-Abashevo technological traditions. Therefore this situation can be considered as an internal development influenced by external impulses which have led to many technological and typological borrowings. Elunino and Seima-Turbino were the main bearers of these impulses. The first show themselves also in the presence of tin alloys with large impurity of lead that is characteristic, mainly, of the forest-steppe Alakul sites.

This tendency remains in the steppe zone for a long time. In any case, metallurgy of Sargari culture can be considered as a successor of the Sintashta-Alakul traditions. Here even such Sintashta type of metallurgical constructions as the furnaces attached to wells remains. Metallurgists smelted the oxidized ore from quartz rocks or the mix of oxidized and sulfide ore. The use of tin alloys remains too. Despite the limited analysed material, it is possible to claim that the Sargari metallurgy was not connected with Fyodorovka metallurgy which was based on smelting of sulfide ores.

In parallel with this line of development in the north of the region another process develops which has started in the east: it is the transition to smelting of sulfides, use of tin alloys, and transition to the corresponding methods of casting and forging, and types of artifacts. Above we have discussed this problem in relation to the Seima-Turbino and Elunino sites. However all this even to a greater extent was characteristic of the Fyodorovka metallurgy. In principle, for Northern Eurasia this was eastern phenomenon with its combination of smelting of chalcopyrite and other sulfides, and use of tin alloys. But the quantity of materials (slags and metallurgical furnaces) is too insignificant to outline accurately a circle of components which led to the rise of Fyodorovka metallurgy. Those materials which have been analysed, allow us to believe that it was based, mainly, on smelting of sulfides. Considering that the Fyodorovka people actively and everywhere penetrated the Alakul areas, in the long term it is not excluded that some other technologies with wider use of the oxidized ore will be found too. In particular it is possible in the areas where it was forced by the local ore base. Nevertheless, the ancestral line of this metallurgy was the smelting of sulfides.

Today it is difficult to tell surely, from where came this tradition. On the one hand we have seen its presence on the earlier sites of the region dated to the Seima time. However, some types of metal objects of Fyodorovka culture have southern parallels. They are present also in the ceramic complex and dwelling architecture (Grigoriev 1999, 2002). Therefore it is impossible to exclude some additional impulse led to formation of this metallurgical tradition. Today it is impossible to answer this question unambiguously. But, if to consider the problem only within Northern Eurasia, for this region it is, certainly, a phenomenon with eastern roots, and from the east this tradition spreads to the west through the forest-steppe zone interacting with Seima-Turbino tradition, and it leads to the rise of metallurgical traditions of Cherkaskul and Mezhovka, and also those of the Late Bronze Age cultures in the northern part of the Volga and Cisural areas (Suskan-Lebyazhinka, Prikazanskaya, Pozdnyakovo). And, in the materials of Prikazanskaya culture the Fyodorovka-Mezhovka tradition of ore smelting is recorded. Influence of this tradition to the south is also visible. In Alakul metallurgy it is expressed not so distinctly, only in the form of the occurance of some types of artifact. The same is true also for the Timber-Grave culture, but here we see also the penetration of tradition of smelting chalcopyrite.

At last, with some delay relative to the formation of Sargari culture and, respectively, Sargari metallurgy, in the east of the region the new transformation happened caused by the appearance of Karasuk, Irmen, Elovka and Begazi-Dandybay cultures. Above all, it shows itself in the northeast of the EAMP where transformations were so essential that they can be considered as a withdrawal from traditions of the EAMP and formation of the new Central Asian Metallurgical Province, CAMP (Chernykh 1978). Most distinctly it is noticeable by essentially new types of metal objects. But it was accompanied by transition to other type of alloys with arsenic, or use of the copper ores enriched with this impurity. Possibly, this alloying became possible for the reason that there was an inexplicable refusal of smelting sulfide ores and the use of oxidized ones. Smelting temperatures decreased too. It is possible to claim absolutely unambiguously that it was not a result of internal development of the production; otherwise we would see the further development of the technologies based on smelting of sulfides and use of tin ligatures. In a sense it is possible to speak not only about the complex transformation, but about a regressive transformation. Therefore, this complex was introduced from some other region together with migrating people.

It is not excluded that the formation of this complex influenced also the Sargari metallurgy as we see in it a sharp increase in the part of alloys with arsenic and antimony. But in this case it is unclear: why just this complex alloying at the preservation of tin alloys and the absence of proper arsenic alloys? This means that this aspect of the problem is absolutely unclear. But impulses of this tradition through the forest zone to the west, in the Western Urals are quite evident, where the tin alloys disappear in Maklasheevka culture, and the arsenic alloys appear.

Influences of the EAMP to the European Metallurgical Province

The processes described above had, probably, a much larger spatial extent, and involved not only Kazakhstan, the Urals and Eastern Europe, but they reached Central and Western Europe. At the beginning of the Bronze Age in Central Europe few artifacts alloyed with tin are known. The situation sharply changed only at the end of the Early Bronze Age (the Langquaid horizon, groups Veterov, Madjarovce) when this tradition of alloying spread widely, and artifacts contain already 6-12% tin. R. Krause believes that, judging from metal of Unĕtice culture, the tradition of tin alloys was introduced from the Balkans and Aegean Sea (Krause 2003, S. 213-215, 220, 221, 249, 265). But this tradition widely spread in the late Unĕtice period and was accompanied by new forms of metal alien to Unĕtice culture. I have written that during this period (BrA2) in Central Europe the artifacts occurred which went back to Seima-Turbino prototypes, and these changes were caused by coming of people from the east (Grigoriev 2002, p. 215). If to be exact, this time when the tin bronzes really widely distributed, BzA2b, is dated in system of the calibrated radiocarbon dates about 18th century BC (Gerloff 1993, p. 66, 83). And then these stereotypes started spreading throughout Europe. Thus, we see that although the tradition of tin alloys existed, its rapid development happened only after the coming of people with new tradition of metalworking and new types of objects.

It is indicative also that we deal, in this case, not only with diffusion of some types of article and alloys. We remember that it was connected also with essential changes in metalworking technologies. However in the same time in Central Europe smelting of chalcopyrite appeared. In particular, it is reliably established that in the Late Bronze Age chalcopyrite was smelted on the well-known mines around Mitterberg in Austria (Tylecote 1987, p. 129). Probably, the transition to smelting of primary sulfide ores, with an optimal ratio of acid and basic oxides and with higher temperatures which everywhere accompanied the chalcopyrite smelting, made possible the subsequent technological transformation: the tapping slag from the furnace. So, it is supposed that on the settlement of Mühlbach in Mitterberg the slag was tapped though it is based only on its form (Herdits 2003, p. 69, 70).

All these innovations extend also further to the west. With formation of Armorican culture of Brittany and Rhône culture in South-Eastern France the technologies based on the tin alloys spread there. It is supposed that it can be considered as penetration of a very developed culture with hierarchical society (Strahm 2005, p. 26). But it was also accompanied there by emergence of the metal artifacts succeeded, eventually, to the Seima-Turbino tradition (Grigoriev 2002, p. 219). It had its continuation also further: tin bronzes started to be actively used in this period in Ireland and Britain (O'Brien 2005, p. 37; Craddock, Craddock 1996, p. 52). But it is not excluded that the first use took place here a century earlier.

As we see in Central and in the most part of Western Europe a complex transformation (change of raw materials, smelting technology, alloys, technologies of metalworking, and types of objects), it is possible to believe that this transformation really had the concrete bearers, although it can be imaged as an internal development too.

An example of the latter is, as though, a situation in Northern Italy where a quite standard technological sequence is observed: from the use of pure copper, to arsenic copper, further to the copper with arsenic, antimony, silver and nickel smelted from fahlores, and further to tin bronzes. The copper with arsenic and antimony from fahlores appeared at the beginning of the EBA I (2077-1992 BC according to dendrochronology) together with the formation of Polada culture. Since the phases B-C (2000-1800 BC) low-tin bronzes started being used more often, and since the EBA II the tin bronzes containing up to 8-10% tin (De Marinis 2005, p. 249, 250). At first sight, this logical sequence can indicate an autochthonic evolutionary development of the production even if the first stage in this chain was stimulated from the outside. However the formation of the Polada culture was accompanied by impulses from Central Europe (Hungary). And at the transition to the following phase destruction of settlements, appearance of artifacts comparable with those of the Veterov group and Unětice culture are fixed that marks coming of people from the north, from Central Europe (Grigoriev 2002, p. 278).

But obviously the changes here were also not limited only to the application of tin alloys. In Liguria the tin bronzes were known in the Early Bronze Age (2000-1600 BC), but during this and earlier periods evidences on smelting ores are absent. When they appeared in the Middle Bronze Age complexes it is accompanied by traces of mining of sulfide ore, and pieces of tin on settlements that points to the alloying of metal tin with metal copper (Delfino 2008, p. 234). Earlier we have already discussed the conditions under which the alloying with metal tin could be invented.

Not always we deal with a full transformation of the whole complex, many earlier traditions often remains. In Iberia already in the Middle Bronze Age the tin is sometimes present in slag (for example, up to 1-2% in slag from the MBA layer of the settlement of El Llanete de los Moros), but it is also present in metal, and, in some cases in higher concentrations (8-9, 13.5 and 17.5%). Thus, we deal with undoubted tin bronzes although at this time the arsenic bronzes dominated. And though then, in the Late Bronze Age, the tin alloys are known here, arsenic alloys continue to be used. Other progressive innovations of the epoch have been also noted. On the settlement of Chinflon of this period the smelting was carried out in small furnaces without slag tapping (though the slag had fayalite composition and therefore its viscosity was low); arsenic impurity is revealed on crucibles and in metal artifacts (Hunt Ortiz 2003, p. 332-334, 352-355). Therefore here we deal more likely with the borrowing of innovations from neighboring areas, although it is not excluded that a more detailed territorial analysis is simply necessary, as some other innovations which had appeared before in the east and in Central Europe are noted here. In particular, in the Late Bronze Age chalcopyrite was mined in the province Huelva in South-West Spain (Rothenberg, Freijeiro 1980, p. 45).

Smelting of chalcopyrite in the LBA becomes the widespread phenomenon. In Serbia many slag heaps are known, but the majority of them is not dated and belongs probably to the latest time. Definitely relating to the LBA are heaps of slag around Trnjane dated to the period of 1300-1100 BC. The slag contains chalcopyrite, cristobalite, magnetite, long crystals of fayalite, characteristic of the fast cooling, and almost total absence of copper. On the basis of the slag analysis a conclusion is drawn that sulfide ores (covellite, partly chalcopyrite) were melted here (Krajmović *et al.* 1990, p. 64).

Thus, everywhere from the Atlantic coast of Europe to the Altai we can see similar innovations in the metallurgical production. Relative synchronism of these innovations and their comparability do not allow us to consider them as phenomena which were completely isolated from each other. It is more reasonably to consider them within a single process that had been started in the east.

Influences of the EAMP on the development of metallurgy in Eastern and South-Eastern Asia

Rise of metallurgy in China

One of the major problems in archaeometallurgy is determination of a role which was played by metallurgy of Northern Eurasia in the rise of metallurgy in Eastern and South-Eastern Asia. There are two main points of view. According to one of them, the most accepted, the Chinese metallurgy originated from influences of the western steppe tribes. But lately among Chinese archeologists an opinion have been formulated on local origins of metallurgy on the Central Plain or in Gansu, from where it spread in other areas of China (for more details see Lin Yun 1991, p. 77; Mei 2003, p. 33, 38; Mei, Li 2003, p. 111, 112; Linduff, Mei 2008, p. 6, 11, 12; Mei *et al.* 2012, p. 36). Unfortunately, the situation is complicated by that the intermediate territory of Mongolia is investigated insufficiently.

Last years some cultures of the Bronze Age have been discovered here which can be compared with cultures in Northern Eurasia. Presence of Afanasievo sites in the northwest, in the Mongolian Altai, is quite expected. To the south, within Dzungaria, spurs of the Mongolian Altai and in the north of Xinjiang (where the eponymous site is situated) the Chemurchek culture has been studied. Its date is within 2800-1800 BC. This culture is characterized by large rectangular stone funeral constructions, the earliest bronze and lead objects, vessels comparable with those of Elunino; and in the cemetery of Chemurchek a casting mould for a celt-shovel is found. For the ceramics both Repino (pre-Pit-Grave) and North Caucasian parallels have been suggested, and it is supposed that the funeral constructions, anthropomorphic stelae and some ceramic types have analogies among megalithic complexes in Western France that allowed a conclusion to be draw about the migration of people from there and their participation in the formation of Seima-Turbino metallurgy (Kovalev 1999, S. 151-171; Kovalev 2005, p. 178-184; Kovalev 2011, p. 11-16; Kovalev 2012, p. 60, 61; Kovalev, Erdenebaatar 2007, p. 80; Erdenebaatar, Kovalev 2009, p. 71-75). Certainly, it was some alien phenomenon from the west, but parallels in the European megalithic complexes are not enough reliable. As a rule, they are based on quite simple and widespread forms. Any specific parallels are absent yet. Therefore at this stage this connection cannot be accepted, but it is impossible to reject it unambiguously. The found stelae really have strong similarity with stelae in France, but they have some similarity also with the Eneolithic stelae in the North Pontic area. Available dates are rather late: the middle and second half of the 3rd millennium BC wich quite corresponds to the Elunino inclusions in the Chemurchek complexes (Kovalev 2011, p. 4-6, 14; Kovalev 2012, p. 61). It calls into question both European megalithic and Repino parallels.

Similarly, until essential accumulation of materials will be happen and its internal chronology will be made, it is difficult to speak about a role of this culture in the formation of Seima-Turbino metallurgy as any similar parallels can be dated to its later period and reflect contacts with the Elunino people.

The subsequent culture of the Bronze Age in Western Mongolia, Munkh-Khayrkhan (1700-1300 BC), contains funnel-shaped earrings of Fyodorovka type; the cultures of Baytag (12-10th centuries BC) and Tevsh in the Gobi Altai (13-10th centuries BC) contain objects of the Karasuk types, and it is supposed that in China the objects of this type belong just to these cultures (Kovalev, Erdenebaatar 2007, p. 80-83; Erdenebaatar, Kovalev 2009, p. 71-78). It is quite logical. Contacts with China were carried out through the Mongolian territory, instead of directly from Southern Siberia.

Unfortunately, metal in Mongolia is studied poorly, and there are no finds of slag as here, mainly, burials are excavated. It weakens a possibility to compare materials from Northern Eurasia and China. Nevertheless, some efforts in this direction have been made. In any case, due to the comparison of materials from Xinjiang and Gansu with those from Siberia and Eastern Kazakhstan we have an opportunity for synchronization of these complexes. However, no Afanasievo influences have been identified in China, and all reasonings about them have no ground (Kovalev 2004, p. 264). The data provided sometimes about the Afanasievo connections are based not on comparisons of metal and ceramics, but on similarity of burial constractions in North-Western China (Mei 2003, p. 39). And therefore they have rather indirect character. There are also no enough opportunities for comparisons with Okunev culture with the exception of tin bronzes in the latter, but this characterizes already the late phase of the culture, and can be considered as Elunino feature, for example.

But already since the Late Bronze Age (according to the North Eurasian chronological system) when the contacts appeared, it is possible to speak about synchronization of these or those complexes. As a result of the carried-out analysis (Bekhter, Khavrin 2002) this scheme looks as follows. Seima-Turbino and Petrovka sites correspond to the first legendary Chinese dynasty the Hsia; and the written sources ascribe to this dynasty already developed casting technologies. On the Central Plain, in the Huang Ho basin, this dynasty is archaeologically identified with the Erh-li-tou period. The culture was replaced by the historically quite authentic Shang dynasty presented by the periods Erh-li-kang and Yin. Then it was replaced by the Western Zhou dynasty (Lin Yun 1991, p. 76). According to the discussed scheme, the Erh-li-kang period correspond to the post-Seima sites, like the Rostovka cemetery and Alakul culture; and the Yin period was contemporary to Karasuk, Sargari and Begazi-Dandybay cultures although their final part, as well as Lugavskaya culture, correspond to the period of Western Zhou.

From the point of view of absolute chronology, these periods are dated as follows: Erh-li-tou –1900-1600 BC, Erh-li-kang –1600-1300 BC, Shan-Yin –1300-1045 BC (Pigott, Ciarla 2007, p. 77).

Running ahead, it should be noted that, no doubt, Northern Eurasia made essential impact on metallurgy development in China. It might be testified by a set of facts which will be discussed below. Nevertheless, there are individual early finds of metal objects which are beyond this scheme and therefore they cause essential objections as doubtful. In the chapter about Sintashta slags an early find of brass in China has been mentioned. There is a knife made of tin bronze (province Gansu) dated to about 3280-2740 BC (Lin Yun 1991, p. 78). But there are no copper objects in China dated before 3000 BC, and it is only four objects found dated to the 3rd millennium BC. And, even if not to consider single and, probably, doubtful objects of Yangshao culture (4400-2500 BC), early articles are known in the east, in the provinces of Henan, Shandong and Inner Mongolia, in the context of Longshan culture (2600-2000 BC). And, because there are no metal objects dated before 2000 BC in Xinjiang, it is difficult to discuss the influence from the west through this region (Mei 2003, p. 38; Mei, Li 2003, p. 112, 114; Wang, Mei 2009, p. 383). Of course, it could be realized also not through Xinjiang, but to the north. However the weak study of Mongolia and also the presence of yet unclear Chemurchek culture force us to be cautious in the problem of the earliest phase of Chinese metallurgy.

But the western impulses are well visible in its further development. First of all, this problem is connected with the Qijia culture (*ca*. 2500-1900 BC) in the provinces of Gansu and in the west of Shanxi. It is very remarkable area. In the west and north it is separated by mountains and deserts, there is a corridor which connects the Central Plain with the Altai. There are not only copper artifacts in this culture, but also artifacts with lead and tin impurities (Linduff, Mei 2008, p. 6-8). Sometimes these alloys are considered as natural (Lin Yun 1991, p. 78), but this type of alloy was also present at this time in metal of Elunino culture, and above we have discussed the same alloy in Iran. It is also interesting that this alloy has been revealed together with tin bronzes in the cemetery of Xsiaohe in eastern Xinjiang, and in Gansu places of ore smelting have been found. Study of slag from one of these places (Houshiliang) has identified a sulfide phase together with iron oxides and silicates. Generalization of data of this culture (there are already more than 100 metal artifacts from its sites) has allowed a conclusion to be drawn that objects from pure copper were present in the early phase of Qijia culture, and then tin alloys appeared which coexisted with arsenic bronzes presented very modestly. It is supposed that it is a justification of the old theory about contacts with ‘steppe’ and Seima-Turbino tradition of metalworking (Mei 2003, p. 31, 34; Mei *et al.* 2012, p. 37-41). It is duplicated by presence of both one-fold and bi-fold casting moulds, and also by cast sockets (Pigott, Ciarla 2007, p. 80). We can state even more concrete assumption although it does not cover early phases of the culture. The appearance of tin bronzes and alloys with lead, and also the beginning of smelting of sulfide ores have Elunino parallels, but against the background of weak study of early metallurgy in Central Asia it is necessary to be cautious. There are also other dates of the beginning of Qijia culture (*ca*. 2200 BC) (Pigott, Ciarla 2007, p. 80), but all the same it is earlier than the beginning of Elunino culture and Seima-Turbino bronzes. Therefore it is not excluded that the rise of metalworking of this culture was initialyl influenced by the late Afanasievo culture or some other cultural complex. However, now earlier Elunino complexes have been found, but so far they are insufficiently studied (Grushin 2013).

The last years in eastern Xinjiang and in the west of Gansu the Siba culture dated since the early 2nd millennium BC has been discovered. It is supposed that exactly it mediated between Seima-Turbino metallurgy and metallurgy of Qijia. Original types of artifacts also occurred; and a complicated system of interregional interaction formed. Now about 270 metal artifacts of this culture are already known which show typological connections with the ‘steppe’. Raw materials for their manufacturing were both tin and arsenic alloys. It is sometimes supposed that the arsenic alloys demonstrate the connection with Seima-Turbino metallurgy (Mei 2003, p. 36-38), but in the latter these alloys were typical only far in the west, and were connected probably with the Sintashta-Abashevo production. Therefore more probable is the subsequent conclusion that arsenic alloys of this culture were based on local copper ores with natural arsenic impurities from deposits in the Gansu province (Linduff, Mei 2008, p. 8). But irrespective of the raw material, the problem of origins of the tradition remains as it is connected also with other technologies of metalworking.

And only after these processes the developed metallurgy appeared in the east, in the Central China of the Erh-li-tou period. Here alloys with arsenic are present already seldom, usually as impurity to tin alloys, alloys with tin dominate, and alloys with both tin and lead are also known. The last alloys were also used more often for complicated castings of vessels which were stimulated by the stratified society which had arisen here, and metal started acting in these societies as a symbol of power and wealth. The subsequent development in the period of the Shang dynasty is expressed in disappearance of arsenic impurities and wider distribution of tin alloys. Tin-lead alloys remain too. But the articles become really mass. Actually, concerning this metallurgical tradition researchers have no special doubts; its connection with Seima-Turbino is confirmed by both types of alloys and types of artifacts (Lin Yun 1991, p. 79; Pigott, Ciarla 2007, p. 80; Linduff, Mei 2008, p. 5, 10-13; Wang, Mei 2009, p. 383). But it is not fully clear: whether was it a direct Seima-Turbino influence or a chain “Elunino – Siba – Qijia – Erh-li-tou” is more correct. As though, the last possibility is specified by a slightly earlier appearance of tin alloys in Siba and Qijia, and also the presence of tin-lead alloys.

Soon metallurgy spread into the central part of Inner Mongolia (Zhukaigou culture), to the north of the province Hebei and the east of Inner Mongolia (Lower Xiajiadian culture); and scholars note the presence of Andronovo and Karasuk parallels. The presence of Andronovo parallels here is not quite explainable, taking into account a distance to eastern frontiers of this culture. Nevertheless, it is more probable to assume that metallurgy penetrated here from the Huang He Basin. The production spread also to the east, to Shandong, where metal appeared in Yushi culture (Linduff, Mei 2008, p. 8).

Thus, in China for the earliest sites of the 3rd millennium BC owing to scarcity of data it is impossible to determine a source of the rise of metallurgical production, although it, certainly, existed, but very weak. But the flourishing of metallurgy in the region was obliged to coming of the Seima-Turbino tradition, and, at a rather early stage. Originally metallurgy arised in the east of Xinjiang and in Gansu, then the middle course of the Huang He, and then rapidly developes thanks to the advanced societies and already quickly enough spreads to the northeast, east and southeast.

In the late 2nd and 1st millennia BC China becomes interesting to us again taking into account the North Eurasian problems. Above we have discussed that during the Final Bronze Age the alloys with tin disappeared in Southern Siberia, and they were succeeded by arsenic alloys that was characteristic of Karasuk culture. Despite the frequent presence of typologically close bronzes in Northern China, and in some instances even in Central China, similar changes have not been recorded there. But they are notable in North-Western Xinjiang, near the border with Kazakhstan. Here in the early 1st millennium BC ones actively produced arsenic bronzes by smelting of copper sulfides together with some alloying arsenic mineral. The produced matte contains copper, arsenic, iron, lead and sulfur. In general, it corresponds to those processes which took place in the north, but there the oxidized ores were smelted. Therefore it is not excluded that there was some further development of the technology that is quite admissible taking into acount relatively later character of the samples. It is supposed that smelting was carried out at first to produce matte, and then the matte was smelted together with an alloying component. Smelting of sulfides about 1000 BC is recorded in Xinjiang (Mei 2003, p. 44; Mei, Li 2003, p. 111-118). It is difficult to tell how it corresponds to the Karasuk smelting traditions. So far we know about the latters not enough. It is impossible to exclude also some variants of alloying with speiss that has been discussed in this book by the example of Iran. But it is obvious that the tradition of tin alloys disappeared here, as well as in Siberia. It remains to the east where in the Western Zhou period (1027-771 BC) the tin dominated (Wang, Mei 2009, p. 383).

Thus, if we consider only the situation in Gansu and on the Central Plain, we see (apart from poorly presented metallurgy of the pure copper which obviously existed earlier) a drastic bloom of metallurgy based on tin alloys. It also forces all scholars to believe that the metallurgical production came to China from the outside in already developed state (Roberts *et al.* 2009, p. 1016). But if we consider also Xinjiang, we receive a quite turned situation when more archaic arsenic alloys revive. And these alloys are produced by intended alloying, instead of from ore with arsenic impurity as it took place earlier.

But this situation is paradoxical at first sight only. It accurately corresponds to similar processes which at the same time happened in Northern Eurasia. And it indicates the undoubted connections of these regions during at least 1000 years. And, these connections, being composite (type of alloys – typology of artifacts), were apparently rather complicated when, along with long interactions, rather fast penetrations over a large distance took place. It is not excluded that the latter shows itself also in South-Eastern Asia.

Formation of metallurgy in South-Eastern Asia

Now the standard point of view is that the metallurgical production was introduced to Vietnam and Thailand in already developed form in the middle of the 2nd millennium BC from the Hunan province in the southwest of China where it got from the Yangtze. In turn, the production in the Yangtze basin was formed by influences from the Huang He (Erh-li-tou – Erh-li-kang), and, eventually, this development was connected with Seima-Turbino metallurgy. In Thailand it is confirmed by tin alloys and production of cast socketed spearheads and celts from the very beginning. And, scholars suppose that it was not influence, but a migration when the people came, who were able to find and smelt ore in crucibles or small furnaces and to alloy copper with tin. This date is also proved by that the socketed artifacts were not so typical for the Erh-li-tou period as for the Erh-li-kang period (Pigott, Ciarla 2007, p. 76-84).

It is a quite logical picture, but recently its essential changes have been suggested as detailed studying of stratigraphy of metallurgical complexes in Thailand and a series of radiocarbon dates have allowed some scholars to assume earlier dates of the existence of early complexes of metal with sockets cast from tin bronzes in Thailand –2000-1700 BC which was contemporary or even slightly preceded the formation of this metallurgy in the Huang He basin. Moreover, technological and typological differences of Thai objects from those in China and their close proximity with proper Seima-Turbino objects have been shown. Therefore a conclusion has been drawn a about rather prompt migration from the Altai to the south, that went by the Huang He basin (White 2006, p. 91-98).

It cannot be regarded as completely proved because in the conditions of monsoonal climate and active growth of plants there could be problems, both with the stratigraphy, and with the radiocarbon analysis. Besides, studies of a smelting place of Non Pa Wai (500-300 BC) have revealed the unskilful and unstandardized smeltings of oxides and in some cases of sulfides in crucibles. Losses of copper decrease during the next period (300 BC – 500 AD) when sulfides start being used more actively, and the smeltings become more standardized which has been recorded by excavations of the settlement of Nil Kham Haeng. Therefore the authors of this research ask: why this primitive technology remains 1000 years later, after the appearance of metallurgy in the region? (Pryce *et al.* 2011, p. 147-158).

But this question is not absolutely true as in new conditions not only the preservation of old technologies could take place, but also their degradation. However for our subject it not so essentially as this discussion concerns only the concrete time and a way of the spread of metallurgy in South-Eastern Asia. But there are no special doubts that this process was begun within the initial phase of the Eurasian Metallurgical Province.

Socio-economic aspects of the production

During the Late Bronze Age essential changes in the nature of metallurgical production happened. Above all, the production significantly extends territorially: it is presented in all areas with available copper ore sources, and the range of used ore increases. Bisides, volumes of mining production in different areas increase considerably. It is rather difficult to estimate them; therefore we have discussed that the volumes of ore extraction on the Kargaly mines are greatly overestimated. However there are no doubts that they were considerable. Large volumes of mining are noted also for the Donetsk and Voronezh regions.

Unfortunately, there were no attempts to calculate the volume of mining on the Altai deposits, but for Central Kazakhstan such calculations have been made. "According to the calculations of G.N. Shcherba on deposits of Central Kazakhstan prior to industrial mining in the 19th century about 10 million tons of ore were extracted from which 450 thousand tons of copper were smelted. According to the calculations of S. Ball, and then K.I. Satpaev, in Dzhezkazgan in the antiquity it was got over 1 million tons of ore containing not less than 10 thousand tons of copper. Volumes of the extracted ores and the scales of metallurgical production exceeding many times the need of inhabitants of Sary-Arka, testify to the existence of metal export in the ancient time" (Margulan 2001, p. 75). A part of this production was made in the Middle Ages, probably, the calculated volumes are overestimated, but there are no doubts that they were enormous, and incomparable with the production in western areas of the Eurasian Metallurgical Province.

The commodity nature of the production is testified also by discovery of large ingots of rough copper weighing from 1 to 5 kg (Margulan 2001, p. 65).

In comparison with the Middle Bronze Age the change in localization of metallurgical sites is evident. If near the settlements of Sintashta culture mines have not been found, Andronovo settlements with traces of ore smelting in most cases are situated near mines. Besides, large slag heaps near mines are known in areas where settlements are not recorded. Partly it was connected with that the inspections of the mines have been carried out by geologists who were not able to find ancient settlements. But a part of such heaps is noted in places inconvenient for usual settlements. It means that there were specialized settlements of miners and smelters. Actually, it characterizes the production of this epoch also in Eastern Europe where specialized settlements have been excavated: Gorny in the Cisural area and a number of settlements of the Donetsk and Voronezh areas.

Similar specialization existed not only in the mining and smelting of ore that was caused, above all, by irregularity in distribution of deposits, but also in the metalworking. It is quite difficult to estimate it too, but the Mosolovka settlement with its abundance of casting moulds indicates it unambiguously.

It is hard to say what served as reasons of the appearance of this specialization besides the irregularity in distribution of ore sources. More complicated casting and forging operations demanding the specialization was probably one of the reasons. We also see the transition to more difficult and various ores in the ore smelting, therefore the need for special knowledge increased. But the changes took place also in the mining. The known today mining places of the Middle Bronze Age are presented by open pits, and those of the Late Bronze Age in different areas are presented by open pits and mines, and, in some cases, very deep. And it, of course, required significant professional knowledge in comparison with the open-pit mining. Thus, a natural process of technological development and complication of all operations of the technological chain was at the heart of the specialization.

An important role was played by tin supply. It is a rare raw material, and it was transported over large distances that led to development of the exchange relations.

It is not also excluded that during this period the society was subjected to some social shifts which promoted these changes, but it is impossible to estimate them within this work.

Nevertheless, as a result of all these processes huge territories were involved in the trade operations and there were specialized communities of metallurgists.

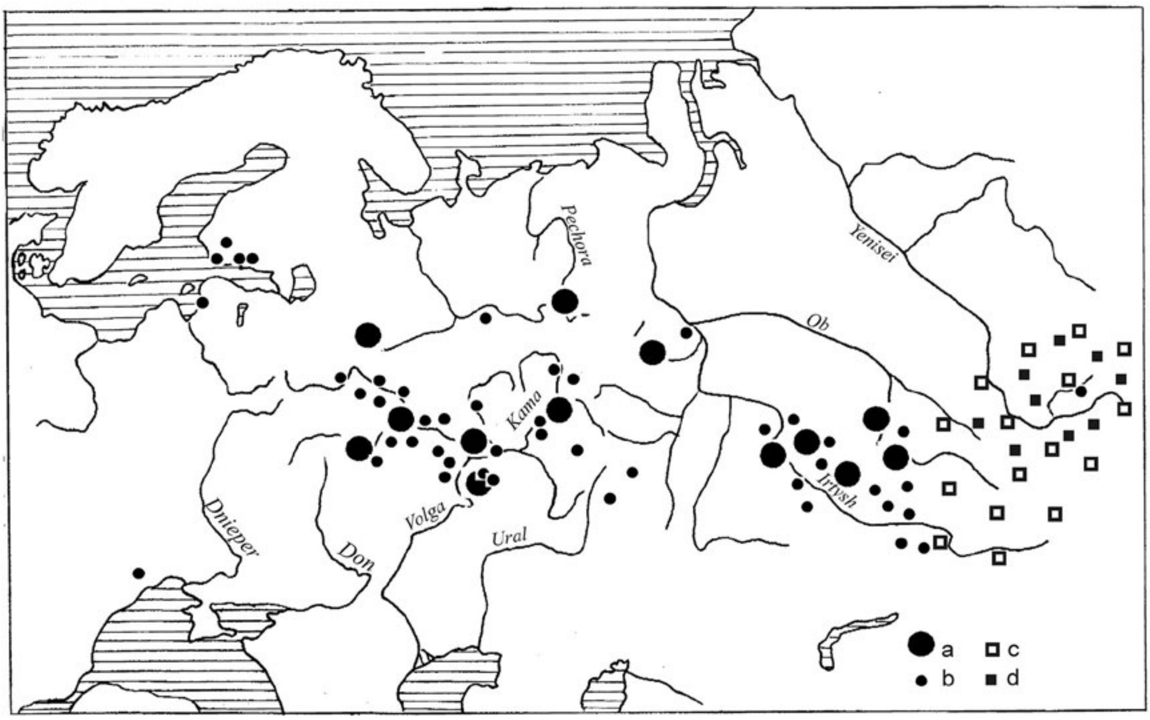


FIG. 11-1. MAP OF THE SEIMA-TURBINO SITES (A – CEMETERIES; B – SINGLE FINDS) AFANASIEVO (C) AND OKUNEV (D) CULTURES.

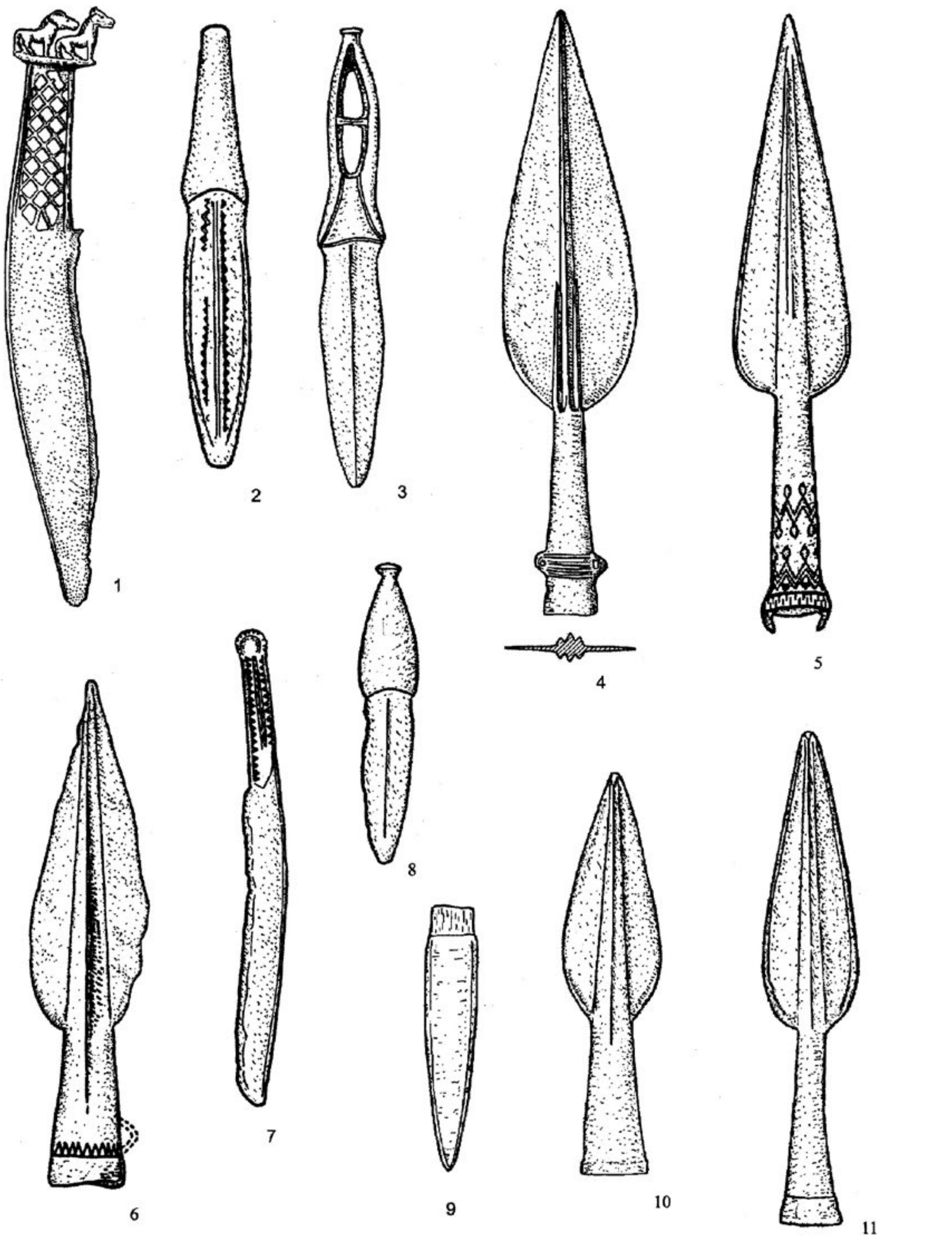


Fig. 11-2. Seima-Turbino artefacts: 1, 6, 9 – Seima; 2 – Irbitskoe; 3 – Novo-Pavlovka; 4 – Rostovka; 5 – Borodino hoard; 7 – Cigankova Sopka; 8 – Novaya Usman; 10 – Krivoe Ozero; 11 – Panovo.

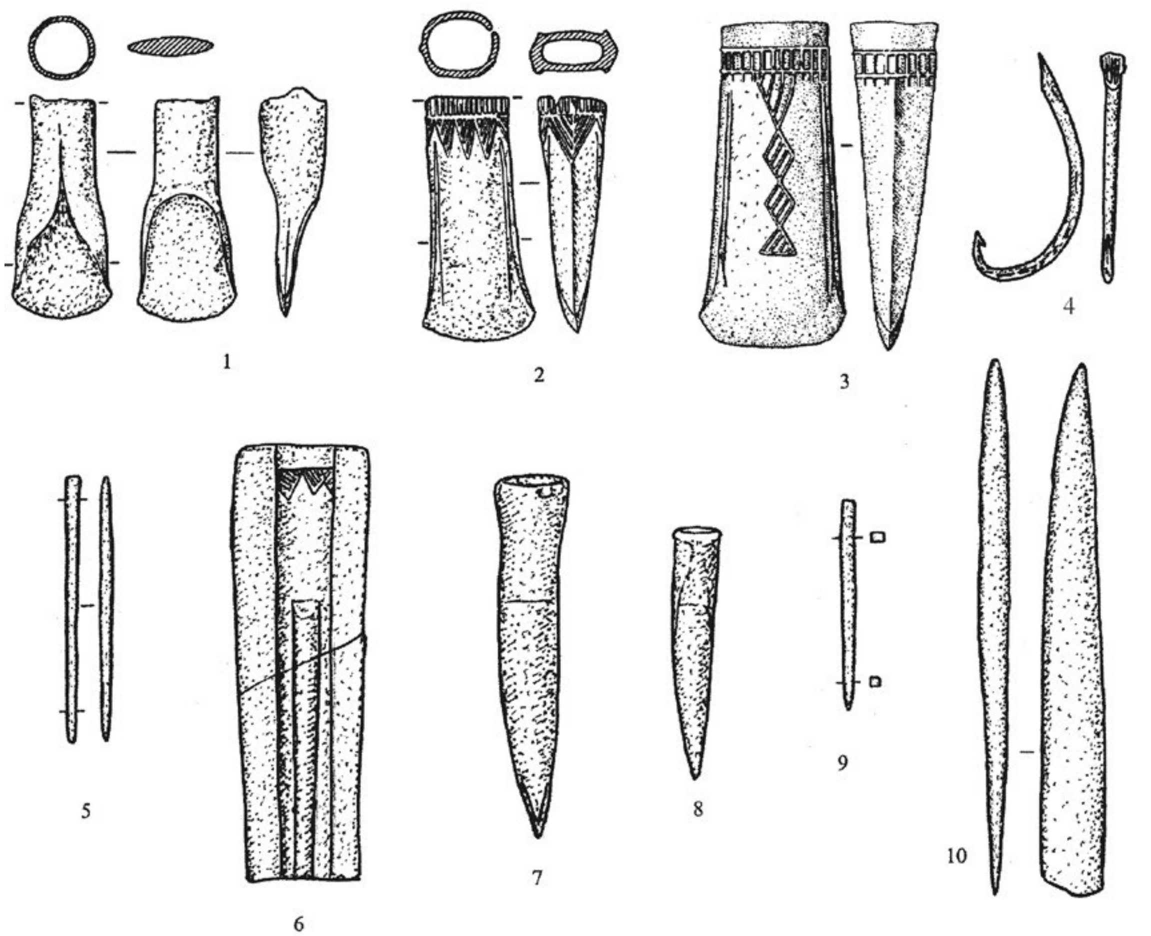


FIG. 11-3. SEIMA-TURBINO ARTEFACTS. 1, 2 – SEIMA; 3 – RESHNOE; 4, 6-8 – ROSTOVKA; 5, 9 – TURBINO I; 10 – SOKOLOVKA.

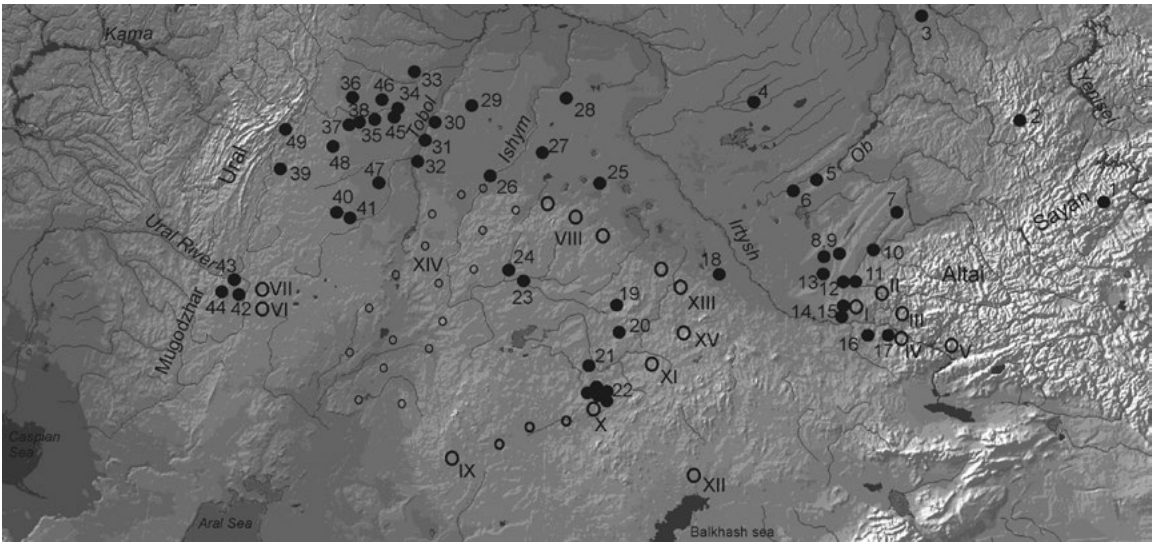


Fig. 11-4. Settlements and ore deposits in Southern Siberia and Kazakhstan mentioned in the text: Settlements: 1 – Kargy; 2 – Poselshchik; 3 – Novokuskovo; 4 – Markovo-2; 5 – Burla-3; 6 – Kaygorodka-3; 7 – Berezovaya Luka; 8 – Kalinovka II; 9 – Chernaya Kurya VI; 10 – Kolyvanskoye I; 11 – Novenkoe-6; 12 – Sovietsky Put'-1; 13 – Rublevo VI; 14 – Chekanovsky Log-I; 15 – Gilevo-II; 16 – Novoshulbinskoye; 17 – Chisty Yar; 18 – Kafarka; 19 – Vishnyovka; 20 – Ust-Kenetay; 21 – Kent; 22 – settlements in the Atasu area (Atasu, Akimbek, Ak-Maya, Ak-Moustapha, Kara-Tybe, Myrzhik); 23 – Telmana XVI; 24 – Sargari; 25 – Stepnyak; 26 – Petrovka II; 27 – Pavlovka; 28 – Novonikolskoye; 29 – Kamyshnoye; 30 – Yazevo; 31 – Verkhnyaya Alabuga; 32 – Ubagan; 33 – Korshunovo; 34 – Tashkovo II; 35 – Kipel; 36 – Graurtly; 37 – Mochishche; 38 – Korkino; 39 – Ilyaska; 40 – Bersuat XVIII; 41 – Atamanovka; 42 – Kupukhta; 43 – Baytu; 44 – Shandasha; 45 – Malookunevskoye; 46 – Novoburino; 47 – Nikolaevka; 48 – Arkhangelskii Priisk II; 49 – Novo Bayramgulovo. Mines and deposits: I – Zmeinogorsk group of deposits; II – Kolyvanovskaya group of deposits; III – Charysh-Anuy group of deposits; IV – Irtysh group of deposits; V – Zyryanovsk group of deposits; VI – Ushkatty; VII – Elenovka; VIII – Kokchetav deposits; IX – Dzhezkazgan; X – Kenkazgan; XI – deposits of the Uspensk-Spassk area; XII – deposits of the Balkhash area; XIII – deposits of the Ekibastuz-Bayanaul area; XIV – copper sandstones of the Atbasar-Tersakkan area; XV – Kargaly mines.

Tab. 11-5. Forms of slag of the settlement of Berezovaya Luka.

Heavy flat slag	**Light flat slag**	**Heavy shapeless slag**	**Other**
7 14.9%	2 4.3%	34 72.3%	4 8.5%

Tab. 11-6. Bulk chemical analyses of slag of the settlement of Berezovaya Luka (weight %). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

№	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	MnO	Cu	SO_3
2037	72.74	2.82	20.33	2.61	0.61	0.50	0.17	1.63	0.08
2044	69.68	11.54	6.78	4.05	1.43	3.20	0.15	0.46	0.11
2048-1	63.92	18.67	6.36	1.74	1.43	2.99	0.07	0.15	0.09
2063	61.78	2.81	27.84	3.48	0.82	0.60	0.25	3.34	0.12

Tab. 11-7. Coefficients of basicity of slag of the settlement of Berezovaya Luka.

Sample	Coefficient of basicity	Group
2063	0.51	acid
2037	0.32	ultra-acid
2044	0.19	ultra-acid
2048-1	0.15	ultra-acid

Tab. 11-8. Coefficients of viscosity of slag of the settlement of Berezovaya Luka the temperature of 1400ºC.

№	K_z	η **1400** (Pa·s)
2048-1	0.16	31.09
2044	0.20	24.15
2037	0.34	13.83
2063	0.56	8.23

Tab. 11-9. Mineralogical groups of slag of the settlement of Berezovaya Luka.

II	IV	Ceramic slag	Total
26 62%	4 9.5%	12 28.5%	42 100%

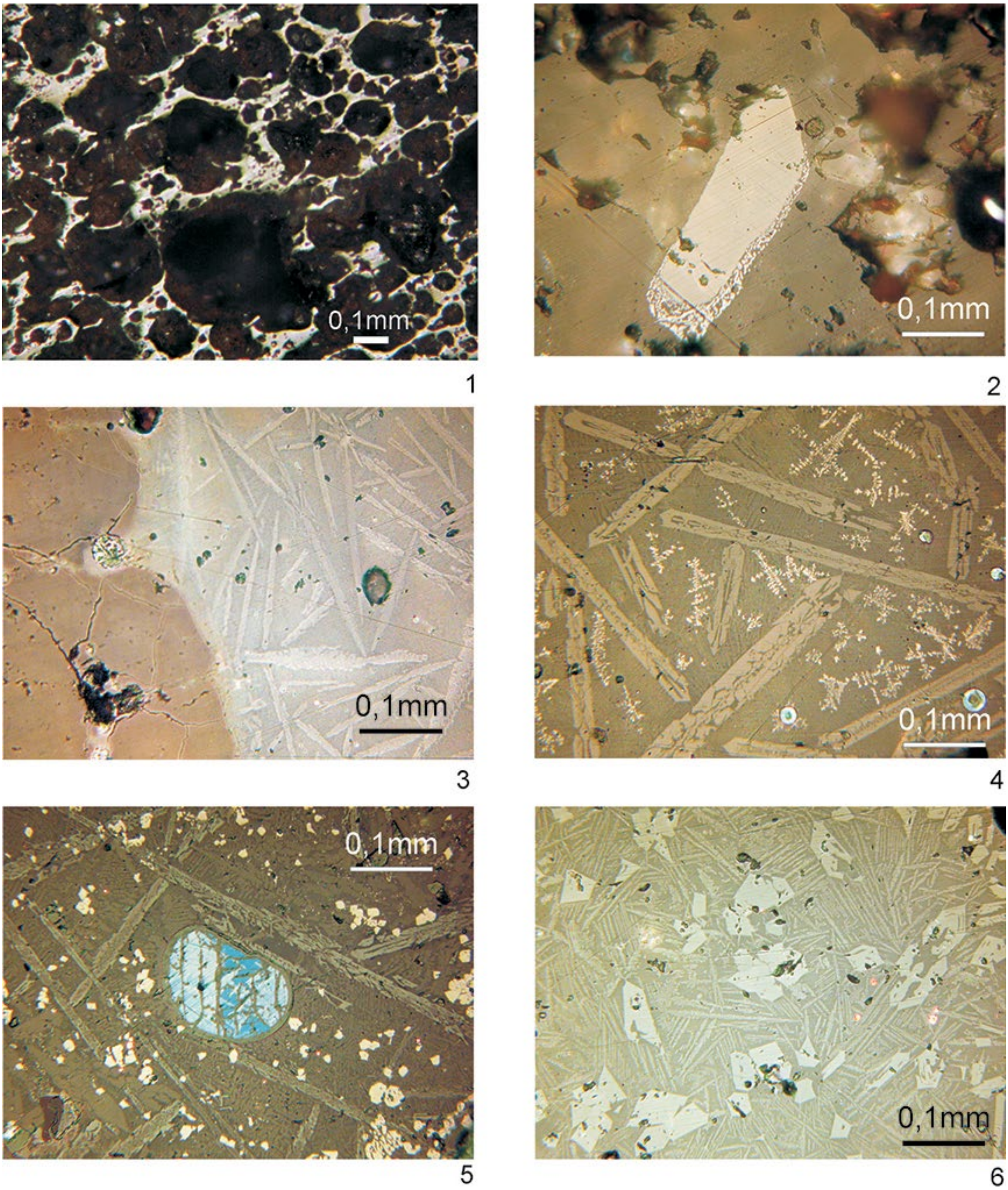


Fig. 11-I. Microstructures of slag of the settlement of Berezovaya Luka, reflected light: 1 – Sample 2043, pores (dark) in the ceramic matrix. 2 – Sample 2068, grain of chromite in the ceramic glass. 3 – Sample 2059, fused quartz grain (light brown on the left) in the silicate glass (on the right) with growing needles of olivine (light inclusions). 4 – Sample 2093, needle-shaped and long prismatic skeletal crystals of olivine and thin dendrites of magnetite (light) in the glass matrix, small oxidized copper prills. 5 – Sample 2094, needle-shaped and long prismatic skeletal crystals of olivine and small octahedral of magnetite (light) in the glass matrix, large globule of covellite (anisotropic effect is well visible: light-blue and dark-blue colors of the grains). 6 – Sample 2070, needle-shaped and prismatic crystals of olivine in the glass matrix, small prills of copper.

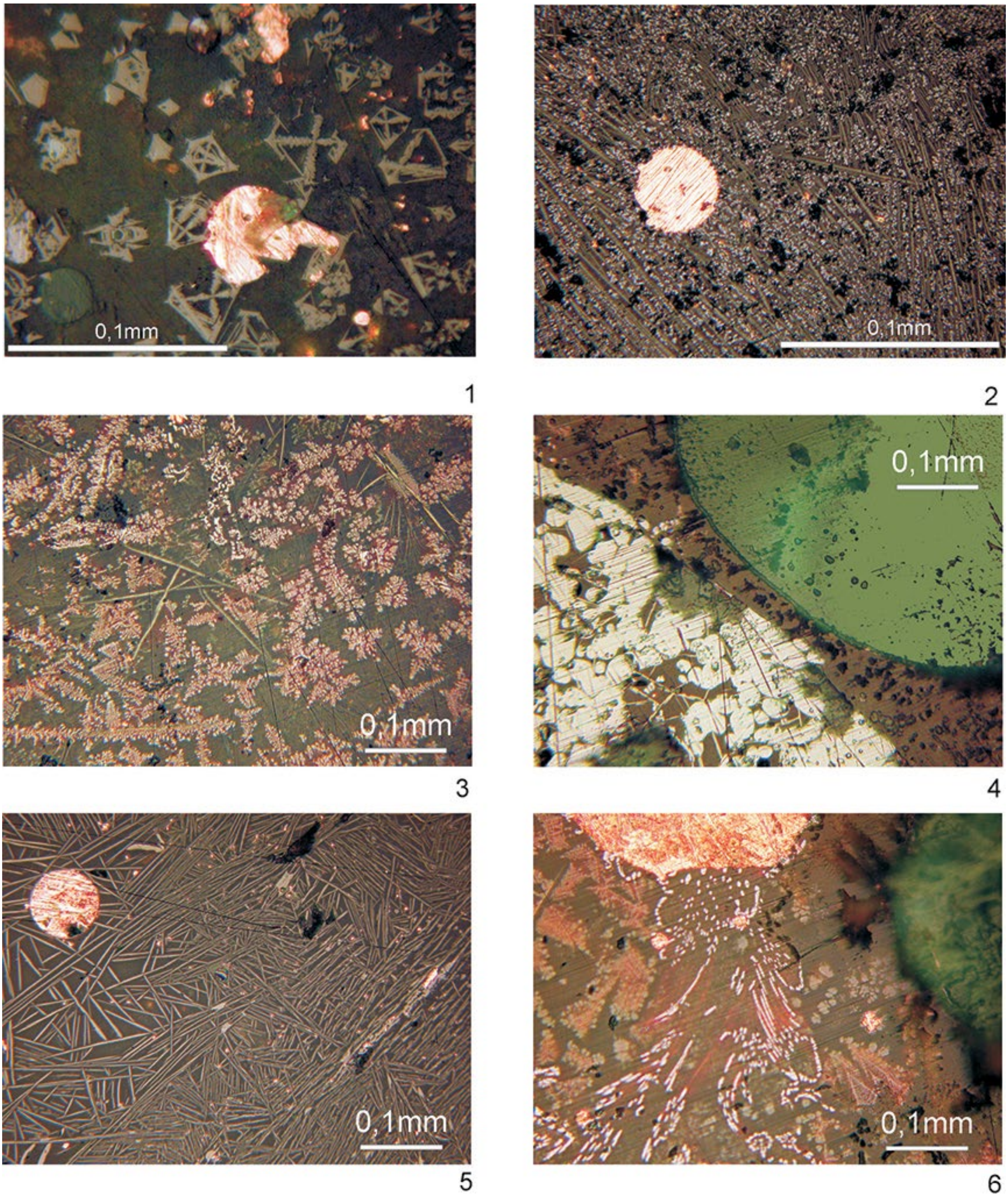


Fig. 11-II. Microstructures of slag of the settlement of Berezovaya Luka, reflected light: 1 – Sample 2069, skeletons and octahedral of magnetite in the glass matrix, copper prills, a globule of malachite below on the left. 2 – Sample 2054, needles of delafossite, small dendrites of cuprite (light) and copper prills. 3 – Sample 2060, needles of delafossite and dendrites of cuprite in the glass matrix. 4 – Sample 2060, fused malachite grain (on the right) and molten inclusion of cuprite (on the left) in the glass matrix. 5 – Sample 2064, needles of delafossite and copper prills. 6 – Sample 2060, malachite grain (on the right), large globule of copper (above) from which molten prills separated. A part of them is oxidized into cuprite. Dendrites of cuprite.

Tab. 11-10. Emission spectral analyses of objects (%) of the settlement of Berezovaya Luka. The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

Material	№	Group	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
goethite	2051		0.02	0.005	0.015	0.3	0.01	0.05	0.0005	<0.0003	0.4
ceramic	2067	к	0.005	0.002	0.03	0.07	0.005	0.5	0.0005	<0.0003	1
ceramic	2067	к	0.007	0.002	0.1	0.07	0.01	0.3	<0.0005	<0.0003	0.7
ceramic	2068	к	0.03	0.003	0.4	0.06	0.01	0.5	0.0005	<0.0003	0.07
bone	2090		0.01	0.003	<0.001	0.3	0.0015	0.01	<0.0005	<0.0003	0.2
copper	2096		0.0015	<0.0003	0.003	0.07	<0.001	0.1	0.0005	<0.0003	>1
ore	2092		0.004	0.0015	0.005	0.09	0.015	0.05	<0.0005	<0.0003	1
ore	2097		0.0015	<0.0003	0.005	0.07	<0.001	0.03	<0.0005	<0.0003	1
ore	2100		0.007	0.003	0.003	0.09	0.015	0.15	<0.0005	<0.0003	1
slag	2034	к	0.02	0.0015	0.1	0.2	0.01	0.5	0.001	<0.0003	0.4
slag	2035	II	0.015	0.003	0.05	0.07	0.007	0.3	0.0005	<0.0003	0.5
slag	2037	II	0.01	0.0015	0.03	0.2	0.003	0.15	<0.0005	<0.0003	>1
slag	2038	к	0.01	0.002	0.05	0.07	0.007	0.3	0.0005	<0.0003	0.1
slag	2038	к	0.015	0.002	0.15	0.09	0.01	0.3	0.0005	<0.0003	0.05
slag	2039	II	0.01	0.0015	0.1	0.15	0.01	0.5	0.001	<0.0003	0.4
slag	2040	II	0.02	0.002	0.05	0.15	0.005	0.2	<0.0005	<0.0003	>1
slag	2041	II	0.015	0.002	0.1	0.1	0.0015	0.15	0.0005	<0.0003	>1
slag	2042	II	0.02	0.0015	0.02	0.2	0.01	0.3	0.0005	0.00015	>1
slag	2043	к	0.02	0.005	0.1	0.1	0.01	0.3	0.001	<0.0003	>1
slag	2044	II	0.01	0.0015	0.1	0.1	0.01	0.5	0.001	<0.0003	0.5
slag	2045	II	0.001	<0.0003	0.015	0.07	<0.001	0.1	<0.0005	<0.0003	0.02
slag	2046	II	0.02	0.003	0.07	0.2	0.01	0.2	<0.0005	<0.0003	>1
slag	2047		0.015	0.003	0.05	0.3	0.003	0.15	<0.0005	<0.0003	1
slag	2048	II	0.01	0.002	0.1	0.07	0.015	0.6	0.001	<0.0003	0.4
slag	2049	II	0.03	0.003	0.1	0.2	0.003	0.1	<0.0005	<0.0003	>1
slag	2050	II	0.015	0.005	0.05	0.15	0.005	0.1	<0.0005	<0.0003	>1
slag	2052	II	0.02	0.002	0.05	0.2	0.003	0.2	<0.0005	<0.0003	>1
slag	2053	II	0.02	0.003	0.05	0.2	0.003	0.2	<0.0005	<0.0003	>1
slag	2054	IV	0.015	0.015	0.03	0.5	0.003	0.2	<0.0005	<0.0003	>1
slag	2055	II	0.015	0.005	0.0015	0.15	0.003	0.15	<0.0005	<0.0003	1
slag	2055	II	0.02	0.003	0.15	0.2	0.007	0.2	<0.0005	<0.0003	0.7

Material	№	Group	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
slag	2056	II	0.03	0.003	0.1	0.2	0.01	0.2	0.0005	<0.0003	>1
slag	2057	II	0.005	0.003	0.1	0.1	0.007	0.15	<0.0005	0.00015	>1
slag	2057	II	0.004	0.002	0.003	0.2	0.005	0.07	0.0005	<0.0003	1
slag	2058	к	0.015	0.0015	0.03	0.07	0.02	0.3	0.0005	<0.0003	1
slag	2058	к	0.01	0.003	0.1	0.5	0.007	0.2	0.0005	0.00015	0.02
slag	2060	IV	0.007	0.0015	0.07	0.05	0.01	0.3	0.001	<0.0003	1
slag	2060	II	0.007	0.003	0.15	0.09	0.01	0.15	0.0005	0.002	>1
slag	2061	к	0.07	0.003	0.2	0.1	0.01	0.5	0.001	<0.0003	0.03
slag	2062	к	0.005	0.003	0.05	0.1	0.005	0.07	<0.0005	<0.0003	>1
slag	2063		0.005	0.003	0.03	0.2	0.005	0.15	<0.0005	<0.0003	>1
slag	2064	IV	0.005	0.004	0.05	0.07	0.01	0.2	<0.0005	<0.0003	>1
slag	2065	к	0.005	0.001	0.07	0.07	0.007	0.1	<0.0005	<0.0003	0.0015
slag	2066	II	0.02	0.003	0.15	0.09	0.01	0.15	<0.0005	<0.0003	0.7
slag	2069	IV	0.007	0.0015	0.03	0.2	0.005	0.3	<0.0005	<0.0003	>1
slag	2070	II	0.01	0.003	0.15	0.15	0.007	0.2	<0.0005	<0.0003	>1
slag	2071	II	0.007	0.003	0.05	0.15	0.015	0.15	<0.0005	<0.0003	>1
slag	2072		0.007	0.001	0.07	0.09	0.015	0.1	<0.0005	<0.0003	0.15
slag	2073	II	0.005	0.002	0.05	0.07	0.007	0.1	<0.0005	<0.0003	0.5
slag	2074	к	0.005	0.002	0.07	0.05	0.007	0.5	0.001	<0.0003	1
slag	2074	к	0.03	0.003	0.5	0.15	0.01	0.5	0.0005	<0.0003	0.15
slag	2091	II	0.01	0.002	0.07	0.15	0.005	0.2	<0.0005	<0.0003	>1
slag	2093	II	0.02	0.003	0.15	0.2	0.01	0.2	<0.0005	<0.0003	>1
slag	2094	II	0.02	0.002	0.4	0.15	0.005	0.2	<0.0005	<0.0003	>1
slag	2095	II	0.015	0.003	0.15	0.07	0.015	0.2	<0.0005	0.0015	>1
slag	2098		0.02	0.003	0.03	0.2	0.003	0.05	<0.0005	<0.0003	1
slag	2099		0.002	0.002	0.0015	0.15	0.007	0.6	<0.0005	<0.0003	1
slag	2048-1	II	0.015	0.002	0.1	0.07	0.015	0.6	0.001	<0.0003	0.015
slag	2095a	II	0.02	0.003	0.15	0.2	0.005	0.2	<0.0005	<0.0003	>1
Sensitivity of the analysis			Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
			0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.0003	0.001

Tab. 11-10. Emission spectral analyses of objects (%) of the settlement of Berezovaya Luka. The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (contd.).

Material	№	Group	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
goethite	2051		0.5	0.05	0.0004	0.05	<0.003	<0.001	<0.001	0.0007	0.015
ceramic	2067	к	0.07	0.05	0.0004	0.005	<0.003	<0.001	0.002	0.0001	0.07
ceramic	2067	к	0.07	0.05	0.0002	0.005	<0.003	<0.001	0.0015	0.0007	0.07
ceramic	2068	к	nd	0.005	0.00007	0.005	0.0015	<0.001	<0.001	0.0015	0.07
bone	2090		0.02	0.005	0.00015	0.005	<0.003	<0.001	<0.001	0.0001	0.2
copper	2096		0.015	0.3	0.00005	0.01	<0.003	<0.001	0.007	0.0001	0.01
ore	2092		1	1	0.002	0.05	<0.003	0.003	0.03	0.005	0.01
ore	2097		0.7	0.5	0.00005	0.01	<0.003	0.005	0.007	0.0001	0.015
ore	2100		1	0.5	0.003	0.1	0.015	0.005	0.02	0.002	0.015
slag	2034	к	nd	0.005	0.00015	0.005	<0.003	<0.001	<0.001	0.0007	0.05
slag	2035	II	0.04	0.02	0.0002	0.005	<0.003	<0.001	<0.001	0.0005	0.07
slag	2037	II	0.3	0.07	0.0007	0.01	<0.003	<0.001	0.007	0.0007	0.015
slag	2038	к	0.01	0.005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0002	0.07
slag	2038	к	nd	0.005	0.00003	0.01	<0.003	<0.001	<0.001	0.001	0.06
slag	2039	II	0.02	0.03	0.00015	0.005	<0.003	<0.001	0.0015	0.0007	0.07
slag	2040	II	0.15	0.02	0.0007	0.005	<0.003	<0.001	< 0.001	0.003	0.015
slag	2041	II	0.15	0.1	0.0007	0.06	<0.003	<0.001	0.0015	0.0007	0.015
slag	2042	II	0.3	0.04	0.0015	0.02	<0.003	<0.001	< 0.001	0.0007	0.02
slag	2043	к	0.4	0.06	0.003	0.005	<0.003	<0.001	0.0015	0.0005	0.05
slag	2044	II	0.03	0.015	0.0003	0.005	<0.003	<0.001	<0.001	0.0002	0.07
slag	2045	II	nd	0.001	<0.00003	0.005	<0.003	<0.001	<0.001	<0.0001	0.15
slag	2046	II	0.2	0.15	0.0007	0.005	<0.003	<0.001	< 0.001	0.002	0.02
slag	2047		0.3	0.05	0.0007	0.005	<0.003	<0.001	<0.001	0.002	0.02
slag	2048	II	0.02	0.005	0.00015	0.005	<0.003	<0.001	<0.001	0.0007	0.2
slag	2049	II	0.5	0.15	0.0007	0.005	<0.003	<0.001	0.002	0.003	0.02
slag	2050	II	1	0.5	0.002	0.01	<0.003	<0.001	0.005	0.003	0.02
slag	2052	II	0.4	0.07	0.001	0.01	<0.003	<0.001	<0.001	0.001	0.1
slag	2053	II	0.7	0.3	0.0007	0.01	<0.003	<0.001	< 0.001	0.003	0.02
slag	2054	IV	1	1	0.0004	0.04	0.007	0.005	0.01	0.01	0.03
slag	2055	II	0.5	0.3	0.0015	0.005	<0.003	<0.001	0.003	0.002	0.02
slag	2055	II	0.4	0.15	0.0007	0.01	<0.003	<0.001	0.001	0.002	0.03

Material	№	Group	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
slag	2056	II	0.07	0.01	0.0003	0.005	<0.003	<0.001	<0.001	0.002	0.02
slag	2057	II	0.07	0.04	0.0005	0.02	0.0015	<0.001	< 0.001	0.003	0.03
slag	2057	II	0.1	0.05	0.002	0.05	0.03	<0.001	0.002	0.003	0.02
slag	2058	к	0.02	0.05	0.003	0.005	<0.003	<0.001	<0.001	0.01	1
slag	2058	к	0.02	0.005	0.00003	0.01	<0.003	<0.001	<0.001	0.001	0.05
slag	2060	IV	0.02	0.003	0.0007	0.005	<0.003	<0.001	<0.001	0.0001	0.07
slag	2060	II	nd	0.03	0.0015	0.005	<0.003	<0.001	<0.001	0.003	0.15
slag	2061	к	nd	0.005	0.00003	0.005	<0.003	<0.001	<0.001	0.001	0.07
slag	2062	к	0.15	0.06	0.0007	0.01	0.0015	0.001	0.001	0.0015	0.02
slag	2063		0.4	0.3	0.0009	0.02	<0.003	<0.001	< 0.001	0.0015	0.02
slag	2064	IV	0.7	0.7	>0.003	0.03	<0.003	<0.001	0.007	0.007	0.07
slag	2065	к	0.02	0.003	0.001	0.005	<0.003	<0.001	<0.001	0.0002	0.015
slag	2066	II	0.07	0.05	0.0005	0.005	<0.003	<0.001	<0.001	0.0015	0.07
slag	2069	IV	0.07	0.02	0.0006	0.015	<0.003	<0.001	0.001	0.002	0.02
slag	2070	II	0.3	0.05	0.0006	0.01	<0.003	<0.001	< 0.001	0.002	0.03
slag	2071	II	0.3	0.4	0.0006	0.005	<0.003	<0.001	0.005	0.002	0.02
slag	2072		0.02	0.03	0.0001	0.005	<0.003	<0.001	<0.001	0.002	0.03
slag	2073	II	0.2	0.07	0.001	0.01	<0.003	<0.001	0.002	0.0007	0.015
slag	2074	к	0.02	0.03	0.0004	0.005	<0.003	<0.001	<0.001	0.00015	0.1
slag	2074	к	nd	0.005	0.00015	0.005	<0.003	<0.001	<0.001	0.0007	0.1
slag	2091	II	0.15	0.02	0.0003	0.005	<0.003	<0.001	<0.001	0.002	0.15
slag	2093	II	0.15	0.03	0.00015	0.005	<0.003	<0.001	<0.001	0.003	0.09
slag	2094	II	0.4	0.15	0.0007	0.01	<0.003	<0.001	<0.001	0.003	0.03
slag	2095	II	nd	0.04	0.0015	0.01	<0.003	<0.001	<0.001	0.005	>1
slag	2098		1	0.5	0.002	0.02	0.003	0.003	0.01	0.003	0.02
slag	2099		1	1	0.003	0.03	0.01	0.003	0.007	0.0015	0.015
slag	2048-1	II	0.01	0.001	<0.00003	0.005	<0.003	<0.001	<0.001	0.001	0.2
slag	2095a	II	0.4	0.1	0.0007	0.01	<0.003	<0.001	<0.001	0.003	0.05
Sensitivity of the analysis			Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
			0.003	0.0003	0.00003	0.01	0.003	0.001	0.001	0.0001	0.01

Tab. 11-10. Emission spectral analyses of objects (%) of the settlement of Berezovaya Luka. The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (contd.).

Material	№	Group	Sr	W	Sn	Be	Zr	Ga	Y	Yb
goethite	2051		0.01	<0.001	0.0007	0.00003	0.003	0.0005	<0.001	<0.0001
ceramic	2067	к	0.02	0.002	0.02	0.0001	0.015	0.001	0.003	0.003
ceramic	2067	к	0.03	0.0015	0.07	0.00015	0.015	0.001	0.003	0.0002
ceramic	2068	к	0.02	0.003	0.0015	0.00015	0.015	0.001	0.003	0.0002
bone	2090		0.1	<0.001	0.007	0.03	nd	<0.00003	<0.001	<0.0001
copper	2096		<0.01	<0.001	<0.0005	0.00003	nd	<0.00003	<0.001	<0.0001
ore	2092		<0.01	<0.001	0.001	0.00015	nd	<0.00003	<0.001	<0.0001
ore	2097		<0.01	<0.001	0.03	0.00003	nd	<0.00003	<0.001	<0.0001
ore	2100		<0.01	0.007	0.3	0.00003	nd	<0.00003	<0.001	<0.0001
slag	2034	к	0.015	0.003	0.001	0.0001	0.003	0.001	0.002	0.0002
slag	2035	II	0.03	0.005	0.05	0.00015	0.01	0.001	0.0015	0.0015
slag	2037	II	0.015	0.005	0.0005	0.00003	0.015	0.001	0.001	0.0001
slag	2038	к	0.03	0.001	0.001	0.00015	0.01	0.001	0.002	0.002
slag	2038	к	0.03	0.0015	0.005	0.00015	0.003	0.0015	0.003	0.0003
slag	2039	II	0.03	0.005	0.1	0.00015	0.01	0.0015	0.003	0.0003
slag	2040	II	0.015	0.015	0.02	0.00005	0.015	0.001	0.002	0.0002
slag	2041	II	0.015	0.001	0.0003	<0.00003	0.007	0.0005	<0.001	<0.0001
slag	2042	II	0.01	0.005	0.0015	0.00005	0.007	0.001	0.001	0.0001
slag	2043	к	0.03	0.0015	> 0.3	0.00015	0.01	0.0015	0.003	0.0003
slag	2044	II	0.02	0.0015	0.03	0.00015	0.015	0.001	0.003	0.0003
slag	2045	II	0.07	<0.001	<0.0005	0.00005	0.005	<0.00003	<0.001	<0.0001
slag	2046	II	0.01	0.005	0.0005	0.00003	0.005	0.001	0.001	0.0001
slag	2047		0.01	0.003	0.0005	0.00015	nd	0.001	<0.001	<0.0001
slag	2048	II	0.04	0.0015	0.0003	0.0002	0.015	0.001	0.003	0.0003
slag	2049	II	0.01	0.02	0.0003	0.00003	0.005	0.001	0.001	0.0001
slag	2050	II	0.015	<0.001	0.0003	0.00003	nd	0.0005	0.001	0.0001
slag	2052	II	0.015	0.002	0.0003	0.00003	0.007	0.0005	0.0015	0.0001
slag	2053	II	0.01	0.005	0.0003	0.00003	0.005	0.0005	0.0015	0.00015
slag	2054	IV	0.01	0.003	0.02	0.00003	0.003	0.001	0.0015	0.0001
slag	2055	II	0.01	0.002	0.003	0.00015	nd	0.001	<0.001	<0.0001
slag	2055	II	0.015	0.007	0.0003	0.00003	0.003	0.0005	0.0015	0.0001

Material	№	Group	Sr	W	Sn	Be	Zr	Ga	Y	Yb
slag	2056	II	0.015	0.015	0.005	0.0001	0.01	0.0005	0.003	0.0003
slag	2057	II	0.015	0.01	0.0003	0.00007	0.007	0.001	0.001	0.0001
slag	2057	II	0.015	0.007	0.005	0.00015	nd	0.0005	<0.001	<0.0001
slag	2058	к	0.07	<0.001	0.003	0.00015	0.015	0.001	0.001	1
slag	2058	к	0.02	0.01	0.0003	0.0001	0.01	0.001	0.002	0.0002
slag	2060	IV	0.015	<0.001	0.001	0.0001	0.01	0.001	0.0015	0.0015
slag	2060	II	0.07	0.015	0.0003	0.0001	nd	0.0015	0.002	0.00015
slag	2061	к	0.03	0.005	<0.0005	0.00015	0.015	0.001	0.003	0.0003
slag	2062	к	0.015	0.003	<0.0005	0.00003	nd	0.0005	<0.001	<0.0001
slag	2063		0.015	0.005	0.0003	0.00005	nd	0.0005	<0.001	<0.0001
slag	2064	IV	0.01	0.015	0.01	0.00005	nd	0.001	0.001	<0.0001
slag	2065	к	0.01	0.001	<0.0005	0.00003	0.005	0.0005	0.001	0.0001
slag	2066	II	0.02	<0.001	0.0003	0.00005	0.007	<0.00003	0.001	0.0001
slag	2069	IV	0.015	0.003	0.03	0.0001	nd	0.001	0.0015	0.0001
slag	2070	II	0.015	0.01	0.0003	0.00007	nd	0.001	0.0015	0.0001
slag	2071	II	0.015	0.001	0.0003	0.00003	nd	0.0005	0.001	0.0001
slag	2072		0.015	0.001	0.0005	0.00007	0.007	0.0005	0.007	0.0007
slag	2073	II	0.015	0.001	<0.0005	0.00003	0.007	<0.00003	0.001	0.0001
slag	2074	к	0.02	0.0015	0.01	0.00015	0.015	0.001	0.003	0.003
slag	2074	к	0.015	0.005	0.002	0.0001	0.015	0.001	0.002	0.00015
slag	2091	II	0.02	0.01	0.0003	0.00007	0.007	0.001	0.0015	0.00015
slag	2093	II	0.02	0.007	0.0003	0.00007	0.007	0.001	0.0015	0.00015
slag	2094	II	0.015	0.005	0.0007	0.00007	0.005	0.001	0.002	0.00015
slag	2095	II	0.15	<0.001	0.0003	0.00015	0.007	0.001	0.0015	0.0001
slag	2098		0.01	<0.001	0.0015	0.00003	nd	<0.00003	<0.001	<0.0001
slag	2099		<0.01	0.1	0.3	0.00015	nd	<0.00003	<0.001	<0.0001
slag	2048-1	II	0.04	0.002	0.0003	0.0002	0.015	0.001	0.003	0.0003
slag	2095a	II	0.02	0.007	0.0007	0.00007	0.005	0.001	<0.001	0.0001
Sensitivity of the analysis			Sr	W	Sn	Be	Zr	Ga	Y	Yb
			0.01	0.001	0.0005	0.00003	0.001	0.00003	0.001	0.0001

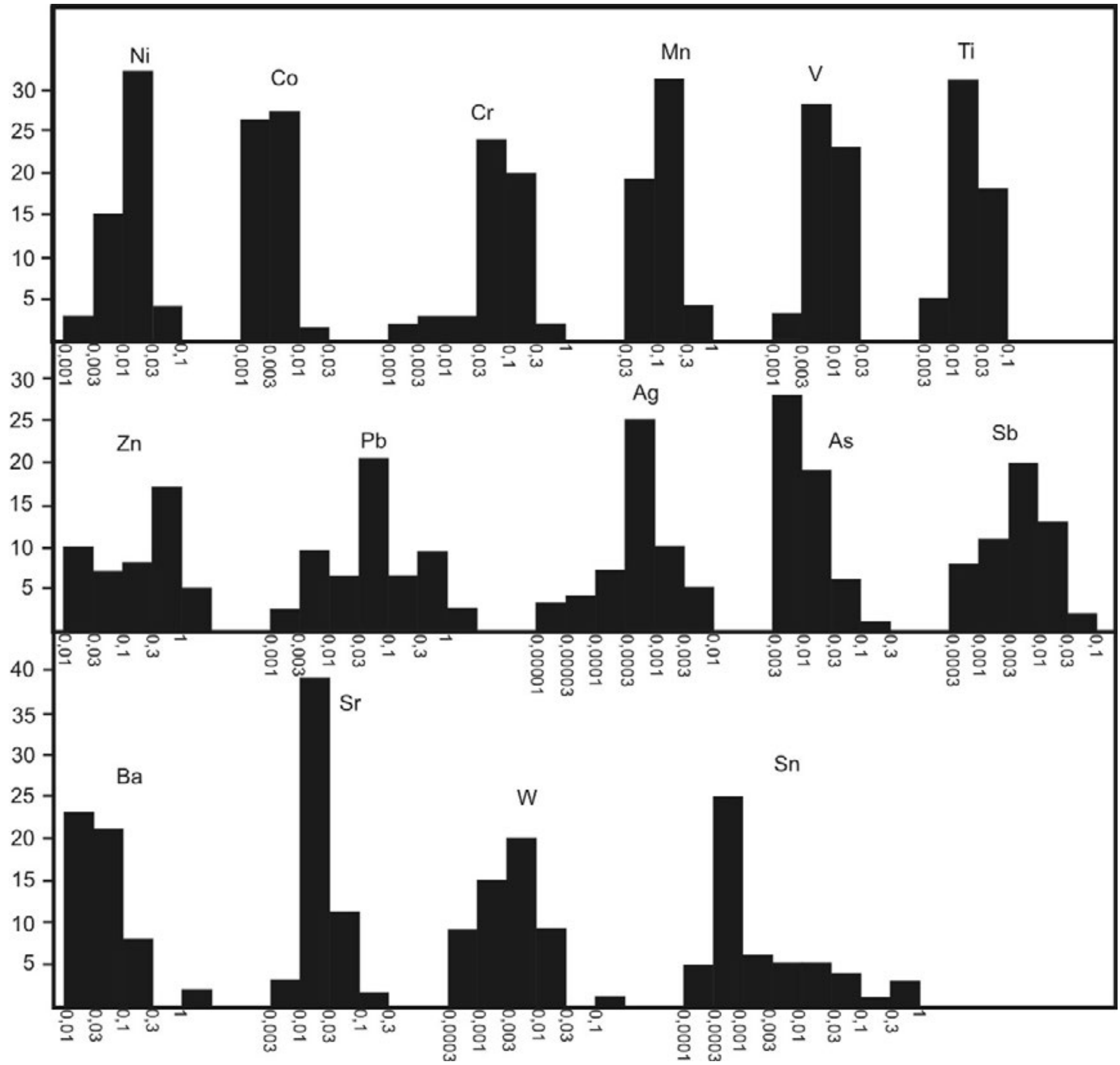


FIG. 11-11. FREQUENCY DIAGRAM OF DISTRIBUTION OF TRACE-ELEMENTS (%) IN SLAG OF THE SETTLEMENT OF BEREZOVAYA LUKA.

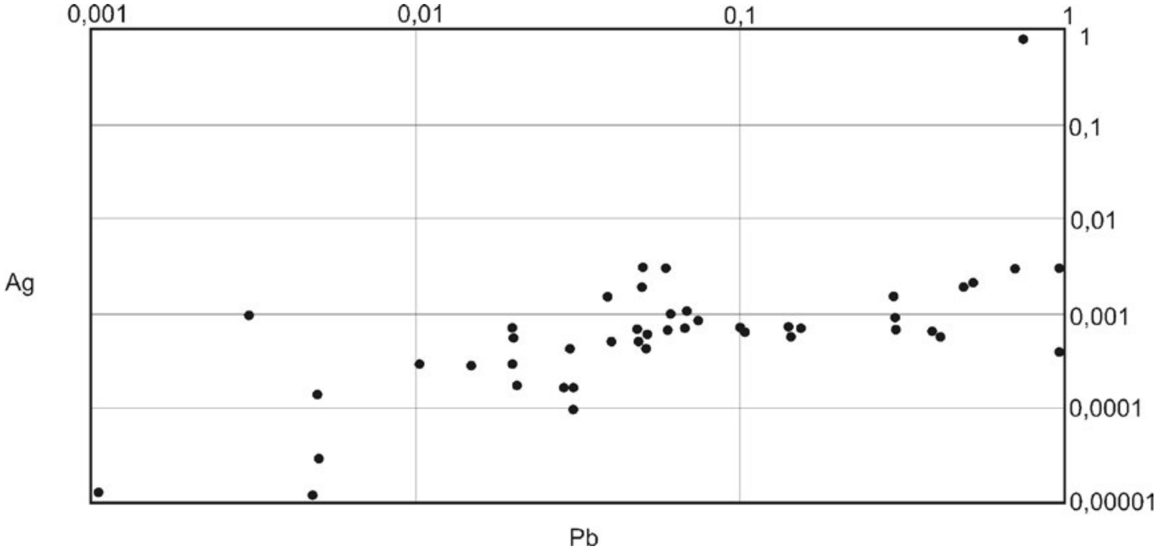


FIG. 11-12. CORRELATION OF CONCENTRATIONS OF PB-AG (%) IN SLAG OF THE SETTLEMENT OF BEREZOVAYA LUKA.

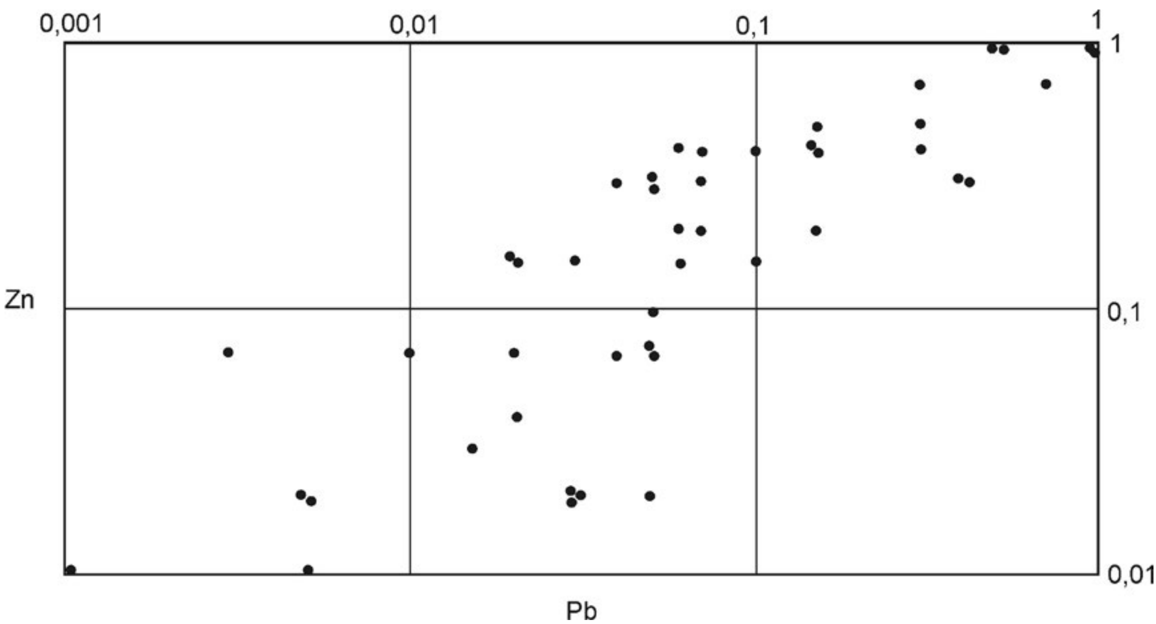


FIG. 11-13. CORRELATION OF CONCENTRATIONS OF PB-ZN (%) IN SLAG OF THE SETTLEMENT OF BEREZOVAYA LUKA.

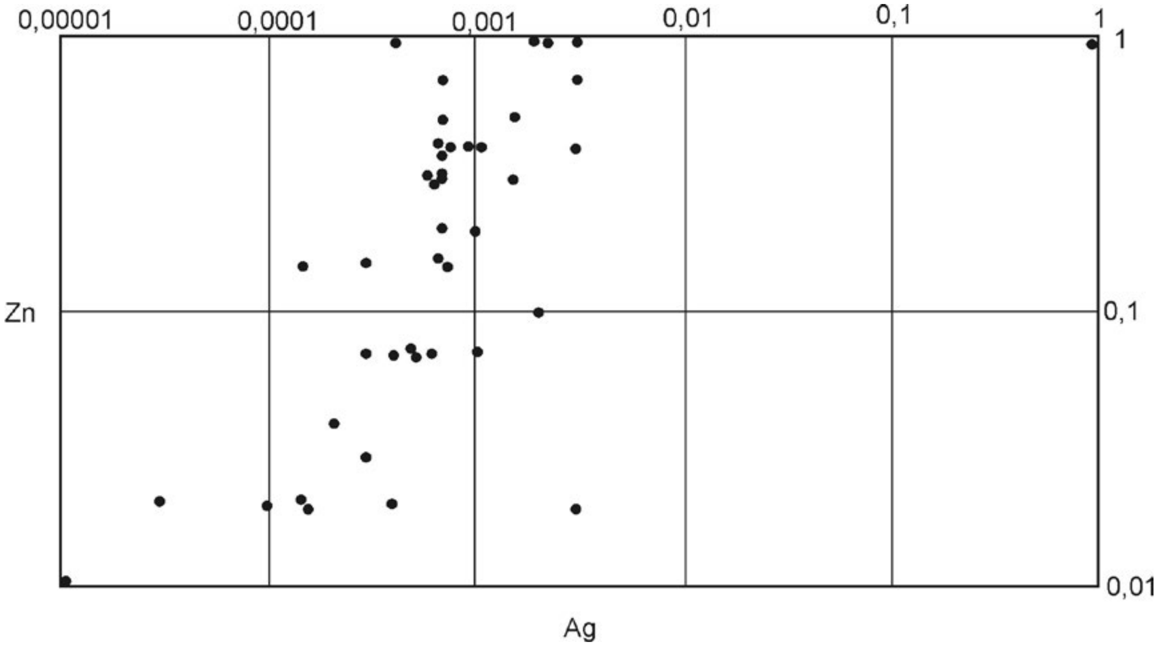


Fig. 11-14. Correlation of concentrations of Ag-Zn (%) in slag of the settlement of Berezovaya Luka.

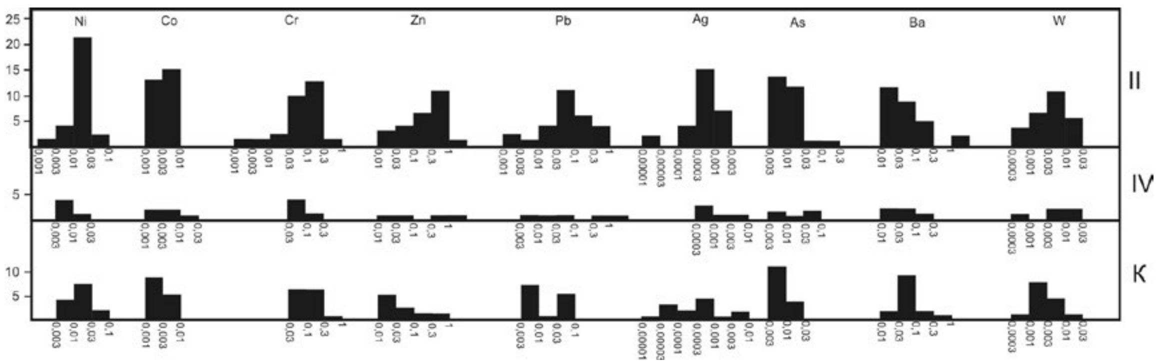


Fig. 11-15. Frequency diagram of distribution of trace-elements (%) over mineralogical groups in slag of the settlement of Berezovaya Luka.

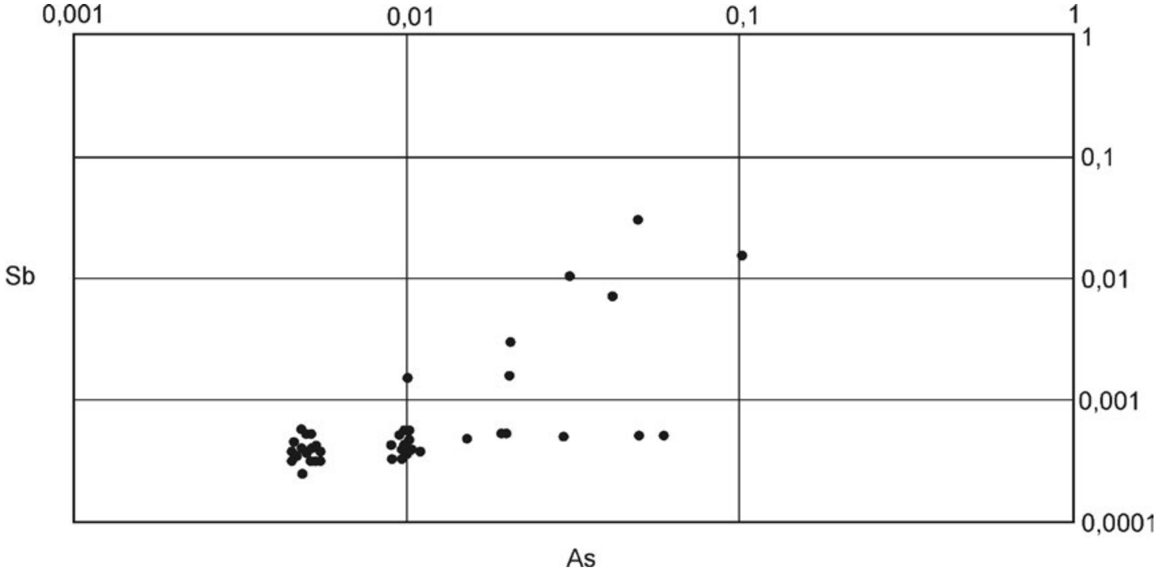


FIG. 11-16. CORRELATION OF CONCENTRATIONS OF AS-SB (%) IN SLAG OF THE SETTLEMENT OF BEREZOVAYA LUKA.

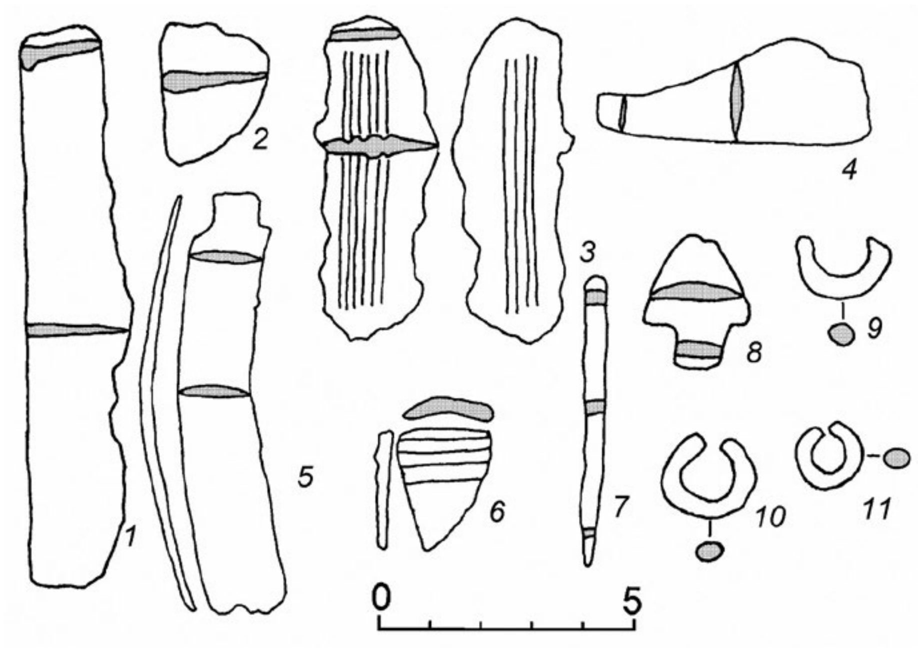


FIG. 11-17. METAL ARTIFACTS OF THE ELUNINO CULTURE: 1-5 – KNIVES; 6 – FRAGMENT OF SOCKET; 7 – AWL; 8 – ARROWHEAD; 9-11 – LEAD RINGS: 1-3, 5, 6, 9-11 – BEREZOVAYA LUKA; 4, 8 – CIGANKOVA SOPKA; 2; 7 – TELEUTSKII VZVOZ 1 (AFTER DEGTYAREVA ET AL. 2010).

Tab. 11-18. Chemico-metallurgical groups of the Seima-Turbino sites and their proportions, % (after Chernykh, Kuzminykh 1989, Tab. 9).

Cu	Cu+As	Cu+As+Sb	Cu+Ag	Ag+Cu	Cu+Sn	Cu+Sn+As	Au
8.5	24.1	11.3	2.5	3.7	24.4	23.5	2

Tab. 11-19. Bulk chemical analyses of slag from the settlements of Vishnyovka and Verkhnyaya Alabuga (weight %). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

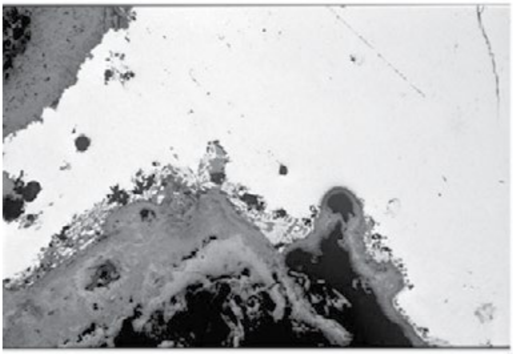
Sample	Site	SiO_2	FeO	CaO	Cu	Fe	Fe_3O_4
54	Vishnyovka	23.64	46.89	7.36	0.06		2.52
66	Verkhnyaya Alabuga	2.34		0.44	1.99	81.4	

Tab. 11-20. Coefficients of basicity of slag from the settlements of Vishnyovka and Verkhnyaya Alabuga.

Site	Sample	Coefficient	Group
Vishnyovka	54	2.41	basic
Verkhnyaya Alabuga	66	38	ultra-basic

Tab. 11-21. Ratio of oxides decreasing viscosity (TiO2, MgO, Fe2O3, MnO, K2O, CaO, Na2O) to those increasing it (SiO2, Al2O3,) – coefficient Kz and coefficient of viscosity (Pa•s) at the temperature of 1400ºC calculated according to Bachmann et al. 1987.

№	Site	Material	Kz	η 1400 (Pa·s)
13	Petrovka II	slag	0.65	7.12
46	Novonikolskoye	slag	1.79	2.29
18	Atasu	slag	1.44	2.96
19	Atasu	slag	2.60	1.44
26	Myrzhik	slag	4.80	0.57
27	Myrzhik	slag	2.45	1.55
44	Sargari	slag	0.92	4.89
53	Ak-Moustapha	slag	0.21	22.60
54	Vishnyovka	slag	2.40	1.59
66	Verkhnyaya Alabuga	iron	35.83	0.31
21	Atasu	furnace charge	5.35	0.47


1

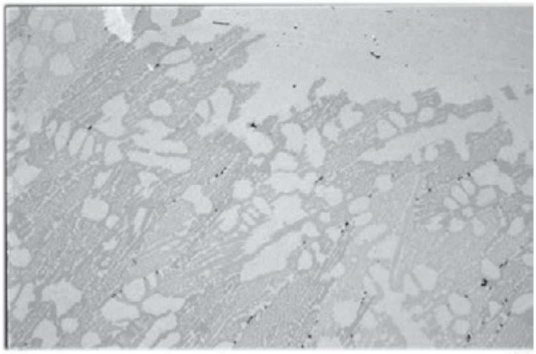

2

FIG. 11-22. MICROSTRUCTURES OF SLAG OF THE SETTLEMENT OF VERKHNYAYA ALABUGA (SAMPLE 66): 1 – IRON (WHITE) WITH COPPER SULFIDE (GREY) BORDERING IT; 2 – MOLTEN STRUCTURES OF IRON (LIGHT GREY).

Tab. 11-23. SEM-analyses of sample 66 of the settlement of Verkhnyaya Alabuga made in the Technical University of Freiberg by means of the Digital Scanning Microscope DSM 960 (weight %). Analyst B. Bleibe.

Weight %			
Analysis	**Material**	**O**	**Fe**
1	iron		100
2	wüstite	22.18	77.82
Atomic %			
1	iron		100
2	wüstite	49.88	50.12

Tab. 11-24. X-ray diffraction analyses of slag from the settlement of Vishnyovka (Department of Physics-1, South-Ural State University).

Settlement	Sample	**quartz**	**tridymite**	**cristobalite**	**FeO**	**Fe_2O_3**	**Fe_3O_4**	**Cu**
Vishnyovka I	54		?	*	*	*		

Tab. 11-25. Generalized chemical composition of the Dzhezkazgan sandstones (Satpaeva 1958).

	SiO_2	**Al_2O_3**	**Fe_2O_3**	**FeO**
%	60-80	10-13	2-3	1-2

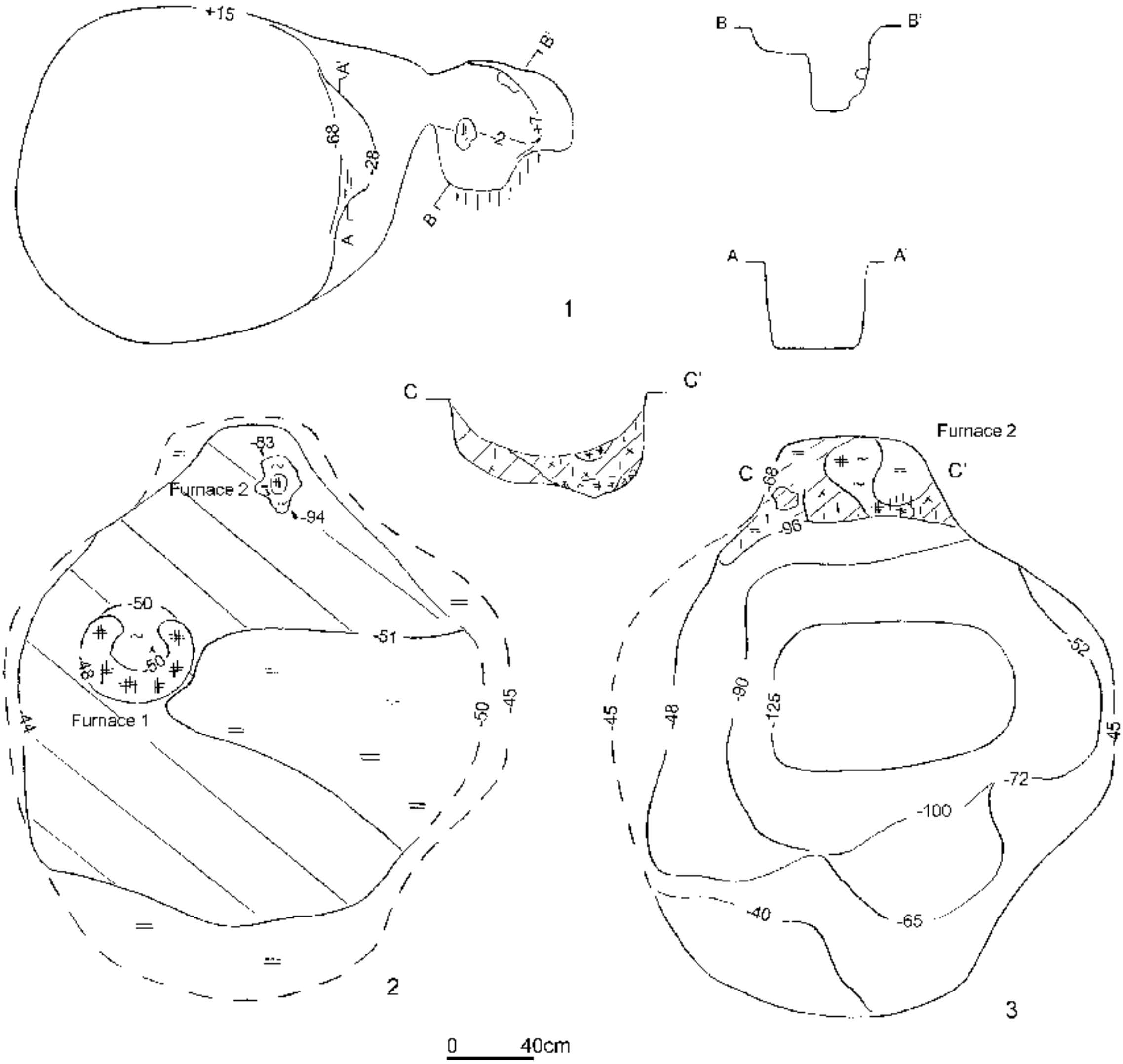


Fig. 11-26. The furnaces attached to wells of the Alakul culture on the settlement of Mochishche (1, 3) and a furnace of Alakul-Fyodorovka time (2) over the earlier well.

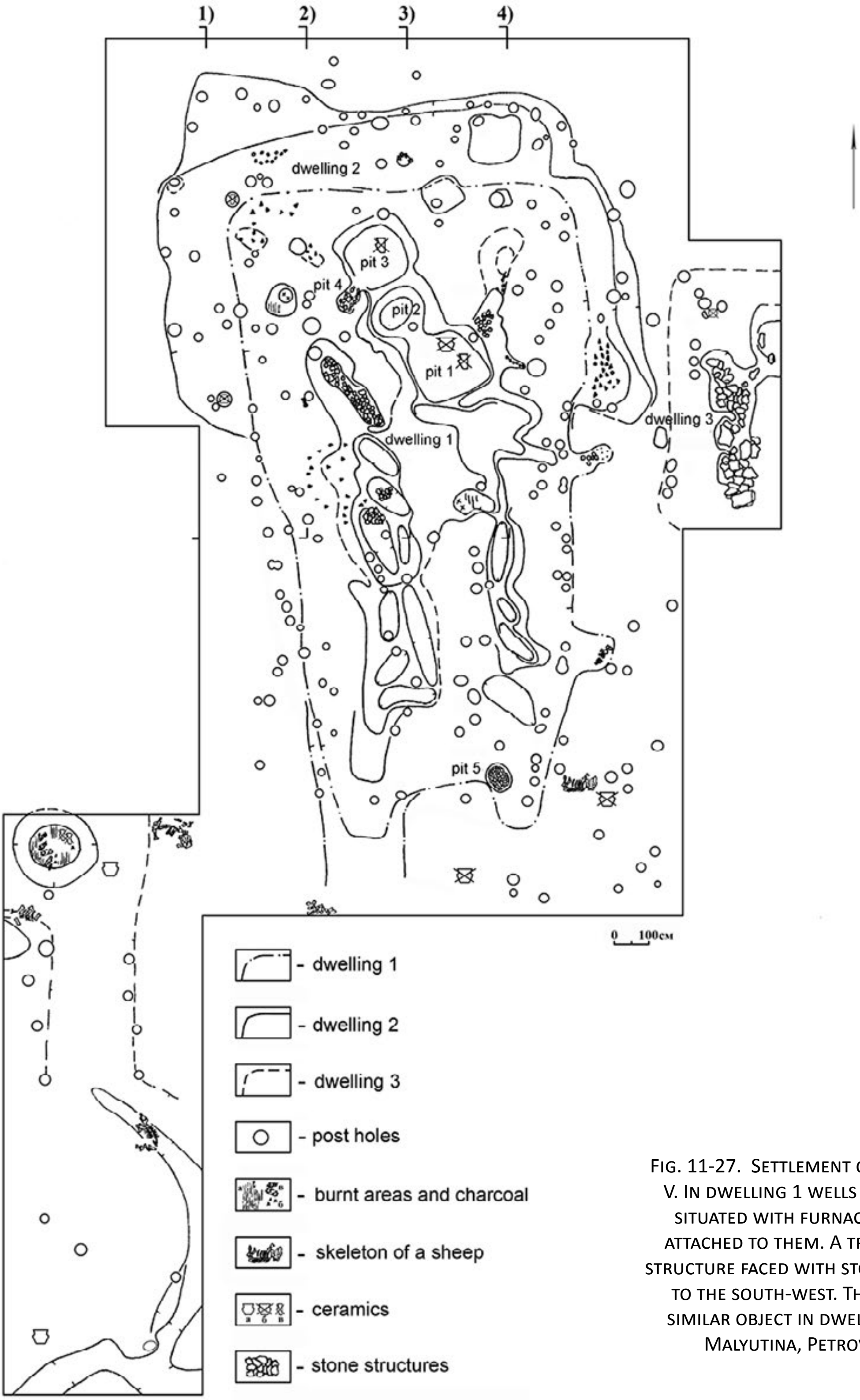


Fig. 11-27. Settlement of Atamanovka V. In dwelling 1 wells (pits 1, 3) are situated with furnaces (pits 2, 4) attached to them. A trench-shaped structure faced with stones is situated to the south-west. There is also a similar object in dwelling 3 (after Malyutina, Petrova 2008).

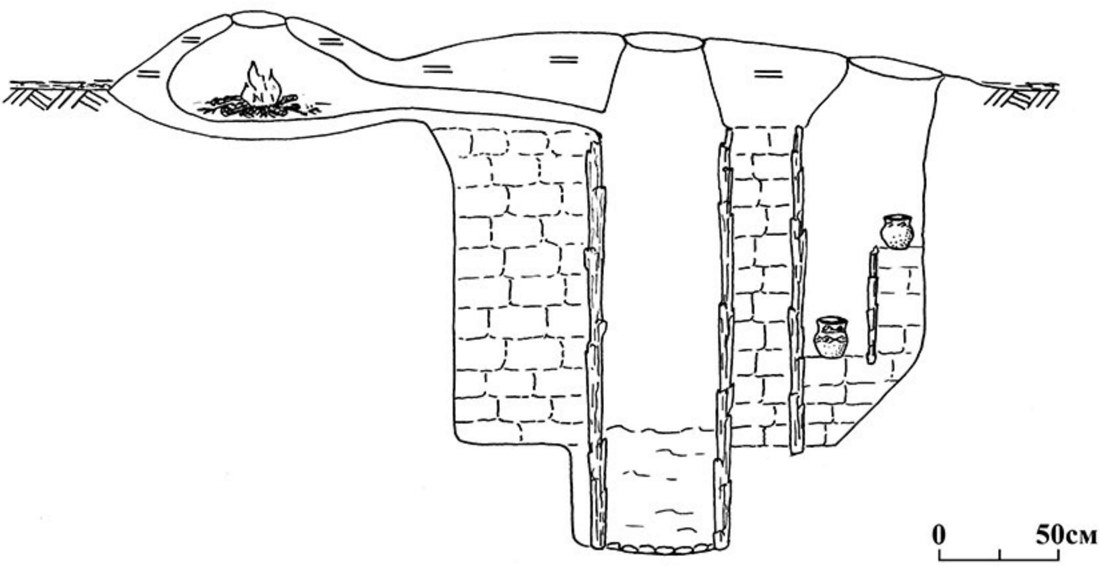


Fig. 11-28. Reconstruction of the well and furnace (pits 1, 2) of the settlement of Atamanovka V (after Malyutina, Petrova 2008).

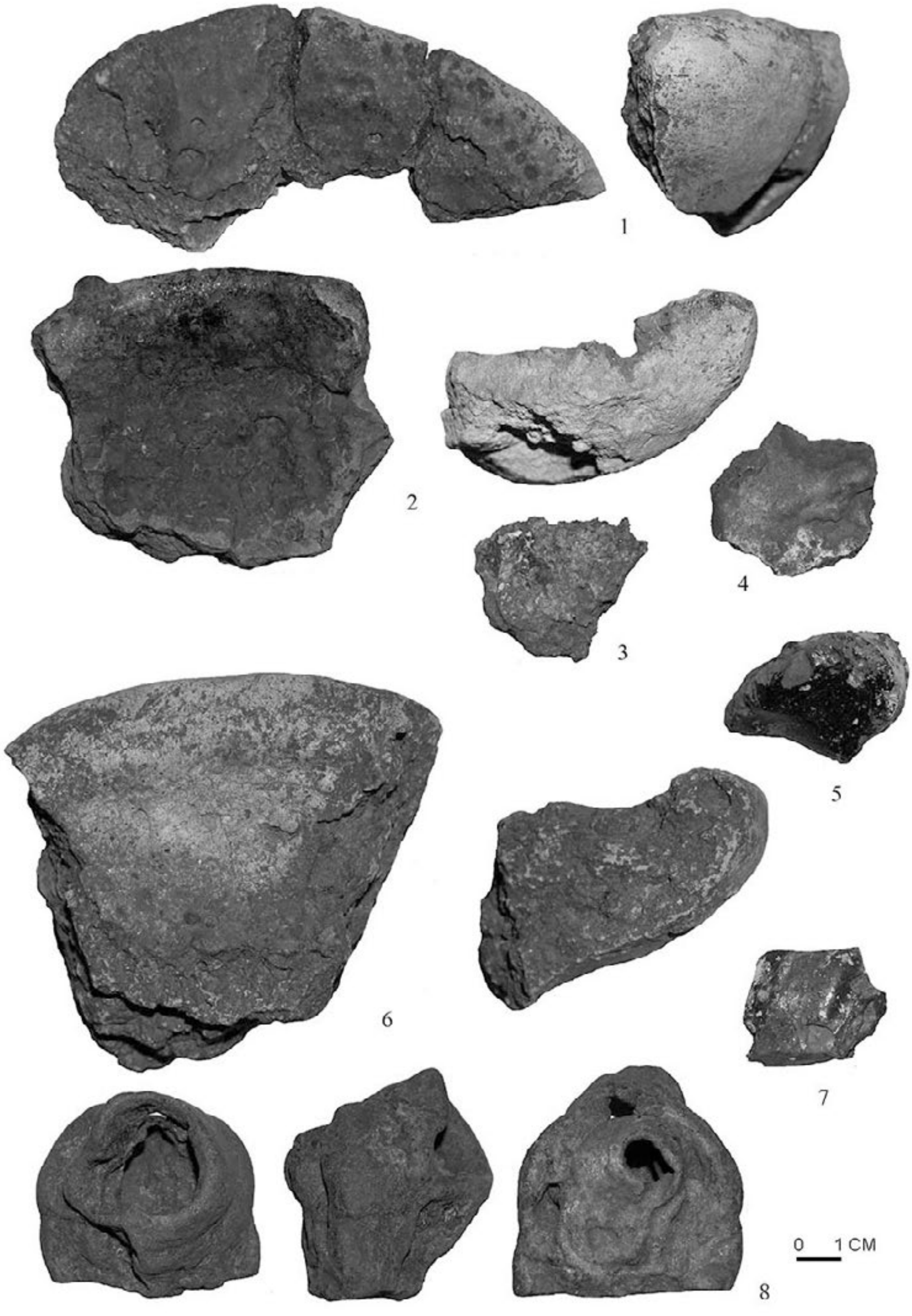


Fig. 11-29. Settlement of Arkhangelskii Priisk II: 1, 2, 6 – fragments of crucibles; 3, 4 – slagged lining; 5, 7 – pieces of dense slag; 8 – slagged tuyere.

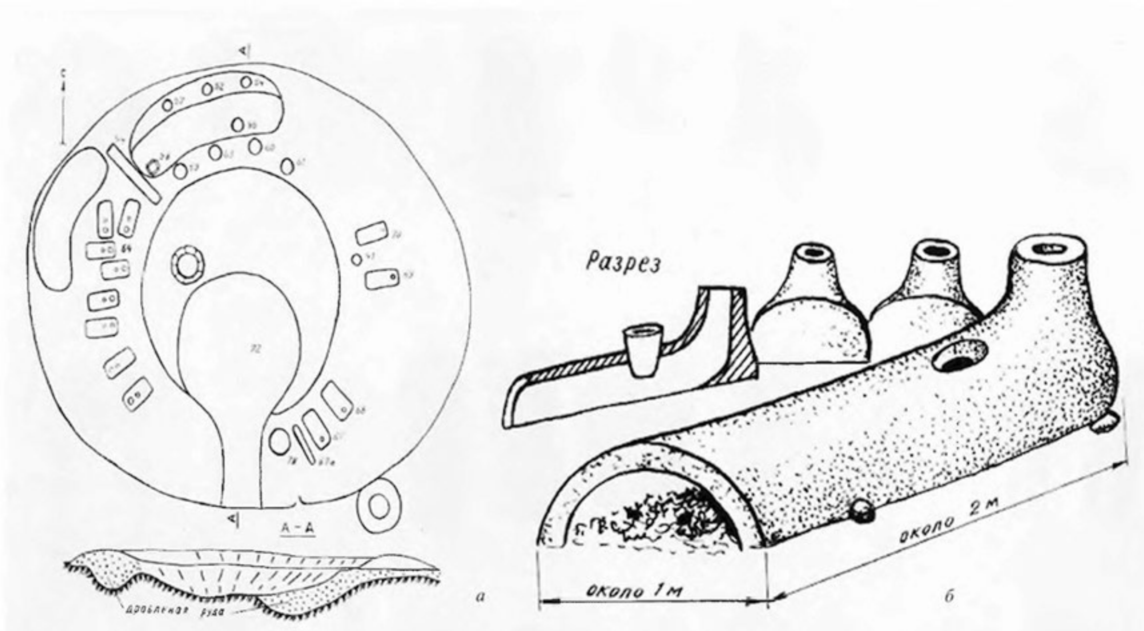


FIG. 11-30. SMELTING PLACE (A) AND RECONSTRUCTION OF A FURNACE OF THE MILYKUDUK SETTLEMENT MADE BY N.V. VALUKINSKII (AFTER MARGULAN 2001).

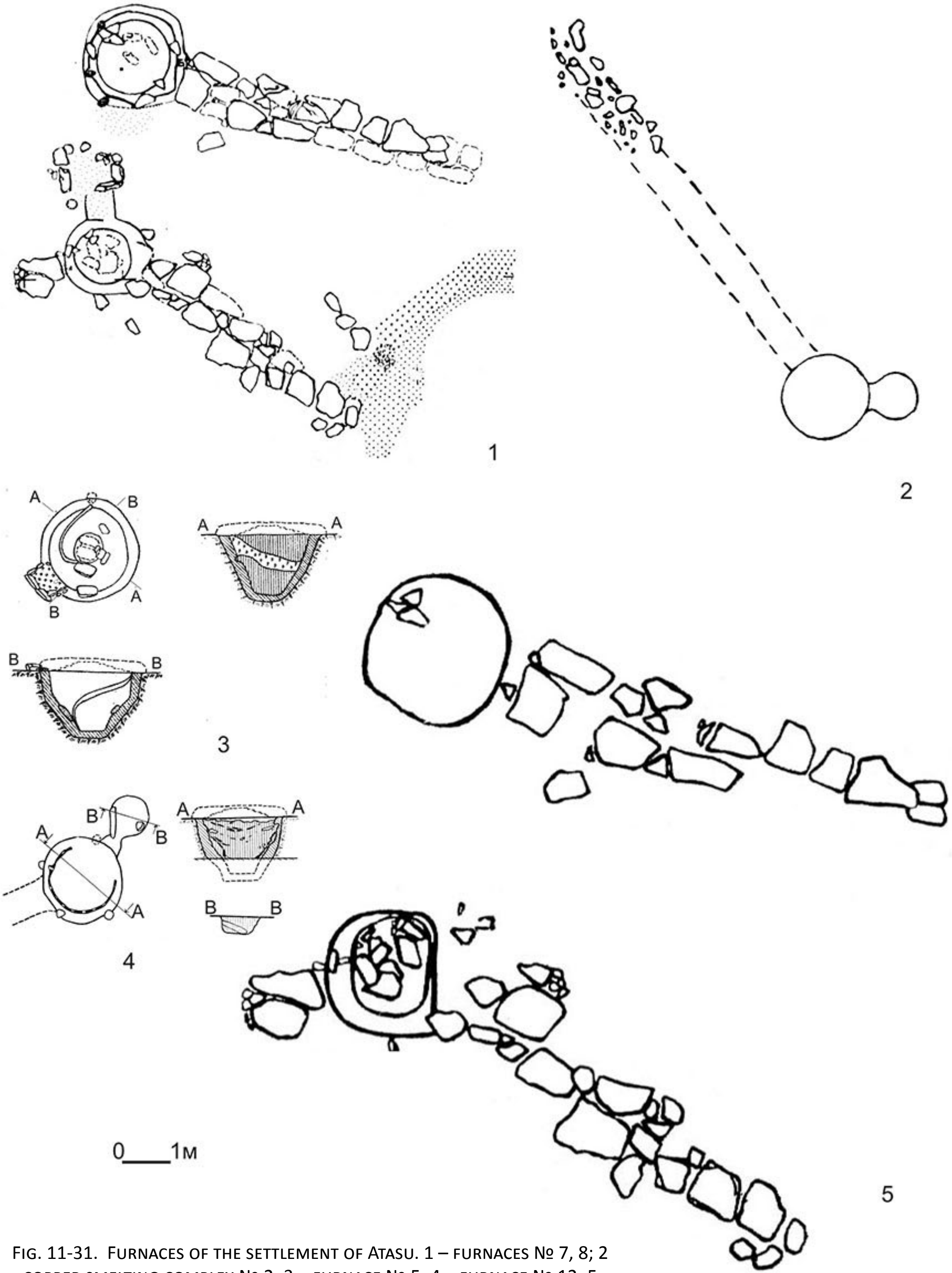


FIG. 11-31. FURNACES OF THE SETTLEMENT OF ATASU. 1 – FURNACES № 7, 8; 2 – COPPER SMELTING COMPLEX № 2; 3 – FURNACE № 5; 4 – FURNACE № 12; 5 – COPPER SMELTING COMPLEX № 5 (AFTER KADYRBAEV, KURMANKULOV 1992).

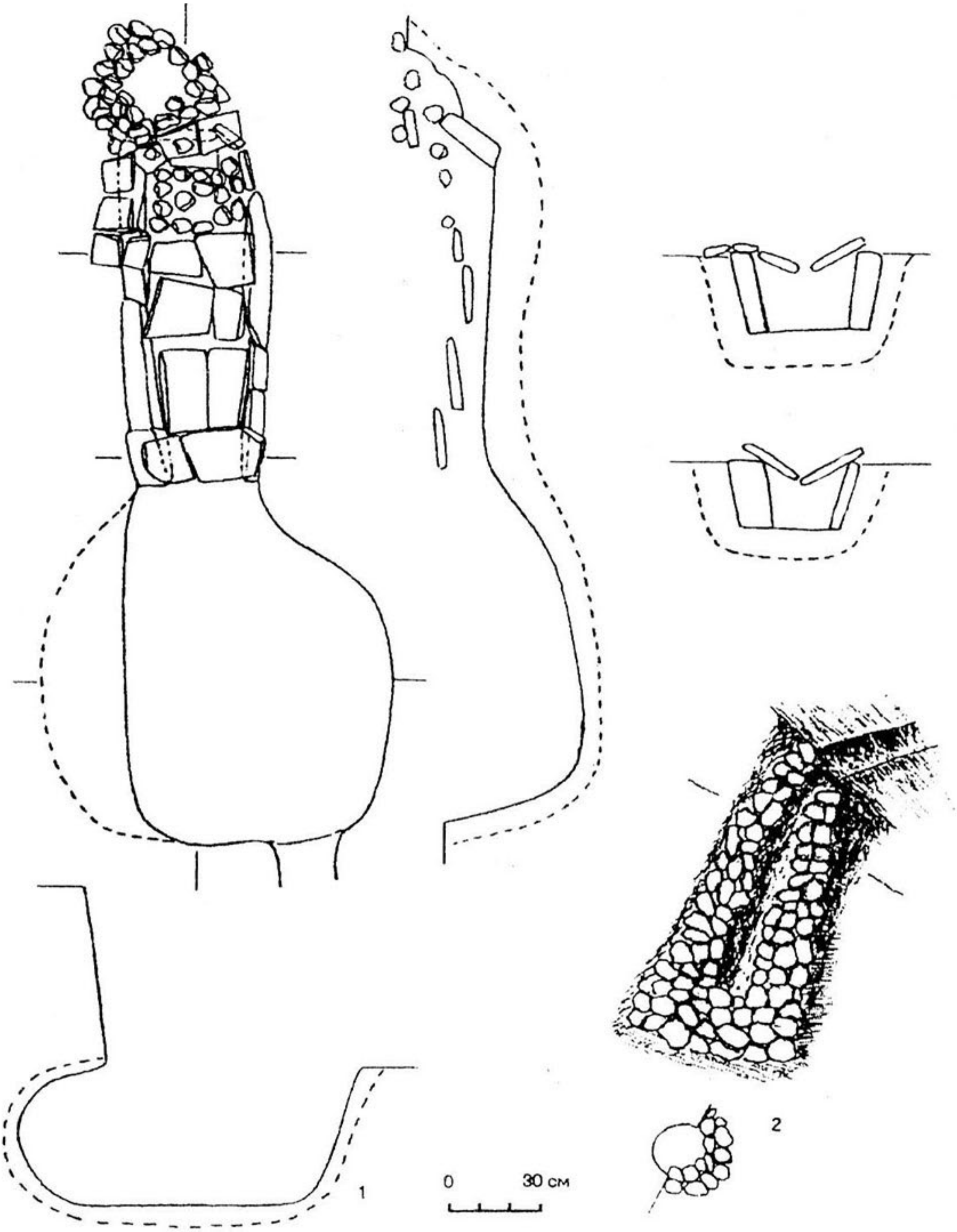


Fig. 11-32. Furnace of the settlement of Ikpen I (after Tkachev 2002).

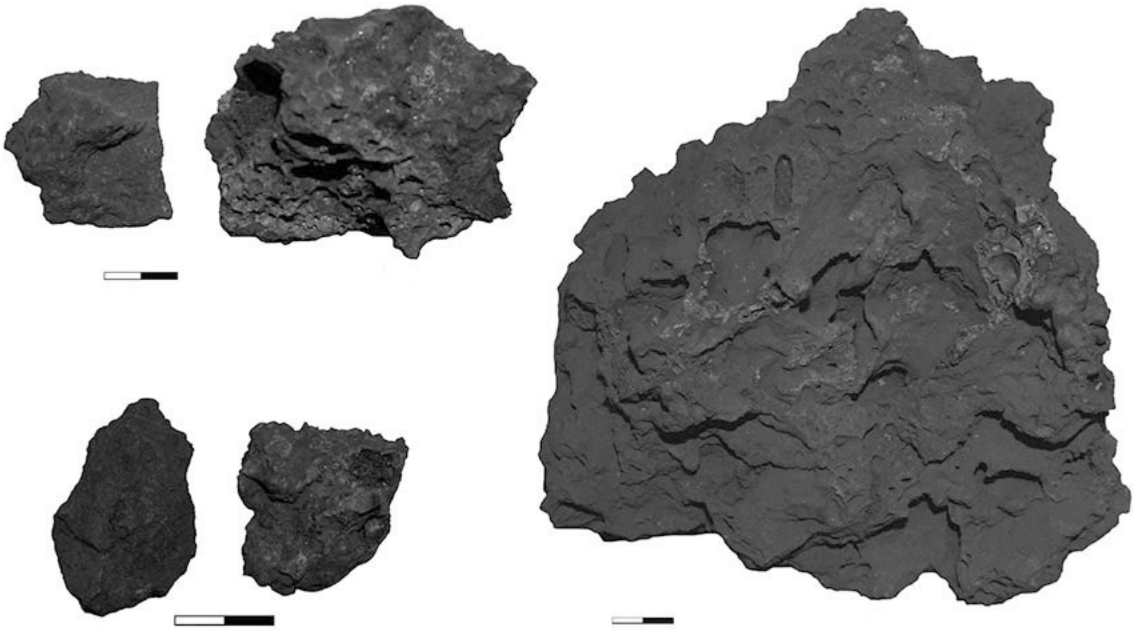


Fig. 11-33. Slag of the Ilyaska settlement.

Tab. 11-34. Emission spectral analyses of ore from Kazakhstan deposits (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).

Deposit	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn	Pb	Ag
Southern Bulattau	890	0.001	<0.0003	0.0015	0.015	<0.001	0.1	<0.0005	<0.0003	>1	nd	0.15	0.0007
Southern Bulattau	891	0.0015	<0.0003	0.001	0.01	0.007	0.2	0.0005	0.0005	1	0.1	>1	0.00015
Southern Bulattau	892	0.001	<0.0003	0.003	0.01	0.01	0.1	<0.0005	0.0005	>>1	nd	>1	0.00007
Southern Bulattau	893	0.0015	<0.0003	0.0015	0.03	0.01	0.2	0.001	0.0005	>1	nd	1	0.00007
Southern Bulattau	894	0.0015	<0.0003	0.003	0.05	0.005	0.07	0.0005	0.0003	>>1	nd	1	0.0001
Southern Bulattau	895	0.0015	<0.0003	0.005	0.03	0.007	0.15	0.0005	<0.0003	1	nd	>1	0.00007
Southern Bulattau	896	0.0015	<0.0003	0.005	0.03	0.007	0.15	<0.0005	0.0003	>>1	nd	>1	0.0001
Southern Bulattau	897	0.001	<0.0003	0.0015	0.02	0.01	0.1	<0.0005	<0.0003	>1	nd	>1	0.00003
Southern Bulattau	898	0.0015	<0.0003	0.003	0.03	0.01	0.1	<0.0005	<0.0003	>>1	nd	1	0.00007
Southern Bulattau	899	0.001	<0.0003	0.0015	0.02	0.007	0.1	<0.0005	<0.0003	1	nd	1	0.0001
Aydygarli	906	0.002	<0.0003	0.005	0.015	0.005	0.07	<0.0005	<0.0003	>>1	0.003	0.003	0.00007
Aydygarli	907	0.01	0.007	0.005	0.02	0.007	0.1	<0.0005	<0.0003	>>1	0.003	0.0015	0.00007
Aydygarli	908	0.002	<0.0003	0.005	0.015	0.0015	0.07	<0.0005	<0.0003	>>1	0.003	0.003	0.00007
Aydygarli	909	0.0015	<0.0003	0.01	0.015	0.0015	0.2	<0.0005	<0.0003	>>1	0.003	0.002	0.00007
Aydygarli	910	0.0015	<0.0003	0.007	0.03	0.001	0.1	<0.0005	<0.0003	>>1	0.003	0.007	0.00003
Aydygarli	911	0.0015	<0.0003	0.015	0.015	0.003	0.2	<0.0005	<0.0003	>>1	0.003	0.002	0.00005
Aydygarli	912	0.005	0.003	0.005	0.05	0.001	0.1	<0.0005	<0.0003	>>1	0.003	0.0015	0.0001
Aydygarli	913	0.002	<0.0003	0.007	0.015	0.005	0.2	<0.0005	0.00015	>>1	0.005	0.0015	0.00015
Aydygarli	914	0.005	0.002	0.015	0.015	0.01	0.1	<0.0005	<0.0003	1	0.005	0.0007	0.0002
Aydygarli	915	0.002	0.001	0.01	0.015	0.007	0.2	<0.0005	0.00015	>>1	0.003	0.0015	0.00007
Aydygarli	916	0.0015	0.0015	0.002	0.015	0.0015	0.07	<0.0005	<0.0003	>>1	0.005	0.0007	0.00007
Aydygarli	917	0.003	0.0015	0.005	0.015	0.003	0.07	<0.0005	<0.0003	>>1	0.003	0.003	0.0001
Aydygarli	918	0.003	0.0015	0.015	0.015	0.007	0.1	<0.0005	<0.0003	>>1	0.005	0.002	0.00007
Aydygarli	919	0.002	0.0015	0.002	0.03	0.0015	0.07	<0.0005	0.00015	>>1	0.005	0.0007	0.00005
Aydygarli	920	0.0015	<0.0003	0.01	0.01	0.003	0.1	<0.0005	0.00015	>>1	0.005	0.002	0.0001

Deposit	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn	Pb	Ag
Southern Bulattau	927	0.0015	<0.0003	0.001	0.005	<0.001	0.07	<0.0005	<0.0003	>1	0.15	>>1	0.0015
Southern Bulattau	928	0.001	<0.0003	0.001	0.01	<0.001	0.15	<0.0005	<0.0003	>1	0.3	>>1	0.0015
Southern Bulattau	929	0.001	<0.0003	0.001	0.01	<0.001	0.1	<0.0005	<0.0003	>1	0.5	>>1	0.0015
Southern Bulattau	930	0.001	<0.0003	0.001	0.01	0.0015	0.07	<0.0005	<0.0003	>1	0.2	>>1	0.001
Southern Bulattau	931	0.001	<0.0003	0.001	0.01	<0.001	0.1	<0.0005	<0.0003	>1	0.5	>>1	0.001
Southern Bulattau	932	0.001	<0.0003	0.001	0.005	<0.001	0.1	<0.0005	<0.0003	>1	0.5	>>1	0.0005
Southern Bulattau	938	0.001	<0.0003	0.007	0.01	<0.001	0.07	<0.0005	<0.0003	>1	0.15	1	0.003
Southern Bulattau	939	0.001	<0.0003	0.005	0.03	<0.001	0.07	<0.0005	<0.0003	>>1	0.3	>1	0.001
Southern Bulattau	940	0.001	<0.0003	0.005	0.015	<0.001	0.05	<0.0005	<0.0003	>>1	0.007	0.1	>0.003
Southern Bulattau	941	0.0005	<0.0003	0.0015	0.005	0.001	0.07	<0.0005	<0.0003	>1	0.05	1	0.0015
Southern Bulattau	942	0.0005	<0.0003	0.005	0.015	0.0015	0.05	<0.0005	<0.0003	>1	0.15	0.7	0.0002
Southern Bulattau	943	0	<0.0003	0.007	0.005	0.0015	0.07	<0.0005	<0.0003	>1	0.015	0.5	0.0015
Southern Bulattau	944	0.0007	<0.0003	0.0015	0.003	0.001	0.05	<0.0005	<0.0003	>1	0.05	>1	0.002
Southern Bulattau	945	0	<0.0003	0.0015	0.01	0.001	0.02	<0.0005	<0.0003	1	0.01	0.5	0.00015
Southern Bulattau	946	0	<0.0003	0.001	0.003	0.0015	0.01	<0.0005	<0.0003	>1	0.007	0.3	0.0001
Southern Bulattau	947	0	<0.0003	0.002	0.01	0.0015	0.03	<0.0005	<0.0003	>1	0.03	>1	0.0015
Southern Bulattau	948	0.0007	<0.0003	0.0015	0.005	0.003	0.07	<0.0005	<0.0003	>1	0.15	0.5	0.00007
Southern Bulattau	949	0.0007	<0.0003	0.002	0.003	0.0015	0.07	<0.0005	<0.0003	>>1	0.15	>1	0.002
Southern Bulattau	950	0.0005	<0.0003	0.002	0.003	<0.001	0.01	<0.0005	<0.0003	>1	0.02	0.7	0.0002
Southern Bulattau	951	0.0007	<0.0003	0.005	0.01	0.005	0.05	<0.0005	<0.0003	>>1	0.15	>1	0.00007
Southern Bulattau	952	0.0007	<0.0003	0.007	0.003	<0.001	0.03	<0.0005	<0.0003	>>1	0.03	0.7	0.0015

Deposit	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn	Pb	Ag
Southern Bulattau	953	0.0007	<0.0003	0.007	0.003	0.003	0.03	0.001	<0.0003	>1	0.07	>1	0.0005
Southern Bulattau	954	0.0015	<0.0003	0.005	0.02	<0.001	0.15	<0.0005	<0.0003	1	0.07	0.5	0.00015
Kenkazgan	959	0.005	0.002	0.015	0.07	0.005	0.3	0.001	<0.0003	>>1	0.2	0.01	>0.003
Kenkazgan	960	0.005	0.002	0.007	0.2	0.005	0.05	<0.0005	<0.0003	>>1	0.15	0.015	0.001
Kenkazgan	961	0.002	0.03	0.01	>1	0.0015	0.1	0.001	<0.0003	>>1	0.15	0.02	0.0003
Kenkazgan	962	0.007	0.005	0.007	0.15	0.007	0.1	<0.0005	<0.0003	>>1	0.2	0.03	0.0005
Kenkazgan	963	0.003	0.007	0.005	0.1	0.01	0.5	0.001	<0.0003	>>1	0.15	0.1	0.0001
Kenkazgan	964	0.0015	<0.0003	0.005	0.2	0.01	0.1	<0.0005	<0.0003	>>1	0.1	0.1	0.00005
Kenkazgan	965	0.002	<0.0003	0.005	0.15	0.007	0.07	0.001	<0.0003	>>1	0.07	0.01	0.0001
Kenkazgan	966	0.002	<0.0003	0.007	0.2	0.01	0.1	<0.0005	<0.0003	>>1	0.3	0.1	0.003
Kenkazgan	967	0.005	0.0015	0.003	0.1	0.003	0.05	<0.0005	<0.0003	>>1	0.2	0.1	0.0007
Kenkazgan	968	0.0015	0.01	0.005	1	0.007	0.2	0.001	<0.0003	>>1	0.1	0.02	0.0001
Kenkazgan	969	0.002	<0.0003	0.007	0.07	0.007	0.3	0.001	<0.0003	>>1	0.07	0.015	>0.003
Kenkazgan	970	0.003	0.0015	0.007	0.3	0.01	0.05	<0.0005	<0.0003	>>1	0.2	0.007	0.00007
Kenkazgan	971	0.003	0.01	0.007	0.5	0.007	0.15	0.001	<0.0003	>>1	0.15	0.015	0.001
Kenkazgan	972	0.007	0.0015	0.007	0.1	0.005	0.1	0.001	<0.0003	>>1	0.2	0.007	0.0003
Kenkazgan	973	0.002	<0.0003	0.007	0.1	<0.001	0.07	<0.0005	<0.0003	>>1	0.07	0.005	>0.003
Kenkazgan	974	0.003	<0.0003	0.007	0.1	0.01	0.05	0.0005	<0.0003	>>1	0.15	0.01	0.00015
Kenkazgan	975	0.002	<0.0003	0.007	0.1	0.005	0.1	0.001	<0.0003	>>1	0.5	0.02	0.00007
Kenkazgan	976	0.003	0.007	0.007	0.7	0.005	0.15	0.001	<0.0003	>>1	0.15	0.15	0.00003
Kenkazgan	977	0.002	<0.0003	0.005	0.07	0.0015	0.05	<0.0005	<0.0003	>>1	0.02	0.007	0.003
Kenkazgan	978	0.003	0.0015	0.003	0.3	0.0015	0.15	0.001	<0.0003	>>1	0.03	0.01	0.00005
Talapty	984	0.002	0.0015	0.007	0.05	0.003	0.1	<0.0005	<0.0003	>>1	0.01	0.007	0.003
Talapty	985	0.0005	<0.0003	0.001	0.005	<0.001	0.005	<0.0005	<0.0003	>>1	0.003	0.0015	0.0015
Talapty	986	0.0007	<0.0003	0.002	0.005	<0.001	0.005	<0.0005	<0.0003	>>1	0.003	0.0005	0.00015
Talapty	987	0.001	<0.0003	0.007	0.02	0.005	0.07	<0.0005	<0.0003	>>1	0.007	0.005	0.0007
Talapty	988	0.0007	<0.0003	0.003	0.005	0.003	0.015	<0.0005	<0.0003	>>1	0.003	0.0007	0.0005
Talapty	989	0.0007	<0.0003	0.005	0.03	0.005	0.05	0.0005	<0.0003	>>1	0.007	0.003	0.003
Talapty	990	0.0007	<0.0003	0.005	0.03	<0.001	0.07	<0.0005	<0.0003	>>1	0.015	0.01	0.003
Talapty	991	0.001	<0.0003	0.003	0.005	0.005	0.1	<0.0005	<0.0003	>1	0.003	0.003	0.00007
Talapty	992	0.0005	<0.0003	0.005	0.02	<0.001	0.05	<0.0005	<0.0003	>>1	0.007	0.003	>>0.003
Talapty	993	0.001	<0.0003	0.007	0.05	0.005	0.05	<0.0005	<0.0003	>>1	0.007	0.007	>0.003

Deposit	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn	Pb	Ag
Talapty	994	0.001	<0.0003	0.005	0.03	0.005	0.05	<0.0005	<0.0003	>>1	0.01	0.005	>0.003
Talapty	995	0.0007	<0.0003	0.007	0.02	0.003	0.05	<0.0005	<0.0003	>>1	0.007	0.007	>0.003
Talapty	996	0.001	<0.0003	0.005	0.015	<0.001	0.03	0.0005	<0.0003	>>1	0.01	0.0007	>0.003
Talapty	997	0.003	<0.0003	0.007	0.03	<0.001	0.05	<0.0005	<0.0003	>>1	0.03	0.005	0.003
Talapty	998	0.001	<0.0003	0.002	0.005	<0.001	0.01	<0.0005	<0.0003	>1	0.005	0.002	0.0007
Talapty	999	0.0007	<0.0003	0.005	0.03	<0.001	0.03	<0.0005	<0.0003	>>1	0.01	0.005	0.0007
Talapty	1000	0.0015	<0.0003	0.007	0.02	0.005	0.07	<0.0005	<0.0003	>>1	0.005	0.003	0.003
Talapty	1001	0.003	<0.0003	0.007	0.05	0.007	0.05	0.0005	<0.0003	>>1	0.01	0.0015	0.0003
Talapty	1002	0.002	<0.0003	0.01	0.03	0.01	0.5	0.0005	<0.0003	>>1	0.01	0.003	0.0002
Talapty	1003	0.001	<0.0003	0.005	0.02	0.003	0.1	<0.0005	<0.0003	>>1	0.015	0.005	>0.003
Verkhnee Umgurlu	1009	0.0007	<0.0003	0.002	0.005	0.005	0.02	<0.0005	<0.0003	>>1	0.005	0.003	>0.003
Verkhnee Umgurlu	1010	0.0007	<0.0003	0.005	0.02	0.007	0.05	<0.0005	<0.0003	>>1	0.005	0.007	>0.003
Verkhnee Umgurlu	1011	0.0015	<0.0003	0.002	0.01	0.005	0.15	<0.0005	<0.0003	>1	0.02	0.05	0.0005
Verkhnee Umgurlu	1012	0.0007	0.0003	0.0015	0.005	0.005	0.02	0.0005	<0.0003	1	0.005	0.01	>>0.003
Verkhnee Umgurlu	1013	0.001	<0.0003	0.0015	0.01	0.003	0.1	<0.0005	<0.0003	1	0.03	0.05	0.00015
Verkhnee Umgurlu	1014	0.0005	<0.0003	0.0015	0.005	0.003	0.02	0.0005	<0.0003	>1	0.005	0.5	0.0015
Verkhnee Umgurlu	1015	0.0007	<0.0003	0.005	0.005	0.007	0.15	<0.0005	<0.0003	>>1	0.02	>1	>0.003
Verkhnee Umgurlu	1016	0.003	0.015	0.015	0.15	0.015	0.15	<0.0005	<0.0003	>>1	1	0.3	0.00015
Verkhnee Umgurlu	1017	0.0007	<0.0003	0.003	0.02	0.015	0.05	<0.0005	<0.0003	>>1	0.01	0.02	>>0.003
Verkhnee Umgurlu	1018	0.0015	<0.0003	0.003	0.03	0.01	0.07	<0.0005	0.0005	>>1	0.03	1	>0.003
Verkhnee Umgurlu	1019	0.005	<0.0003	0.003	0.05	0.015	0.2	0.0005	0.0003	>>1	0.015	0.5	0.001
Verkhnee Umgurlu	1020	0.003	<0.0003	0.0015	0.02	0.01	0.15	0.0005	0.00015	>1	0.005	0.03	>0.003
Verkhnee Umgurlu	1021	0.001	<0.0003	0.002	0.02	0.005	0.2	<0.0005	0.0003	>>1	0.02	0.3	>>0.003
Verkhnee Umgurlu	1022	0.003	0.015	0.005	0.1	0.005	0.1	0.0005	<0.0003	1	0.1	0.015	0.003

Deposit	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn	Pb	Ag
Verkhnee Umgurlu	1023	0.003	<0.0003	0.005	0.01	0.01	0.3	0.0005	<0.0003	>>1	0.007	>1	0.003
Efimovskoye	1029	0.005	0.001	0.007	0.03	0.0015	0.1	0.0005	<0.0003	>>1	0.3	0.1	0.00007
Efimovskoye	1030	0.007	0.003	0.007	0.1	0.005	0.15	0.001	<0.0003	>>1	0.2	0.03	0.0003
Efimovskoye	1031	0.005	0.002	0.007	0.02	0.007	0.5	0.001	<0.0003	>>1	0.2	0.03	0.0002
Efimovskoye	1032	0.007	0.0015	0.007	0.02	0.003	0.1	0.0005	<0.0003	>>1	0.3	0.02	0.00007
Efimovskoye	1033	0.0005	<0.0003	0.001	0.015	<0.001	0.015	<0.0005	<0.0003	>1	0.015	0.007	0.0007
Efimovskoye	1034	0.0015	<0.0003	0.002	0.03	<0.001	0.1	<0.0005	<0.0003	1	0.15	0.02	0.00003
Efimovskoye	1035	0.015	0.005	0.007	0.03	0.007	0.2	0.001	<0.0003	>>1	0.3	0.07	0.0015
Efimovskoye	1036	0.001	0.0003	0.001	0	<0.001	0.1	0.0005	<0.0003	1	0.02	0.003	0.00007
Efimovskoye	1037	0.0015	<0.0003	0.005	0.03	0.003	0.15	0.001	<0.0003	>>1	0.15	0.015	0.00005
Efimovskoye	1038	0.0005	<0.0003	0.0015	0.005	<0.001	0.005	<0.0005	<0.0003	1	0.015	0.002	0.00005
Efimovskoye	1039	0.0015	<0.0003	0.005	0.02	<0.001	0.1	<0.0005	<0.0003	1	0.2	0.03	0.0003
Efimovskoye	1040	0.002	0.0005	0.005	0.05	0.0015	0.07	0.0005	<0.0003	>>1	0.15	0.03	0.0002
Efimovskoye	1041	0.007	0.005	0.007	0.03	0.01	0.5	0.001	<0.0003	>>1	0.3	0.05	0.001
Efimovskoye	1042	0.0007	<0.0003	0.002	0.02	<0.001	0.07	0.0005	<0.0003	1	0.1	0.01	0.00005
Efimovskoye	1043	0.007	0.005	0.01	0.15	0.003	0.15	0.001	<0.0003	>>1	0.3	0.03	0.001
East Kurday	1045	0.007	0.03	0.003	0.15	0.01	0.03	<0.0005	0.00015	>>1	0.1	0.005	0.00005
East Kurday	1046	0.007	0.02	0.015	0.15	0.015	0.7	0.001	0.00015	>1	0.2	0.005	<0.00003
East Kurday	1047	0.003	0.02	0.003	0.15	0.0015	0.07	<0.0005	<0.0003	>>1	0.03	0.005	<0.00003
East Kurday	1048	0.003	0.05	0.005	0.3	<0.001	0.07	<0.0005	0.00015	>>1	0.15	0.02	<0.00003
East Kurday	1049	0.007	0.03	0.01	0.3	0.015	1	0.0015	<0.0003	>>1	0.3	0.7	<0.00003
East Kurday	1050	0.005	0.01	0.007	0.15	0.015	0.2	0.0005	0.00015	>>1	0.07	0.05	<0.00003
East Kurday	1051	0.002	0.01	0.007	0.2	0.003	0.1	<0.0005	<0.0003	>>1	0.2	0.1	0.00005
East Kurday	1052	0.001	<0.0003	0.001	0.005	<0.001	0.01	<0.0005	<0.0003	>1	0.07	0.015	0.00007
East Kurday	1053	0.015	0.03	0.001	0.1	0.01	0.02	0.001	<0.0003	1	0.15	0.015	<0.00003
East Kurday	1054	0.0007	<0.0003	0.001	0.005	0.003	0.01	<0.0005	<0.0003	>1	0.1	0.015	<0.00003
Chatyrkul	1059	0.005	<0.0003	0.007	0.1	<0.001	0.07	<0.0005	<0.0003	>>1	0.01	0.01	0.0007
Chatyrkul	1060	0.003	0.002	0.01	1	0.007	0.07	<0.0005	<0.0003	>>1	0.1	0.07	0.0007
Chatyrkul	1061	0.001	<0.0003	0.005	0.05	0.02	0.07	<0.0005	<0.0003	>>1	0.01	0.03	0.003
Chatyrkul	1062	0.005	0.01	0.007	0.7	0.05	0.07	<0.0005	<0.0003	>>1	0.3	0.01	0.003
Chatyrkul	1063	0.007	0.0005	0.005	0.5	0.007	0.05	0.0005	0.0003	>>1	0.15	0.01	0.0002
Chatyrkul	1064	0.005	<0.0003	0.007	0.15	0.015	0.15	0.0015	<0.0003	>>1	0.1	0.1	>0.003

Deposit	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn	Pb	Ag
Chatyrkul	1065	0.005	0.003	0.007	0.7	0.01	0.5	0.005	<0.0003	>>1	0.03	0.007	0.002
Chatyrkul	1066	0.003	<0.0003	0.007	0.15	0.005	0.07	0.002	<0.0003	>>1	0.1	0.007	>>0.003
Chatyrkul	1067	0.015	<0.0003	0.007	0.1	0.03	0.1	0.002	<0.0003	>>1	0.2	0.03	0.003
Chatyrkul	1068	0.005	<0.0003	0.005	0.1	0.005	0.05	0.0015	0.0007	>>1	0.15	0.015	>0.003
Chatyrkul	1069	0.005	<0.0003	0.01	0.1	0.005	0.1	0.0015	<0.0003	>>1	0.07	0.007	>>0.003
Chatyrkul	1070	0.003	<0.0003	0.007	0.5	<0.001	0.07	<0.0005	<0.0003	>>1	0.05	0.01	0.0007
Chatyrkul	1071	0.007	0.015	0.007	0.7	0.01	0.05	0.0005	<0.0003	>>1	0.15	0.02	0.0007
Chatyrkul	1072	0.001	<0.0003	0.007	0.15	<0.001	0.1	0.0015	0.0005	>>1	0.015	0.015	0.003
Chatyrkul	1073	0.003	0.001	0.007	0.3	0.01	0.15	0.0015	0.0003	>>1	0.07	0.1	>0.003
Chatyrkul	1074	0.005	<0.0003	0.015	0.1	0.01	0.05	0.001	<0.0003	>>1	0.15	0.005	0.003
Chatyrkul	1075	0.01	<0.0003	0.007	0.15	<0.001	0.15	0.003	0.0003	>>1	0.2	0.015	0.0005
Chatyrkul	1076	0.005	<0.0003	0.007	0.2	0.003	0.05	0.002	<0.0003	>>1	0.07	0.015	>0.003
Chatyrkul	1077	0.007	<0.0003	0.007	0.3	<0.001	0.05	0.0015	<0.0003	>>1	0.1	0.01	>0.003
Altyn-Tyube	1082	0.01	<0.0003	0.007	0.1	0.015	0.05	0.0015	<0.0003	>>1	0.03	0.005	0.00003
Altyn-Tyube	1083	0.03	<0.0003	0.007	0.07	0.0015	0.07	0.0015	<0.0003	>>1	0.7	0.1	0.00003
Altyn-Tyube	1084	0.03	0.003	0.01	0.2	0.003	0.3	0.0015	<0.0003	>>1	0.5	0.7	0.00003
Altyn-Tyube	1085	0.02	<0.0003	0.007	0.2	0.07	0.05	<0.0005	<0.0003	>>1	0.3	0.01	0.00003
Altyn-Tyube	1086	0.001	<0.0003	0.002	0.015	0.015	0.15	<0.0005	<0.0003	>1	0.007	0.007	0.00005
Altyn-Tyube	1087	0.007	<0.0003	0.007	0.15	0.07	0.05	<0.0005	<0.0003	>>1	0.1	0.03	0.0001
Altyn-Tyube	1088	0.007	0.003	0.007	0.1	0.1	0.2	0.0015	<0.0003	>>1	0.3	0.05	0.00015
Altyn-Tyube	1089	0.005	0.002	0.007	0.3	0.1	0.1	<0.0005	<0.0003	>>1	0.2	0.03	0.0003
Altyn-Tyube	1090	0.015	0.0005	0.007	0.1	0.01	0.2	0.001	<0.0003	>>1	0.2	0.03	0.00003
Altyn-Tyube	1091	0.003	0.0015	0.007	0.01	<0.001	0.05	<0.0005	<0.0003	>>1	0.1	0.015	0.00003
Altyn-Tyube	1092	0.007	<0.0003	0.007	0.02	0.1	0.1	<0.0005	<0.0003	>>1	0.15	0.015	0.00003
Altyn-Tyube	1093	0.003	<0.0003	0.005	0.03	0.01	0.05	<0.0005	<0.0003	>>1	0.007	0.003	0.0002
Altyn-Tyube	1094	0.005	<0.0003	0.007	0.5	0.003	0.05	<0.0005	<0.0003	>>1	0.07	0.005	0.00003
Altyn-Tyube	1095	0.02	0.001	0.005	0.15	0.007	0.3	0.001	<0.0003	>>1	0.07	0.01	0.00003
Altyn-Tyube	1096	0.002	<0.0003	0.003	0.02	0.0015	0.02	<0.0005	<0.0003	>>1	0.005	0.0015	0.00003
Altyn-Tyube	1097	0.01	<0.0003	0.005	0.03	0.05	0.05	<0.0005	<0.0003	>>1	0.07	0.003	0.00003
Altyn-Tyube	1098	0.001	<0.0003	0.003	0.015	0.01	0.05	<0.0005	<0.0003	>>1	0.005	0.02	>0.003
Altyn-Tyube	1099	0.001	<0.0003	0.007	0.02	<0.001	0.05	<0.0005	<0.0003	>>1	0.007	0.003	<0.00003
Altyn-Tyube	1100	0.007	0.0005	0.007	0.3	0.015	0.05	<0.0005	<0.0003	>>1	0.15	0.01	<0.00003

Deposit	**№**	**Ni**	**Co**	**Cr**	**Mn**	**V**	**Ti**	**Sc**	**Ge**	**Cu**	**Zn**	**Pb**	**Ag**
Sensitivity of the analysis		Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn	Pb	Ag
		0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.0003	0.001	0.003	0.0003	0.00003

Tab. 11-34. Emission spectral analyses of ore from Kazakhstan deposits (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30)(contd.).

Deposit	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn	Be	Zr
Southern Bulattau	1	0.0015	<0.001	0.03	0.1	<0.01	0.05	<0.001	0.01	0.05	0.01
Southern Bulattau	1	<0.003	<0.001	0.005	0.03	0.015	0.05	<0.001	0.007	>0.1	0.07
Southern Bulattau	>>1	<0.003	<0.001	0.03	>0.1	<0.01	0.1	<0.001	0.15	>0.1	0.02
Southern Bulattau	>>1	0.003	<0.001	>0.05	>0.1	<0.01	0.1	<0.001	>0.3	0.01	0.03
Southern Bulattau	>>1	0.0015	<0.001	0.05	>0.1	<0.01	0.07	<0.001	0.007	>0.1	0.015
Southern Bulattau	1	<0.003	<0.001	0.02	>0.1	<0.01	0.1	<0.001	0.03	0.003	0.03
Southern Bulattau	>1	0.0015	<0.001	0.03	0.05	0.3	0.07	0.0015	0.3	>0.1	0.15
Southern Bulattau	>1	<0.003	<0.001	>>0.05	>0.1	<0.01	0.1	<0.001	0.01	0.005	0.05
Southern Bulattau	>>1	<0.003	<0.001	0.05	>0.1	<0.01	0.1	<0.001	0.01	0.01	0.15
Southern Bulattau	>1	<0.003	<0.001	0.03	0.1	<0.01	0.1	<0.001	0.007	0.002	0.15
Aydygarli	0.005	<0.003	<0.001	>>0.05	0.0003	<0.01	<0.01	0.001	0.005	0.00015	nd
Aydygarli	0.005	<0.003	<0.001	0.03	0.0001	<0.01	<0.01	0.001	0.01	0.0001	nd
Aydygarli	0.005	<0.003	<0.001	0.015	0.0001	<0.01	<0.01	0.001	<0.0005	0.0002	nd
Aydygarli	0.005	<0.003	<0.001	0.01	<0.0001	<0.01	<0.01	0.001	0.003	0.0002	nd
Aydygarli	0.015	0.0015	<0.001	0.005	<0.0001	0.01	<0.01	<0.001	0.005	0.0002	nd
Aydygarli	0.005	<0.003	<0.001	0.015	<0.0001	<0.01	<0.01	<0.001	0.007	0.00015	nd
Aydygarli	0.005	<0.003	<0.001	0.03	0.0002	<0.01	<0.01	0.001	0.005	0.00015	nd
Aydygarli	0.005	<0.003	<0.001	>0.05	0.0007	<0.01	<0.01	0.001	0.005	0.00015	nd
Aydygarli	0.005	<0.003	<0.001	0.003	0.0005	<0.01	0.01	<0.001	0.0007	0.00015	nd
Aydygarli	0.005	<0.003	<0.001	0.05	0.0007	<0.01	<0.01	0.001	0.007	0.00015	nd
Aydygarli	0.005	<0.003	<0.001	0.005	0.0005	<0.01	<0.01	0.001	0.001	0.00015	nd
Aydygarli	0.005	<0.003	<0.001	>>0.05	0.0003	<0.01	<0.01	0.001	0.015	0.00015	nd
Aydygarli	0.005	0.0015	<0.001	0.003	0.0002	<0.01	<0.01	0.001	0.001	0.00015	nd
Aydygarli	0.005	0.0015	<0.001	0.001	0.0001	<0.01	<0.01	0.001	0.0007	0.00015	nd
Aydygarli	0.005	<0.003	<0.001	0.015	<0.0001	<0.01	0.01	0.001	0.005	0.0003	nd

Deposit	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn	Be	Zr
Southern Bulattau	>>1	0.007	<0.001	>>0.05	0.1	0.03	0.02	<0.001	0.03	0.0003	nd
Southern Bulattau	>>1	0.007	<0.001	>>0.05	0.07	0.01	0.01	<0.001	0.005	0.0007	nd
Southern Bulattau	>>1	0.01	<0.001	>>0.05	0.015	0.07	0.015	<0.001	0.05	0.0015	nd
Southern Bulattau	>>1	0.01	<0.001	>>0.05	0.05	0.03	0.015	<0.001	0.015	0.001	nd
Southern Bulattau	>>1	0.03	<0.001	>>0.05	0.02	0.03	0.02	<0.001	0.005	0.001	nd
Southern Bulattau	>>1	0.05	<0.001	>>0.05	>0.1	0.03	0.01	<0.001	0.02	0.0003	nd
Southern Bulattau	1	<0.003	<0.001	>>0.05	0.05	0.01	0.01	<0.001	0.02	0.0003	nd
Southern Bulattau	>1	0.01	<0.001	>0.05	0.005	0.015	<0.01	<0.001	0.1	0.0002	nd
Southern Bulattau	0.07	<0.003	<0.001	0.05	0.002	0.02	<0.01	<0.001	0.01	0.0002	nd
Southern Bulattau	0.2	<0.003	<0.001	>0.05	0.0005	<0.01	0.01	0.001	0.015	0.0002	nd
Southern Bulattau	0.5	<0.003	<0.001	0.03	0.00015	<0.01	<0.01	<0.001	0.1	0.0003	nd
Southern Bulattau	0.2	<0.003	<0.001	0.015	0.0001	<0.01	<0.01	<0.001	<0.0005	0.0007	nd
Southern Bulattau	1	<0.003	<0.001	0.015	0.003	<0.01	0.15	<0.001	0.015	0.0003	nd
Southern Bulattau	0.2	<0.003	<0.001	0.01	0.0007	0.01	0.01	<0.001	0.007	0.0002	nd
Southern Bulattau	0.2	<0.003	<0.001	0.005	0.0003	<0.01	<0.01	<0.001	<0.0005	0.00015	nd
Southern Bulattau	1	<0.003	<0.001	>0.05	0.003	0.02	0.01	0.001	0.1	0.0003	nd
Southern Bulattau	0.07	<0.003	<0.001	0.005	0.0005	<0.01	0.02	<0.001	0.03	0.0007	nd
Southern Bulattau	1	<0.003	<0.001	0.015	0.005	<0.01	0.05	0.001	0.007	0.0002	nd
Southern Bulattau	0.5	<0.003	<0.001	0.015	0.0003	<0.01	0.015	<0.001	0.003	0.00015	nd
Southern Bulattau	>1	0.0015	<0.001	0.02	0.005	<0.01	<0.01	<0.001	0.003	0.001	0.005
Southern Bulattau	0.2	<0.003	<0.001	0.02	0.0003	<0.01	<0.01	<0.001	0.0007	0.0002	nd

Deposit	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn	Be	Zr
Southern Bulattau	>1	<0.003	<0.001	>>0.05	0.005	0.02	0.1	<0.001	0.05	0.0015	0.007
Southern Bulattau	1	<0.003	<0.001	0.05	0.015	0.02	0.05	<0.001	0.001	0.00015	0.05
Kenkazgan	0.07	0.0015	<0.001	0.007	0.0002	0.02	<0.01	<0.001	0.003	0.002	0.01
Kenkazgan	0.03	<0.003	<0.001	0.001	0.0001	0.015	<0.01	0.001	<0.0005	0.0007	nd
Kenkazgan	0.15	<0.003	<0.001	0.05	0.002	0.5	<0.01	<0.001	0.0005	0.003	nd
Kenkazgan	0.02	<0.003	<0.001	0.015	0.001	0.015	0.01	<0.001	0.0015	0.001	0.01
Kenkazgan	0.07	<0.003	<0.001	<0.001	0.0005	0.015	<0.01	<0.001	<0.0005	0.0015	0.007
Kenkazgan	0.07	<0.003	<0.001	<0.001	0.0001	0.01	<0.01	<0.001	<0.0005	0.002	nd
Kenkazgan	0.1	0.003	<0.001	0.0015	0.0005	0.02	<0.01	<0.001	<0.0005	0.0015	nd
Kenkazgan	0.05	0.005	<0.001	<0.001	<0.0001	0.01	<0.01	<0.001	<0.0005	0.0015	nd
Kenkazgan	0.015	<0.003	<0.001	<0.001	<0.0001	<0.01	<0.01	0.001	0.0003	0.005	nd
Kenkazgan	0.15	<0.003	<0.001	<0.001	0.00015	0.02	<0.01	<0.001	<0.0005	0.003	nd
Kenkazgan	0.07	<0.003	<0.001	0.001	0.001	0.015	<0.01	<0.001	<0.0005	0.0007	0.007
Kenkazgan	0.05	<0.003	<0.001	<0.001	0.0001	0.02	<0.01	<0.001	0.0003	0.003	nd
Kenkazgan	0.15	<0.003	<0.001	<0.001	0.0007	0.05	<0.01	<0.001	0.001	0.002	0.007
Kenkazgan	0.02	<0.003	<0.001	<0.001	0.0007	0.05	<0.01	<0.001	0.0003	0.001	nd
Kenkazgan	0.05	<0.003	<0.001	0.005	0.001	0.02	<0.01	<0.001	0.0007	0.001	nd
Kenkazgan	0.1	<0.003	<0.001	0.0015	0.00015	0.015	<0.01	<0.001	<0.0005	0.002	nd
Kenkazgan	0.02	<0.003	<0.001	<0.001	0.0005	0.01	<0.01	<0.001	<0.0005	0.001	nd
Kenkazgan	0.15	<0.003	<0.001	0.001	0.001	0.05	<0.01	<0.001	<0.0005	0.003	nd
Kenkazgan	0.03	<0.003	<0.001	0.01	<0.0001	0.01	<0.01	<0.001	<0.0005	0.001	nd
Kenkazgan	0.03	<0.003	<0.001	0.01	0.0005	0.03	<0.01	<0.001	<0.0005	0.001	nd
Talapty	0.015	<0.003	<0.001	0.05	0.0001	0.01	<0.01	<0.001	0.0007	0.00005	nd
Talapty	<0.01	<0.003	<0.001	0.003	0.0001	<0.01	<0.01	<0.001	<0.0005	<0.00003	nd
Talapty	<0.01	<0.003	<0.001	0.003	<0.0001	<0.01	<0.01	<0.001	<0.0005	<0.00003	nd
Talapty	<0.01	<0.003	<0.001	0.02	0.0001	<0.01	<0.01	<0.001	0.0003	<0.00003	nd
Talapty	<0.01	<0.003	<0.001	0.003	<0.0001	<0.01	<0.01	<0.001	<0.0005	<0.00003	nd
Talapty	<0.01	<0.003	<0.001	0.05	<0.0001	0.01	0.01	<0.001	<0.0005	0.00003	nd
Talapty	0.005	<0.003	<0.001	0.05	0.0001	0.015	0.15	<0.001	<0.0005	0.00003	nd
Talapty	0.005	<0.003	<0.001	0.005	0.0001	0.01	0.01	<0.001	<0.0005	0.00003	nd
Talapty	0.005	<0.003	<0.001	0.02	<0.0001	0.01	0.015	<0.001	0.0003	0.00005	nd
Talapty	0.005	<0.003	<0.001	0.007	0.0002	<0.01	<0.01	<0.001	0.0005	0.00003	nd

Deposit	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn	Be	Zr
Talapty	0.005	<0.003	<0.001	0.03	0.0002	0.02	<0.01	<0.001	<0.0005	0.00003	nd
Talapty	0.005	<0.003	<0.001	0.03	0.0001	0.015	0.15	<0.001	<0.0005	0.00003	nd
Talapty	0.005	<0.003	<0.001	0.01	0.0001	<0.01	0.02	<0.001	<0.0005	<0.00003	nd
Talapty	0.005	<0.003	<0.001	0.02	<0.0001	0.01	0.02	<0.001	0.0007	0.00003	nd
Talapty	0.005	<0.003	<0.001	0.003	0.0001	<0.01	0.01	<0.001	<0.0005	<0.00003	nd
Talapty	0.005	<0.003	<0.001	0.03	<0.0001	0.05	0.15	<0.001	<0.0005	<0.00003	nd
Talapty	0.005	<0.003	<0.001	0.02	<0.0001	<0.01	<0.01	<0.001	0.0003	0.00003	nd
Talapty	0.005	<0.003	<0.001	0.02	0.0001	<0.01	<0.01	<0.001	0.001	0.00003	nd
Talapty	0.005	<0.003	<0.001	0.003	0.0001	<0.01	<0.01	<0.001	0.0005	0.00005	0.015
Talapty	0.005	<0.003	<0.001	0.03	0.0001	0.01	0.1	<0.001	<0.0005	<0.00003	nd
Verkhnee Umgurlu	0.015	0.0015	<0.001	0.0007	0.0002	0.01	0.01	<0.001	<0.0005	<0.00003	nd
Verkhnee Umgurlu	0.03	<0.003	<0.001	<0.001	0.0001	0.05	<0.01	<0.001	<0.0005	0.00005	nd
Verkhnee Umgurlu	0.07	<0.003	<0.001	0.002	0.0002	0.03	0.01	0.001	<0.0005	0.00015	0.007
Verkhnee Umgurlu	0.005	<0.003	<0.001	0.0007	0.015	0.01	<0.01	<0.001	<0.0005	0.00003	nd
Verkhnee Umgurlu	0.1	<0.003	<0.001	0.005	0.0007	<0.01	0.02	0.001	<0.0005	<0.00003	nd
Verkhnee Umgurlu	<0.01	<0.003	<0.001	<0.001	0.0005	0.2	0.01	<0.001	<0.0005	0.00003	nd
Verkhnee Umgurlu	0.01	<0.003	<0.001	<0.001	0.03	0.5	0.05	<0.001	0.001	0.00005	nd
Verkhnee Umgurlu	0.05	<0.003	<0.001	<0.001	0.0002	0.03	<0.01	0.001	<0.0005	0.0005	nd
Verkhnee Umgurlu	0.015	<0.003	<0.001	<0.001	0.002	0.03	<0.01	<0.001	<0.0005	0.00003	nd
Verkhnee Umgurlu	0.015	<0.003	<0.001	<0.001	0.015	0.015	<0.01	<0.001	0.0005	0.00007	nd
Verkhnee Umgurlu	0.07	<0.003	<0.001	0.001	0.0002	0.02	<0.01	<0.001	0.0003	0.0003	0.01
Verkhnee Umgurlu	0.015	<0.003	<0.001	<0.001	0.001	0.15	0.01	<0.001	0.001	0.0002	0.01
Verkhnee Umgurlu	0.03	<0.003	<0.001	<0.001	0.02	0.02	<0.01	<0.001	0.001	0.0001	0.005
Verkhnee Umgurlu	0.01	<0.003	<0.001	<0.001	0.0002	0.3	0.01	0.001	<0.0005	0.0003	0.01

Deposit	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn	Be	Zr
Verkhnee Umgurlu	0.015	<0.003	<0.001	<0.001	0.015	0.05	0.01	0.001	0.0005	0.0002	0.02
Efimovskoye	0.1	0.03	<0.001	<0.001	0.0001	0.02	0.01	<0.001	0.001	0.01	0.005
Efimovskoye	0.07	0.015	<0.001	<0.001	0.0001	0.02	0.01	<0.001	0.0003	0.005	0.007
Efimovskoye	0.07	0.03	<0.001	<0.001	0.0001	0.02	0.01	0.001	0.0003	0.005	0.015
Efimovskoye	0.07	0.05	<0.001	<0.001	0.0001	0.01	0.01	<0.001	0.0003	0.007	0.007
Efimovskoye	0.01	0.005	<0.001	<0.001	0.0001	0.015	<0.01	<0.001	<0.0005	0.0007	nd
Efimovskoye	0.05	0.03	<0.001	<0.001	0.0001	0.01	<0.01	<0.001	<0.0005	0.0003	nd
Efimovskoye	0.07	0.02	<0.001	<0.001	0.0001	0.05	0.01	0.001	0.0003	0.005	0.01
Efimovskoye	0.02	0.005	<0.001	<0.001	0.0001	0.01	<0.01	<0.001	<0.0005	0.0005	nd
Efimovskoye	0.07	0.03	<0.001	<0.001	0.0001	0.015	0.01	<0.001	0.0003	0.01	0.007
Efimovskoye	0.015	0.01	<0.001	<0.001	0.0001	<0.01	<0.01	<0.001	<0.0005	0.001	nd
Efimovskoye	0.1	0.03	<0.001	<0.001	0.0001	0.01	<0.01	<0.001	<0.0005	0.01	nd
Efimovskoye	0.1	0.03	<0.001	<0.001	0.0001	0.5	0.01	<0.001	0.0003	0.01	nd
Efimovskoye	0.1	0.02	<0.001	<0.001	0.0001	0.02	0.01	<0.001	0.0003	0.003	0.015
Efimovskoye	0.07	0.03	<0.001	<0.001	0.0001	0.02	<0.01	<0.001	<0.0005	0.007	nd
Efimovskoye	0.3	0.03	<0.001	<0.001	0.0001	0.03	0.015	<0.001	0.0003	0.007	0.007
East Kurday	0.01	<0.003	<0.001	<0.001	0.0015	0.15	0.01	0.001	0.0005	0.0002	nd
East Kurday	0.005	<0.003	<0.001	<0.001	0.0015	0.15	<0.01	<0.001	0.0015	0.0005	0.02
East Kurday	0.01	<0.003	<0.001	<0.001	0.005	0.03	<0.01	<0.001	0.0003	0.00007	0.005
East Kurday	0.01	<0.003	<0.001	<0.001	0.03	0.2	<0.01	<0.001	<0.0005	0.0001	nd
East Kurday	0.01	0.003	<0.001	<0.001	0.0015	0.15	<0.01	<0.001	0.0003	0.0005	0.015
East Kurday	0.01	<0.003	<0.001	<0.001	0.0007	0.2	0.02	0.001	0.003	0.0002	0.01
East Kurday	0.03	0.01	0.001	<0.001	0.002	1	0.01	<0.001	0.0005	0.0002	nd
East Kurday	0.015	0.01	<0.001	<0.001	0.0015	0.2	<0.01	<0.001	<0.0005	0.00007	nd
East Kurday	0.03	<0.003	<0.001	<0.001	0.001	>3	0.15	<0.001	0.001	0.001	nd
East Kurday	0.03	0.005	<0.001	<0.001	0.0003	0.15	<0.01	<0.001	<0.0005	0.0001	nd
Chatyrkul	0.015	<0.003	<0.001	<0.001	0.0001	0.015	<0.01	<0.001	<0.0005	0.003	nd
Chatyrkul	0.02	<0.003	<0.001	<0.001	0.0001	0.2	<0.01	<0.001	<0.0005	0.007	nd
Chatyrkul	0.015	<0.003	<0.001	<0.001	0.0001	0.02	<0.01	<0.001	<0.0005	0.00007	nd
Chatyrkul	0.2	<0.003	<0.001	<0.001	0.0001	0.03	<0.01	<0.001	<0.0005	0.01	nd
Chatyrkul	0.02	<0.003	<0.001	<0.001	0.0001	0.03	<0.01	<0.001	<0.0005	0.001	nd
Chatyrkul	0.03	<0.003	<0.001	<0.001	0.002	0.05	<0.01	<0.001	<0.0005	0.0002	nd

Deposit	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn	Be	Zr
Chatyrkul	0.03	<0.003	<0.001	<0.001	0.0001	0.07	<0.01	<0.001	<0.0005	0.0007	0.02
Chatyrkul	0.02	<0.003	<0.001	<0.001	0.0001	0.05	<0.01	<0.001	<0.0005	0.0002	0.005
Chatyrkul	0.07	<0.003	<0.001	<0.001	0.0001	0.02	<0.01	<0.001	<0.0005	0.002	0.005
Chatyrkul	0.015	<0.003	<0.001	<0.001	0.0001	0.01	<0.01	<0.001	<0.0005	0.0002	nd
Chatyrkul	0.03	<0.003	<0.001	<0.001	0.0001	0.015	<0.01	<0.001	<0.0005	0.0003	nd
Chatyrkul	0.02	<0.003	<0.001	<0.001	0.0001	0.02	<0.01	<0.001	<0.0005	0.003	nd
Chatyrkul	0.1	<0.003	<0.001	<0.001	0.0001	0.03	<0.01	<0.001	<0.0005	0.003	nd
Chatyrkul	0.03	0.003	<0.001	<0.001	0.0001	0.03	<0.01	<0.001	<0.0005	0.0002	nd
Chatyrkul	0.07	<0.003	0.001	0.001	0.002	0.15	<0.01	<0.001	<0.0005	0.0007	nd
Chatyrkul	0.02	0.0015	0.001	<0.001	0.0001	0.02	<0.01	<0.001	<0.0005	0.002	nd
Chatyrkul	0.03	<0.003	<0.001	<0.001	0.0001	0.015	<0.01	<0.001	<0.0005	0.0003	0.007
Chatyrkul	0.02	<0.003	0.001	<0.001	0.0001	0.01	<0.01	<0.001	<0.0005	0.0005	nd
Chatyrkul	0.015	<0.003	<0.001	<0.001	<0.0001	0.02	<0.01	<0.001	<0.0005	0.0003	nd
Altyn-Tyube	0.07	<0.003	0.0005	<0.001	<0.0001	0.01	<0.01	<0.001	<0.0005	0.003	nd
Altyn-Tyube	0.03	<0.003	0.001	<0.001	<0.0001	0.03	<0.01	<0.001	<0.0005	0.0015	0.007
Altyn-Tyube	0.03	<0.003	0.001	<0.001	<0.0001	0.05	0.01	<0.001	<0.0005	0.001	0.007
Altyn-Tyube	0.1	<0.003	0.001	<0.001	<0.0001	0.02	<0.01	<0.001	<0.0005	0.002	nd
Altyn-Tyube	0.015	<0.003	<0.001	<0.001	0.0003	0.03	<0.01	<0.001	0.0003	0.00015	nd
Altyn-Tyube	0.2	<0.003	0.001	<0.001	0.0001	0.07	<0.01	<0.001	<0.0005	0.02	nd
Altyn-Tyube	0.15	0.0015	0.001	0.001	0.0002	0.015	<0.01	<0.001	<0.0005	0.01	nd
Altyn-Tyube	0.15	0.0015	0.0015	<0.001	0.0001	0.07	<0.01	<0.001	<0.0005	0.015	nd
Altyn-Tyube	0.015	<0.003	0.0005	<0.001	<0.0001	0.015	0.01	<0.001	<0.0005	0.0005	0.01
Altyn-Tyube	0.01	<0.003	<0.001	<0.001	0.02	<0.01	<0.01	<0.001	0.0007	0.0001	nd
Altyn-Tyube	0.15	<0.003	0.002	<0.001	0.0001	0.01	<0.01	<0.001	<0.0005	0.01	nd
Altyn-Tyube	0.01	<0.003	<0.001	<0.001	0.003	<0.01	<0.01	<0.001	<0.0005	0.0002	nd
Altyn-Tyube	0.02	<0.003	0.0005	<0.001	0.0001	0.015	<0.01	<0.001	<0.0005	0.0015	nd
Altyn-Tyube	0.015	<0.003	<0.001	<0.001	<0.0001	0.02	<0.01	<0.001	<0.0005	0.001	0.015
Altyn-Tyube	0.015	<0.003	<0.001	<0.001	0.0001	0.01	<0.01	<0.001	<0.0005	0.0007	nd
Altyn-Tyube	0.1	<0.003	0.001	<0.001	0.0001	0.01	<0.01	<0.001	<0.0005	0.0015	nd
Altyn-Tyube	0.02	<0.003	<0.001	<0.001	0.0007	0.01	<0.01	0.0015	<0.0005	0.002	nd
Altyn-Tyube	0.02	0.0015	0.001	<0.001	0.0001	0.01	<0.01	<0.001	0.0007	0.0002	nd
Altyn-Tyube	0.07	0.0015	0.0015	<0.001	0.0001	0.015	<0.01	<0.001	<0.0005	0.0015	nd

Deposit	**As**	**Sb**	**Cd**	**Bi**	**Mo**	**Ba**	**Sr**	**W**	**Sn**	**Be**	**Zr**
Sensitivity of the analysis	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn	Be	Zr
	0.01	0.003	0.001	0.001	0.0001	0.01	0.01	0.001	0.0005	0.00003	0.001

Tab. 11-34. Emission spectral analyses of ore from Kazakhstan deposits (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30)(contd.).

Deposit	Ga	Y	Yb	La	Nb	Li	Hg
Southern Bulattau	0.001	>0.03	>0.003	<0.01	0.003	<0.01	<0.001
Southern Bulattau	0.003	>0.03	>0.003	<0.01	0.03	<0.01	<0.001
Southern Bulattau	0.002	>0.1	>0.003	<0.01	>>0.03	<0.01	<0.001
Southern Bulattau	0.01	>0.03	>0.003	<0.01	0.01	<0.01	<0.001
Southern Bulattau	0.0015	>0.03	>0.003	<0.01	0.005	<0.01	<0.001
Southern Bulattau	0.015	>0.03	>0.003	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.01	>0.03	>0.003	<0.01	0.03	<0.01	<0.001
Southern Bulattau	0.005	>0.03	>0.003	<0.01	0.01	<0.01	<0.001
Southern Bulattau	0.007	>0.03	>0.003	<0.01	0.01	<0.01	<0.001
Southern Bulattau	0.005	>0.03	>0.003	<0.01	0.015	<0.01	<0.001
Aydygarli	0.001	0.01	0.0003	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.0005	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.0005	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.0015	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.001	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.0015	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.001	0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.001	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.0015	0.003	0.0001	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.001	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.0015	0.002	0.0001	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.001	0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.0015	0.0015	0.0001	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.0015	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Aydygarli	0.0015	0.002	0.00015	<0.01	<0.003	<0.01	<0.001

Deposit	Ga	Y	Yb	La	Nb	Li	Hg
Southern Bulattau	0.003	0.002	0.0002	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.001	0.015	0.001	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	<0.0005	0.005	0.0002	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.0005	0.005	0.0002	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.007	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.002	>>0.03	>0.003	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	<0.0005	0.015	0.001	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	<0.0005	0.003	0.00015	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.001	0.015	0.001	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	<0.0005	0.015	0.0015	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	<0.0005	0.02	0.0015	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.0015	>>0.03	>0.003	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.001	0.015	0.002	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	<0.0005	0.0015	0.00015	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.005	0.007	0.002	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.01	0.02	0.0015	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.0015	>0.03	>0.003	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	<0.0005	0.03	0.003	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.0005	0.003	0.00015	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	<0.0005	0.01	0.0007	<0.01	<0.003	<0.01	<0.001

Deposit	**Ga**	**Y**	**Yb**	**La**	**Nb**	**Li**	**Hg**
Southern Bulattau	0.003	>0.03	>0.003	<0.01	<0.003	<0.01	<0.001
Southern Bulattau	0.003	>0.03	>0.003	<0.01	<0.003	<0.01	<0.001
Kenkazgan	0.0015	0.005	0.00015	<0.01	<0.003	<0.01	<0.001
Kenkazgan	<0.0005	0.002	0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	<0.0005	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	0.0015	0.005	0.0003	<0.01	<0.003	<0.01	<0.001
Kenkazgan	0.001	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	<0.0005	<0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	<0.0005	0.002	<0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	0.0005	0.002	0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	0.0005	0.0015	0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	<0.0005	0.005	0.0003	<0.01	<0.003	<0.01	<0.001
Kenkazgan	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	0.0005	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	0.001	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Kenkazgan	0.0005	0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	0.001	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	0.001	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001

Deposit	Ga	Y	Yb	La	Nb	Li	Hg
Talapty	0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	0.002	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Talapty	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	0.002	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	0.003	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	0.0015	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	0.003	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	0.002	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnee Umgurlu	0.0015	0.003	0.0002	<0.01	<0.003	<0.01	<0.001

Deposit	Ga	Y	Yb	La	Nb	Li	Hg
Verkhnee Umgurlu	0.003	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Efimovskoye	0.0005	0.003	0.0002	<0.01	<0.003	<0.01	<0.001
Efimovskoye	0.0005	0.005	0.0002	<0.01	<0.003	<0.01	<0.001
Efimovskoye	0.001	0.005	0.0002	<0.01	<0.003	<0.01	<0.001
Efimovskoye	<0.0005	0.003	0.00015	<0.01	<0.003	<0.01	<0.001
Efimovskoye	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Efimovskoye	<0.0005	0.003	0.0001	<0.01	<0.003	<0.01	<0.001
Efimovskoye	<0.0005	0.003	0.0002	<0.01	<0.003	<0.01	<0.001
Efimovskoye	0.0005	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Efimovskoye	<0.0005	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Efimovskoye	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Efimovskoye	<0.0005	0.005	0.0002	<0.01	<0.003	<0.01	<0.001
Efimovskoye	<0.0005	0.003	0.00015	<0.01	<0.003	<0.01	<0.001
Efimovskoye	0.0015	0.005	0.0002	<0.01	<0.003	<0.01	<0.001
Efimovskoye	<0.0005	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Efimovskoye	<0.0005	0.02	0.0015	<0.01	<0.003	<0.01	<0.001
East Kurday	0.005	0.0015	0.00015	<0.01	<0.003	<0.01	<0.001
East Kurday	0.003	0.005	0.0003	<0.01	<0.003	<0.01	<0.001
East Kurday	<0.0005	0.0015	0.0001	<0.01	<0.003	<0.01	<0.001
East Kurday	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
East Kurday	0.0015	0.003	0.00015	<0.01	<0.003	<0.01	<0.001
East Kurday	0.003	0.007	0.001	<0.01	<0.003	<0.01	<0.001
East Kurday	0.001	0.001	0.0001	<0.01	<0.003	<0.01	<0.001
East Kurday	0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
East Kurday	0.0015	0.015	0.0015	<0.01	<0.003	<0.01	<0.001
East Kurday	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Chatyrkul	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	0.01
Chatyrkul	<0.0005	0.0015	<0.0001	<0.01	<0.003	<0.01	0.001
Chatyrkul	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	0.001
Chatyrkul	<0.0005	0.002	0.0001	<0.01	<0.003	<0.01	<0.001
Chatyrkul	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Chatyrkul	0.001	0.001	<0.0001	<0.01	<0.003	<0.01	0.01

Deposit	Ga	Y	Yb	La	Nb	Li	Hg
Chatyrkul	0.001	0.002	0.0001	<0.01	<0.003	<0.01	0.0015
Chatyrkul	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	0.01
Chatyrkul	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Chatyrkul	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	0.03
Chatyrkul	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	0.01
Chatyrkul	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	0.005
Chatyrkul	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	0.001
Chatyrkul	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	0.002
Chatyrkul	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	0.001
Chatyrkul	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	0.02
Chatyrkul	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Chatyrkul	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	0.03
Chatyrkul	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	0.03
Altyn-Tyube	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	0.002	0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	0.001	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	0.01	0.0007	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	0.0015	0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	0.002	0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	0.001	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001

Deposit	Ga	Y	Yb	La	Nb	Li	Hg
Sensitivity of the analysis	Ga	Y	Yb	La	Nb	Li	Hg
	0.0005	0.001	0.0001	0.01	0.003	0.01	0.001

Tab. 11-35. Forms of slag of the Late Bronze Age.

Form / Period	Flat slag cakes	Flattened slag	Heavy shapeless slag	Light shapeless slag	others
Bersuat XVIII					1
Ubagan II	1		1		
Shandasha			3		
Kupukhta	1		2	1	
Baytu	1		1		1
Ak-Moustapha	1			1	
Atasu			4		
Myrzhik	2				
Alakul	**6 28.6%**		**11 52.4%**	**2 9.5%**	**2 9.5%**
Graurtly			1		
Pavlovka		2			
Ust-Kenetay			5	14	
Ilyaska			26		
Novo Bayramgulovo			2		
Arkhangelskii Priisk			19	16	17 slagged lining
Fyodorovka-Mezhovka		**2 1.9%**	**59 54.6%**	**30 27.8%**	**17 15.7%**
Kipel	1				
Yazyovo III			1		
Korkino	1		1	4	1
Ak-Maya		1	1		
Andronovo	**2 18.2%**	**1 9.1%**	**3 27.2%**	**4 36.4%**	**1 9.1%**
Kafarka			1		
Kent			1		
Telmana XVI	1				
Sargari	1				
Kalinovka II			3		
Final Bronze Age	**2 28.6%**		**5 71.4%**		

Form / Period	Flat slag cakes	Flattened slag	Heavy shapeless slag	Light shapeless slag	others
Atamanovka V					1
Kamyshnoye II		1			1
Kara-Tyube			1		
Novonikolskoye	1				
Stepnyak		1			
Eastern Koinda			5	2	
Chisty Yar	1		1		
Altyn-Tyube					2
Akimbek		2			
Ikpen I					5
Nikolaevka					1
Late Bronze Age	**2** **3.9%**	**4** **7.9%**	**33** **64.7%**	**2** **3.9%**	**10** **19.6%**
Total:	**12** **6.1%**	**7** **3.5%**	**111** **56.1%**	**38** **19.2%**	**30** **15.1%**

Tab. 11-36. Distribution of the forms of slag over areas.

Form / Area	Flat slag cakes	Flattened slag	Heavy shapeless slag	Light shapeless slag	others
Transurals	5 4.7%	1 0.9%	57 53.3%	21 19.6%	23 21.5%
Northern and Central Kazakhstan	6 14.6%	4 9.8%	14 34.1%	15 36.6%	2 4.9%
Altai and Eastern Kazakhstan	1 5.9%		9 52.9%	2 11.8%	5 29.4%
Total:	**12** **7.3%**	**5** **3%**	**80** **48.5%**	**38** **23%**	**30** **18.2%**

Tab. 11-37. Bulk chemical analyses of slag (%) from the LBA sites in Kazakhstan. The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

Sample	Settlement	Material	SiO_2	FeO	CaO	Cu	Fe_3O_4
18	Atasu	slag	27.26	6.23	3.27	28.93	0.77
19	Atasu	slag	18.96	4.98	1.76	42.00	0.50
21	Atasu	furnace charge	3.36	0.14	н/о	17.67	0.16
26	Myrzhik	slag	14.96	9.25	2.18	60.00	0.34
27	Myrzhik	slag	24.36	12.90	2.60	40.00	4.25
44	Sargari	slag	33.34	7.56	6.12	14.40	2.52
46	Novonikolskoye	slag	29.62	39.42	10.39	0.36	2.85
53	Ak-Moustapha	slag	10.16	0.36	1.33	0.05	0.42

Tab. 11-38. Ratio of $SiO_2/FeO+Fe_3O_4$ in slag and charge of the settlements in Kazakhstan.

Sample	Settlement	Material	$SiO_2/Fe0+Fe_3O_4$
46	Novonikolskoye	slag	0.7
27	Myrzhik	slag	1.42
26	Myrzhik	slag	1.56
44	Sargari	slag	3.3
19	Atasu	slag	3.45
18	Atasu	slag	3.89
21	Atasu	furnace charge	11.2
53	Ak-Moustapha	slag	13

Tab. 11-38. Ratio of $SiO_2/FeO+Fe_3O_4$ in slag and charge of the settlements in Kazakhstan.

Sample	Settlement	Material	$SiO_2/Fe0+Fe_3O_4$
46	Novonikolskoye	slag	0.7
27	Myrzhik	slag	1.42
26	Myrzhik	slag	1.56
44	Sargari	slag	3.3
19	Atasu	slag	3.45
18	Atasu	slag	3.89
21	Atasu	furnace charge	11.2
53	Ak-Moustapha	slag	13

Tab. 11-39. Bulk chemical analyses of slag and ore (%) from the Mezhovka settlements. The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

№	Settlement	Material	SiO_2	TiO2	Al_2O_3	FeO	CaO	K_2O	S	Cu	CuO	Total
2231	Novo Bayramgulovo	slag	49.76	0.53	20.36	8.28	11.50	1.45	0.05	0.02	0.02	91.90
2358	Arkhangelskii Priisk	slagged rock	63.46	0.26	13.67	4.03	6.80	3.90	0.05	0.73	0.91	92.85
2422	Arkhangelskii Priisk	heavy dense slag	52.18	0.66	16.86	12.53	5.87	2.36	0.05	2.60	3.25	93.71
2429	Arkhangelskii Priisk	heavy dense slag	46.00	0.74	20.94	15.49	3.52	1.94	0.05	3.08	3.85	92.48
2451	Arkhangelskii Priisk	slagged crucible	54.24	0.35	10.33	19.09	2.58	2.08	0.05	2.66	3.33	92.00
2467	Arkhangelskii Priisk	slagged crucible	63.58	0.66	13.17	3.96	8.22	2.30	0.05	0.17	0.21	92.20
2477	Arkhangelskii Priisk	slagged crucible	63.92	0.66	12.90	4.18	8.92	2.30	0.05	0.10	0.12	93.00

Tab. 11-40. Average chemical compositions of the ore bearing rock, heavy slag and slagged parts of the crucibles from the settlement of Arkhangelskii Priisk II (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

Material	SiO_2	TiO_2	Al_2O_3	FeO	CaO	K_2O	S	Cu	CuO
slagged rock	63.46	0.26	13.67	4.03	6.80	3.90	0.05	0.73	0.91
heavy dense slag	49.09	0.7	18.9	14.01	14.01	2.12	0.05	2.84	3.55
slagged crucible	60.58	0.56	12.13	9.08	9.08	2.23	0.05	0.98	1.22

Tab. 11-41. Coefficients of basicity slag of the Mezhovka settlements.

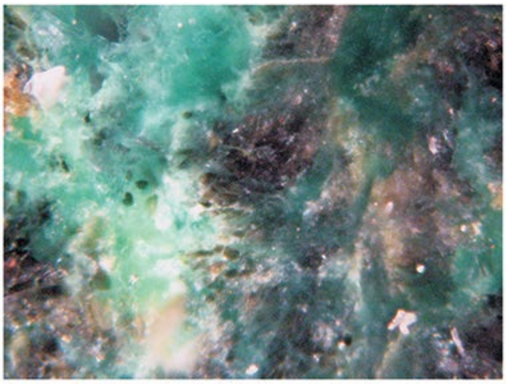
№	Settlement	Material	Basicity	Group
2231	Novo Bayramgulovo	slag	0.3	ultra-acid
2358	Arkhangelskii Priisk	slagged rock	0.19	ultra-acid
2422	Arkhangelskii Priisk	heavy dense slag	0.3	ultra-acid
2429	Arkhangelskii Priisk	heavy dense slag	0.31	ultra-acid
2451	Arkhangelskii Priisk	slagged crucible	0.37	ultra-acid
2467	Arkhangelskii Priisk	slagged crucible	0.19	ultra-acid
2477	Arkhangelskii Priisk	slagged crucible	0.2	ultra-acid

Tab. 11-42. Coefficients of viscosity (Pa•s) of slag of the Mezhovka settlements at the temperature of 1400ºC.

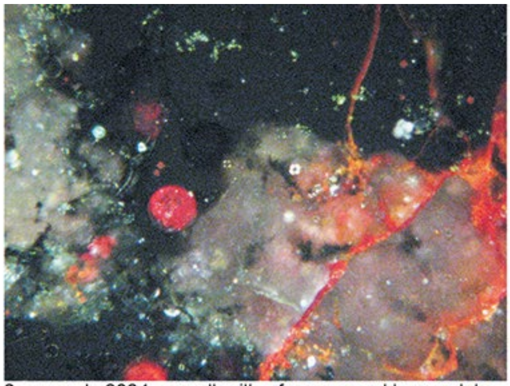
№	Settlement	Material	Pa·s
2231	Novo Bayramgulovo	slag	16.47
2358	Arkhangelskii Priisk	slagged rock	33.63
2422	Arkhangelskii Priisk	heavy dense slag	17.30
2429	Arkhangelskii Priisk	heavy dense slag	16.16
2451	Arkhangelskii Priisk	slagged crucible	13.92
2467	Arkhangelskii Priisk	slagged crucible	28.84
2477	Arkhangelskii Priisk	slagged crucible	26.91

Tab. 11-43. X-ray diffraction analyses of slag from the LBA settlement in Kazakhstan (Department of Physics-1, South-Ural State University).

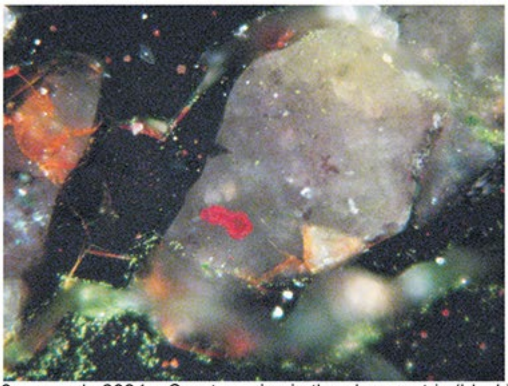
Settlements	**Sample**	**quartz**	**tridymite**	**cristobalite**	**FeO**	**Fe_2O_3**	**Fe_3O_4**	**Cu**
Petrovka II	12	*	*	*	*	?		?
Atasu	19				*			
Myrzhik	27	*	*	*	*	*	?	*
Sargari	44	*	?	*		?		*
Novonikolskoye I	46	*		*		?		*
Telmana XVI	49	*	*	*	*	?	*	?
Vishnyovka I	54		?	*	*	*		



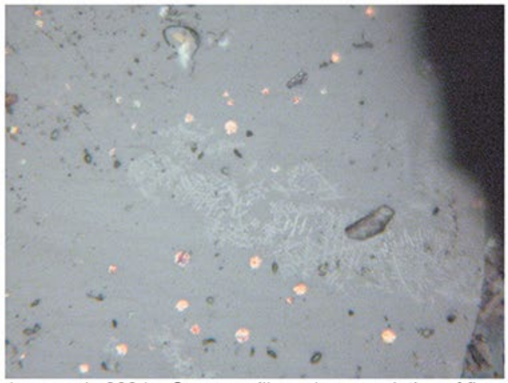
1 – sample 2028 – Malachite in quartz rock.



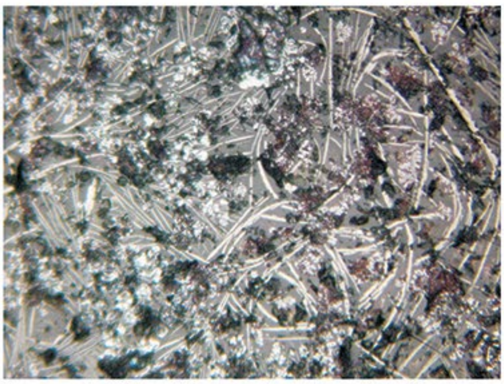
2 – sample 2024 – small prills of copper and larger globules of cuprite in the glass matrix. Cracks in the glass and quartz are filled with cuprite.



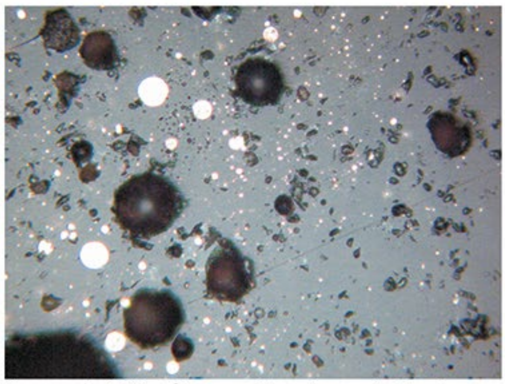
3 – sample 2024 – Quartz grains in the glass matrix (black). Cuprite inclusion (red) in quartz.



4 – sample 2024 – Copper prills and accumulation of fine dendritic skeletons of magnetite in the glass matrix.

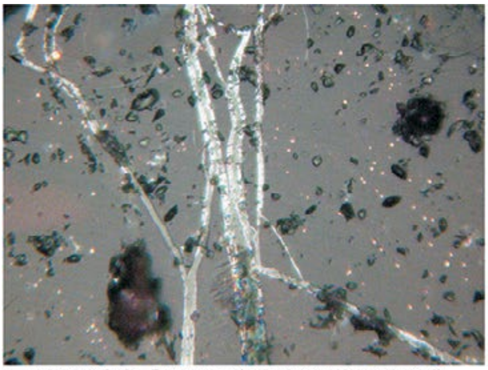


5 – sample 2026 – Thin curved needles of delafossite, dendrites and prills of cuprite, iron hydroxides.

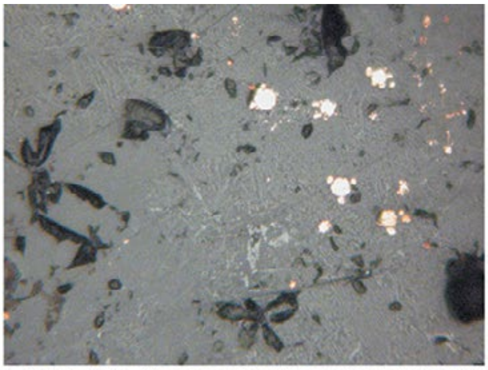


6 – sample 1846 – Copper prills and pores in the glass matrix.

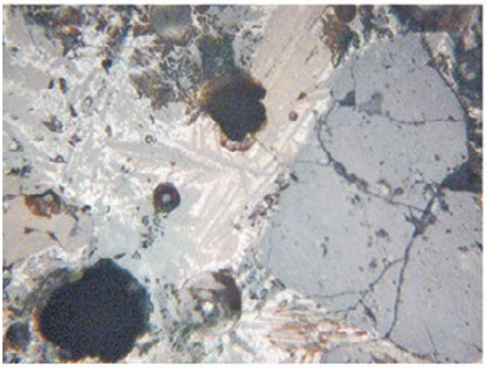
Fig. 11-III. Microstructures of ore and slag of the 4th mineralogical group from sites of the Alakul culture in the Dombarovsky area of Orenburg region, reflected light: (length of the photos is 0.62 mm): 1-5 – Baytu, 6 – Kupukhta: 1 – sample 2028 – Malachite in quartz rock; 2 – sample 2024 – small prills of copper and larger globules of cuprite in the glass matrix. Cracks in the glass and quartz are filled with cuprite; 3 – sample 2024 – Quartz grains in the glass matrix (black). Cuprite inclusion (red) in quartz; 4 – sample 2024 – Copper prills and accumulation of fine dendritic skeletons of magnetite in the glass matrix; 5 – sample 2026 – Thin curved needles of delafossite, dendrites and prills of cuprite, iron hydroxides; 6 – sample 1846 – Copper prills and pores in the glass matrix.



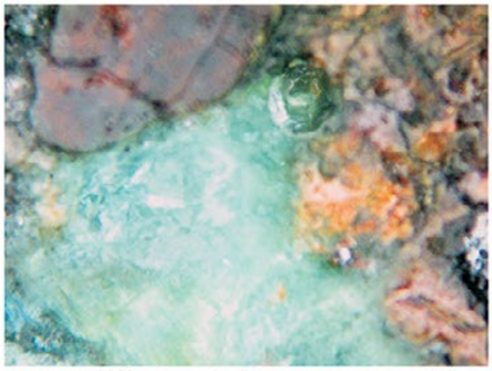
1 – sample 1846 – Pores, cuprite in the cracks and small copper prills in the glass matrix (length of the photo is 0.46 mm).



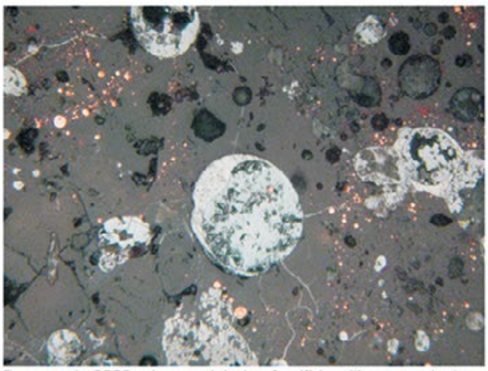
2 – sample 2022 – Copper prills and fine skeletons of magnetite (length of the photo is 0.46 mm).



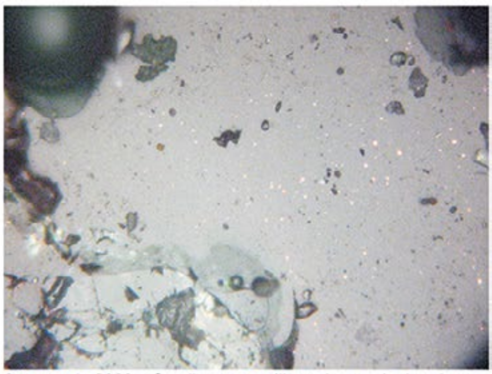
3 – sample 2023 – Quartz grains, dendrites of hydroxides and pores (length of the photo is 0.62 mm).



4 – sample 2023 – Iron hydroxides and quartz in association with malachite (length of the photo is 0.62 mm, crossed nicols).

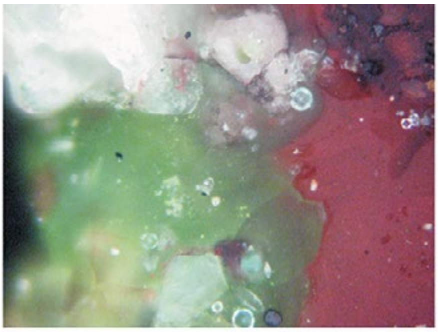


5 – sample 2023 – Large globule of sulfide with copper inclusions and cuprite border, prills of cuprite and copper, small cracks filled with cuprite, pores (length of the photo is 0.62 mm).

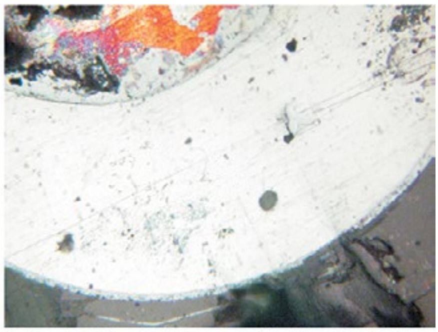


6 – sample 2023 – Small copper prills and pores in the glass matrix (length of the photo is 0.62 mm).

Fig. 11-IV. Microstructures of slag of the 4th mineralogical group from the Alakul settlement of Kupukhta in the Dombarovsky area of Orenburg region, reflected light: 1 – sample 1846 – Pores, cuprite in the cracks and small copper prills in the glass matrix (length of the photo is 0.46 mm); 2 – sample 2022 – Copper prills and fine skeletons of magnetite (length of the photo is 0.46 mm); 3 – sample 2023 – Quartz grains, dendrites of hydroxides and pores (length of the photo is 0.62 mm); 4 – sample 2023 – Iron hydroxides and quartz in association with malachite (length of the photo is 0.62 mm, crossed nicols); 5 – sample 2023 – Large globule of sulfide with copper inclusions and cuprite border, prills of cuprite and copper, small cracks filled with cuprite, pores (length of the photo is 0.62 mm); 6 – sample 2023 – Small copper prills and pores in the glass matrix (length of the photo is 0.62 mm).

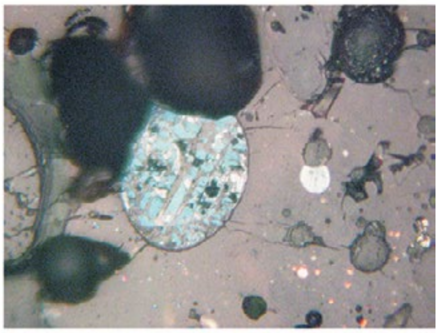


1 – Grains of quartz, malachite and chrysocolla in the glass in the red color by small particles of cuprite (length of the photo is 0.62 mm, crossed nicols).

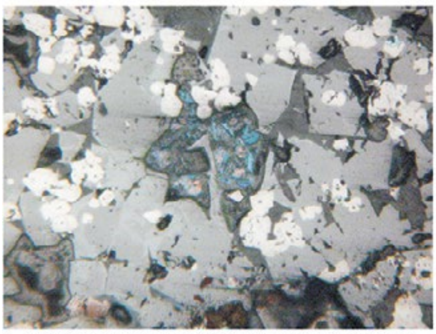


2 – Large globule of sulfide surrounded with cuprite border. There is a copper core inside, separated from the sulfide by a rim of cuprite (length of the photo is 0.62 mm).

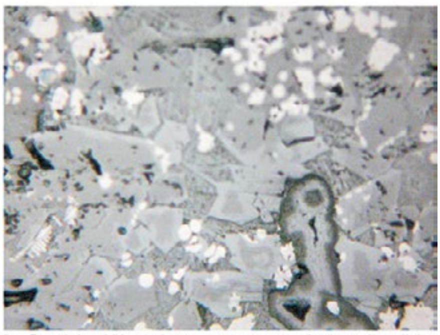
3 – A globule of copper and malachite surrounded with sulfide border in the painted glass matrix. A fused grain of malachite and quartz particles forming a structure of sandstone (length of the photo is 0.62 mm, crossed nicols).



4 – Prills of covellite (blue), cuprite (white), small prills of copper and pores in the painted glass matrix (length of the photo is 0.46 mm).

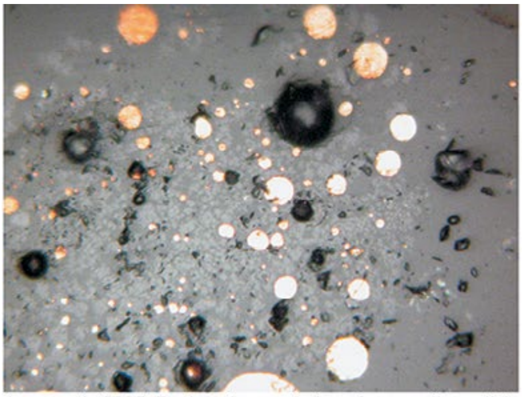


5 – Polygonal crystals of olivine (grey), and magnetite octahedral (white) formed earlier. A blue grain of covellite in the center (length of the photo is 0.46 mm).

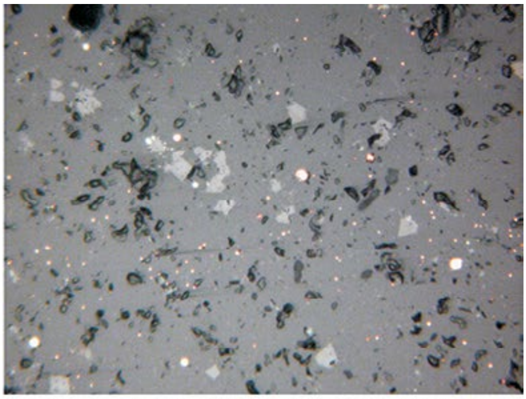


6 – Small dendritic skeletons and crystals of magnetite, olivine crystals with zonal structure: the outer part is lighter (length of the photo is 0.46 mm).

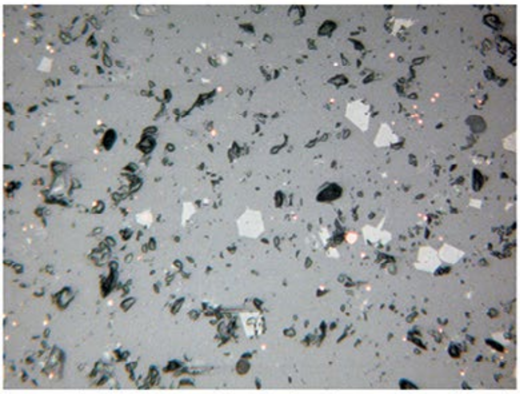
FIG. 11-V. MICROSTRUCTURES OF SLAG OF THE 4TH (1-4 – SAMPLE 2023) AND 1ST (5,6 – SAMPLE 2021) MINERALOGICAL GROUPS FROM THE ALAKUL SETTLEMENT OF KUPUKHTA IN THE DOMBAROVSKY AREA OF ORENBURG REGION, REFLECTED LIGHT: 1 – GRAINS OF QUARTZ, MALACHITE AND CHRYSOCOLLA IN THE GLASS PAINTED IN THE RED COLOR BY SMALL PARTICLES OF CUPRITE (LENGTH OF THE PHOTO IS 0.62 MM, CROSSED NICOLS); 2 – LARGE GLOBULE OF SULFIDE SURROUNDED WITH CUPRITE BORDER. THERE IS A COPPER CORE INSIDE, SEPARATED FROM THE SULFIDE BY A RIM OF CUPRITE (LENGTH OF THE PHOTO IS 0.62 MM); 3 – A GLOBULE OF COPPER AND MALACHITE SURROUNDED WITH SULFIDE BORDER IN THE PAINTED GLASS MATRIX. A FUSED GRAIN OF MALACHITE AND QUARTZ PARTICLES FORMING A STRUCTURE OF SANDSTONE (LENGTH OF THE PHOTO IS 0.62 MM, CROSSED NICOLS); 4 – PRILLS OF COVELLITE (BLUE), CUPRITE (WHITE), SMALL PRILLS OF COPPER AND PORES IN THE PAINTED GLASS MATRIX (LENGTH OF THE PHOTO IS 0.46 MM); 5 – POLYGONAL CRYSTALS OF OLIVINE (GREY), AND MAGNETITE OCTAHEDRAL (WHITE) FORMED EARLIER. A BLUE GRAIN OF COVELLITE IN THE CENTER (LENGTH OF THE PHOTO IS 0.46 MM); 6 – SMALL DENDRITIC SKELETONS AND CRYSTALS OF MAGNETITE, OLIVINE CRYSTALS WITH ZONAL STRUCTURE: THE OUTER PART IS LIGHTER (LENGTH OF THE PHOTO IS 0.46 MM).



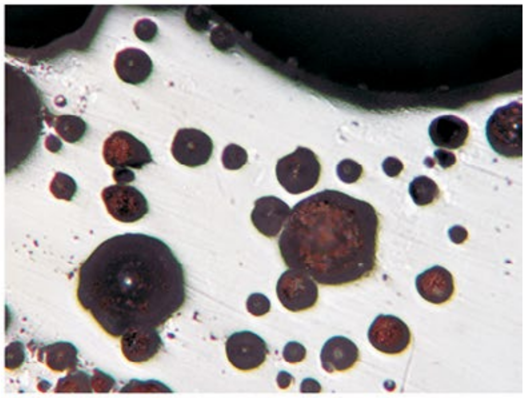
1 – sample 2025, Baytu – Accumulation of magnetite particles disintegrating from a larger grain. Copper prills are inside.



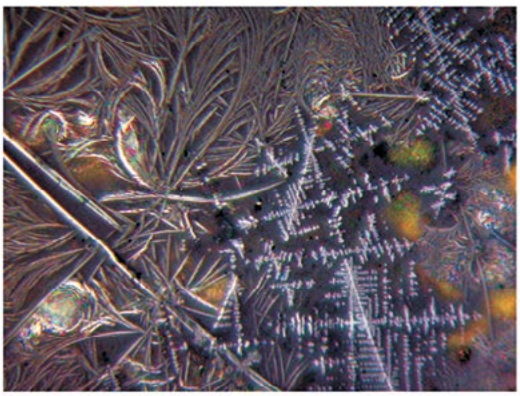
2– sample 2025, Baytu – Octahedra of magnetite, copper prills and pores in the glass matrix.

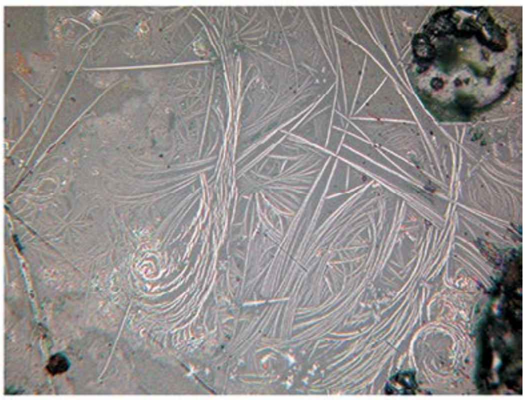


3 – sample 2025, Baytu – Octahedra of magnetite, prills and pores in the glass matrix. One copper prill is included into magnetite.



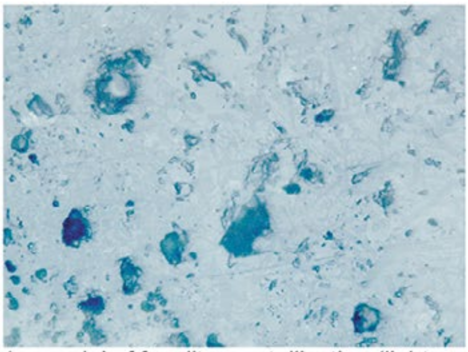
4 – sample 2218, Ilyaska I – Porous glass without crystallization.

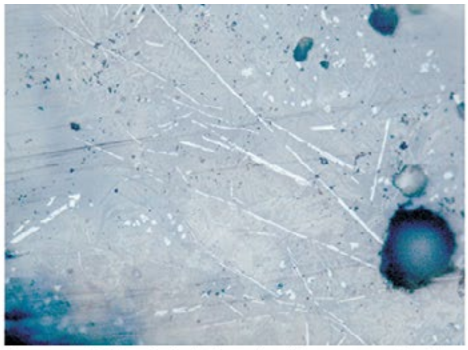


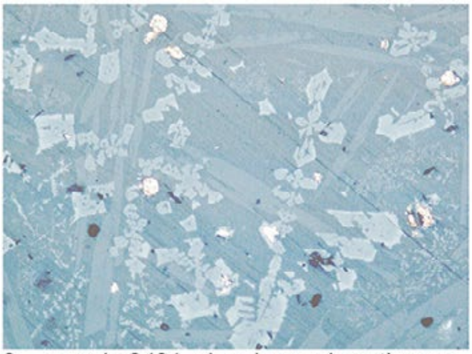


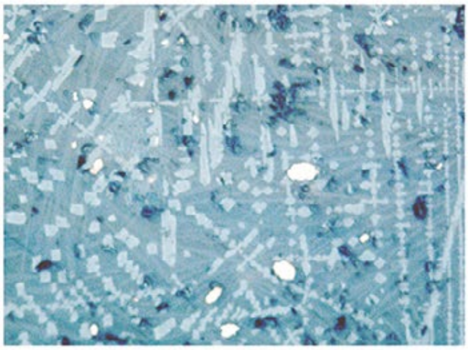
5,6 – sample 793, Kalinovka II – curved needles of delafossite, small copper prills and dendrites of magnetite in the glass matrix.

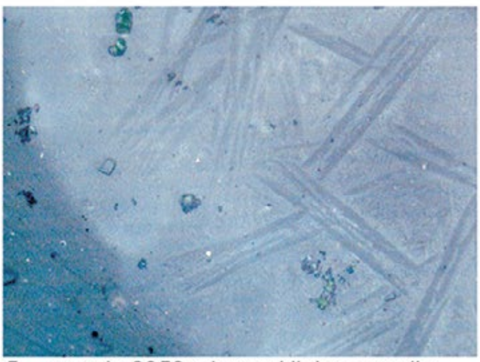
Fig. 11-VI. Microstructures of slag of the 1st (1-3), 4th (5,6) and 6th (4) mineralogical groups, length of the photos is 0.62 mm: 1 – sample 2025, Baytu – Accumulation of magnetite particles disintegrating from a larger grain. Copper prills are inside; 2– sample 2025, Baytu – Octahedra of magnetite, copper prills and pores in the glass matrix; 3 – sample 2025, Baytu – Octahedra of magnetite, copper prills and pores in the glass matrix. One copper prill is included into magnetite; 4 – sample 2218, Ilyaska I – Porous glass without crystallization; 5,6 – sample 793, Kalinovka II – curved needles of delafossite, small copper prills and dendrites of magnetite in the glass matrix.


1 – nuclei of fayalite crystallization (lighter crystals).


2 – crystals of delafossite (long needles) and small octahedra of magnetite (lighter crystals).


3 – sample 2431, slag: long prismatic crystals of fayalite, dendrites and skeletons of magnetite, copper prills.


4 – sample 2431, slag: needle-shaped crystals of fayalite (background), dendrites of magnetite and copper prills.


5 – sample 2353, slagged lining: needle-shaped crystals of fayalite and copper prills.

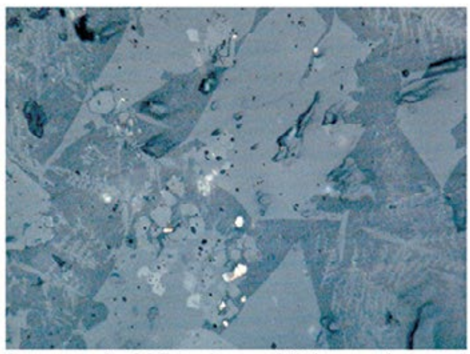
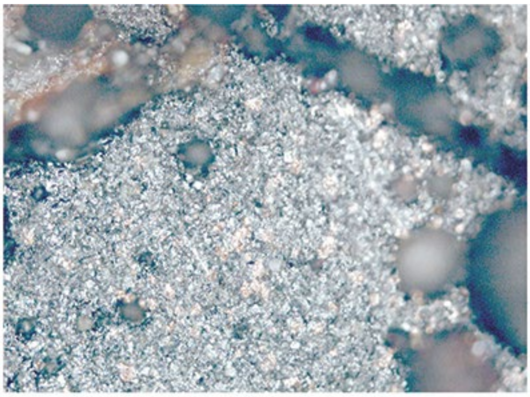
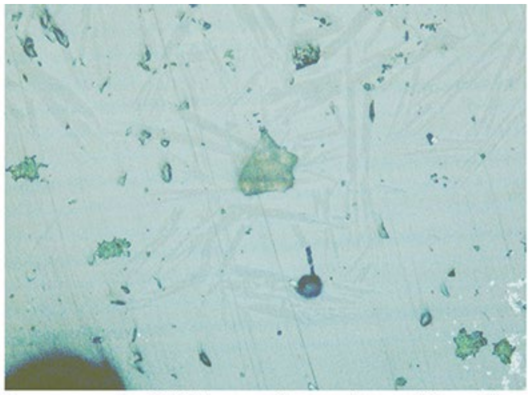

6 – sample 2354, slagged lining: polygonal crystals of fayalite, its small needle-shaped crystals, copper prills, small octahedra of magnetite (light grey).

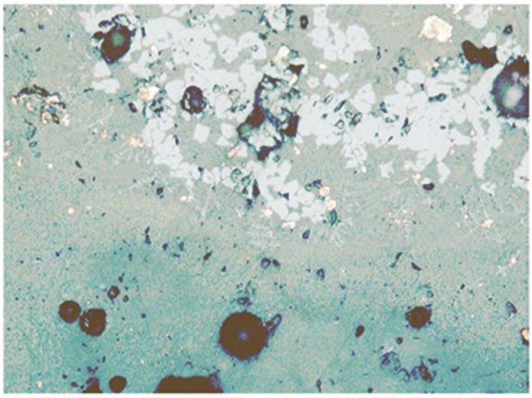
Fig. 11-VII. Microstructures of slag of the Mezhovka settlements: 1,2 – Novo Bayramgulovo (№ 2231), 3-6 – Arkhangelskii Priisk II: 1 – nuclei of fayalite crystallization (lighter crystals); 2 – crystals of delafossite (long needles) and small octahedra of magnetite (lighter crystals). 3 – sample 2431, slag: long prismatic crystals of fayalite, dendrites and skeletons of magnetite, copper prills; 4 – sample 2431, slag: needle-shaped crystals of fayalite (background), dendrites of magnetite and copper prills. 5 – sample 2353, slagged lining: needle-shaped crystals of fayalite and copper prills; 6 – sample 2354, slagged lining: polygonal crystals of fayalite, its small needle-shaped crystals, copper prills, small octahedra of magnetite (light grey).



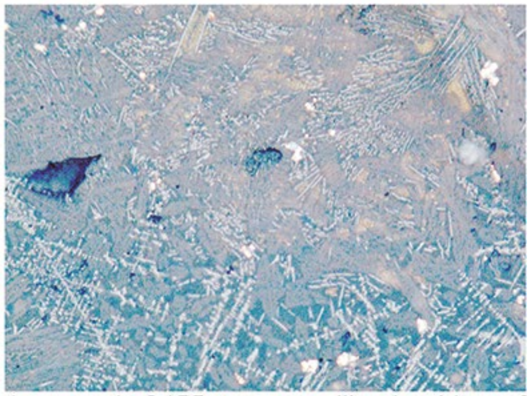
1 – sample 2479, copper prills in the slagged ceramic mass.



2 – sample 2467: small needles of fayalite in the glass matrix.

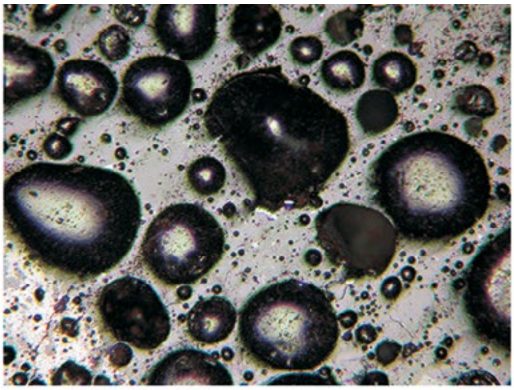


3 – sample 2455, copper prills, magnetite particles separating from a larger grain and small dendrites of magnetite.

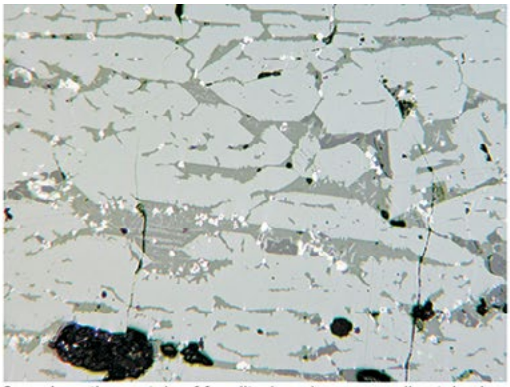


4 – sample 2455: copper prills, dendrites of magnetite and needles of delafossite in the glass painted with cuprite.

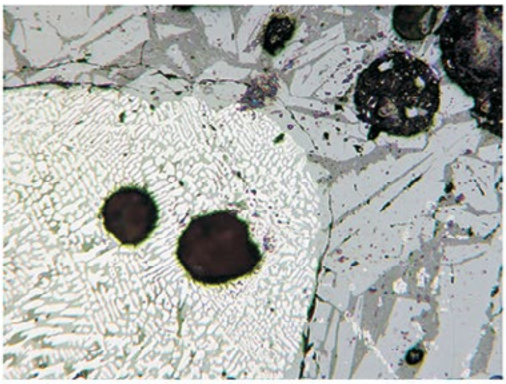
FIG. 11-VIII. MICROSTRUCTURES OF SLAGGED CRUCIBLES FROM THE SETTLEMENT OF ARKHANGELSKII PRIISK II: CRUCIBLE SLAG: 1 – SAMPLE 2479, COPPER PRILLS IN THE SLAGGED CERAMIC MASS, 2 – SAMPLE 2467: SMALL NEEDLES OF FAYALITE IN THE GLASS MATRIX; 3 – SAMPLE 2455, COPPER PRILLS, MAGNETITE PARTICLES SEPARATING FROM A LARGER GRAIN AND SMALL DENDRITES OF MAGNETITE; 4 – SAMPLE 2455: COPPER PRILLS, DENDRITES OF MAGNETITE AND NEEDLES OF DELAFOSSITE IN THE GLASS PAINTED WITH CUPRITE.



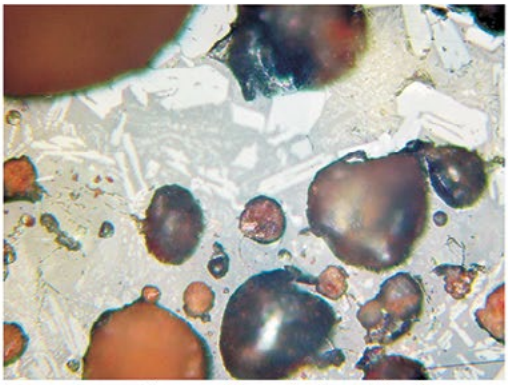
1 – porous ceramic mass.



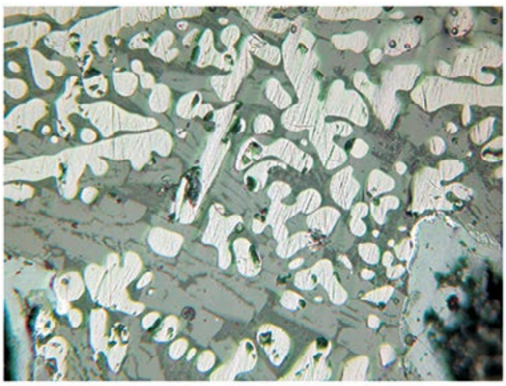
2 – prismatic crystals of fayalite (grey), very small octahedra of magnetite (white) and needles of fayalite in the glass matrix (dark grey).



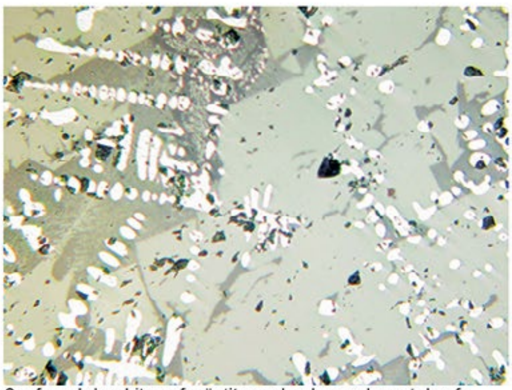
3 – prismatic crystals of fayalite (grey), accumulation of fused lattice structures of wüstite with the border of a primary grain (white) and pores (black) in the glass matrix (dark grey).



4 – porous ceramic mass with small prisms of fayalite.

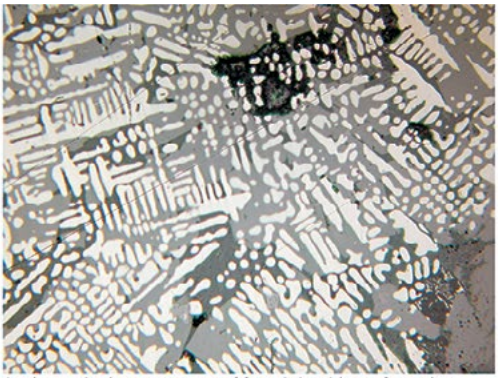


5 – fused dendrites of wüstite; skeletal prisms of fayalite formed after them.

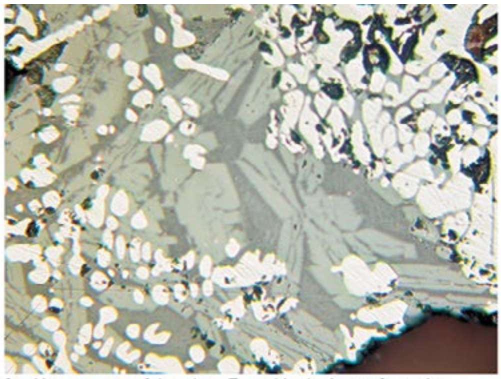


6 – fused dendrites of wüstite and polygonal crystals of fayalite.

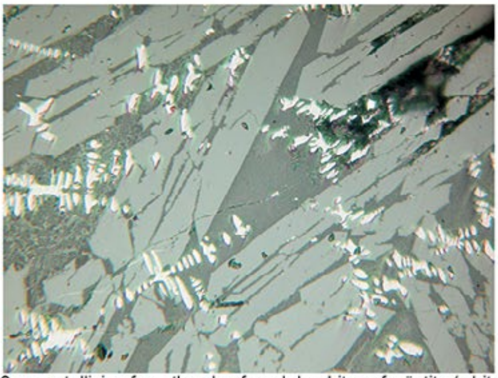
Fig. 11-IX. Settlement of Akshuben I. 1-3 – sample 762 (length of the photo is 1.55 mm), 4-6 – sample 703 (length of the photo is 0.54 mm): 1 – porous ceramic mass; 2 – prismatic crystals of fayalite (grey), very small octahedra of magnetite (white) and needles of fayalite in the glass matrix (dark grey); 3 – prismatic crystals of fayalite (grey), accumulation of fused lattice structures of wüstite with the border of a primary grain (white) and pores (black) in the glass matrix (dark grey); 4 – porous ceramic mass with small prisms of fayalite; 5 – fused dendrites of wüstite; skeletal prisms of fayalite formed after them; 6 – fused dendrites of wüstite and polygonal crystals of fayalite.



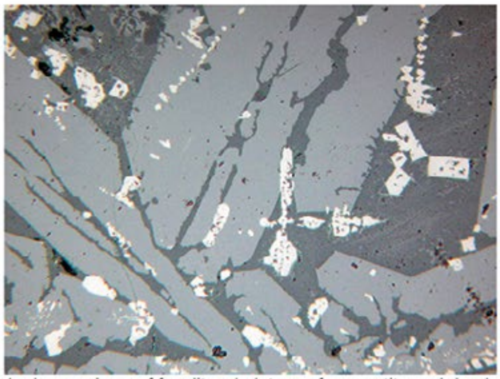
1 – Large lattice structures of fused dendrites of wüstite (white), joint polygonal crystals of fayalite (grey).



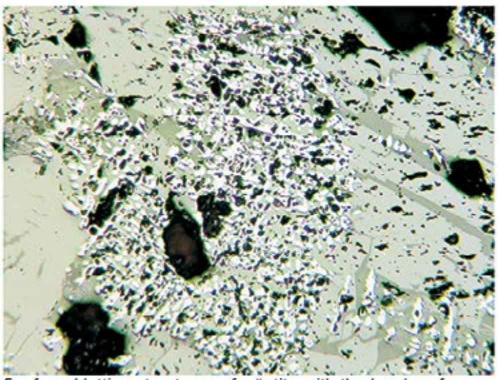
2 – Upper zone of the slag. Fused inclusions of wüstite (white), some particles are grouped and keep borders of a primary grain. Skeletal prisms of fayalite (grey).



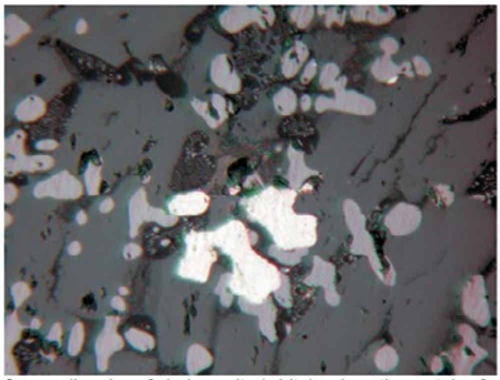
3 – crystallizing from the slag fused dendrites of wüstite (white) and prismatic crystals of fayalite (grey).



4 – large prisms of fayalite, skeletons of magnetite and dendrites of wüstite (white) and prisms of fayalite (grey).



5 – fused lattice structures of wüstite with the border of a primary grain (white), polygonal and prismatic crystals of fayalite (grey).



6 – small grains of chalcopyrite (white), prismatic crystals of fayalite (grey) and remains of fused dendrites of wüstite (light grey).

Fig. 11-X. Settlement of Akshuben I. 1,4 – sample 761, 2,3,5,6 – sample 703. 1 – Large lattice structures of fused dendrites of wüstite (white), joint polygonal crystals of fayalite (grey); 2 – Upper zone of the slag. Fused inclusions of wüstite (white), some particles are grouped and keep borders of a primary grain. Skeletal prisms of fayalite (grey); 3 – crystallizing from the slag fused dendrites of wüstite (white) and prismatic crystals of fayalite (grey); 4 – large prisms of fayalite, skeletons of magnetite and dendrites of wüstite (white) and prisms of fayalite (grey); 5 – fused lattice structures of wüstite with the border of a primary grain (white), polygonal and prismatic crystals of fayalite (grey); 6 – small grains of chalcopyrite (white), prismatic crystals of fayalite (grey) and remains of fused dendrites of wüstite (light grey) (length of the photos is: 1 – 0.62 mm, 2-4 – 0.54 mm, 5 – 1.55 mm, 6 – 0.22 mm).

Tab. 11-44. SEM-analyses of slag from the Kazakhstan settlements made in the Technical University of Freiberg by means of the Digital Scanning Microscope DSM 960 (weight %). Analyst B. Bleibe.

Weight %													
Settlement	**Sample**	**Analysis**	**Material**	**O**	**Si**	**Cu**	**Fe**	**Mg**	**Al**	**Ca**	**Cl**	**Mn**	**Zn**
Atasu	262	a	copper			X							
		b	cuprite	little		X							
		1	copper chloride	16.68		67.6					15.72		
		c	copper			X							
		d	magnetite	X		little	X					little	little
		2	glass	28.17	24.12	18.15	7.33	0.43	3.36	4.7		8.24	4.89
		e	delafossite	X		X	X						
Ust-Kenetay	236	a	fayalite	X	X		X						
		b	wüstite	X	little		X		little				
		c	wüstite	X			X						
		1	wüstite	21.8	0.6		77.6						
Atomic %													
Settlement	Sample	Analysis	Material	O	Si	Cu	Fe	Mg	Al	Ca	Cl	Mn	Zn
Atasu	262	1	copper chloride	40.89		41.73					17.39		
		2	glass	49.71	24.84	8.07	3.71	0.49	3.52	3.31		4.23	2.11
Ust-Kenetay	236	1	wüstite	49.14	0.77		50.09						

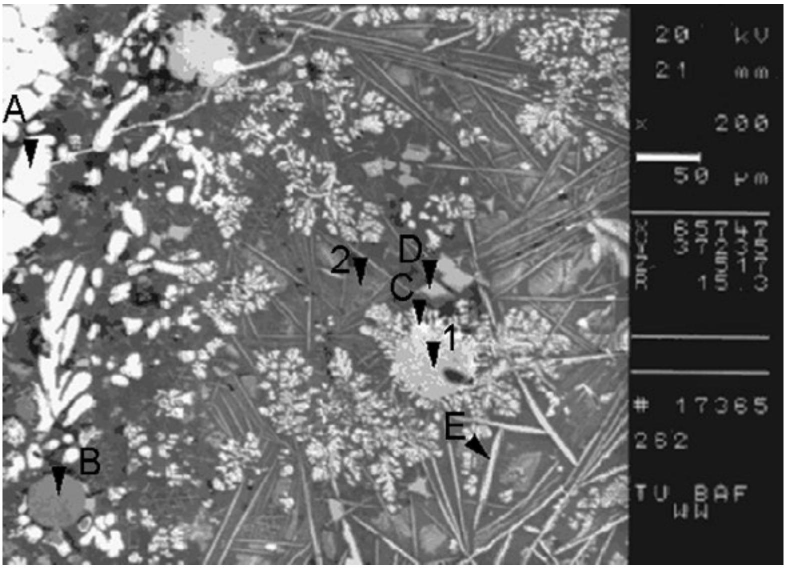


FIG. 11-45. MICROSTRUCTURE OF SLAG (SAMPLE 262) FROM THE SETTLEMENT OF ATASU AND ITS SEM-ANALYSES: NEEDLES OF DELAFOSSITE, DENDRITES OF CUPRITE, PRILLS OF COPPER (WHITE), OCTAHEDRA OF MAGNETITE (GREY). A – COPPER, B – CUPRITE, C – COPPER, D – MAGNETITE, E – DELAFOSSITE, 1 – COPPER CHLORIDE, 2 – GLASS MATRIX. TECHNICAL UNIVERSITY OF FREIBERG BY MEANS OF THE DIGITAL SCANNING MICROSCOPE DSM 960 (WEIGHT %). ANALYST B. BLEIBE.

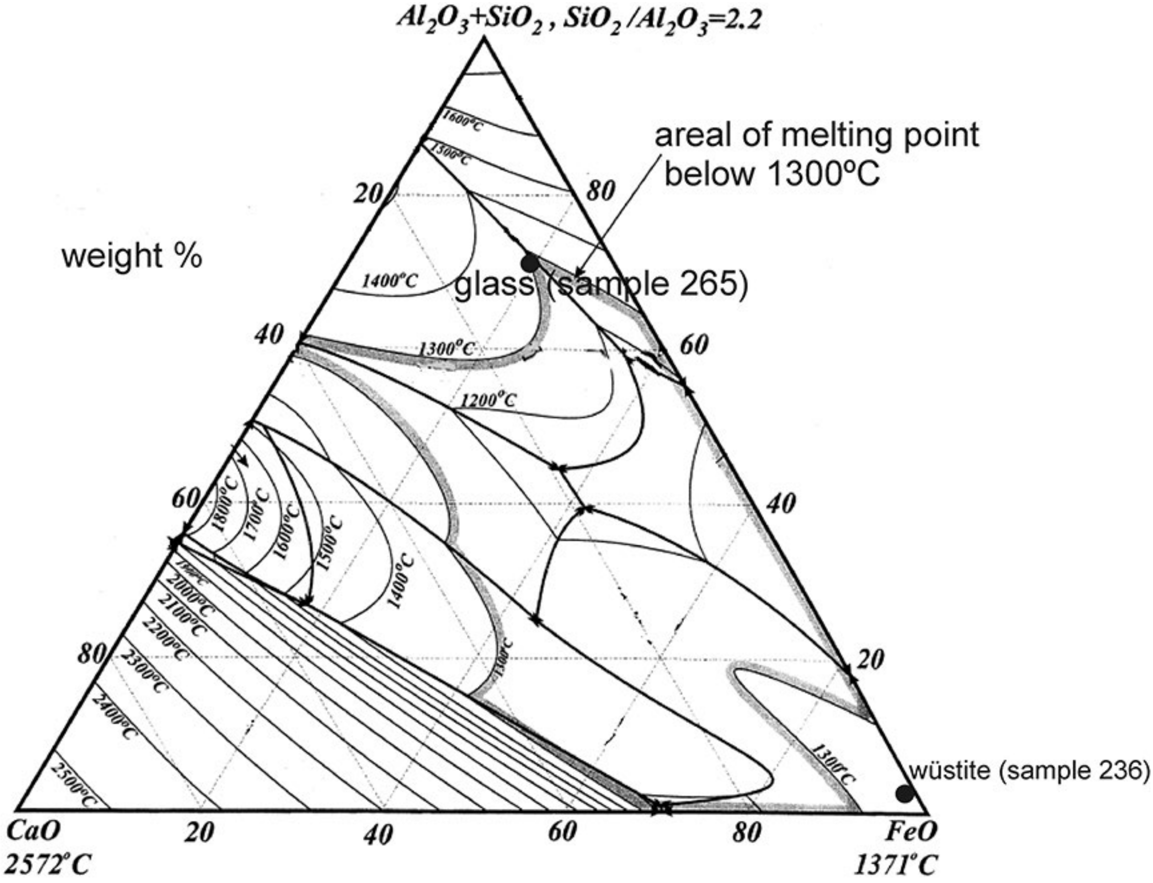


FIG. 11-46. PHASE PLOT OF FEO-AL2O3+SIO2-CAO FOR THE GLASS IN SLAG (SAMPLE 262) FROM THE SETTLEMENT OF ATASU.

Tab. 11-47. Mineralogical groups of slag from settlements of the Alakul culture in the Transurals and Kazakhstan.

Mineralogical group **Settlement**	**I**	**II**	**IV**	**II- VI/VI**
Kupukhta	1		4	
Shandasha		1	2	
Baytu	1		4	
Bersuat XVIII			1	
Ak-Moustapha			2	
Atasu			5	
Myrzhik			2	
Ubagan II				2
Alakul culture	2 8%	1 4%	20 80%	2 8%

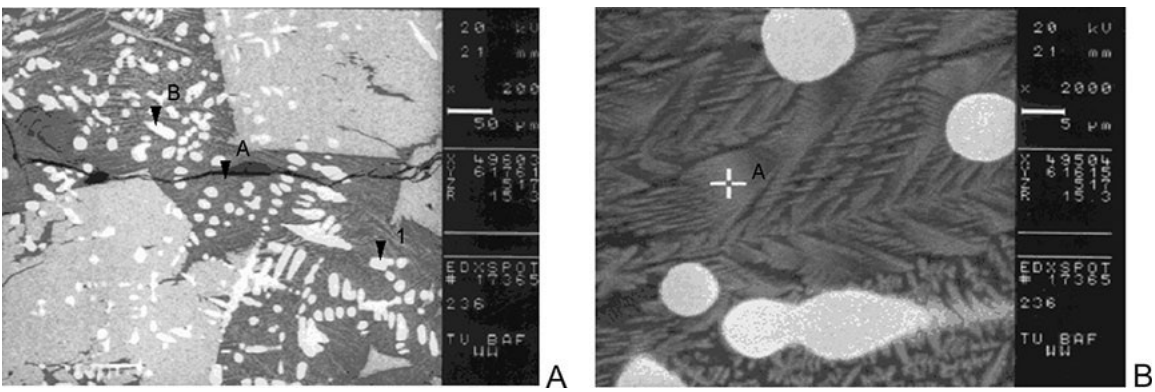


Fig. 11-48. Microstructure of slag (sample 236) from the settlement of Ust-Kenetay and its SEM-analyses: A) glass matrix (dark grey) large polygonal and long skeletal crystals of olivine (grey). The second component is fused dendrites of wüstite (white). B) Long crystallizing skeletons of fayalite (grey) and prills of wüstite (white) in the glass matrix (dark grey). Technical University of Freiberg by means of the Digital Scanning Microscope DSM 960 (weight %). Analyst B. Bleibe.

Tab. 11-49. Mineralogical groups of slag from settlements of the Fyodorovka culture in the Transurals and Kazakhstan.

Mineralogical group / Settlement	IV	VI
Ust-Kenetay		19
Pavlovka	1	1
Graurtly		1
Fyodorovka culture	1 4.5%	21 95.5%

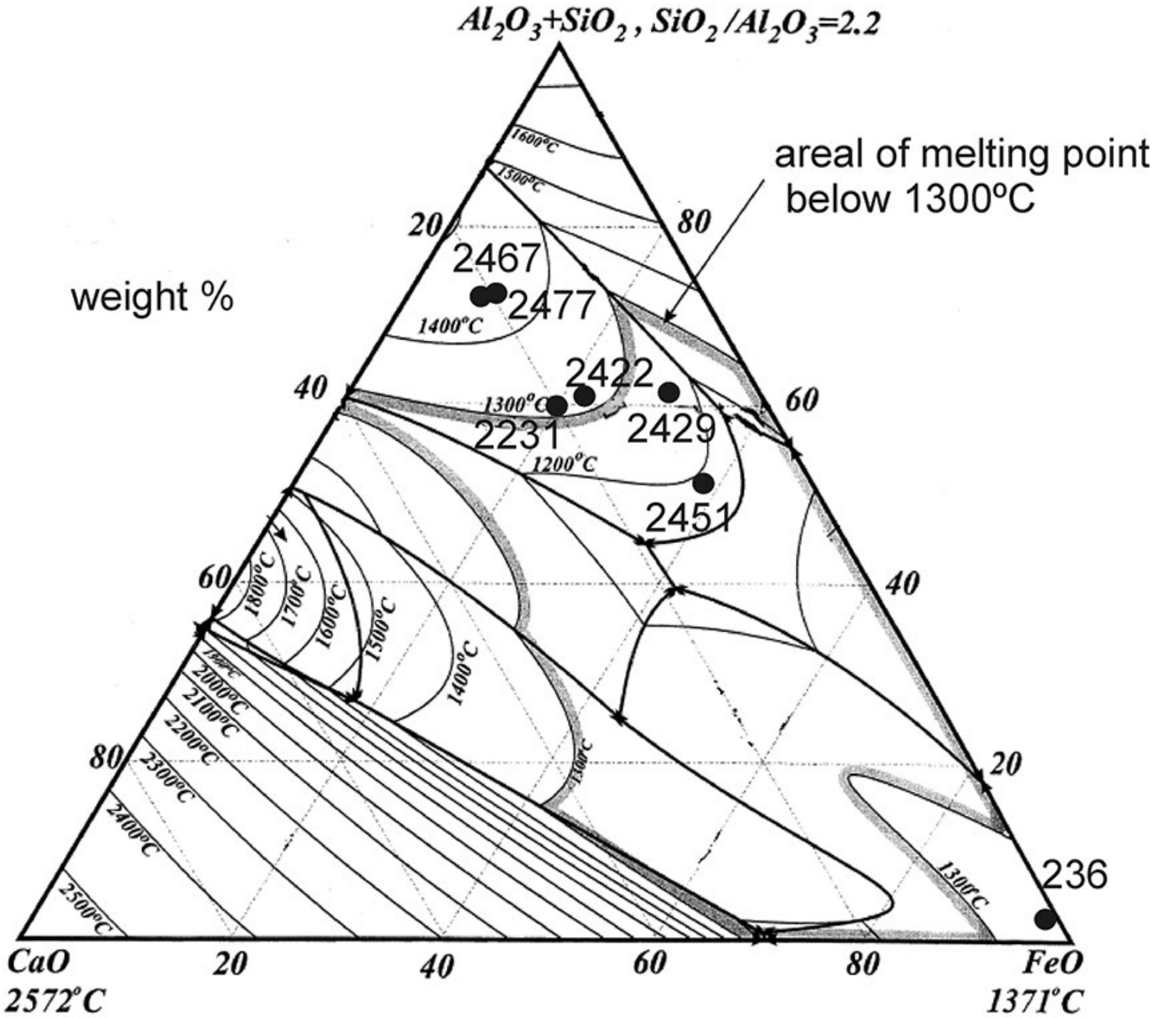


FIG. 11-50. PHASE PLOT OF FEO-AL2O3+SIO2-CAO FOR WÜSTITE IN SLAG FROM THE SETTLEMENT OF UST-KENETAY (SAMPLE 236), SLAG MASS (SAMPLE 2422, 2429) AND SLAGGED CRUCIBLES (SAMPLE 2451, 2467, 2477) FROM THE SETTLEMENTS OF ARKHANGELSKII PRIISK II AND NOVO BAYRAMGULOVO (SAMPLE 2231).

Tab. 11-51. Distribution of mineralogical groups of slag of the Mezhovka culture.

Mineralogical group / **Settlement**	**I**	**II-VI**
Ilyaska I		6
Novo Bayramgulovo		2
Arkhangelskii Priisk II	2	17
Mezhovka culture	2 7.4%	25 92.6%

Tab. 11-52. Emission spectral analyses of slag from the settlement of Arkhangelskii Priisk II (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).

№	Material	Ni	Co	Cr	Mn	V	Ti	Cu	Zn	Pb	Ag	As	Bi	Mo	Ba	Sn	Sb
2402	ceramics	0.01	0.002	0.07	0.09	0.015	0.2	0.02	0.01	0.002	0.00005	0.015	<0.001	0.0015	0.07	0.005	<0.003
2403	ceramics	0.01	0.003	0.07	0.09	0.015	0.2	0.15	0.01	0.002	0.00007	0.015	<0.001	0.0015	0.07	0.0005	<0.003
2451	crucible	0.07	0.05	0.03	0.09	0.005	0.15	>1	nd	0.02	0.001	0.07	<0.001	>0.03	0.05	0.0015	0.005
2455	crucible	0.01	0.003	0.07	0.09	0.01	0.4	0.9	0.01	0.007	0.0007	0.02	<0.001	0.002	0.07	0.0015	0.0015
2457	crucible	0.01	0.002	0.05	0.07	0.01	0.4	0.05	0.01	0.003	0.00005	0.007	<0.001	0.001	0.07	0.0005	<0.003
2466	crucible	0.015	0.005	0.05	0.07	0.01	0.4	>1	0.02	0.005	0.002	0.01	<0.001	0.03	0.09	0.005	<0.003
2467	crucible	0.015	0.003	0.05	0.1	0.01	0.3	0.15	0.01	0.003	0.00015	0.015	<0.001	0.002	0.1	0.0005	<0.003
2473	crucible	0.015	0.005	0.05	0.09	0.01	0.4	0.1	0.01	0.002	0.00015	0.005	<0.001	0.0007	0.07	0.0007	0.0015
2477	crucible	0.01	0.003	0.05	0.07	0.01	0.4	0.15	0.01	0.003	0.00015	0.01	<0.001	0.003	0.07	0.0005	0.0015
2479	crucible	0.1	0.04	0.03	0.09	0.015	0.3	>>1	nd	0.03	0.002	0.15	<0.001	0.015	0.07	0.01	0.01
2480	crucible	0.015	0.005	0.03	0.09	0.01	0.3	0.7	0.07	0.007	0.0004	0.03	<0.001	0.01	0.07	0.0005	0.0015
2439	slag	0.03	0.01	0.07	0.07	0.01	0.2	>1	0.1	0.05	0.001	0.05	<0.001	0.01	0.07	0.03	0.007
2445	slag	0.07	0.1	nd	>1	>0.1	0.3	0.3	0.1	0.03	0.0015	0.01	<0.001	0.002	0.1	0.001	0.0015
2352	slagged lining	0.015	0.003	0.1	0.07	0.01	0.2	0.3	0.007	0.003	0.0001	0.01	<0.001	0.001	0.07	0.0005	<0.003
2353	slagged lining	0.015	0.005	0.07	0.07	0.01	0.1	0.7	0.03	0.015	0.0009	0.03	<0.001	0.003	0.07	0.0007	0.003
2354	slagged lining	0.015	0.003	0.05	0.09	0.01	0.1	0.5	0.04	0.007	0.0002	0.015	<0.001	0.007	0.07	0.0007	<0.003
2356	slagged lining	0.015	0.003	0.07	0.07	0.015	0.2	0.3	0.02	0.003	0.0002	0.03	<0.001	0.005	0.06	0.0005	<0.003
2357	slagged lining	0.015	0.003	0.04	0.07	0.01	0.15	0.3	0.03	0.005	0.00015	0.015	<0.001	0.01	0.07	0.0005	<0.003

№	Material	Ni	Co	Cr	Mn	V	Ti	Cu	Zn	Pb	Ag	As	Bi	Mo	Ba	Sn	Sb
2358	slagged lining	0.01	0.003	0.05	0.07	0.01	0.1	1	0.03	0.01	0.0015	0.02	<0.001	0.002	0.03	0.0005	<0.003
2416	slagged lining	0.015	0.007	0.1	0.1	0.015	0.2	>1	0.04	0.02	0.0015	0.04	<0.001	0.0015	0.03	0.0015	0.003
2440	slagged lining	0.007	0.003	0.07	0.07	0.01	0.3	0.3	0.015	0.007	0.0002	0.015	<0.001	0.002	0.05	0.0005	<0.003
2442	slagged lining	0.02	0.01	0.05	0.09	0.015	0.3	>1	0.15	0.05	0.0015	0.03	<0.001	0.007	0.07	0.0005	0.003
2443	slagged lining	0.01	0.003	0.1	0.1	0.015	0.3	0.2	0.015	0.03	0.0001	0.007	<0.001	0.001	0.07	0.0005	<0.003
2444	slagged lining	0.03	0.015	0.1	0.1	0.003	0.3	>1	0.09	0.015	0.0015	0.01	<0.001	0.02	0.03	0.0005	0.007
2420	slag	0.02	0.007	0.07	0.1	0.015	0.3	>1	0.15	0.07	0.0015	0.04	<0.001	0.005	0.07	0.0005	0.003
2421	slag	0.02	0.007	0.07	0.1	0.015	0.3	>1	0.2	0.07	0.0015	0.04	<0.001	0.005	0.07	0.0005	0.003
2422	slag	0.02	0.007	0.05	0.1	0.015	0.3	>>1	0.07	0.03	0.0015	0.05	<0.001	0.007	0.07	<0.0005	0.005
2423	slag	0.02	0.007	0.15	0.1	0.015	0.3	1	0.05	0.015	0.0007	0.05	<0.001	0.007	0.07	<0.0005	0.003
2424	slag	0.02	0.007	0.07	0.1	0.015	0.3	>1	0.15	0.1	0.0015	0.04	<0.001	0.007	0.05	0.0005	0.003
2425	slag	0.02	0.007	0.05	0.1	0.015	0.3	1	0.1	0.05	0.0015	0.03	<0.001	0.005	0.07	0.0003	0.0015
2426	slag	0.03	0.007	0.05	0.1	0.015	0.2	1	0.1	0.05	0.0015	0.03	<0.001	0.005	0.05	0.0003	0.0015
2427	slag	0.05	0.015	0.07	0.1	0.015	0.2	>1	0.1	0.05	0.0015	0.06	<0.001	0.01	0.07	0.0003	0.003
2428	slag	0.015	0.01	0.07	0.1	0.015	0.2	>1	0.1	0.05	0.002	0.03	<0.001	0.005	0.05	0.0003	0.0015
2429	slag	0.03	0.01	0.05	0.09	0.015	0.4	>1	0.15	0.05	0.002	0.04	<0.001	0.005	0.05	0.0005	0.0015
2430	slag	0.02	0.01	0.07	0.1	0.015	0.2	>1	0.15	0.05	0.0015	0.02	<0.001	0.005	0.09	0.0003	0.0015
2431	slag	0.05	0.015	0.07	0.1	0.015	0.2	>>1	0.3	0.1	0.002	0.15	<0.001	0.03	0.05	0.0005	0.01
2432	slag	0.02	0.005	0.07	0.1	0.015	0.2	>1	0.07	0.05	0.0015	0.07	<0.001	0.015	0.03	0.0003	0.007

№	Material	Ni	Co	Cr	Mn	V	Ti	Cu	Zn	Pb	Ag	As	Bi	Mo	Ba	Sn	Sb
2433	slag	0.03	0.01	0.07	0.1	0.015	0.2	>1	0.15	0.05	0.002	0.05	<0.001	0.007	0.07	0.0003	0.003
2434	slag	0.05	0.01	0.1	0.09	0.01	0.3	>1	0.1	0.05	0.001	0.05	<0.001	0.007	0.07	0.0005	0.003
2435	slag	0.02	0.01	0.07	0.1	0.015	0.2	>1	0.09	0.03	0.001	0.05	<0.001	0.01	0.09	0.0005	0.003
2436	slag	0.02	0.01	0.07	0.09	0.01	0.3	>1	0.07	0.03	0.001	0.03	<0.001	0.005	0.06	0.0003	0.003
2437	slag	0.02	0.007	0.07	0.09	0.015	0.2	>1	0.07	0.03	0.0009	0.03	<0.001	0.003	0.06	0.0007	0.0015
2438	slag	0.03	0.007	0.15	0.1	0.01	0.2	>1	0.07	0.03	0.001	0.07	<0.001	0.004	0.09	0.0007	0.005
Sensitivity of the analysis		0.0005	0.0003	0.001	0.003	0.001	0.005	0.001	0.003	0.0003	0.00003	0.01	0.001	0.0001	0.01	0.0005	0.003
Ni			Co	Cr	Mn	V	Ti	Cu	Zn	Pb	Ag	As	Bi	Mo	Ba	Sn	Sb

Tab. 11-53. Average contents of trace-elements in different groups of slag from the settlement of Arkhangelskii Priisk II.

Material	Ni	Co	Cr	Mn	V	Ti	Cu	Zn	Pb	Ag	As	Ba	Sn	Sb
ceramic slag	0,01	0,003	0,07	0,09	0,015	0,2	0,09	0,01	0,002	0,00006	0,015	0,0015	0,07	0,0028
crucible slag	0,029	0,013	0,05	0,08	0,01	0,34	0,56	0,02	0,009	0,00073	0,035	0,0104	0,07	0,0023
slagged lining	0,015	0,005	0,07	0,08	0,011	0,2	0,6	0,0425	0,015	0,00071	0,02	0,0054	0,06	0,0006
heavy dense slag	0,027	0,009	0,08	0,1	0,014	0,25	1	0,1179	0,05	0,00143	0,049	0,0077	0,06	0,0004
slag (?)	0,05	0,055	0,07	0,54	0,055	0,25	0,65	0,1	0,04	0,00125	0,03	0,006	0,09	0,0155

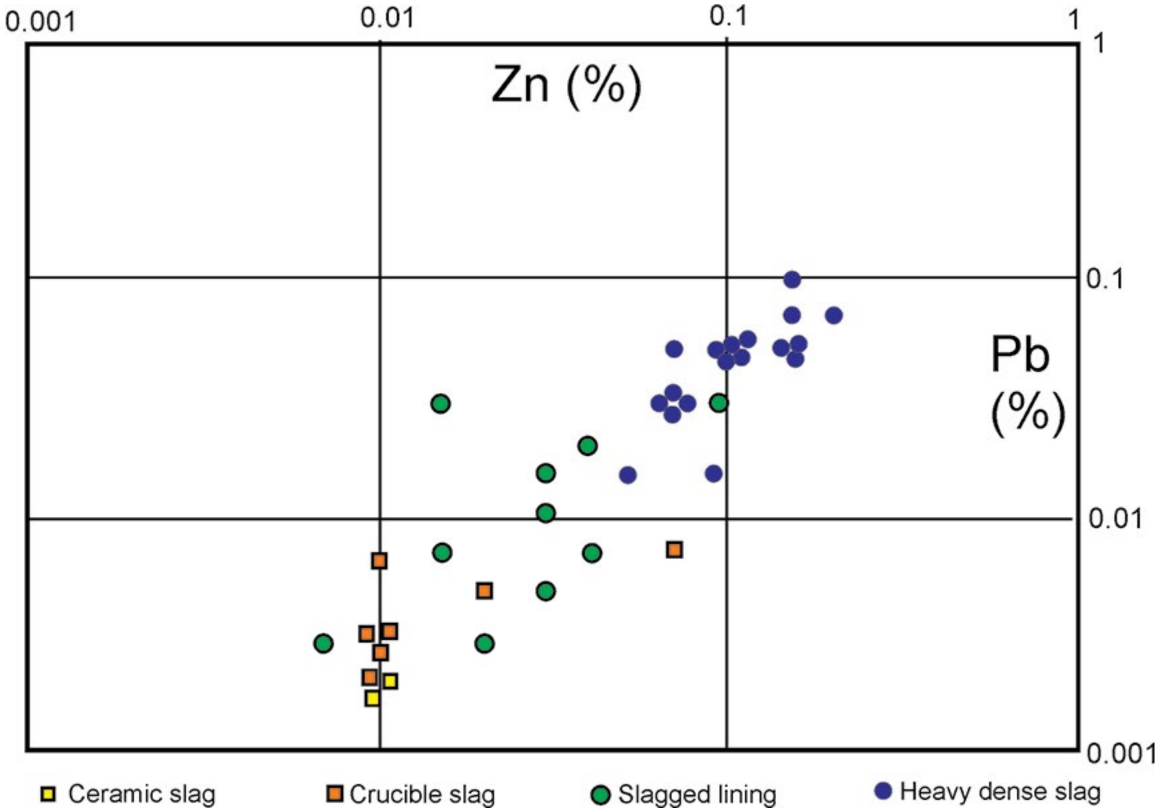


FIG. 11-54. CORRELATION OF ZN-PB IN SLAG FROM THE SETTLEMENT OF ARKHANGELSKII PRIISK II.

Tab. 11-55. Mineralogical groups of slag from the Andronovo settlements in the Transurals and Kazakhstan.

<table>
<tr><th>Mineralogical groups
Settlements</th><th>I</th><th>II</th><th>VI</th></tr>
<tr><td>Korkino</td><td>3</td><td>2</td><td>2?</td></tr>
<tr><td>Yazyovo III</td><td></td><td>1</td><td></td></tr>
<tr><td>Kipel</td><td></td><td>1</td><td></td></tr>
<tr><td>Ak-Maya</td><td></td><td>1</td><td>1?</td></tr>
<tr><td rowspan="2">Total:</td><td></td><td>5
46%</td><td>3?
27%</td></tr>
<tr><td>3
27%</td><td colspan="2">8
73%</td></tr>
</table>

Tab. 11-56. Forms of slag of the Final Bronze Age.

Settlement	Shapeless slag	Flat slag cakes
Kalinovka II	2	
Kafarka	1	
Kent	1	
Telmana XVI		1
Sargari		1
Total:	**4** **66.6%**	**2** **33.3%**

Tab. 11-57. Mineralogical groups of slag of the Final Bronze Age.

Mineralogical groups **Settlements**	**I**	**II**	**IV**
Telmana XVI	1 100%		
Kafarka		1 100%	
Sargari		1 100%	
Kent			1 100%
Kalinovka II			1 100%
Total:	**1** **20%**	**2** **40%**	**2** **40%**

Tab. 11-58. Mineralogical groups of slag without clear cultural affiliation.

Mineralogical groups / Sites	I	II	IV	VI
Chisty Yar	2			
Atamanovka V		1		
Kamyshnoye II		2		
Stepnyak		1		
Akimbek		2		
Novonikoskoye				1
Kara-Tyube				1
Eastern Koinda				7
Total:	**2 11.8%**	**6 35.3%**		**9 52.9%**

Tab. 11-59. Distribution of mineralogical groups of slag of the Late Bronze Age of the Transurals, Kazakhstan and Altai.

Mineralogical groups / Cultural groups	I	II	IV	VI	II-VI	Ceramic slag
Elunino culture		26 62%	4 9.5%			12 28.5%
Sites of the Vishnyovka-Odino type				7 100%		
Alakul culture	2 8%	2 8%	20 80%	1 4%		
Fyodorovka culture			1 4.5%	21 95.5%		
Mezhovka culture	2 7.4%				25 92.6%	
Andronovo sites	3 27%	5 46%		3? 27%		
Final Bronze Age	1 20%	2 40%	2 40%			
Late Bronze Age	2 11.8%	6 35.3%		9 52.9%		
Total:	**10 6.4%**	**41 26.3%**	**27 17.3%**	**41 26.3%**	**25 16%**	**12 7.7%**

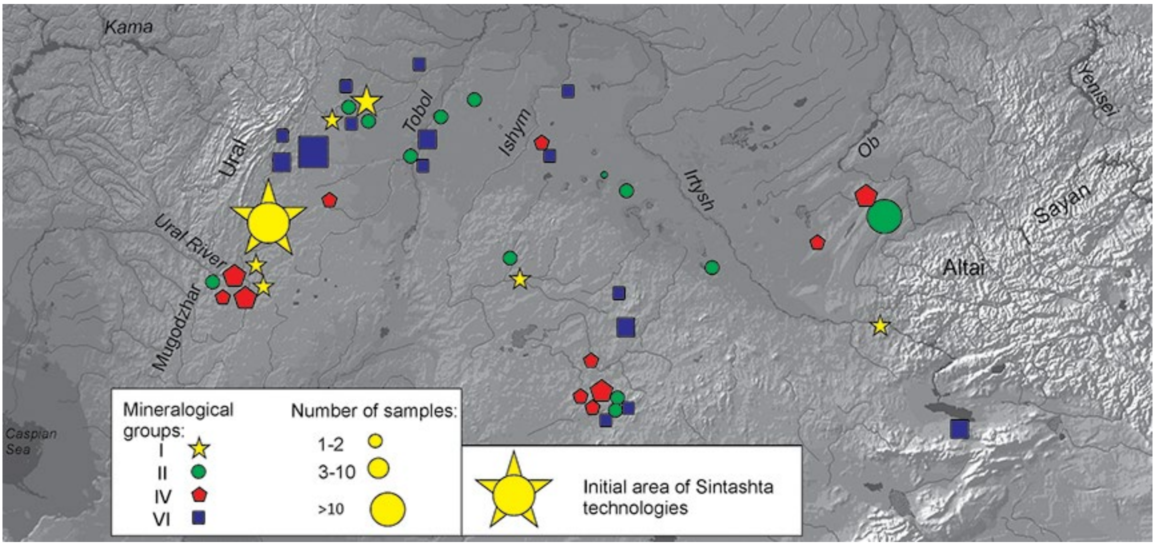


FIG. 11-60. MAP OF DISTRIBUTION OF MINERALOGICAL GROUPS OF SLAG OF THE LATE BRONZE AGE IN THE ASIAN ZONE OF THE EAMP.

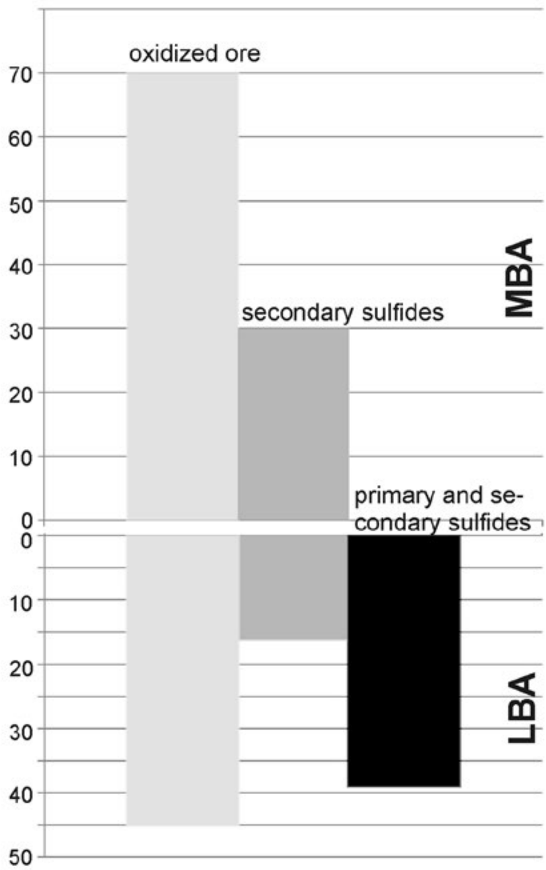


FIG. 11-61. RATIO OF OXIDIZED AND SULFIDE ORES USED IN THE MIDDLE BRONZE AGE AND THE LATE BRONZE AGE.

Tab. 11-62. Emission spectral analyses of slag of the Andronovo sites and the Final Bronze Age in the Asian zone of the EAMP (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).

Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn
Novonikolskoye	ore	11	0.0005	<0.0003	0.003	0.005	<0.001	0.1	<0.0005	<0.0003	>1	0.003
Atasu	ore	15	0.001	<0.0003	0.001	0.03	<0.001	0.15	0.0005	<0.0003	>>1	0.15
Atasu	ore	16	0.003	<0.0003	0.005	0.05	0.015	0.15	0.0005	<0.0003	>>1	>1
Atasu	ore	17	0.0015	0.0003	0.002	0.02	0.0015	0.15	0.0005	<0.0003	>>1	0.1
Atasu	ore	22	0.001	0.0015	0.001	0.3	0.0015	0.07	<0.0005	<0.0003	0.7	0.07
Atasu	ore	23	0.001	0.001	0.001	0.2	0.0015	0.015	<0.0005	<0.0003	>1	0.05
Atasu	ore	24	0.001	0.0015	0.0015	0.2	0.0015	0.02	<0.0005	<0.0003	>>1	0.15
Myrzhik	slag	26	0.007	0.003	0.005	>1	0.015	0.07	0.0005	0.00015	>>1	>1
Myrzhik	ore	28	0.01	<0.0003	0.005	0.2	0.007	0.05	<0.0005	0.00015	>>1	>>1
Novoburino	ore	30	0.003	0.002	0.005	0.05	0.015	0.05	0.002	0.00015	>1	0.15
Nikolaevka	slag	31	0.01	0.015	0.005	0.15	0.015	0.5	0.001	<0.0003	>1	0.03
Kipel	slag	32	0.0007	0.0005	0.005	0.1	0.007	0.5	<0.0005	<0.0003	0.2	0.01
Kuropatkino	ore	41	0.0015	0.0003	0.001	0.03	0.01	0.02	<0.0005	<0.0003	>>1	1
Sargari	slag	44	0.02	0.07	0.005	0.15	0.003	0.2	<0.0005	0.001	>>1	1
Petrovka	slag	58	0.1	0.01	0.002	0.05	0.005	0.2	<0.0005	<0.0003	0.7	0.01
Malookunevo	ore	71	0.005	0.003	0.001	0.02	0.015	0.5	0.0015	<0.0003	0.5	0.005
Malookunevo	ore	72	0.03	0.0015	0.005	0.15	0.007	0.1	<0.0005	<0.0003	>>1	>>1
Verkhnyaya Alabuga	slag	73	0.007	0.002	0.007	0.2	0.007	0.15	0.0005	<0.0003	0.05	0.007
Yazyovo	ore	79	0.003	0.01	0.005	0.03	0.02	0.03	<0.0005	<0.0003	>>1	0.1
Graurtly	slag	218	0.002	0.001	0.005	0.1	0.007	0.5	0.001	<0.0003	0.02	0.01
Altyn-Tyube	slag (ore?)	250	0.001	0.02	nd	>1	<0.001	0.05	<0.0005	<0.0003	1	nd
Altyn-Tyube	slag (ore?)	251	0.0015	0.03	nd	>1	<0.001	0.15	<0.0005	<0.0003	1	nd
Korkino	slag	269	0.002	0.0005	0.005	0.1	0.001	0.1	<0.0005	0.00015	0.3	0.03
Chisty Yar	slag	315	0.005	0.0007	0.01	0.1	0.003	0.3	<0.0005	<0.0003	0.07	0.015
Chisty Yar	slag	316	0.003	0.02	0.001	0.07	0.0015	0.15	<0.0005	0.0003	>1	1
Nikolskoye	slag	467	0.007	0.002	0.02	0.07	0.007	0.5	0.0015	0.00015	0.5	0.007
Nikolskoye	slag	468	0.007	0.003	0.015	0.05	0.01	0.5	0.0015	0.00015	0.7	0.01
Nikolskoye	slag	469	0.005	0.002	0.015	0.07	0.007	0.5	0.001	0.00015	0.03	0.007

Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn
Ikpen I	slag	672	0.01	0.01	nd	>1	0.0015	0.2	0.001	<0.0003	>1	0.5
Ikpen I	slag	673	0.007	0.002	0.007	0.3	0.007	0.3	0.001	<0.0003	>1	0.1
Ikpen I	slag	674	0.005	0.003	nd	>1	0.0015	0.15	0.001	<0.0003	>1	1
Ikpen I	slag	675	0.01	0.007	0.007	1	0.003	0.3	0.001	<0.0003	>1	0.5
Ikpen I	slag	676	0.003	0.01	nd	>1	0.003	0.15	0.001	<0.0003	>1	1
Satyga	slag	696	0.002	0.0005	0.01	0.3	0.005	0.15	0.0005	0.00015	0.3	0.1
Satyga	slag	697	0.0015	0.0015	0.0015	0.5	0.005	0.2	0.0005	0.00015	0.07	0.03
Satyga	slag	698	0.005	0.002	0.001	0.3	0.005	0.2	<0.0005	0.00015	0.015	0.1
Satyga	slag	699	0.0015	0.0007	0.001	0.3	0.005	0.1	<0.0005	0.00015	0.03	0.02
Satyga	slag	700	0.0015	0.0005	0.001	0.3	0.003	0.1	<0.0005	0.00015	0.1	0.02
Satyga	slag	701	0.005	0.005	0.001	0.3	0.003	0.15	<0.0005	0.0003	0.02	0.2
Satyga	slag	702	0.001	0.0005	0.002	0.5	0.007	0.2	<0.0005	0.00015	0.02	0.015
Atamanovka	slag	706	0.005	0.0003	0.003	0.7	0.007	0.07	<0.0005	0.00015	0.1	0.05
Kent	slag	757	0.005	0.007	0.002	0.07	0.0015	0.15	0.0005	0.00015	>>1	0.7
Burla-3	ceramics	783	0.003	0.002	0.015	0.07	0.01	0.3	0.001	<0.0003	0.02	nd
Kalinovka	slag	793	0.007	0.003	0.01	0.15	0.01	0.3	0.001	<0.0003	>>1	0.3
Kalinovka	slag	794	0.01	0.01	0.01	0.15	0.01	0.3	0.0015	<0.0003	>>1	1
Korkino	slag	815	0.007	0.0015	0.015	0.1	0.01	0.5	0.002	<0.0003	0.05	0.01
Korkino	slag	816	0.007	0.0015	0.015	0.1	0.01	0.5	0.002	<0.0003	0.15	0.015
Korkino	slag	817	0.007	0.002	0.015	0.1	0.015	0.5	0.0015	<0.0003	0.05	0.007
Korkino	slag	818	0.005	0.0015	0.015	0.07	0.01	0.5	0.0015	<0.0003	0.01	0.007
Korkino	slag	819	0.005	0.0015	0.015	0.07	0.01	0.5	0.0015	<0.0003	0.007	0.007
Korkino	slag	820	0.007	0.0015	0.015	0.1	0.01	0.5	0.0015	<0.0003	0.01	0.015
Korkino	slag	821	0.007	0.002	0.015	0.07	0.01	0.5	0.0015	<0.0003	0.2	1
Burla-3	ore	1114	0.003	<0.0003	0.01	0.05	0.007	0.2	0.001	<0.0003	>>1	0.15
Kaygorodok	ore	1115	0.0015	<0.0003	0.007	0.03	0.003	0.15	0.0005	<0.0003	>>1	0.01
Kaygorodok	ore	1116	0.01	0.005	0.01	0.05	<0.001	0.1	0.0005	<0.0003	>>1	>1
Burla-3	ore	1117	0.005	0.002	0.007	0.07	0.007	0.2	0.0005	<0.0003	>>1	0.15
Chernaya Kurya	ore	1118	0.003	0.001	0.007	0.015	0.005	0.07	<0.0005	<0.0003	>>1	>1
Chernaya Kurya	ore	1119	0.007	0.01	0.003	0.5	<0.001	0.07	<0.0005	0.0003	>>1	>>1
Chernaya Kurya	ore	1120	0.003	0.015	0.007	1	<0.001	0.07	<0.0005	0.0005	>>1	>>1
Chernaya Kurya	ore	1121	0.0007	0.0007	0.001	0.01	<0.001	0.005	<0.0005	0.0005	1	>>1
Chernaya Kurya	ore	1122	0.002	0.0015	0.005	0.3	<0.001	0.07	<0.0005	0.0003	>>1	>>1

Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn
Chernaya Kurya	ore	1123	0.007	0.01	0.001	0.2	<0.001	0.15	<0.0005	0.0003	>1	>>3
Chernaya Kurya	ore	1124	0.0015	<0.0003	0.005	0.03	<0.001	0.07	0.0015	0.0003	>>1	>>1
Chernaya Kurya	ore	1125	0.015	0.02	0.001	0.15	0.003	0.1	<0.0005	0.0003	>1	>>3
Ilyaska	ore	1240	0.001	0.0003	0.003	0.03	0.003	0.15	0.001	0.0003	>1	0.01
Ilyaska	ore	1240a	0.07	0.02	0.02	0.1	0.003	0.07	<0.0005	0.0003	1	0.03
Ilyaska	ore	1241	0.001	0.0015	0.002	0.015	0.003	0.1	0.0005	<0.0003	>1	0.015
Ilyaska	ore	1241a	0.05	0.02	0.02	0.07	0.0015	0.07	<0.0005	<0.0003	>1	0.015
Ilyaska	ore	1242	0.05	0.015	0.02	0.07	0.0015	0.05	<0.0005	0.00015	>1	0.02
Ilyaska	ore	1242a	0.003	0.0015	0.007	0.05	0.007	0.2	0.001	0.0003	>1	0.015
Ilyaska	ore	1243	0.03	0.02	0.03	0.07	<0.001	0.02	<0.0005	0.00015	0.7	0.1
Ilyaska	ore	1243a	0.005	0.0015	0.007	0.01	0.0015	0.5	0.001	0.00015	>1	0.007
Ilyaska	ore	1244	0.15	0.015	0.03	0.15	0.0015	0.05	<0.0005	0.0003	>1	0.07
Ilyaska	ore	1244a	0.01	0.002	0.01	0.05	0.015	0.3	0.001	0.00015	>1	0.01
Ilyaska	ore	1245	0.05	0.007	0.01	0.07	0.0015	0.03	<0.0005	<0.0003	>1	0.02
Ilyaska	ore	1245a	0.001	0.001	0.0015	0.015	0.005	0.07	<0.0005	0.0003	>1	0.007
Ilyaska	ore	1246	0.15	0.015	0.02	0.1	0.0015	0.05	<0.0005	0.00015	>1	0.02
Ilyaska	ore	1246a	0.001	0.0015	0.005	0.03	0.01	0.1	0.0005	0.0003	>1	0.01
Ilyaska	ore	1247	0.015	0.003	0.02	0.03	0.01	0.7	0.0015	0.0003	>1	0.015
Ilyaska	ore	1247a	0.1	0.007	0.02	0.07	0.0015	0.05	<0.0005	0.0003	>1	0.07
Ilyaska	ore	1248	0.005	0.001	0.01	0.03	0.005	0.3	0.001	0.0003	>1	0.01
Ilyaska	ore	1249	0.001	0.001	0.003	0.02	0.005	0.03	<0.0005	0.00015	>1	0.005
Ilyaska	ore	1250	0.005	0.001	0.007	0.05	0.01	0.2	0.001	0.0007	>1	0.01
Ilyaska	ore	1251	0.002	0.002	0.0015	0.15	0.002	0.07	<0.0005	0.0003	>1	0.01
Ilyaska	ore	1252	0.007	0.002	0.01	0.015	0.01	0.5	0.001	0.00015	1	0.005
Ilyaska	slag	1253	0.007	0.003	0.02	0.15	0.015	0.5	0.001	0.00015	0.05	0.01
Ilyaska	slag	1254	0.005	0.002	0.02	0.1	0.015	0.5	0.001	0.00015	0.02	0.005
Ilyaska	slag	1255	0.007	0.002	0.015	0.15	0.01	0.5	0.001	0.00015	0.07	0.005
Ilyaska	slag	1256	0.007	0.002	0.015	0.15	0.01	0.5	0.001	0.00015	0.1	0.005
Ilyaska	slag	1257	0.005	0.002	0.015	0.1	0.01	0.5	0.001	0.00015	0.07	0.005
Ilyaska	slag	1258	0.007	0.0015	0.02	0.1	0.01	0.5	0.001	0.00015	0.03	0.005
Ilyaska	slag	1259	0.007	0.002	0.015	0.1	0.01	0.5	0.001	<0.0003	0.15	0.005
Ilyaska	slag	1260	0.007	0.0015	0.01	0.1	0.01	0.5	0.001	<0.0003	0.03	0.007
Ilyaska	slag	1261	0.005	0.002	0.015	0.1	0.01	0.5	0.001	<0.0003	0.015	0.005

Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn
Ilyaska	slag	1262	0.003	0.001	0.007	0.07	0.007	0.5	0.0005	<0.0003	0.07	0.005
Ilyaska	slag	1263	0.005	0.0015	0.015	0.07	0.01	0.5	0.001	<0.0003	0.05	0.007
Ilyaska	slag	1264	0.005	0.0015	0.01	0.07	0.007	0.5	0.0005	<0.0003	0.05	0.005
Ilyaska	slag	1265	0.003	0.001	0.01	0.05	0.007	0.3	0.0015	0.0003	1	0.015
Ilyaska	slag	1266	0.003	0.001	0.01	0.05	0.007	0.5	0.0015	0.0003	>1	0.007
Ilyaska	slag	1267	0.007	0.0015	0.02	0.1	0.015	0.5	0.0015	<0.0003	0.02	0.005
Ilyaska	slag	1268	0.007	0.002	0.015	0.07	0.01	0.5	0.001	0.00015	0.1	0.01
Ilyaska	slag	1269	0.005	0.002	0.015	0.1	0.01	0.5	0.001	0.00015	0.02	0.005
Ilyaska	slag	1270	0.005	0.0015	0.007	0.1	0.007	0.5	0.001	<0.0003	0.03	0.005
Ilyaska	slag	1271	0.007	0.002	0.02	0.07	0.015	0.5	0.0015	<0.0003	0.1	0.005
Ilyaska	slag	1272	0.005	0.0015	0.01	0.1	0.01	0.5	0.001	<0.0003	0.015	0.005
Ilyaska	slag	1273	0.007	0.002	0.015	0.07	0.01	0.5	0.001	<0.0003	0.2	0.005
Ilyaska	slag	1274	0.005	0.002	0.015	0.1	0.01	0.5	0.001	<0.0003	0.07	0.007
Ilyaska	slag	1275	0.005	0.002	0.01	0.07	0.01	0.5	0.001	<0.0003	0.03	0.005
Ilyaska	slag	1276	0.005	0.0015	0.015	0.07	0.01	0.5	0.001	<0.0003	0.07	0.005
Ilyaska	slag	1277	0.003	0.001	0.007	0.07	0.007	0.3	0.0005	<0.0003	0.02	0.005
Ilyaska	slag	1278	0.003	0.001	0.007	0.07	0.007	0.5	0.0005	<0.0003	0.07	0.005
Ilyaska	slag	1279	0.003	0.001	0.005	0.1	0.007	0.3	0.0005	<0.0003	0.07	0.005
Novo-Burino	slag	1404	0.005	0.003	0.002	0.5	<0.001	0.005	<0.0005	<0.0003	0.07	0.07
Baytu	slag	2027	0.003	0.005	0.005	0.05	0.015	0.3	0.0015	<0.0003	1	nd
Baytu	ore	2029	0.007	0.007	0.005	0.05	0.015	0.2	0.001	<0.0003	1	nd
Baytu	ore	2030	0.005	0.007	0.01	0.05	0.02	0.5	0.0015	<0.0003	1	0.05
Baytu	ore	2031	0.005	0.007	0.005	0.05	0.015	0.5	0.0015	<0.0003	1	0.02
Novo Bayramgulovo	slag	2231	0.02	0.007	0.04	0.07	0.015	0.15	nd	nd	0.05	0.015
Novo Bayramgulovo	slag	2232	0.01	0.003	0.07	0.05	0.01	0.3	nd	nd	0.15	0.01
Sensitivity of the analysis			Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn
			0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.0003	0.001	0.003

Tab. 11-62. Emission spectral analyses of slag of the Andronovo sites and the Final Bronze Age in the Asian zone of the EAMP (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).(contd.)

Site	Material	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn
Novonikolskoye	ore	0.0003	0.003	<0.01	<0.003	<0.001	<0.001	0.0001	0.03	0.01	<0.001	<0.0005
Atasu	ore	>1	0	0.03	0.0015	<0.001	<0.001	0.0001	<0.01	<0.01	<0.001	<0.0005
Atasu	ore	>1	0.00015	0.05	0.003	0.001	<0.001	0.0001	0.015	<0.01	<0.001	<0.0005
Atasu	ore	0.01	0.00007	0.01	<0.003	0.0005	<0.001	0.0001	0.015	<0.01	<0.001	<0.0005
Atasu	ore	0.2	0.003	0.015	<0.003	<0.001	0.02	0.0001	0.02	<0.01	<0.001	0.002
Atasu	ore	0.2	>3	0.02	<0.003	0.001	>>0.05	0.00015	0.01	0.01	<0.001	0.007
Atasu	ore	0.1	>3	0.07	<0.003	0.0015	>>0.05	0.0001	0.015	0.01	<0.001	0.015
Myrzhik	slag	0.5	0.00005	0.05	0.01	0.001	<0.001	0.0003	0.3	<0.01	<0.001	<0.0005
Myrzhik	ore	0.07	0.0003	0.07	0.0015	0.005	<0.001	0.0003	0.01	0.01	<0.001	<0.0005
Novoburino	ore	0.0015	0.0001	0.05	<0.003	<0.001	<0.001	<0.0001	0.03	0.01	<0.001	<0.0005
Nikolaevka	slag	0.05	0.0001	0.01	0.003	<0.001	<0.001	0.00015	0.1	0.01	<0.001	0.0003
Kipel	slag	0.002	0.00003	<0.01	<0.003	<0.001	<0.001	0.0001	0.05	0.01	<0.001	0.02
Kuropatkino	ore	>>1	>3	0.3	1	0.02	<0.001	0.00015	>>3	0.5	<0.001	<0.0005
Sargari	slag	0.3	>>3	0.15	0.7	<0.001	0.005	0.0003	0.05	0.01	<0.001	>>1
Petrovka	slag	0.015	0.001	0.005	0.003	<0.001	<0.001	0.001	0.05	0.01	<0.001	0.02
Malookunevo	ore	0.0007	0.0001	0.005	<0.003	<0.001	<0.001	0.0007	0.01	0.015	<0.001	0.0005
Malookunevo	ore	0.03	0.0002	0.1	0.01	0.005	<0.001	0.00015	0.015	0.01	0.001	0.0003
Verkhnyaya Alabuga	slag	0.002	0.00007	0.01	<0.003	<0.001	<0.001	0.001	0.07	0.05	<0.001	<0.0005
Yazyovo	ore	0.03	>>3	0.2	0.015	<0.001	0.03	0.0005	0.015	0.01	<0.001	0.015
Graurtly	slag	0.002	0.00003	0.01	<0.003	<0.001	<0.001	0.0001	0.3	0.5	0.0015	0.0005
Altyn-Tyube	slag (ore?)	0.002	0.0007	0.01	<0.003	<0.001	<0.001	0.0005	0.1	0.02	<0.001	0.0015
Altyn-Tyube	slag (ore?)	0.007	0.0007	0.01	<0.003	<0.001	<0.001	0.0005	0.1	0.02	<0.001	0.003
Korkino	slag	0.01	0.0003	<0.01	<0.003	<0.001	<0.001	0.0002	0.05	0.01	<0.001	0.3
Chisty Yar	slag	0.001	0.00005	0.005	<0.003	<0.001	<0.001	0.00015	0.05	0.015	<0.001	0.0005
Chisty Yar	slag	0.1	0.0003	0.005	<0.003	<0.001	<0.001	0.0005	0.02	0.01	<0.001	0.05
Nikolskoye	slag	0.003	0.0003	0.005	<0.003	<0.001	<0.001	0.00015	0.2	0.05	<0.001	0.0007
Nikolskoye	slag	0.003	0.00003	0.005	<0.003	<0.001	<0.001	0.0002	0.15	0.05	<0.001	0.001
Nikolskoye	slag	0.02	0.00003	0.005	<0.003	<0.001	<0.001	0.00015	0.2	0.05	<0.001	0.002

Site	Material	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn
Ikpen I	slag	0.01	0.0002	0.015	<0.003	<0.001	<0.001	0.0002	0.7	0.02	<0.001	<0.0005
Ikpen I	slag	0.005	0.0003	0.01	<0.003	<0.001	<0.001	0.0001	0.2	0.02	<0.001	<0.0005
Ikpen I	slag	0.015	0.0001	0.005	<0.003	<0.001	<0.001	0.0001	0.5	0.02	<0.001	<0.0005
Ikpen I	slag	0.015	0.001	0.015	<0.003	<0.001	<0.001	0.00015	0.3	0.03	<0.001	<0.0005
Ikpen I	slag	0.015	0.001	0.01	<0.003	<0.001	<0.001	0.0001	0.7	0.02	<0.001	<0.0005
Satyga	slag	0.0015	0.0005	0.005	<0.003	<0.001	<0.001	0.00015	0.015	0.01	<0.001	<0.0005
Satyga	slag	0.001	0.0002	0.005	<0.003	<0.001	<0.001	0.00015	0.015	0.01	<0.001	<0.0005
Satyga	slag	0.01	0.00003	<0.01	<0.003	<0.001	<0.001	0.00015	0.03	0.01	<0.001	<0.0005
Satyga	slag	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.0001	0.015	0.01	<0.001	<0.0005
Satyga	slag	0.001	0.00003	0.005	<0.003	<0.001	<0.001	0.0001	0.01	0.01	<0.001	0.0015
Satyga	slag	0.003	0.00003	0.005	<0.003	<0.001	<0.001	0.00015	0.01	0.01	<0.001	<0.0005
Satyga	slag	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.0002	0.02	0.01	<0.001	<0.0005
Atamanovka	slag	0.003	0.00005	0.005	<0.003	<0.001	<0.001	0.0003	0.015	0.01	<0.001	0.0005
Kent	slag	0.005	0.002	0.005	<0.003	<0.001	<0.001	0.0003	0.015	0.01	<0.001	<0.0005
Burla-3	ceramics	0.002	0.00005	0.005	<0.003	<0.001	<0.001	0.0001	0.05	0.02	0.001	<0.0005
Kalinovka	slag	0.015	>3	0.005	<0.003	0.001	<0.001	0.0001	0.03	0.01	0.001	0.0003
Kalinovka	slag	0.02	>3	0.005	<0.003	<0.001	<0.001	0.0001	0.05	0.01	<0.001	0.0015
Korkino	slag	0.003	0.00003	0.005	<0.003	<0.001	<0.001	0.001	0.1	0.03	0.001	0.0005
Korkino	slag	0.002	0.0001	0.005	<0.003	<0.001	<0.001	0.0015	0.1	0.05	0.001	0.0003
Korkino	slag	0.005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0007	0.1	0.03	<0.001	<0.0005
Korkino	slag	0.0007	<0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.07	0.03	<0.001	<0.0005
Korkino	slag	0.0007	<0.00003	0.005	<0.003	<0.001	<0.001	0.0002	0.07	0.02	<0.001	<0.0005
Korkino	slag	0.002	0.00003	0.005	<0.003	<0.001	<0.001	0.0007	0.07	0.03	<0.001	0.0005
Korkino	slag	0.03	0.0007	0.005	<0.003	0.001	<0.001	0.007	0.07	0.03	0.001	0.0003
Burla-3	ore	0.001	0.001	0.005	<0.003	<0.001	<0.001	0.00015	0.02	<0.01	<0.001	0.001
Kaygorodok	ore	0.001	0.003	0.005	0.0015	<0.001	<0.001	0.0001	0.1	0.01	<0.001	0.001
Kaygorodok	ore	0.01	>>3	0.005	0.0015	<0.001	<0.001	0.0002	0.015	<0.01	<0.001	0.1
Burla-3	ore	0.007	0.0007	0.005	<0.003	<0.001	<0.001	0.00015	0.02	<0.01	0.001	0.0005
Chernaya Kurya	ore	>1	>3	0.005	<0.003	0.0015	0.02	0.07	0.02	0.01	0.001	0.0005
Chernaya Kurya	ore	>1	0.0005	0.02	<0.003	>0.1	0.015	0.01	0.03	<0.01	<0.001	<0.0005
Chernaya Kurya	ore	>1	<0.00003	0.01	<0.003	0.07	>0.05	0.003	0.05	<0.01	<0.001	<0.0005
Chernaya Kurya	ore	>>1	>3	0.5	0.003	0.02	0.007	0.0005	0.02	<0.01	<0.001	<0.0005
Chernaya Kurya	ore	1	0.0007	0.01	<0.003	0.05	0.01	0.0005	0.03	<0.01	<0.001	<0.0005

Site	Material	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn
Chernaya Kurya	ore	>1	>>3	0.02	0.03	0.1	0.05	>0.1	0.1	<0.01	<0.001	0.0005
Chernaya Kurya	ore	>1	0.001	0.005	0.0015	0.002	0.003	0.03	0.05	<0.01	<0.001	0.0005
Chernaya Kurya	ore	>1	0.001	0.005	0.01	>0.1	0.03	0.02	0.02	<0.01	<0.001	<0.0005
Ilyaska	ore	0.02	>3	0.015	<0.003	<0.001	<0.001	0.0001	>>3	>1	<0.001	<0.0005
Ilyaska	ore	0.001	0.0002	0.005	<0.003	<0.001	<0.001	0.0001	0.03	0.015	<0.001	<0.0005
Ilyaska	ore	0.002	>3	0.005	<0.003	<0.001	<0.001	<0.0001	>>3	1	<0.001	<0.0005
Ilyaska	ore	0.001	>3	0.005	<0.003	<0.001	<0.001	0.0001	0.01	0.015	<0.001	0.0003
Ilyaska	ore	0.001	0.00015	0.005	<0.003	<0.001	<0.001	0.0001	0.01	<0.01	<0.001	<0.0005
Ilyaska	ore	0.07	0.003	0.01	<0.003	<0.001	<0.001	0.001	>3	0.15	<0.001	<0.0005
Ilyaska	ore	0.001	0.00015	0.005	<0.003	<0.001	<0.001	0.0002	<0.01	0.01	<0.001	<0.0005
Ilyaska	ore	0.005	0.0005	0.005	<0.003	<0.001	<0.001	<0.0001	>>3	>1	0.001	<0.0005
Ilyaska	ore	0.001	0.00015	0.005	<0.003	<0.001	<0.001	0.0001	0.03	0.01	<0.001	<0.0005
Ilyaska	ore	0.01	0.002	0.015	<0.003	<0.001	<0.001	0.0002	0.7	0.02	<0.001	<0.0005
Ilyaska	ore	0.001	0.00015	0.005	<0.003	<0.001	0.001	0.0001	0.01	0.01	<0.001	<0.0005
Ilyaska	ore	0.02	>3	0.005	<0.003	<0.001	<0.001	0.00015	>>3	1	<0.001	<0.0005
Ilyaska	ore	0.0015	0.0003	0.005	<0.003	<0.001	<0.001	0.0001	0.01	0.015	<0.001	<0.0005
Ilyaska	ore	0.02	>3	0.015	<0.003	<0.001	<0.001	<0.0001	>>3	1	<0.001	<0.0005
Ilyaska	ore	0.015	0.003	0.015	<0.003	<0.001	<0.001	0.0001	0.2	0.015	<0.001	0.0003
Ilyaska	ore	0.0015	0.0002	0.005	<0.003	<0.001	<0.001	0.0001	<0.01	0.01	<0.001	<0.0005
Ilyaska	ore	0.015	>3	0.02	<0.003	<0.001	0.002	0.0007	>>3	0.7	<0.001	<0.0005
Ilyaska	ore	0.015	>3	0.005	<0.003	<0.001	<0.001	0.0001	>>3	1	<0.001	<0.0005
Ilyaska	ore	0.01	>3	0.01	<0.003	<0.001	0.001	0.0001	>>3	0.3	0.001	<0.0005
Ilyaska	ore	0.03	>3	0.1	<0.003	<0.001	<0.001	0.0002	>>3	1	<0.001	0.0003
Ilyaska	ore	0.007	0.003	0.005	<0.003	<0.001	<0.001	0.0002	>>3	0.5	0.001	<0.0005
Ilyaska	slag	0.0015	0.00015	0.005	<0.003	<0.001	<0.001	0.001	0.15	0.05	<0.001	<0.0005
Ilyaska	slag	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.0007	0.1	0.05	<0.001	<0.0005
Ilyaska	slag	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.0015	0.1	0.05	0.001	<0.0005
Ilyaska	slag	0.001	0.00003	0.005	<0.003	<0.001	<0.001	0.0007	0.07	0.02	<0.001	0.0003
Ilyaska	slag	0.001	0.00007	0.005	<0.003	<0.001	<0.001	0.001	0.07	0.02	<0.001	0.0003
Ilyaska	slag	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.002	0.07	0.02	<0.001	<0.0005
Ilyaska	slag	0.0007	0.0001	0.005	<0.003	<0.001	<0.001	0.0007	0.07	0.02	<0.001	<0.0005
Ilyaska	slag	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.0015	0.07	0.02	<0.001	0.0003
Ilyaska	slag	0.0005	<0.00003	0.005	<0.003	<0.001	<0.001	0.001	0.07	0.02	<0.001	<0.0005

Site	**Material**	**Pb**	**Ag**	**As**	**Sb**	**Cd**	**Bi**	**Mo**	**Ba**	**Sr**	**W**	**Sn**
Ilyaska	slag	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.003	0.07	0.02	0.001	<0.0005
Ilyaska	slag	0.0007	<0.00003	0.005	<0.003	<0.001	<0.001	0.001	0.07	0.02	<0.001	<0.0005
Ilyaska	slag	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.0015	0.07	0.03	<0.001	<0.0005
Ilyaska	slag	0.007	0.0015	0.005	<0.003	<0.001	<0.001	0.0015	>3	0.3	<0.001	<0.0005
Ilyaska	slag	0.005	0.0015	0.005	<0.003	<0.001	<0.001	0.001	>3	0.2	<0.001	<0.0005
Ilyaska	slag	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.0005	0.1	0.02	<0.001	<0.0005
Ilyaska	slag	0.0007	0.00005	0.005	<0.003	<0.001	<0.001	0.0015	0.1	0.03	<0.001	<0.0005
Ilyaska	slag	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.1	0.02	<0.001	0.0003
Ilyaska	slag	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.07	0.03	<0.001	0.0003
Ilyaska	slag	0.0005	0.00005	0.005	<0.003	<0.001	<0.001	0.0015	0.1	0.03	0.001	<0.0005
Ilyaska	slag	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.003	0.1	0.03	0.001	<0.0005
Ilyaska	slag	0.001	0.00015	0.005	<0.003	<0.001	<0.001	0.0015	0.15	0.03	<0.001	<0.0005
Ilyaska	slag	0.001	0.00005	0.005	<0.003	<0.001	<0.001	0.0015	0.07	0.02	<0.001	0.0003
Ilyaska	slag	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.002	0.07	0.03	0.001	0.0003
Ilyaska	slag	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.003	0.1	0.02	<0.001	<0.0005
Ilyaska	slag	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.0015	0.07	0.03	<0.001	<0.0005
Ilyaska	slag	0.0007	0.00003	0.005	<0.003	<0.001	<0.001	0.002	0.1	0.03	<0.001	<0.0005
Ilyaska	slag	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.001	0.05	0.02	<0.001	<0.0005
Novo-Burino	slag	0.005	0.00005	0.005	<0.003	<0.001	<0.001	0.001	0.01	0.01	<0.001	<0.0005
Baytu	slag	0.05	0.0009	0.1	0.0015	<0.001	0.005	0.005	0.07	0.03	0.005	0.2
Baytu	ore	0.015	0.002	0.015	<0.003	<0.001	0.001	0.0015	0.015	0.015	<0.001	0.015
Baytu	ore	0.05	0.002	0.02	<0.003	<0.001	0.01	0.0015	0.015	0.01	<0.001	0.01
Baytu	ore	0.02	0.0009	0.03	<0.003	<0.001	0.003	0.003	0.02	0.01	<0.001	0.01
Novo Bayramgulovo	slag	0.001	0.00005	0.005	<0.003	nd	<0.001	0.001	0.05	nd	nd	0.0005
Novo Bayramgulovo	slag	0.002	0.00015	0.005	<0.003	nd	<0.001	0.0007	0.03	nd	nd	0.001
Sensitivity of the analysis		Pb	Ag	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn
		0.0003	0.00003	0.01	0.003	0.001	0.001	0.0001	0.01	0.01	0.001	0.0005

Tab. 11-62. Emission spectral analyses of slag of the Andronovo sites and the Final Bronze Age in the Asian zone of the EAMP (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).(contd.)

Site	Material	Be	Zr	Ga	Y	Yb	La	Nb	Li	Hg
Novonikolskoye	ore	0.00005	nd	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Atasu	ore	0.0007	nd	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Atasu	ore	0.0015	nd	0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Atasu	ore	0.0002	nd	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Atasu	ore	0.00015	nd	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Atasu	ore	0.00003	nd	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Atasu	ore	0.00005	nd	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Myrzhik	slag	0.003	nd	0.001	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Myrzhik	ore	0.007	nd	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Novoburino	ore	0.00007	nd	0.001	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Nikolaevka	slag	0.0015	0.01	0.001	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Kipel	slag	0.0002	0.02	0.0005	0.0015	0.00015	<0.01	<0.003	<0.01	<0.001
Kuropatkino	ore	0.00003	nd	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Sargari	slag	0.00015	nd	0.01	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Petrovka	slag	0.0001	nd	0.0005	0.001	0.00015	<0.01	<0.003	<0.01	<0.001
Malookunevo	ore	0.0002	0.015	0.0015	<0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Malookunevo	ore	0.001	nd	<0.0005	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Verkhnyaya Alabuga	slag	0.00015	0.015	0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Yazyovo	ore	0.00005	nd	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Graurtly	slag	0.0003	0.015	0.0005	0.005	0.0003	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	slag (ore?)	0.0002	0.001	<0.0005	0.005	0.0002	<0.01	<0.003	<0.01	<0.001
Altyn-Tyube	slag (ore?)	0.0003	0.002	<0.0005	0.015	0.0007	<0.01	<0.003	<0.01	<0.001
Korkino	slag	0.00015	0.001	0.0005	0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Chisty Yar	slag	0.0003	0.007	0.001	0.003	0.0003	<0.01	<0.003	<0.01	<0.001
Chisty Yar	slag	<0.00003	nd	0.005	<0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Nikolskoye	slag	0.0002	0.015	0.001	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Nikolskoye	slag	0.0002	0.01	0.0015	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Nikolskoye	slag	0.0002	0.01	0.0015	0.001	0.0001	<0.01	<0.003	<0.01	<0.001

Site	Material	Be	Zr	Ga	Y	Yb	La	Nb	Li	Hg
Ikpen I	slag	0.0015	0.02	0.0015	0.005	0.0002	<0.01	0.0015	<0.01	<0.001
Ikpen I	slag	0.001	0.02	0.0015	0.003	0.00015	<0.01	0.003	<0.01	<0.001
Ikpen I	slag	0.001	0.007	0.001	0.01	0.0005	<0.01	<0.003	<0.01	<0.001
Ikpen I	slag	0.001	0.02	0.0015	0.007	0.0002	<0.01	<0.003	<0.01	<0.001
Ikpen I	slag	0.003	0.007	0.001	0.007	0.0002	<0.01	<0.003	<0.01	<0.001
Satyga	slag	0.0001	0.003	0.001	0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Satyga	slag	0.00007	0.01	0.001	0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Satyga	slag	0.00007	0.007	0.001	<0.001	0.00015	<0.01	<0.003	<0.01	<0.001
Satyga	slag	0.00007	0.005	0.001	0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Satyga	slag	0.00003	0.002	0.0005	<0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Satyga	slag	0.00003	0.002	0.0005	<0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Satyga	slag	0.0001	0.01	0.001	<0.001	0.00015	<0.01	<0.003	<0.01	<0.001
Atamanovka	slag	0.00007	0.0015	<0.0005	<0.001	0.00015	<0.01	<0.003	<0.01	<0.001
Kent	slag	0.0002	0.002	0.0005	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Burla-3	ceramics	0.00015	0.01	0.001	0.0015	0.0001	<0.01	<0.003	<0.01	<0.001
Kalinovka	slag	0.0002	0.01	0.001	0.002	0.0001	<0.01	<0.003	<0.01	<0.001
Kalinovka	slag	0.0002	0.01	0.001	0.005	0.0002	<0.01	<0.003	<0.01	<0.001
Korkino	slag	0.0002	0.01	0.001	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Korkino	slag	0.0002	0.01	0.0015	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Korkino	slag	0.00015	0.015	0.001	0.002	0.0002	<0.01	<0.003	<0.01	<0.001
Korkino	slag	0.00015	0.01	0.001	0.0015	0.00015	<0.01	<0.003	<0.01	<0.001
Korkino	slag	0.0002	0.01	0.001	0.0015	0.0002	<0.01	<0.003	<0.01	<0.001
Korkino	slag	0.0002	0.01	0.0015	0.0015	0.00015	<0.01	<0.003	<0.01	<0.001
Korkino	slag	0.00015	0.01	0.002	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Burla-3	ore	0.0002	0.01	0.001	0.002	0.0001	<0.01	<0.003	<0.01	<0.001
Kaygorodok	ore	0.00015	0.007	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Kaygorodok	ore	0.00015	0.007	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Burla-3	ore	0.00015	0.007	0.001	0.0015	<0.0001	<0.01	<0.003	<0.01	<0.001
Chernaya Kurya	ore	0.0002	0.005	0.001	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Chernaya Kurya	ore	0.00007	nd	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Chernaya Kurya	ore	0.00007	nd	0.002	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Chernaya Kurya	ore	0.00003	nd	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Chernaya Kurya	ore	0.00005	nd	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001

Site	Material	Be	Zr	Ga	Y	Yb	La	Nb	Li	Hg
Chernaya Kurya	ore	0.00003	nd	0.001	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Chernaya Kurya	ore	0.00003	nd	0.002	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Chernaya Kurya	ore	0.00003	nd	0.002	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	<0.00003	0.003	0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	<0.00003	0.003	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	0.00003	0.003	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	<0.00003	0.003	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	<0.00003	0.003	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	0.00015	0.01	0.001	0.002	0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	<0.00003	0.003	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	0.00003	0.003	0.001	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	<0.00003	0.003	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	0.00015	0.015	0.001	0.0015	0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	<0.00003	0.005	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	<0.00003	0.005	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	<0.00003	0.005	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	0.00005	0.007	<0.0005	0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	0.00015	0.015	0.001	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	<0.00003	0.003	<0.0005	<0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	0.0001	0.007	0.0005	0.001	0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	0.00003	0.003	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	0.0001	0.007	0.001	0.002	0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	0.00005	0.005	<0.0005	0.0015	0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	ore	0.0001	0.01	0.0015	0.0015	0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.0002	0.015	0.001	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.0002	0.015	0.0015	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.0002	0.015	0.001	0.003	0.0002	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.015	0.001	0.0015	0.0002	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.0002	0.015	0.0015	0.002	0.0002	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.015	0.0015	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.015	0.002	0.002	0.0002	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.015	0.002	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.01	0.0015	0.002	0.0002	<0.01	<0.003	<0.01	<0.001

Site	Material	Be	Zr	Ga	Y	Yb	La	Nb	Li	Hg
Ilyaska	slag	0.00015	0.01	0.001	0.0015	0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.01	0.0015	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.01	0.0015	0.0015	0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.01	0.002	0.002	0.0002	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.015	0.002	0.003	0.0002	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.02	0.001	0.003	0.0002	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.015	0.002	0.002	0.0002	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.02	0.0015	0.002	0.0002	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.015	0.001	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.0002	0.015	0.0015	0.003	0.0002	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.01	0.0015	0.002	0.00015	<0.010	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.015	0.001	0.003	0.0002	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.015	0.0015	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.015	0.001	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.0001	0.015	0.001	0.002	0.00015	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.0001	0.01	0.001	0.0015	0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.015	0.001	0.002	0.0001	<0.01	<0.003	<0.01	<0.001
Ilyaska	slag	0.00015	0.01	0.001	0.0015	0.0001	<0.01	<0.003	<0.01	<0.001
Novo-Burino	slag	<0.00003	0.0015	<0.0005	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Baytu	slag	0.0001	nd	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Baytu	ore	0.0001	nd	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Baytu	ore	0.00015	0.007	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Baytu	ore	0.0001	0.007	0.0015	<0.001	<0.0001	<0.01	<0.003	<0.01	<0.001
Novo Bayramgulovo	slag	nd	nd	nd	nd	nd	nd	nd	nd	nd
Novo Bayramgulovo	slag	nd	nd	nd	nd	nd	nd	nd	nd	nd
Sensitivity of the analysis		Be	Zr	Ga	Y	Yb	La	Nb	Li	Hg
		0.00003	0.001	0.0005	0.001	0.0001	0.01	0.003	0.01	0.001

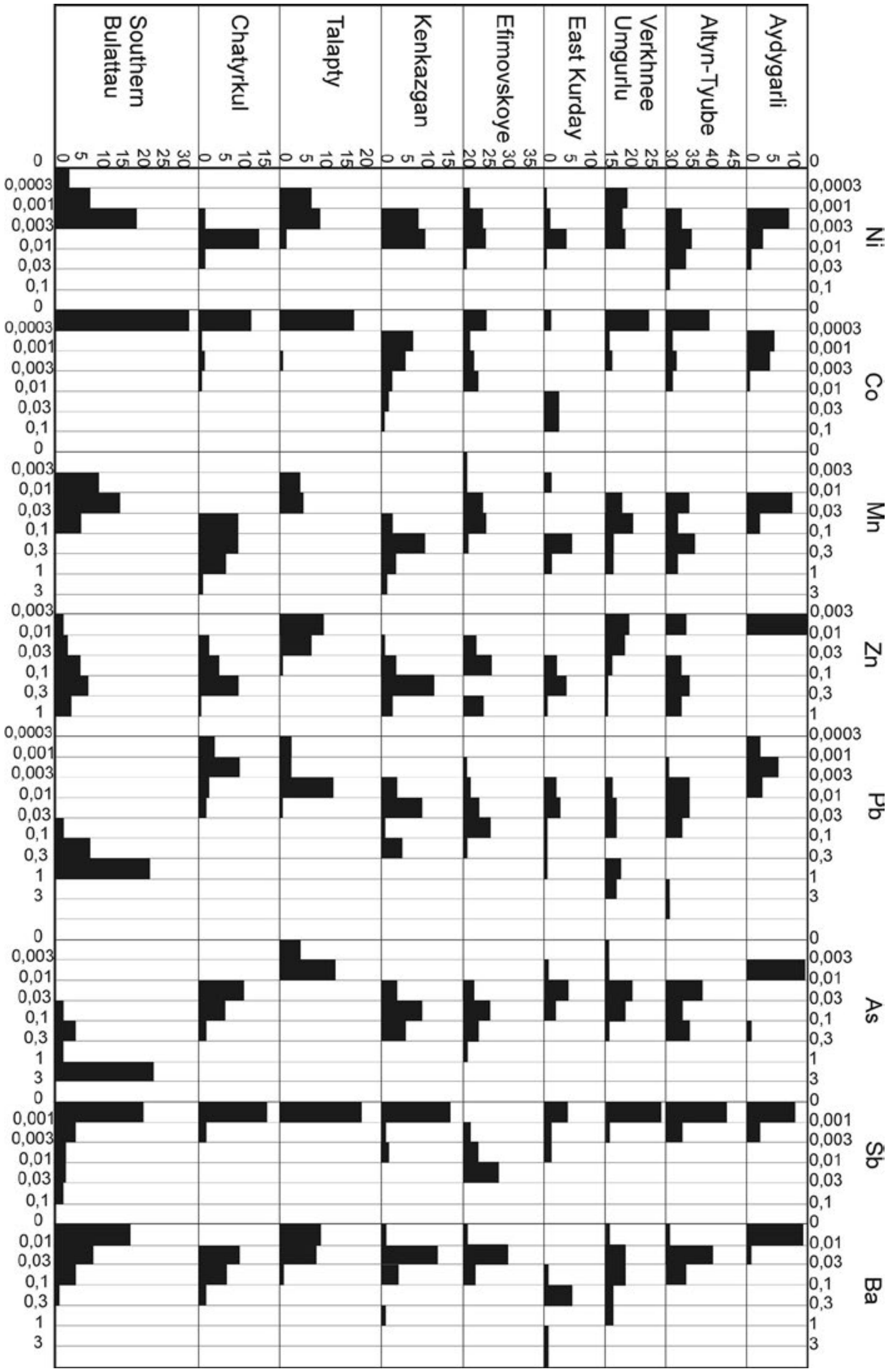


FIG. 11-63. FREQUENCY DIAGRAM OF DISTRIBUTION OF TRACE-ELEMENTS (%) IN ORE FROM DEPOSITS OF CENTRAL KAZAKHSTAN.

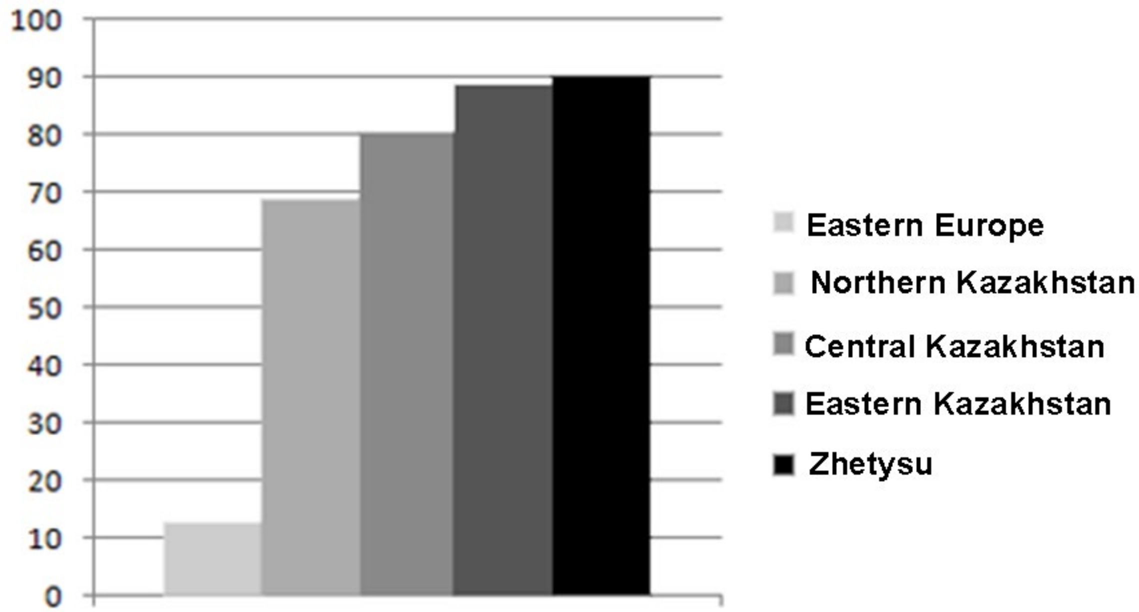


Fig. 11-64. Part of tin alloys in metal of the Final Bronze Age.

Tab. 11-65. Part of As+Sb alloys in metal of the Bronze Age (%).

Seima-Turbino sites	Timber-Grave culture	Andronovo sites	LBA of the Don area	Prikazanskaya culture	Final Bronze Age of the European steppe европейской степи	Final Bronze Age of the Asian ateppe	Irmen culture	Lugavskaya culture	Elovka culture	Korchazhka culture	Karasuk culture
11.3	2	8	25.7	70.8	17	36.1	7.9	6	0	0	0

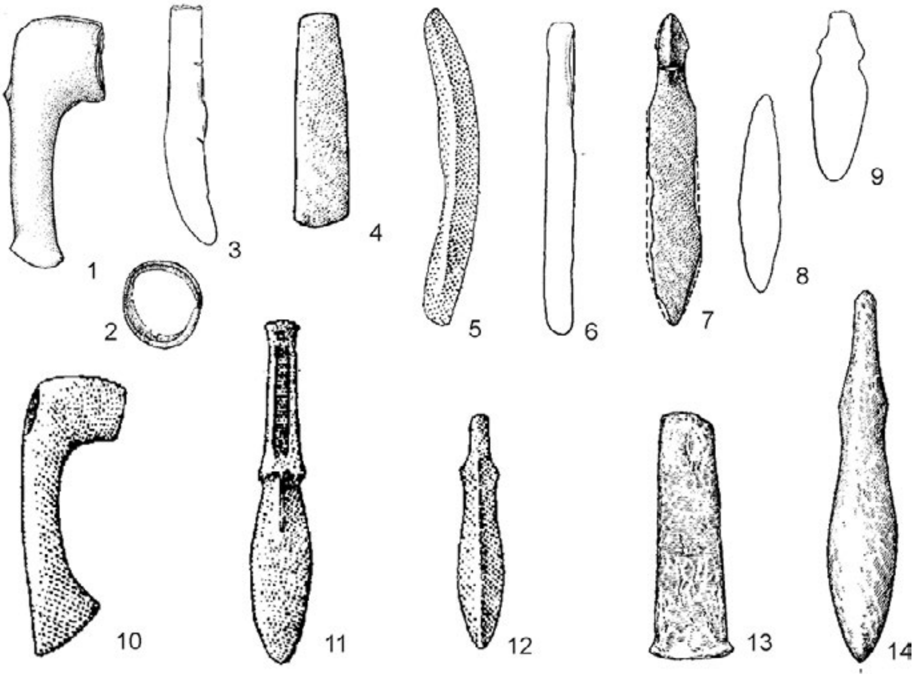


FIG. 11-66. METAL ARTIFACTS OF THE PETROVKA (1-9) AND ALAKUL (10-14) CULTURES.

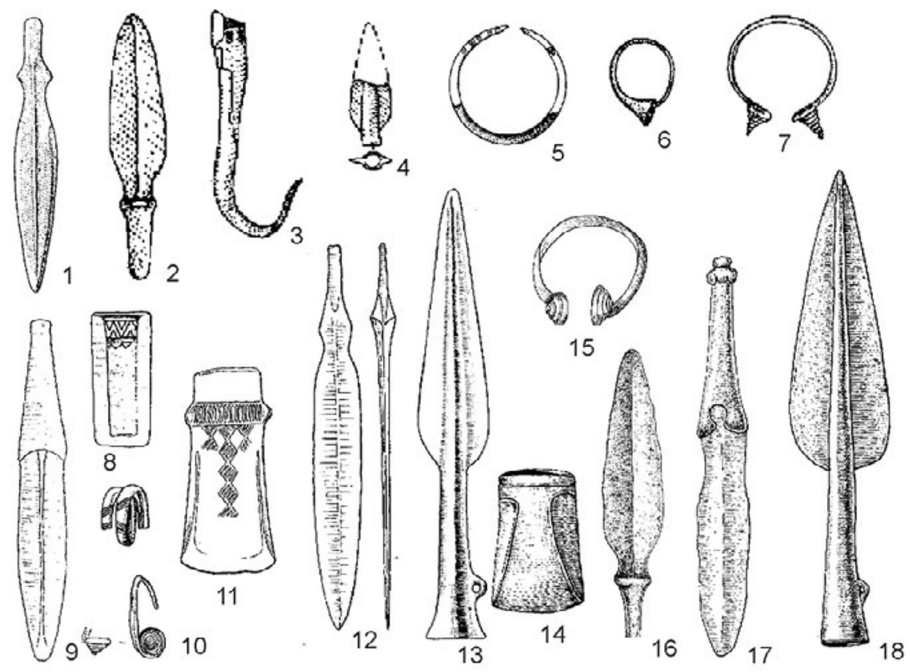


FIG. 11-67. METAL ARTIFACTS OF THE FYODOROVKA (1-7), CHERKASKUL (8-13) AND POZDNYAKOVO (14-18) CULTURES.

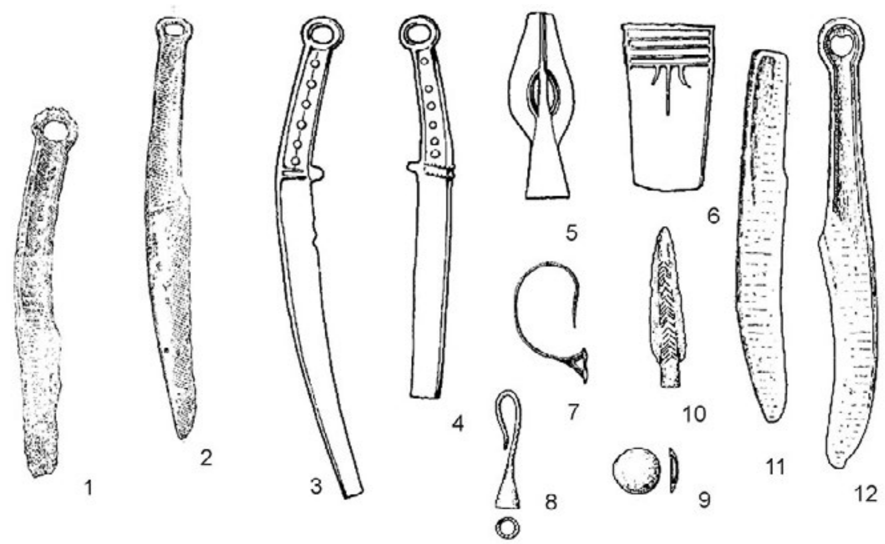


FIG. 11-68. METAL ARTIFACTS OF THE KARASUK (1, 2), IRMEN (3-7) AND ELOVKA (8-12) CULTURES.

Tab. 11-69. Emission spectral analyses of slag from the settlement of Akshuben I (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition (spectrograph ISP-30).

Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu	Zn	Pb
slag	703	0.002	0.0007	0.0015	0.07	<0.001	0.07	<0.0005	0.00015	0.15	0.015	0.0007
slag	761	0.01	0.002	0.05	0.1	0.015	0.5	0.0015	<0.0003	0.2	0.01	0.002
lining	762	0.007	0.0015	0.03	0.2	0.015	0.2	0.001	<0.0003	0.3	0.01	0.0015
Sensitivity of the analysis		0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.0003	0.001	0.003	0.0003

Material	№	Ag	As	Sb	Cd	Bi	Mo	Ba	Sr	W	Sn	Be
slag	703	0.00003	0.005	<0.003	<0.001	<0.001	0.0002	0.015	0.01	<0.001	0.0003	0.00003
slag	761	0.00005	0.005	<0.003	<0.001	<0.001	0.0001	0.05	0.01	0.001	0.0003	0.00015
lining	762	0.00007	0.005	<0.003	<0.001	<0.001	0.0002	0.07	0.015	<0.001	0.0003	0.00015
Sensitivity of the analysis		0.00003	0.01	0.003	0.001	0.001	0.0001	0.01	0.01	0.001	0.0005	0.00003

Material	№	Zr	Ga	Y	Yb
slag	703	0.0015	0.001	<0.001	0.0001
slag	761	0.015	0.001	0.0015	0.0001
lining	762	0.01	0.001	0.0015	0.00015
Sensitivity of the analysis		0.001	0.0005	0.001	0.0001

Chapter 12.
Metallurgical Production in the Kyzyl-Kum

Above we have considered not only the dynamics of development of the production in the Eurasian Metallurgical Province, but also some questions of interaction of this production with other traditions in contact zones with other metallurgical provinces, the European and Central Asian. But in the south the EAMP contacted with one more metallurgical province, the Irano-Afghan (Chernykh 1978). Interaction of these provinces is observed in a boundary area, in the territory of the Kyzyl-Kum Desert. Archaeological investigations in the Central Kyzyl-Kum have revealed a series of sites with remains of metallurgical production (Vakturskaya *et al.* 1968; Vinogradov A. Kuzmina 1970; Vinogradov A. *et al.* 1972).

The area of the Central Kyzyl-Kum represents now deserts with many heights consisted of limestone and marble. These relatively young formations had been often divided by intrusions of rocks, and therefore containing calcite and quartz veins (Vinogradov A., Mamedov 1975, p. 6, 15). The copper ores are connected with these intrusions; the deposits are insignificant in comparison with other mining and metallurgical areas.

The studied collection includes slags and ores from 10 sites in the Lyavlyakan depression, 8 sites in Ayakagitma and 5 sites in Besh-Bulak. In total 108 mineralogical analyses and 98 spectral analyses have been made[1]. In addition to this, two samples from the sites located to the south of Margiana have been studied: from Kelleli 4 and Dashli 3 (Fig. 12-1.). Certainly, all this is not enough to understand the development of metallurgical production in this region.

Slags of the Kyzyl-Kum

The classification of slag from the Kyzyl-Kum raises serious difficulties caused both by character of sites, and nature of ore base. The main problem is that the large part of materials occurs from the eroded sites. It is, practically, all points where the slags have been found. Only small part of these objects has been excavated. However, the authors of publications were interested, first of all, in Neolithic materials, and the materials of the Bronze Age have been studied worse. Therefore only in rare instances it is possible to date the slag accurately. Besides, usually in the publication the materials of this time are described as relating to the Early Bronze Age of the Kyzyl-Kum or relating to the 'steppe bronze'. On this basis it is impossible to connect slags with any cultural complex (Alakul, Fyodorovka or Sargari). Sometimes the Tazabagyab ceramics is mentioned which was genetically connected, apparently, with Timber-Grave or Alakul, and is well familiar to researchers of the south of Central Asia.

In the course of studying mineralogy of the slag one more problem has been brought to light. It was absolutely obvious that the majority of slag is smelted from ore in quartz veins. But a part of ores was connected with the basic rocks. However in some cases there were signs that the iron-rich basic rocks were divided by the quartz veins. In these cases it was rather difficult to relate the slag accurately to this or that mineralogical group. In the course of this classification I was trying to hold the same nomenclature of groups which is used for more northern territories. But often it was impossible definitely to say: to which group some samples belong. In principle, this slag could be smelted from ore in the basic rocks divided by quartz veins or from a field in the quartz rock whose upper part is enriched with iron oxides. Therefore a number of samples were related to intermediate groups, for example, the 3rd if the slag combines signs of smelting the ore from iron-rich and quartz rocks. But genetically this group, most likely, does not correspond to the similar Ural group,

[1] The author expresses his thanks to A.V. Vinogradov who has given slag collections for studies to the laboratory of natural-science methods of the Institute of Archaeology of Russian Academy of Sciences, and also to E.N. Chernykh who has given the opportunity for their analysis.

although its formal signs are the same. There is an opportunity to designate it as a group '1st-2nd ?', but I have preferred to avoid so exotic nomenclature.

In many cases the oxidized ore, mainly, malachite was smelted. However often there are also sulfide ores in the slag, even if the basic ore was oxidized. Chalcopyrite inclusions are also present. It is not always possible to understand, how casual is the presence of a larger quantity of chalcopyrite in the smelting and formation of the structures typical of the slags of 6th mineralogical group. In some cases their deliberate smelting is quite obvious, but in other cases it is not so. And, the chalcopyrite was extracted in the same quartz rocks typical of the Kyzyl-Kum. Therefore if the relation to any certain group caused difficulties, there was a desire to relate the slag to an intermediate group 2nd -6th . However more attentive studying of this material has allowed me to keep it in the 2nd group as the ore mix was used here, instead of the deliberate smelting of chalcopyrite.

All these ambiguities prevent to achieve that rather accurate picture which has been revealed to the north. As a result, it is possible to speak, mainly, about most general tendencies and the presence of this or that type of smelting in this area.

In total, 108 samples of slag have been subjected to the mineralogical analysis. Their form allows this slag to be divided into four types: 1 – heavy shapeless slag, 2 – flat slag, 3 – slag crust on the sandstone or furnace lining, 4 – thin curved slag plate. In principle, the slag crusts on the sandstone or ceramic masses can be characteristic of smeltings of different types. Similar slag was present, however in quite limited quantity, also in some other collections of Northern Eurasia. Usually it is slagged walls or bottom of the furnaces. Therefore it can quite be united with the shapeless slag. But on the sites in the Kyzyl-Kum the part of this slag is very great that causes a question of reasons of this phenomenon. In the north analogs to it are known only in the Elunino and Mezhovka series.

Description of ore samples

Some samples are presented by roasted ore (No. 549, 550, 561, 562, and 585). But they have been found on three sites of one area only: Besh-Bulak 1, 2, 10. All they are malachite, rarer cuprite with impurity of secondary sulfides in the quartz rock enriched in some cases with iron oxides. One sample from the site of Lyavlyakan 44-Ia is presented by roasted ore conglomerate containing a significant quantity of quartz grains (55-60%) with inclusions of copper, cuprite, malachite and chalcopyrite. Between the quartz grains small areas of slag glass with rare nuclei of olivine crystallization and ore inclusions are present.

Mineralogy of slag

1st mineralogical group

Unlike slag of this mineralogical group in the Urals, where it was clearly diagnosed by the presence of chromite, the Kyzyl-Kum material is united into this group as on this sign as if it was visible that the ore was connected with iron-containing minerals and quartz inclusions in a sample are absent. Chromite grains in quantity of about 1% are present only in five samples (No. 485,489,513,530,581). Respectively, these samples could be smelted from the ore from the ultrabasic rocks. The others were extracted from rocks of the basic composition, but probably of another genesis. The main inclusions in the slag of this group are olivine crystals. As a rule, they are long prismatic and large skeletal (Fig. 12-I.1), but there are also polygonal forms. Between them needle crystals and nuclei of olivine crystallization grow. The contents of olivine vary in samples with chromite inclusion within 45-66%. In other samples the dispersion of the olivine contents is higher: from 10.3 to 66%, although the majority shows, nevertheless, the high contents.

In many samples iron components (magnetite and wüstite with prevalence of the latter) are presented in the form of octahedra (Fig. 12-I.1), skeletons, small crystallizing dendrites and rash, and in case of a significant quantity also dendrites and large grains. In some instances the octahedra form accumulations, a result of disintegration of larger grains. Grains of regenerating iron hydroxides (goethite) in such slags can be rather numerous. But usually they are replaced with hematite. In such grains or accumulations there are in some cases oxidized copper minerals (malachite, cuprite, chalcocite) and copper prills. Usually these minerals are not melted, although there are sometimes fused dendrites and even prills. But it is in cases if the reduction into wüstite occurred. The contents of magnetite and wüstite vary from 0.2 to 23%, but usually in the range of 5-12%.

Actually, just such good presence of olivine and iron minerals and also the recorded cases of connection of the ore with the latter allows us to relate the slag to this group.

Copper prills (Fig. 12-I.1) in this slag are small and their quantity is insignificant (0.1-2.5%, but the range of 0.4-1.5% is more typical). Cuprite is presented by prills or rare small particles, usually it was molten. Its content is much lower than that of copper: from an absolutely insignificant presence to 1.5%, but usually to 0.5%. All this indicates the low slag viscosity and the reducing smelting atmosphere.

Ore minerals are presented usually by malachite. However their range is rather wide. Besides malachite there are cuprite, occasionally azurite, and often in small quantity sulfide minerals: covellite (Fig. 12-I.1), chalcocite, occasionally small cubes of chalcopyrite and inclusions of bornite. Covellite and chalcocite are presented usually by prills. In this case, as well as everywhere, there are no bases to speak about a deliberate mixing of ore, it only reflects the character of ore: occasionally associations of malachite and secondary sulfides are present within one ore grain.

Thus, the 1st mineralogical group reflects smelting of ore from rocks of the basic compound. The ores were, mainly, oxidized minerals like malachite although often there are also impurities of sulfides. Probably, the sulfides promoted the reducing atmosphere and prevented from oxidation of the slag. Other factors are not also excluded, but we do not know the construction of furnaces. Judging from molten cuprite, in the course of smelting the temperatures were in the limit of 1200-1300 °C. However in individual samples the fused particles of wüstite and occasionally even its prills are noted. In some instances its fused surface can be explained by impact of fluid slag. Nevertheless, we can assume that sometimes the temperature reached a melting point of wüstite (1360 °C) or was close to it. The slag was rather fluid as separation of metal happened very well and copper losses in the slag are insignificant. Taking it into account, and also that the olivine often forms rather large crystals, the cooling of slag happened slowly, respectively, the smelting was carried out in metallurgical furnaces, and the slag was not tapped.

2nd mineralogical group

The mineralogical group is connected with smelting ore from quartz rocks in the reducing conditions. It is the most representative group in the entire sampling. And, it is very non-uniform. Crystallization of fayalite in slags of this group shows a maximal dispersion from 1 to 76%. Depending on the quantity of fayalite it can be presented by small needles and nuclei of crystallization, skeletal prisms or long prisms (Fig. 12-I.2).

The second leading component in the slag is magnetite (Fig. 12-I.2). It is presented by octahedra of various sizes, skeletons and dendrites growing from the liquid slag. Occasionally its grains and dendrites are slightly fused. In some cases there are large grains from which small octahedra separate. In some instances it is visible that this mineral is concluded in quartz grains. This circumstance and also such unstable contents of fayalite specify that a deliberate compositing of the furnace charge or fluxing were not applied. There is also no distinct connection between the contents of fayalite and magnetite. In slag groups with different contents of fayalite (1-10%, 10-20% …) the content of magnetite varies from 0 to 20-30% in individual samples, and the average contents inside the groups does from 3.5 to 7.5-10%, and, any quantitative dependences on the fayalite contents are absent.

Copper is presented by small prills (Fig. 12-I.2). Its content is insignificant; on the average in the 2nd group it is 1.27%. It has been calculated that from the slags with the low contents of the crystallized fayalite to those with its high contents the content of copper decreases from 2 to 0.8% that is quite explainable by the decrease in slag viscosity.

Cuprite is presented by grains, prills, substitution of ore minerals, rare dendrites, and borders round prills of chalcocite. Its contents in different samples vary, but as a whole they are insignificant, at the average 1.1%. In this case a vague dependence between the contents of fayalite and cuprite is traced too: the content of cuprite decreases from 2 to 0.1% in the process of growth of the fayalite contents. Thus, the tendency revealed in the analysis of the contents of copper is confirmed: the fayalite slag provided lower viscosity that promoted the decrease in copper losses in slag. But in this case an additional factor was that the cuprite forms in the oxidizing conditions, and for formation of fayalite the reducing conditions are necessary.

The low contents of copper and cuprite indicate also the reducing smelting atmosphere that is confirmed also by the presence of iron particles in some samples. It is hard to say how the reducing atmosphere was reached against the absence of information on furnaces, especially as the quantity of sulfide minerals in slag of this mineralogical group is not so great. The ore is presented, mainly, by malachite and cuprite (chrysocolla and azurite grains are rare) although in some samples occasionally fine grains of chalcopyrite and bornite are present, small prills of covellite are more often also chalcocite, sometimes covellite (in one case bornite) forms associations with malachite. Respectively, it reflects the ore base, instead of deliberate compositing of the furnace charge. It is not excluded that the quantity of the secondary sulfides in the charge was higher, but they at first turned into cuprite, and then were reduced to copper. It also provided the reducing smelting atmosphere. In several samples the content of chalcopyrite was higher that makes these slags similar to those of the 6th mineralogical group. However the oxidized minerals have been also identified in the same samples, and, in some cases, in one grain with chalcopyrite. Therefore these samples reflect a casual situation when a larger part of chalcopyrite got into the furnace charge, but it allows us neither to separate these samples into another group nor to include them into 6th group.

In the technological meaning these slags are close to those of the 1st mineralogical group, but some samples show much more high temperatures. Below, at the discussion of chemical analysis, it will be shown that for the fusion of slags of this group the temperatures within 1300-1400 °C were sometimes required, that is quite natural taking into account their acid composition.

3rd mineralogical group

Slags of this group (No. 486,491,499,528) have been found only on three sites of the Ayakagitma depression. The group is characterized by signs of two previous mineralogical groups. It influenced also the microstructure of this slag. Olivine (fayalite) crystallization in the slag took place worse than in slags of the 1st group. The contents of olivine vary from 9.2 to 41%, and, the crystals are presented by less developed forms (needles and skeletal prisms) (Fig. 12-I.4-6) are present more often, but there are also polygonal forms. A lot of magnetite (9.2-37%) presented by octahedra, crystallizing from the slag dendrites and small particles (Fig. 12-I.4-6) have been detected. Some of the particles are fused or molten. Therefore it is not excluded that at some stage of smelting owing to the reducing atmosphere they were wüstite, and then were oxidized to magnetite. Dendrites of the wüstite have been found too (Fig. 12-I.3). In some cases the octahedra of magnetite form large accumulations in which copper and cuprite are present. Thus, the ore was situated in the iron-rich rocks. Some octahedra of magnetite form a border round copper prills that reflects their crystallization from the slag.

Copper is presented by small prills (1-3.5%) (Fig. 12-I.6), cuprite (1.5-2.3%) is by prills and molten inclusions. The latter also replaces at the edges the grains of malachite which obviously was the main ore. Ore is connected with rare small grains of quartz.

Proceeding from said above, the slag of this group, in general, is close to the slag of the 1st group, but it contains more silicate component, as a result its viscosity was slightly higher, the olivine crystals grew worse and metal losses were slightly higher.

4th mineralogical group

Slags of this group are characterized by the oxidizing smelting atmosphere and many inclusions of cuprite.

Because of the oxidizing atmosphere the wüstite in the slag was not almost formed. Therefore fayalite is also almost absent. It is presented by small prismatic, long skeletal and needle crystals (Fig. 12-II.2), in many places, which had been especially enriched with cuprite, the crystallization did not happen. In some samples nuclei of the fayalite crystallization are recorded only. The contents of fayalite vary in the range of 1-5%, reaching 11.2% only in one sample.

Magnetite is presented in the form of small thin rash, small octahedra, grains replaced by hematite, in some cases by small dendrites (Fig. 12-II.1). Sometimes octahedra form accumulations that specify that they were formed disintegrating from grains of oxide iron. Some octahedra are slightly fused, there are even small accumulations of magnetite prills, but in general magnetite was not molten. Presence of the prills was probably caused by that in this concrete smelting (No. 583) at some stage a higher temperature was reached in conditions of the reducing atmosphere (prills of covellite and chalcocite have been detected in this sample), as a result wüstite formed, and then it was partially molten, and then was oxidized again to magnetite. Usually the contents of magnetite and iron components are absolutely small (within 1-2%). Only in one sample (No. 514) the general content of magnetite and hematite reaches 12-15%. Thus, in these slags the part of the iron components was very insignificant that also was one of the reasons interfering with the formation of fayalite slag.

Copper is presented by small prills (Fig. 12-II.1-3). Its contents in different samples vary from 1.5 to 5%, with the average value of 2.8%. Cuprite in the slag is presented better, in the form of prills, molten inclusions, accumulations of octahedra, and small dendrites (Fig. 12-II.1-4). Sometimes its small prills are set very densely and paint the glass matrix. Cuprite replace edges of malachite grains, forms borders round pores, besides, its molten inclusions have been found. The content of cuprite fluctuates from 4 to 15% with the average content of 9.3%. All this unambiguously indicates the mainly oxidizing smelting atmosphere. To the north, in Kazakhstan, crystallization of delafossite is rather characteristic of similar slag, but here it is absent. In some samples single small particles of iron are noted. Therefore, at some stages of smelting (possibly, at the end) it was possible to create the reducing atmosphere.

The ore is obviously connected with quartz rocks. Quartz is very well presented in slag of this group, and contains prills of copper, cuprite and malachite (Fig. 12-II.3,4). There is a lot of malachite; it is the main type of ore. Another oxidized mineral, azurite, is rarer presented. Secondary sulfides are present, but they are not so typical. These are prills of chalcocite and its border round the copper, and fused grains of covellite. Even rarer, in single cases the chalcopyrite and bornite grains are noted.

Thus, technologically this group differs from the above described groups by the much lesser contents of the sulfide minerals and iron-rich components though they are present in limited quantities. Judging from the molten cuprite, the temperature limits were close to the above described groups. Thus, in this case this group cannot indicate the existence of some other technological tradition, different from the tradition reflected in the 2nd mineralogical group. It might be explained also by an unsuccessful compositing of the furnace charge.

6th mineralogical group

The mineralogical group is connected with smelting of chalcopyrite. This mineral in different quantities is presented in all slags of this group. Certainly, it is present also in other groups, but here it was the main ore component, and the oxidized ores were either absent, or their content was absolutely insignificant. Chalcopyrite is presented by small or rather large grains. Some large grains show the porous structure, probably a result of separation of molten copper components. In these cases the grains of chalcopyrite can be replaced on the edge with wüstite.

The last mineral is presented in slag rather well (Fig. 12-II.6; Fig. 12-III.1). Sometimes it can be presented in the form of grains with lattice and porous structure (a result of separation of copper sulfide from chalcopyrite), often forms the large fused dendritic structures disintegrating from the lattice structures of wüstite or its crystallization. Wüstite and magnetite are present also in the form of skeletons, small sometimes fused particles, small dendrites, and rare prills. The molten wüstite inclusions are typical. The total content of wüstite and magnetite very much differs from 2.2 to 35%.

A leading component in this slag is fayalite. In some samples in reflected light it almost merges with glass matrix that complicates calculation of its contents. Its contents vary in the interval of 50-68%. Fayalite is presented by needle, long prismatic, long skeletal and polygonal forms (Fig. 12-II.6; Fig. 12-III.1). All this indicates a rather low rate of slag cooling and optimal composition of the furnace charge.

As a result, metal losses in the slag are very insignificant. Copper and cuprite are presented by small prills (Fig. 12-III.4). The content of copper fluctuates in the range of 0.1-2%, cuprite does in the range of 0-1.6%.

There are grains of quartz (Fig. 12-III.4) with which the ore is connected (small quartz grains are found in chalcopyrite, and copper inclusions in quartz). As it has been already spoken above, chalcopyrite was the main ore although in isolated cases malachite and fahlores are revealed. Presence of small prills and particles of reduced iron in these slags is very indicative too.

The relation of three samples to this group is questionable. First of all, it is sample 592 with molten cuprite and a grain of chalcopyrite, probably a result of incomplete smelting process. Samples 574 and 582 are presented by slag crusts on the furnace lining. Therefore they do not contain such indicative structures of wüstite as in other samples of this group. Fayalite is also presented much more badly. Besides, the samples have a zonal structure: 1. Porous ceramic glass in which crystallization did not occur. 2. The fayalite glass with weak crystallization, 3. Slag masses. Nevertheless, they contain chalcopyrite and it is noticeable that the small fused fragments of wüstite were formed from pieces of some other mineral. Therefore the relation of this slag to this group is more probable.

It is necessary to discuss the ceramic part of these slags separately, as some other slags of this group, as well as some slags of other groups, are fused with the furnace lining or sandstone. In reflected light it is possible to receive very limited information on this ceramic part of the slag. As a rule, in these slags several zones can be distinguished. The lowermost zone is presented by the porous ceramic masses and glass with inclusions of grains of quartz, occasionally with small fayalite crystallization (Fig. 12-II.5; Fig. 12-III.2). In the middle part of these ceramic crusts the glass matrix contains with small prisms of fayalite (Fig. 12-III.3), and above the copper prills (Fig. 12-III.4) and slag mass. The microstructure of the latter depends already on a mineralogical group of slag. It is obvious that crystallization of the lower part of this slag occurred faster. It could be caused as by tapping of this slag on a cold surface, as by shortage of iron components on contact with the ceramic mass of the furnace lining.

In general, in case with the 6th mineralogical group ones smelted chalcopyrite from quartz rocks. Other ores could get to the furnace charge as natural impurity. There is no evidence on deliberate additional fluxing. Smelting temperatures exceeded the melting point of wüstite, they reached 1400 °C. And, thanks to the smelting of sulfides, the reducing atmosphere was formed, and because of a significant quantity of iron components it was possible to form the fluid fayalite slag and to gain insignificant losses of metal. It is a quite standard technological scheme noted also on the Late Bronze Age sites in Northern Eurasia.

Ceramic slag

In the studied collection two samples of ceramic slag (No. 519, 532) from the sites of Lyavlyakan 26a and Ayakagitma 17 have been revealed. The porous silicate glass of these samples contains rare thin crystals of fayalite, occasionally fine quartz grains, and a small grain of chromite, a grain of magnetite and prills of copper. A small fragment of malachite is found in one of the samples, but there is no confidence that it testifies the ore smelting, because it can be a product of secondary mineralization. Therefore these samples can be connected both with metallurgy, and with metalworking. Besides, they can be only ceramic fragments of slag of the 3rd type. Therefore it makes no sense to focus attention on these samples.

At the analysis of nature of distribution of the mineralogical groups over sites it is necessary to take into account that these samples occur mostly from the eroded sites. Theoretically the area of any site could be visited repeatedly. Therefore it is more correct to compare materials from individual accumulations within framework of an individual site. If to look at the Tab. 12-2., it is evident that all mineralogical groups are present together with the others on the same sites and in the same accumulations. If any group is the single on the object, there is only one sample. An exception is the 2nd mineralogical group which is rather often presented by several samples on one object and in some instances is not accompanied by slag of other groups. But it is explained by a larger part of this mineralogical group, and also by that the ore in this area of the Kyzyl-Kum is connected, mainly, with quartz. Proceeding from this picture, at first sight, it is possible to draw a conclusion that this mineralogical group was the basic, and if more iron-rich ore was extracted on a deposit in quartz rock, the ore with the smaller content of sulfides or pure chalcopyrite, it resulted in the appearance of slags of other mineralogical groups, and it has purely arbitrary character. However it must be kept in mind that, at least, smelting of chalcopyrite is a bit different technological process.

Connection of individual mineralogical groups with certain periods is rather problematic too. The materials from the Kyzyl-Kum can be related to the so-called Early Bronze Age of this region and to the 'steppe' Late Bronze Age. However only in rare instances it is possible to reliable identify individual sites with a concrete period. So, some sites relate to the Early Bronze Age: Lyavlyakan 7, 94 with slag of the 2nd and 6th mineralogical groups, and some others to the Late Bronze Age: Lyavlyakan 120, 121 with slag of the 1st , 2nd , 4th and 6th groups, i.e., of all groups, except for the 3rd group. However in the entire collection only 5 samples are related to 3rd group, and on other sites they are present together with samples of the 1st , 2nd and 6th groups. This means that this group is not technological. It is connected with the presence of iron components in the furnace charge (ore from quartz rocks). A sampling from the sites with only materials of the Early Bronze Age is very insignificant: 4 samples. Therefore, taking into account their division into two groups it cannot be excluded that the absence of other mineralogical groups is caused by this small sampling.

The only useful conclusions which we can draw on this basis are the following:

1. In the Late Bronze Age in the Kyzyl-Kum there were the same types of smelting which are known in the steppe and forest-steppe belts of Northern Eurasia. And, the smelting of oxidized ores with the impurity of secondary sulfides from quartz rocks (60%) dominated. The part of slag of the 3rd and 4th mineralogical groups is absolutely insignificant, and can be considered as a casual composition of the furnace charge because of features of a concrete zone in the ore field. The part of slag from the iron-rich rocks is rather high (16%) and points probably to a deliberate choice of ore from more fusible rocks. At last, the existence of 10% of the slag smelted from chalcopyrite, and also technological features of smelting of this type, allow us to think that it was one more technological tradition.
2. Already in the period of the Early Bronze Age the smelting of chalcopyrite was practiced in the Kyzyl-Kum.

Unlike mineralogical groups, the types distinguished by form of the slag, rather reliably correspond to individual sites or accumulations. In the whole collection only two samples have been revealed which are met together with slag of other type (Tab. 12-3.). Thus, it already cannot be considered as a chance and has some real reasons. Also there is a positive correlation between these types and periods although the quantity of the dated samples is small: only slags of the 3rd type (slag crusts, fused with sandstone or lining) are connected with the listed above sites of the Early Bronze Age, and the shapeless slags of the 1st type are with the Late Bronze Age.

Correlation of forms and mineralogical groups of slag has been carried out (Tab. 12-4.). The slag crusts fused with sandstone and lining practically are not present among slags of the 1st mineralogical group. The thin curved slag plates reflecting the low slag viscosity are not numerous, but in general it is a rare type of slag. Together with the flat slag reflecting the low viscosity too, their total part is 46.25% that exceeds the part of more viscous shapeless slag. In principle, for the slag smelted from ore in rocks of the basic composition, it is quite expected result, but it is much lower, than in Sintashta metallurgy where the majority of slag of this mineralogical group forms the regular flat cakes. As this slag could be formed at lower temperature, the slagging of the lining did not occur that explains the lack of slag crusts in this mineralogical group.

Among slags of the 2nd and 4th mineralogical groups surely more viscous shapeless samples dominate that is also natural for the group smelted from ore in quartz rock. Slag crusts in the 2nd group are also present at noticeable quantity as this slag was more high-temperature.

The 3rd mineralogical group is insignificant therefore it is impossible to discuss any statistical regularity on its base. But the 6th group is very remarkable. It contains both shapeless and flat slags, however 2/3 of the samples are presented by slag crusts. Recognizing that this type of slag was characteristic of the Early Bronze Age metallurgy, and the 6th mineralogical group is recorded on sites of this time, it is possible to assume that in this time some special technology of smelting was practiced that was based on the smelting of mix of malachite and secondary sulfides from quartz rocks, but to a greater extend, on the smelting of chalcopyrite.

In this regard the slag crusts arouse a particular interest. As it has been already noted, these slags were melted of chalcopyrite or oxidized ores from quartz rocks.

It is not excluded that the analysis of fayalite contents in slags of different types can promote the solution of the problem. In all slags fayalite is presented by nuclei of crystallization, needle, dendritic, small prismatic, long prismatic and polygonal crystals. Their ratio can be very various and often depends on the presence of components necessary for their formation and the smelting atmosphere, but only the last two types of structures are an indicator of the low rate of slag solidification. In 8.5% of the slag crusts such crystals are present. They are better presented in the shapeless slags (37%) and in the shapeless flat slags (50%). Their maximal quantity is contained in a small group of thin slag plates (4th type) revealed on two Ayakagitma sites (62.5%).

Therefore the rate of solidification of the slag crusts was maximal, and that of the other types of slag it was significantly less. It was a reason of an earlier supposition that these slags cooled down quicker because it was poured out from a crucible (Grigoriev, 1996). But the degree of crystallization depends not only on the rate of slag cooling, but also on its chemical composition. Therefore it is necessary to discuss several chemical analyses.

Chemical analysis

In the table of chemical analysis (Tab. 12-5.) we see a slightly higher content of Al_2O_3 in samples No. 567 and 580 whose forms relate to the 3rd type, i.e., to the slag crusts. Respectively, the share of clay of the furnace lining in the analyzed samples was slightly higher than in the others. It is hard to say about the reason of the high contents of CaO in samples 483 and 588: whether it is explained by the use of special fluxes or specifics of ore. It is impossible to answer this question as we have no series of ore's analyses. The analysis has also shown insignificant losses of copper in the slag (usually from 0.19 to 2.44% including cuprite and other ore remains). They are higher only in sample 580. Despite the additions of sulfide ores in smelting, and the presence of chalcopyrite in one of the analyzed samples, the content of sulfur in slag is very low. It burned out during the smelting.

Taking into account the considered problem calculations of coefficients of basicity are more important for us (Tab. 12-6.). As one would expect, the flat slag (sample 483) smelted from chalcopyrite belongs to the basic group. Therefore fayalite crystallized well in it. Samples 588 and 590 presented by shapeless slag demonstrate the average coefficient. Respectively, the crystallization of fayalite took place in them worse. And samples 567 and 580 have been related to the acid and ultra-acid groups; they are slag crusts fused with the lining. Their mineralogy relates to the 2nd group. Therefore the weak crystallization in this case could be caused not so much by special conditions promoting a faster cooling as by the chemical composition.

It is also rather obvious at calculation of slag viscosity (Tab. 12-7.). The minimal viscosity is demonstrated by the slag of the 2nd type, the 6th mineralogical group (sample 483). Slag crusts of the 2nd mineralogical group fused with the furnace lining have the maximal viscosity. Owing to their high viscosity it seems to be doubtful that these slags were tapped. More probably, they were formed on the bottom and walls of the furnace. More often it is the case with the slag smelted of chalcopyrite, which is explained probably by higher temperatures, larger duration of smelting process, and respectively, by more active contacts of the slag with the furnace bottom and the gradual destruction of the lining. But slags of 2nd mineralogical group also often contain inclusions of sulfide minerals providing higher temperature in conditions of possibility to keep the reducing atmosphere.

Chemical analyses allow us to determine the temperatures which were necessary for fusion of slag of this composition (Fig. 12-8.). They are the highest (about 1400 °C) for samples 567 and 580. These are slag crusts of the 2nd mineralogical group contacted with the lining. But, as it has been already discussed, they contain also the unmolten lining, the reached temperatures were probably slightly lower. Shapeless slag of the 6th mineralogical group smelted from chalcopyrite (sample 483) can be molten at the temperature of about 1300 °C. Smelting temperature of two other samples is below 1200 °C. These are the samples of heavy shapeless slag smelted from ore mix with oxides and sulfides including chalcopyrite from quartz rock (590), and sample 588 in which iron oxides are better presented.

But it must be kept in mind that the quantity of the analyses is low. Besides, the lower part of the slags containing ceramic parts got also to the analyzed mass. It inevitably affected the result of the bulk analysis. Therefore on the basis of these limited chemical analyses it is difficult to judge about the specifics of formation of these slags.

Slags from other places in the south of Central Asia

Two samples of slag from Margiana have been investigated too. The first (sample 2032) occurs from the Kelleli settlement. It is a small fragment of slag. Its lower part is more porous, and fused with the loam. The top part is the typical slag mass; it contains inclusions of oxidized copper and cuprite. The bottom surface of the slag is curved, and the top is on the contrary concave. Thus, the slag has the cup-shaped form and probably was formed on of the furnace bottom or in a shallow depression beyond it.

The ore was obviously connected with quartz. There are small prisms and long needles of fayalite in the slag (Fig. 12-II.1,2), but the quantity of these crystals is insignificant. The fayalite crystallization happened obviously quickly enough. Magnetite grains, small copper prills are rarely present, but dendrites, grains and small prills of cuprite are more typical. Occasionally there are needles of delafossite, some of them are bent. All this unambiguously indicates the oxidizing atmosphere of the smelting. However malachite is accompanied by well-presented covellite, but it did not result in the formation of the reducing atmosphere. Thus, the slag belongs to the 3rd type and to the 4th mineralogical group.

Similar slag, both in the form and microstructure, has been found in the late layer of Dashli-3. Near it a furnace consisted of two parts, a casting mould for axe-adze, and drops of metal have been found. But the most important find is a crucible with a massive handle filled with caked malachite (Sarianidi 1977, p. 71; Sarianidi *et al.* 1977, p. 35, 36). The slag has the same zonal structure. One its surface has a lot of cuprite inclusions, and fayalite crystallization took place very poorly.

The presence of the crucible near this slag allows us to reconstruct allegedly the smelting process as follows. The smelting was done in the crucible. After its completion the slag accumulating on the surface was poured out forming (depending on its fluidity) the slag crusts or shapeless slags fused with the sandstone or loam.

Slag of similar form has been found on the settlement of Khopuz-Depe (Terekhova 1980, p. 141-144). This technology provided very high temperatures, and, the slag cooled down quickly enough. The partial oxidization with the formation of cuprite could occur at the time when the slag was poured out.

But it should be kept in mind that the fact of presence of the sandstone or ceramic crust does not allow us to consider all these slags as a result of crucible smelting with the slag tapping. In some such slags the fayalite crystallized very well; therefore they could not be tapped or poured-out, and were obviously formed in the furnace and the slag was fused with the lining of walls or bottom. Therefore, conceding the existence of this technology we are not able to determine now its real part and in which concrete samples it is reflected.

Spectral analysis

In the total 92 samples of slag and 6 samples of ores have been investigated by the spectral analysis (Tab. 12-9.). Frequency diagrams of distribution of trace-elements have demonstrated irregularity of the studied collection (Fig. 12-10.1). Above all the displacement of tops in the diagrams of cobalt, chrome, vanadium, lead, silver, and arsenic and the bimodal diagram of zinc and antimony are noteworthy. Comparison of diagrams of individual groups (Ayakagitma, Lyavlyakan and Besh-Bulak) has allowed essential distinctions (Fig. 12-10.2-4) between them to be revealed. The samples from Besh-Bulak differ by the lower concentration of the majority of trace-elements, except for chrome, vanadium and molybdenum whose concentrations are higher. Samples from the Lyavlyakan sites differ by relatively higher concentrations of zinc and cobalt, and samples from the Ayakagitma depression have higher concentrations of lead, zinc, and antimony. This picture testifies the use by the people in each depression of own ore base that is quite natural in view of the fact that the copper ores and ancient mines have been found in all these areas (Vinogradov A. *et al.* 1971, p. 509; Vinogradov A. 1981, p. 20).

However the materials of individual depressions are not monotonous from the geochemical point of view. Their statistical processing allowed the use of various ore sources to be revealed.

Trace-elements in slag of the Ayakagitma sites are most irregularly distributed. Some diagrams are bimodal. These are such trace-elements as zinc, lead, arsenic, antimony, molybdenum, and vanadium. Tops of diagrams of other elements are displaced. Correlation diagrams have demonstrated the heterogeneity of the Ayakagitma series rather clearly. Already the analysis of Co-Zn ratio distinguished in the collection the group A-1 that is characterized by higher concentration of zinc. The same picture is seen also on the diagram of As-Sb where this group differs by the higher concentrations of antimony and arsenic (Fig. 12-11.1). The clearly bimodal diagrams of these trace-elements, at first sight, can testify to the artificial alloying at the stage of ore smelting as it took place on Sintashta sites in the Southern Transurals. However the connection of these higher concentrations with one chemical group which, besides, is characterized by higher contents of lead and zinc forces us to assume another reason. Probably we deal with a complex field which in addition to the main copper ores includes fahlores (tennantite, tetrahedrite and so on), and also galenite and sphalerite. This complex character is, as a whole, characteristic of Central Asia (Vakturskaya *et al.* 1968, p. 124; Ruzanov 1980, p. 56-58; 1988; Sarianidi *et al.* 1977, p. 37, 38). In this case it is impossible to reliable answer this question in view of the small quantity of analyzed ore, small quantity of slag of this group, and by that the most material have been gathered on the surface.

The diagram of Cr-Pb has distinguished two more groups: A-2 (with the low content of chrome) and A-3 (with the average content of chrome) (Fig. 12-11.2).

Samples of the A-2 group differ, besides, by the low concentrations of vanadium and molybdenum. One sample has not been included in any of the distinguished groups. It is characterized by the average values of lead and zinc and high concentrations of chrome and cobalt. The higher contents of antimony and arsenic make it similar with the A-1 group. This sample occurs from the site of Ayakagitma 95B. Other chemical groups are distributed over the site as follows: A-1 group: the sites of Ayakagitma 10, 17, 187, 209; A-2 group: the site of Ayakagitma 234; A-3 group: the sites of Ayakagitma 10 (two samples), 224, 239.

The situation on the Lyavlyakan sites is more complicated. Diagrams of silver and lead are bimodal, and the top of the diagram of cobalt is displaced to the left (Fig. 12-10.3). It has made possible to distinguish on the correlation diagrams the samples with higher contents of these trace-elements from the samples with the low contents. This division is not very accurate. There are samples with average contents. In general, the geochemistry of mines used by Lyavlyakan metallurgists is very similar. Therefore the division here is very relative. Materials of the sites of 7, 120, 131, and 322 characterized by the low contents of the discussed elements are quite similar.

Materials of the sites of 40 and 121 are comparable too. Two samples from the site 120 are also close to this group. They are characterized also by slightly higher contents of antimony and arsenic. Some samples from the sites of 26, 120, and 121 take an intermediate position. Samples of the site 338 contain a small quantity of arsenic and rather high concentrations of silver and cobalt. At last, a sample from the site 94 differs by the very high content of lead and the low content of cobalt. Only for the last samples it is possible to speak about an individual ore source. The main mass of ore originated either from close mines with very similar geochemistry, or even from one field but from its various zones.

Materials from the Besh-Bulak sites demonstrate the greatest uniformity. But, after the closer examination, the asymmetry of some diagrams attracts attention (Fig. 12-10.2). After the analysis of ratio of individual trace-elements, due to the low content of silver and higher contents of cobalt and nickel, from the main body of samples (B-1) the B-2 group has been distinguished including all materials of the site of Besh-Bulak 2. This connection of the group with the single site indicates a separate ore source.

All materials of the Besh-Bulak sites are characterized by the low contents of such elements as antimony and arsenic. Smelting of these ores produced chemically pure copper. Unlike the Besh-Bulak ores, many ores of Ayakagitma and Lyavlyakan contain these impurities in higher concentrations. However, as it has been already noted, the higher concentrations of antimony and arsenic are connected probably with characteristics of the used ore material. Tin in all samples is present in the insignificant concentrations, no more than 0.0015%.

A comparison of the chemical and mineralogical groups of slag has been also done (Tab. 12-12.). It has obviously demonstrated that the distinct correlation of these groups is absent. Some connections between the groups can be outlined only in cases if the quantity of samples in any group is insignificant, i.e. they have an accidental character. Respectively, at this stage for the situation in the Kyzyl-Kum we can assume that these chemical groups have mostly the territorial character; they were not caused by the character of ore. However because of the insignificance of the collection this conclusion cannot be considered as unconditional too.

Sorting of data of individual trace-elements has also demonstrated that in slag of different mineralogical groups the basic elements are distributed randomly: their contents can be high or absolutely insignificant.

The content of arsenic is of special interest as the presence of the 1st mineralogical group in the Kyzyl-Kum allows us to suppose also the existence of that stage of metallurgical production when the fusible ore from ultrabasic rocks was used and the alloying with arsenic was carried out at the stage of ore smelting which has been found in Sintashta culture. If to be based on the already discussed threshold of the 0.01% arsenic content in slag which indicates the arsenic bronzes, 60 from 88 analyzed samples (68.2%) is below this threshold, and 28 (31.8%) reach this value or contain higher concentrations of arsenic. But taking into account that in the last group four samples belong to the 6th mineralogical group which was smelted of chalcopyrite, it is more logical to assume the connection of arsenic with sulfide ores. Besides, this mineralogical group is high-temperature, and arsenic could not remain in metal. Only five samples of the more fusible 1st mineralogical group show the higher arsenic concentration. However the threshold of 0.01% taken here is the lowest for the chemical-metallurgical group TK and respectively for the slags reflecting the artificial alloying. A higher threshold of 0.03% is demonstrated by only 12 samples from which only three belong to the 1st mineralogical group. Respectively, the technology of alloying of arsenical minerals with copper ore at the stage of its smelting either did not exist here, or it was very limited. In isolated cases it can be assumed, but an assumption that it is a statistical dispersion is more lawful. At this stage this problem has no solution.

There is no opportunity to speak also about the deliberate producing of antimony-arsenic bronzes as it took place sometimes in the north. The correlation diagram of As-Sb (Fig. 12-13.) shows that the overwhelming quantity of slags shows the low contents of these elements. Only in single samples it is higher, but even in them the interdependence in the contents of these elements is absent. Therefore it is a question of casual contents.

Problem of dating of the slag

Connection of the revealed slag groups with certain chronological periods is a serious problem. And, it is possible to lean only on the Lyavlyakan materials published most fully.

Here the most mass ceramic material (apart from the Neolithic ceramics) are materials of the Early Bronze Age (32 sites). Extremely seldom the ceramics of the Early Iron Age and the Middle Ages is present. The last types of ware can be also met on sites with slags; however it is impossible to connect with them the metallurgical production. Traces of copper casting and ironworks have been found in the Amu-Darya delta on sites of the Kuyusay culture of the Early Iron Age, but, apparently, as for the copper metallurgy, it is the traces of the metalworking only (Vainberg 1979, p. 7, 12, 24). In the Kyzyl-Kum by this time the desert landscape finally formed that complicated the providing of smelting operations with fuel. Besides, economically it was senseless as the production centers located in the area of civilizations of Central Asia gain strength (Buryakov 1974).

Rare finds of ceramics of the Early Iron Age and the Middle Ages in the Kyzyl-Kum are caused apparently by that there passed the caravan ways served by nomads. They did not change from the Bronze Age to the 19th century (Vakturskaya *et al.* 1968, p. 334; Novozhenov 1994, p. 89).

Thus, the metallurgical remains in this region can be dated to the Early and Late Bronze Age only. The absence of the Middle Bronze Age in this is explained by the use of different schemes of periodization which is caused by the contact characteristic of the region. And, there are no doubts concerning a possibility of production during the Early Bronze Age. Despite the begun processes of aridization the climatic changes, apparently, did not result yet in the landscape desertification. Besides, the casting workshop of this time (Lyavlyakan 506) has been found, and one vessel contained a small inclusion of copper that proves its use as a crucible (Vinogradov A. Mamedov 1975, p. 228).

In the Besh-Bulak area metallurgical production is dated to both the Early Bronze Age and the Late Bronze Age (Vinogradov A. *et al.* 1972, p. 509). Apparently during the 2nd millennium BC the processes of desertification were not so prompt. In any case, on the Upper Zerafshan the climate in the second half of the 2nd millennium BC was more humid and cool than now (Isakov, Potyomkina 1989; Spiridonova 1989).

However it is impossible to date reliably individual slags, and even the production on individual sites. As it has been already discussed earlier the correlation of presence of different mineralogical groups of slag gives no possibility to connect any of them with a concrete epoch reliably. Contrary to it, the same procedure made for types of slag distinguished by their form has allowed us to assume that the local Early Bronze Age production is characterized by the slag crusts fused with lining, and other types are connected with sites of the ‘steppe Bronze Age’. But it is necessary to understand that it is only possible tendency which cannot be considered as an unambiguous result. This tendency does not correspond to the conclusion of A.V. Vinogradov and E.D. Mamedov about the Early Bronze Age belonging of the Lyavlyakan production (Vinogradov A. Mamedov 1975, p. 228). But insignificance of the Late Bronze Age collection in comparison with of the Early Bronze Age proves nothing in the dating of metallurgical complexes.

If to recognize that other types of slag are dated to the Late Bronze Age, the Late Bronze Age metallurgy in the Besh-Bulak area is presented much more widely than in Lyavlyakan. It corresponds to the opinions of some scholars (Vinogradov A. *et al.* 1972, p. 509; Itina 1977, p. 42, 43, 136). It is worthy of attention that a lot of slag crusts are found on the site of Besh-Bulak 1 where the Early Bronze Age materials are presented very well (Vinogradov 1981, p. 101).

Probably, slags of different types can be dated to different periods, but the slag crusts are more characteristic of the Early Bronze Age. Partly it was connected with the use of sulfide ores.

Main stages in development of metallurgical production in the south of Central Asia

Most early the metallurgical production appeared in the south of Central Asia in the Eneolithic (Anau culture). This production was closely connected with cultures of the Near East and especially with Iranian cultures. Apparently, there was initially only metalworking (Kuzmina, 1966, p. 86-87), but some scholars assume a possibility of the beginning of ore smelting (Saiko, Terekhova 1981, p. 102). Nevertheless, now it is not absolutely clear with which production the finds of metallurgical slags from Ilginli-Depe and Geoksyur (layers of the Namazga III period) were connected (Kuzmina 1966, p. 87).

More confidently it is possible to speak about the metallurgical production in the south of Central Asia only since the beginning of the Bronze Age, the period of Namazga IV. Earlier the following dating of archaeological complexes in Central Asia was accepted: the period of Namazga IV — 2800–2400 (2300) BC, the Middle Bronze Age, Namazga V — 2300-1800 BC, the Late Bronze Age, Namazga VI — 1800-1000 BC. The calibrated radiocarbon dates are different: Namazga IV – the first half of the 3rd millennium BC; Namazga V — the second half of the 3rd millennium BC, Namazga VI — the late 3rd – the mid-2nd millennium BC. Zamanbaba culture is dated to the mid-3rd millennium BC (Kutimov 2009, p. 9, 12).

There are well documented finds connected with ore smelting of the Namazga IV period. These are finds of tools for ore crushing from Altyn-Depe (Kircho 1983, p. 74) and metallurgical slags from Khopuz-Depe (Terekhova 1980). The metalworking of this period is characterized by arsenic alloys. As well as the evidence on crucible smelting here (unfortunately, confirmed by a single analysis only) it allows us to connect this metallurgical tradition with Iran that fully corresponds also to the accepted ideas about cultural genesis in this area. During the Eneolithic in Iran ones produced arsenic copper, and, the smelting was carried out in crucibles. But already in the late 4th – early 3rd millennium BC more active use of sulfides begins, and we see a transition to smelting in the furnaces and normal metallurgical slags occur (Pigott 2004a, p. 312; Thornton 2009, p. 309-218; Thornton *et al.* 2009, p. 314). But this transition was not probably momentary. In the Early Bronze Age layers of the settlement of Shahr-I-Sokhta dated to 2700-2500 BC, the smelting in crucibles of mix of the oxidized and sulfide ores has been reconstructed. It is indicative that chalcopyrite was also used here in the smelting, but as an impurity only (Hauptmann *et al.* 2003, p. 197-200, 205-208). This technology of crucible smelting of originally native copper and then the ores got from Iran to Pakistan and into North-Western India. On the settlement of Merghar in Pakistan slagged crucibles have been found, and in the north-west of Rajasthan about 1000 bronze and copper artifacts are known (Babu 2003, p. 174, 175).

To the north and north-east from the Southern Turkmenistan during this period the Neolithic Kelteminar tribes lived. With intensification of aridization in the second half of the 3rd BC considerable qualitative changes begun here. The Kelteminar culture is succeeded by a series of cultures of the Early Bronze Age. It is the Suyargan culture on the lower Amu-Darya River. Despite the difference in estimation of this culture all scholars share a common position: the Suyargan culture formed on the basis of the late Kelteminar under an influence of the southern impulses from North-Eastern Iran (Itina 1977, p. 40; Tolstov, Itina 1960, p. 14-21; Central Asia 1966, p. 214).

In addition the Zaman-Baba culture on the Zerafshan belongs to this time (Central Asia 1966, p. 206). It is believed that the local Neolithic culture with very strong southern influence was a basis for its formation. Especially it is visible in borrowings of forms of metal artifacts from Southern Turkmenistan. And, it was the local production including the ore smelting. In opinion of some scholars it can be confirmed by lack of alloys and a typical set of trace-elements (Kuzmina 1966, p. 89, 90).

At last, in the Kyzyl-Kum Desert the Early Bronze Age culture arose different from both Suyargan and Zaman-Baba, that has obtain no name yet. Most widely it is presented in the Lyavlyakan area. On the site of Lyavlyakan 506 the materials of this culture are accompanied by casting moulds for an axe-adze and axe-hammer having broad analogies not only in the south of Central Asia, but also in the Balkan Peninsula. However if on the Balkans similar axes are dated to the 5th – 4th millennia BC, in Iran the same articles have been found in layers of the late 3rd – early 2nd millennium BC (Chernykh 1978a, p. 89, 96; Vinogradov A., Kuzmina 1970, p. 125-133). Therefore it is not excluded that this culture was formed a little later than Zaman-Baba, about the late 3rd millennium BC. A similar axe-adze is found in the Zerafshan mountains (Kuzmina 1966, p. 14). It was made of pure copper that demonstrates some isolation of this center of production of these axes from the southern metallurgical centers which used arsenic alloys.

But it is necessary to remember that the discussed sites are investigated very poorly. There is no confidence also in their full belonging to the same time span or relative cultures. It is obvious that they are dated to the interval between Kelteminar and the penetration of steppe tribes. Metallurgical production appearing here was based not only on the oxidized ores, but also on the use of sulfides including chalcopyrite. Above we have already repeatedly discussed that this technological tradition had the southern roots.

At last, the last zone which should be mentioned, Northern Bactria, the south of Uzbekistan and the Murghab oasis where in the late 3rd – early 2nd millennium BC a Bactro-Margianan archaeological complex (BMAC) arose, and the discussed above site of Dashli-3 belongs to it. The formation of the BMAC resulted from impulses from the Syro-Anatolian area (Sarianidi 1989, 1993).

Unfortunately, all ideas about technology of ore smelting are based on a single slag sample and a single crucible. On this basis it is possible to assume the crucible smelting of oxidized ores, but it is impossible to be sure that some other technologies and other ore bases were absent.

There is no evidence data on furnaces of this period. Small round hearths with slagged walls are found in Sapalli. One of them was divided by a partition (Askarov 1977, p. 123). On Dashli-3 in Bactria a furnace consisting of two parts has been excavated (Sarianidi 1977, p. 71). In the Kyzyl-Kum evidences on furnaces of this time are absent. But the slagged walls of the furnace in Sapalli demonstrate the ore smelting directly in the furnace. Unfortunately, the information is very limited.

It is extremely important that in Central Asia in the second half or in the late 3rd millennium the smelting of chalcopyrite was known that we also see after this time in the north.

Thus, along with processes of spreading of the southern metalworking over the south of Central Asia already noted by E.E. Kuzmina (Kuzmina 1966, p. 86-90) we see that during the whole 3rd millennium BC the technology of metallurgical production was distributed in the northerly and easterly directions. It is possible to distinguish probably two impulses occurred at different times: at the beginning of this millennium (or earlier) and in its second half.

A new stage of metallurgical history of Central Asia begins since the mid-2nd millennium BC. In this period steppe tribes penetrated to the south of Central Asia. In the south of the Aral and the South-Eastern Caspian areas the bearers of the Tazabagyab culture came from Western Kazakhstan that was a synthesis of the Timber-Grave culture and a western variant of the Alakul culture (Vinogradov A. *et al.* 1986, p. 188; Itina 1962; 1967; 1977, p. 39; Kuzmina 1964, p. 147; Anthropological types 1988, p. 114). Most likely, the local Suyargan people took part in its formation too (Tolstov, Itina 1960, p. 22, 23). This culture moved ahead along the Amu-Darya River penetrating also into the Kyzyl-Kum (Vinogradov A. Mamedov 1975, p. 229). Therefore it is not excluded that a part of the late slags found here can belong to it.

In addition to this, from areas of Central and Southern Kazakhstan the Alakul and Fyodorovka peoples moved to the south (Isakov, Potyomkina 1989, p. 165; Sarianidi 1975; Central Asia, 1966, p. 227). At this stage these migrations to the south were yet not as large as in the Final Bronze Age (Isakov, Potyomkina 1989, p. 165), but the materials of these cultures are present in the Kyzyl-Kum.

New migrations were connected with cultures of the Final Bronze Age. On the basis of these processes in different time some new cultures formed in the south of Central Asia: Kayrakkum in Ferghana, Burgulyuk in the Tashkent oasis, Amirabad, Chust, and Yaz I (Askarov 1979, p. 34-36; Sagdullaev 1985, p. 50-59; 1989, p. 30; Saltovskaya 1978, p. 95, 96; Sarianidi 1972, p. 22; Ruzanov 1980, p. 55-58).

Since this time the south of Central Asia was included into the Eurasian Metallurgical Province with the Eurasian complex of metal (Kuzmina 1966, p. 90-94; Kozhamberdyev, Kuzmina 1980, p. 144-152; Ryndina *et al.* 1980, p. 154-158). The production was based on local ores. The steppe cultures introduced also their technologies of ore smelting. We see here the same mineralogical groups of slag as in the north. But the Sintashta technology did not obviously penetrate: there is no tradition of alloys with arsenic at the stage of ore smelting. Smelting of the oxidized ore or its mix with sulfides mined on deposits in quartz rocks dominated. It is the tradition of Alakul culture. The Fyodorovka tradition of chalcopyrite smelting was not so widely distributed. However in the latter case it is not excluded that it was either preservation or development of the former local tradition.

Thus, the history of metallurgical production in the south of Central Asia is characterized by two processes. The first one was connected with the period of its inclusion into the Irano-Afghan Metallurgical Province in the late 5th – mid-2nd millennia BC, after the spreading of the Iranian complex of copper and bronze artifacts and ore smelting (Chernykh 1978; Kuzmina 1960, p. 86-90). The second process was caused by the penetration of steppe (Timber-Grave and Andronovo) tribes to the south, that caused the expansion to the south of the territory of the Eurasian Metallurgical Province with its set of metal artifacts (Chernykh 1978; Kuzmina 1960, p. 90-94).

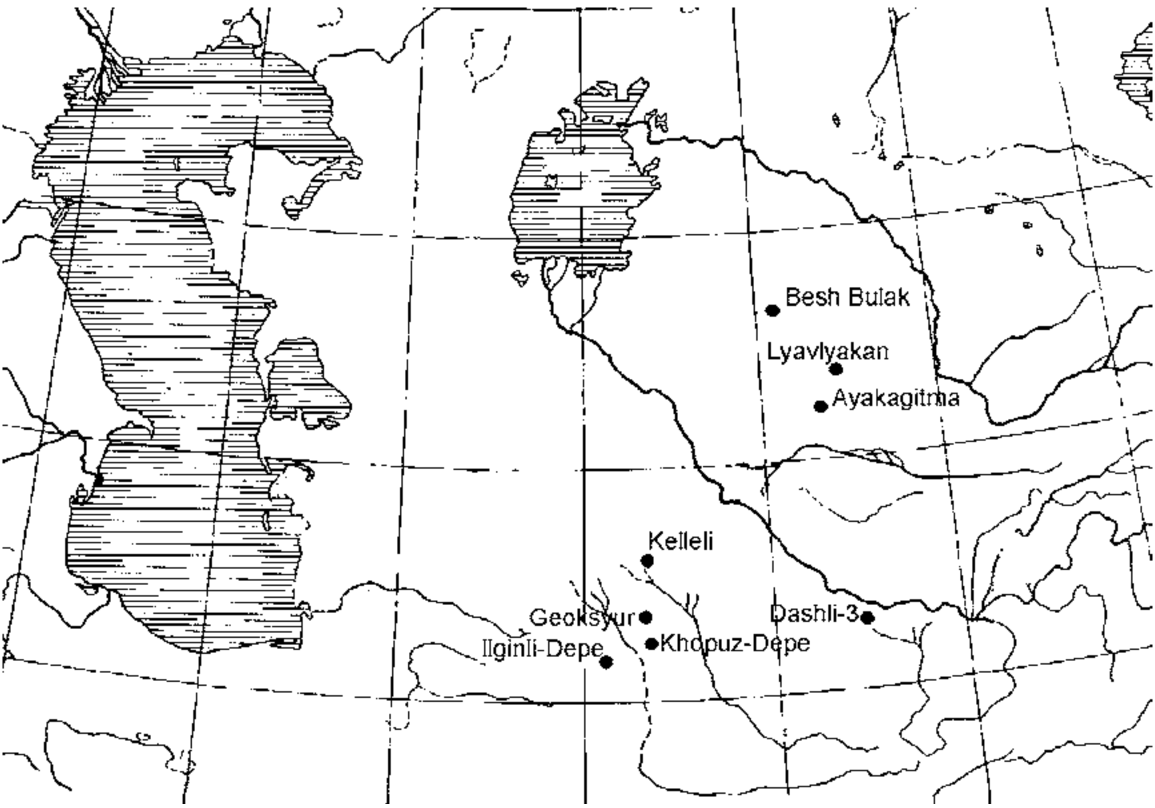
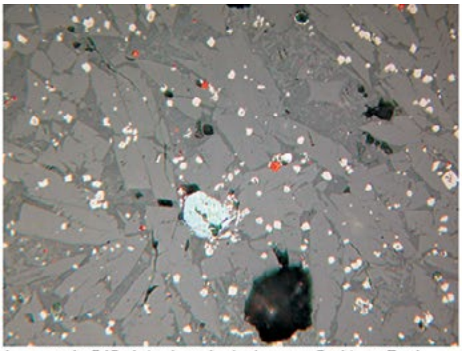
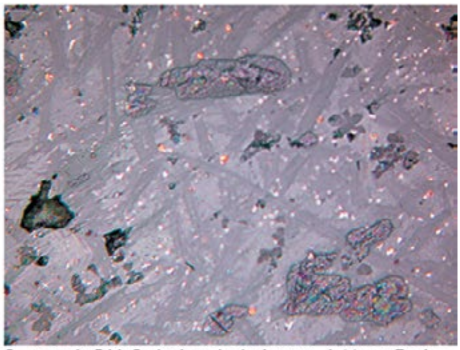


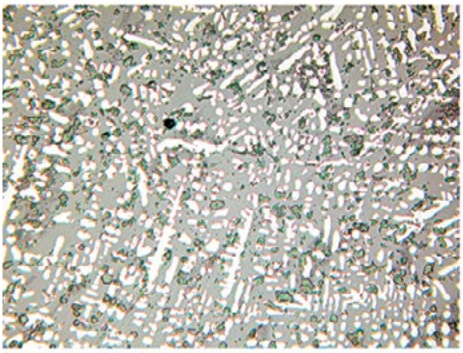
FIG. 12-1. MAP OF SITES IN THE SOUTH OF CENTRAL ASIA MENTIONED IN THE TEXT.



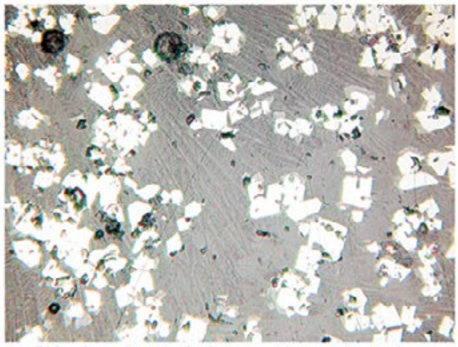
1 – sample 540, 1st mineralogical group, 2nd type Besh-Bulak 3: prismatic crystals of olivine (grey) in the glass matrix (dark grey), small needles and nuclei of olivine crystallization; octahedra of magnetite, small copper prills, fused grain of covellite (blue) and pores (black).



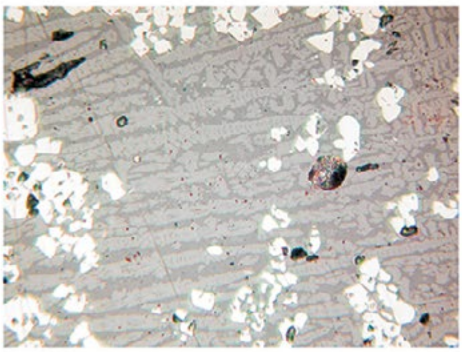
2 – sample 544, 2nd mineralogical group, 1st type, Besh-Bulak 3: long prismatic crystals of olivine (dark grey) in the light glass matrix, particles of magnetite (white) and copper prills.



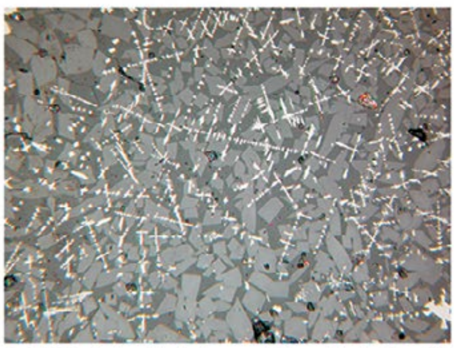
3 – sample 486a, 3rd mineralogical group, 2nd type, Ayakagitma 234: dendrites of wüstite.



4 – 528a, 3rd mineralogical group, 4th type, Ayakagitma 209: octahedra of magnetite and small needles of olivine.

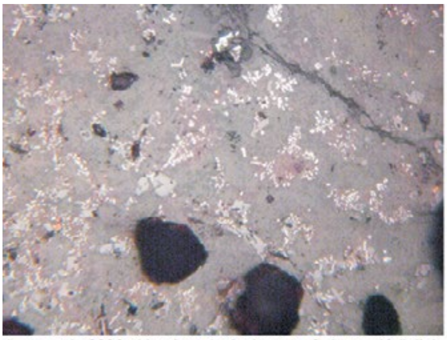


5 – 528, 3rd mineralogical group, 4th type, Ayakagitma 209: long skeletal crystals of olivine and octahedra of magnetite.

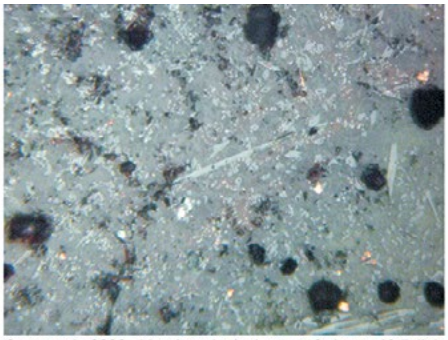


6 – 528, 3rd mineralogical group, 4th type, Ayakagitma 209: dendrites of magnetite, small prisms of olivine and prills of copper.

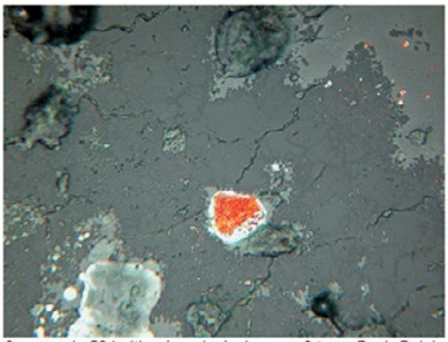
Fig. 12-I. Microstructures of slag from the Kyzyl-Kum (length of the photos is 0.54 mm): 1 – sample 540, 1st mineralogical group, 2nd type Besh-Bulak 3: prismatic crystals of olivine (grey) in the glass matrix (dark grey), small needles and nuclei of olivine crystallization; octahedra of magnetite, small copper prills, fused grain of covellite (blue) and pores (black). 2 – sample 544, 2nd mineralogical group, 1st type, Besh-Bulak 3: long prismatic crystals of olivine (dark grey) in the light glass matrix, particles of magnetite (white) and copper prills. 3 – sample 486a, 3rd mineralogical group, 2nd type, Ayakagitma 234: dendrites of wüstite. 4 – 528a, 3rd mineralogical group, 4th type, Ayakagitma 209: octahedra of magnetite and small needles of olivine. 5 – 528, 3rd mineralogical group, 4th type, Ayakagitma 209: long skeletal crystals of olivine and octahedra of magnetite. 6 – 528, 3rd mineralogical group, 4th type, Ayakagitma 209: dendrites of magnetite, small prisms of olivine and prills of copper.



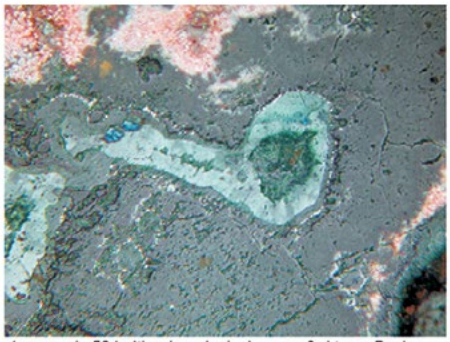
1 – sample 2032, 4th mineralogical group, 3rd type, Kelleli 4: small octahedra of magnetite (grey), prills of copper and dendrites of cuprite (red fields with white inclusions).



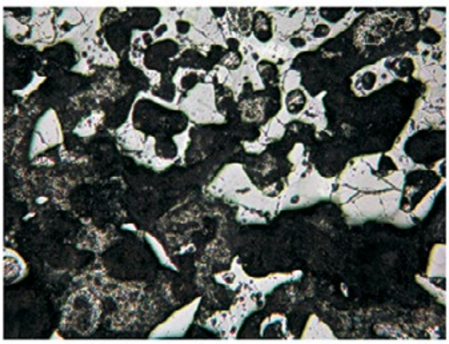
2 – sample 2032, 4th mineralogical group, 3rd type, Kelleli 4: long needles of olivine, small dendrites of cuprite (red fields), small grain and a prill of cuprite (white with blue tint), copper prills.



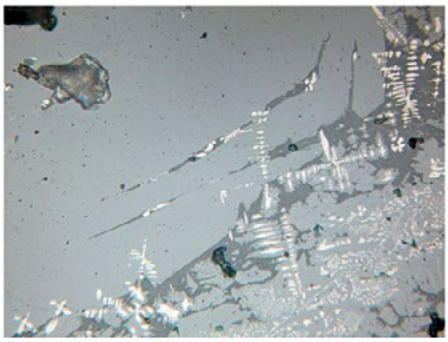
3 – sample 584, 4th mineralogical group, 3 type, Besh-Bulak 1, area 8: grain of copper surrounded with cuprite in the melting quartz grain (dark grey), in the upper right corner – small copper prills in the glass matrix.



4 – sample 584, 4th mineralogical group, 3rd type, Besh-Bulak 1, area 8: malachite and cuprite in the quartz rock.

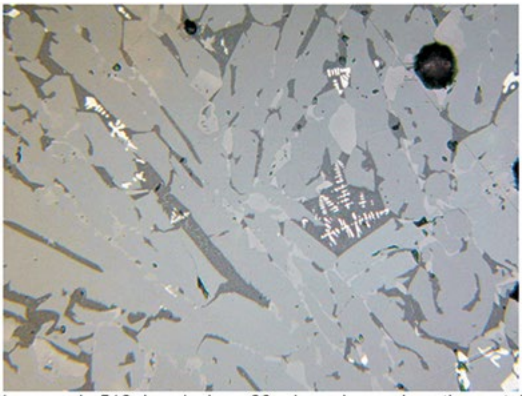


5 – sample 511, 6th mineralogical group, 3rd type, Lyavlyakan, 26: porous lower part of slagged ceramic crust.

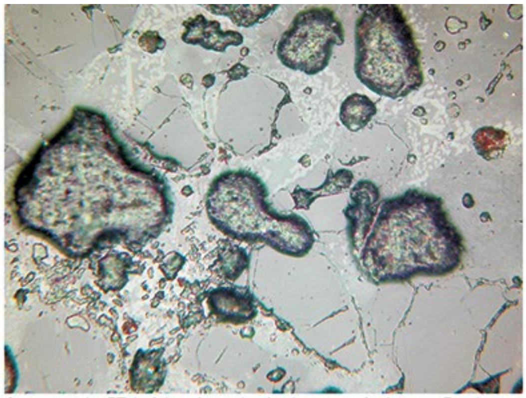


6 – sample 518, 6th mineralogical group, 3rd type, Lyavlyakan 26: large polygonal and smaller prismatic crystals of olivine (dark grey) formed after crystallization of dendrites of wüstite (white), small pores (black).

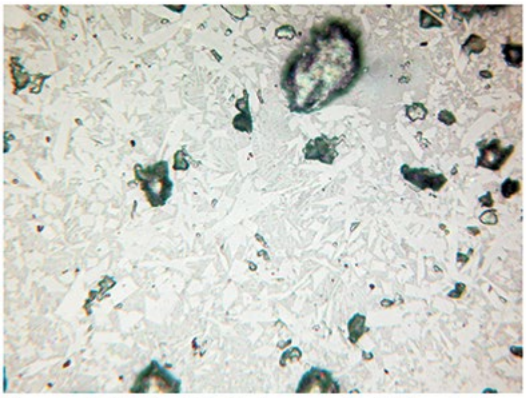
Fig. 12-II. Microstructures of slag from the Kyzyl-Kum (length of the photos is: 1,2 – 0.46 mm, 3-5 – 0.54 mm, 6 – 0.62 mm): 1 – sample 2032, 4th mineralogical group, 3rd type, Kelleli 4: small octahedra of magnetite (grey), prills of copper and dendrites of cuprite (red fields with white inclusions). 2 – sample 2032, 4th mineralogical group, 3rd type, Kelleli 4: long needles of olivine, small dendrites of cuprite (red fields), small grain and a prill of cuprite (white with blue tint), copper prills. 3 – sample 584, 4th mineralogical group, 3 type, Besh-Bulak 1, area 8: grain of copper surrounded with cuprite in the melting quartz grain (dark grey), in the upper right corner – small copper prills in the glass matrix. 4 – sample 584, 4th mineralogical group, 3rd type, Besh-Bulak 1, area 8: malachite and cuprite in the quartz rock. 5 – sample 511, 6th mineralogical group, 3rd type, Lyavlyakan, 26: porous lower part of slagged ceramic crust. 6 – sample 518, 6th mineralogical group, 3rd type, Lyavlyakan, 26: large polygonal and smaller prismatic crystals of olivine (dark grey) formed after crystallization of dendrites of wüstite (white), small pores (black).



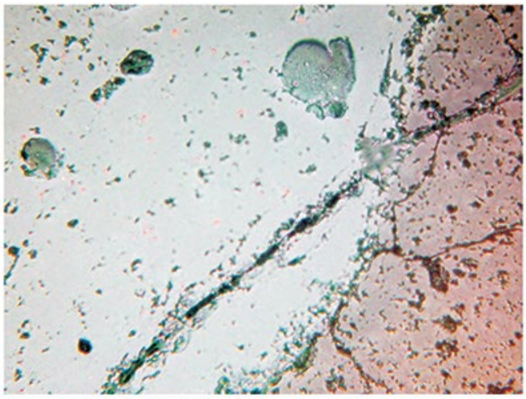
1 – sample 518, Lyavlyakan, 26a: large long prismatic crystals of olivine and small dendrites of wüstite in the glass matrix.



2 – sample 574, 6th mineralogical group, 3rd type, Besh-Bulak 4, accum. 2: lower part of slagged ceramic crust (quartz and ceramic mass, glass, small prisms of olivine).



3 – sample 574, Besh-Bulak 4, accum. 2: middle part of slagged ceramic crust (glass with small prisms of olivine).



4 – sample 574, Besh-Bulak 4, accum. 2: upper part of slagged ceramic crust (pure glass, with inclusions of copper prills and grain of quartz on the left).

FIG. 12-III. MICROSTRUCTURES OF SLAG FROM THE KYZYL-KUM (LENGTH OF THE PHOTOS IS 0.54 MM), 6TH MINERALOGICAL GROUP, 3RD TYPE: 1 – SAMPLE 518, LYAVLYAKAN, 26A: LARGE LONG PRISMATIC CRYSTALS OF OLIVINE AND SMALL DENDRITES OF WÜSTITE IN THE GLASS MATRIX. 2 – SAMPLE 574, 6TH MINERALOGICAL GROUP, 3RD TYPE, BESH-BULAK 4, ACCUM. 2: LOWER PART OF SLAGGED CERAMIC CRUST (QUARTZ AND CERAMIC MASS, GLASS, SMALL PRISMS OF OLIVINE). 3 – SAMPLE 574, BESH-BULAK 4, ACCUM. 2: MIDDLE PART OF SLAGGED CERAMIC CRUST (GLASS WITH SMALL PRISMS OF OLIVINE). 4 – SAMPLE 574, BESH-BULAK 4, ACCUM. 2: UPPER PART OF SLAGGED CERAMIC CRUST (PURE GLASS, WITH INCLUSIONS OF COPPER PRILLS AND GRAIN OF QUARTZ ON THE LEFT).

Tab. 12-2. Distribution of mineralogical groups of slag over sites of the Kyzyl-Kum.

Mineralogical group / Site	I	II	III	IV	VI	Ceramic slag
Ayakagitma 10		5				
Ayakagitma 17				1		1
Ayakagitma 187	3		1			
Ayakagitma 209	1	2	2			
Ayakagitma 224	1	1	1			
Ayakagitma 234	1		1		2	
Ayakagitma 239		4				
Ayakagitma 10A	2	3				
Ayakagitma 95B		2				
Besh Bulak, 1, area 1	1					
Besh Bulak, 1, area 7		3			1	
Besh Bulak, 1, area 8	1	1		3	1	
Besh Bulak, 3	1	5				
Besh Bulak, 4		2				
Besh Bulak, 10, area 5		2				
Besh Bulak, 2, accum.1		5				
Besh Bulak, 2, accum.5	1	2				
Besh Bulak, 2, area 1	1	3		1		
Besh Bulak, 4, accum.1		4		1		
Besh Bulak, 4, accum.2		3			1	
Besh Bulak, 4, accum.3		2				
Lyavlyakan, 7		1				
Lyavlyakan, 26					1	
Lyavlyakan, 26a					1	1
Lyavlyakan, 26-V		1				
Lyavlyakan, 40	1					
Lyavlyakan, 94		1			2	
Lyavlyakan, 322		1				
Lyavlyakan, 120-II	2					
Lyavlyakan, 120-IX		2		1		
Lyavlyakan, 121-I		2			1	
Lyavlyakan, 131-I,II		1				
Lyavlyakan, 338-I		2				
Total (quantity and %):	**16**	**60**	**5**	**7**	**10**	**2**

Tab. 12-3. Distribution of forms of slag over sites of the Kyzyl-Kum.

Form / **Site**	**1** formless slag	**2** flat slag	**3** slug crust	**4** thin slag pate
Ayakagitma 10	5			
Ayakagitma 17			1	
Ayakagitma 187				4
Ayakagitma 209				5
Ayakagitma 224	3			
Ayakagitma 234		4		
Ayakagitma 239		4		
Ayakagitma 10A	6			
Ayakagitma 95B	2			
Besh Bulak, 1, area 1	1			
Besh Bulak, 1, area 7		4		
Besh Bulak, 1, area 8			5	
Besh Bulak, 3	5	1		
Besh Bulak, 4			2	
Besh Bulak, 10, area 5	3			
Besh Bulak, 2, accum.1	4			
Besh Bulak, 2, accum.5		2		
Besh Bulak, 2, area 1	4	1		
Besh Bulak, 4, accum.1	4		1	
Besh Bulak, 4, accum.2	3		1	
Besh Bulak, 4, accum.3	2			
Lyavlyakan, 7			1	
Lyavlyakan, 26			1	
Lyavlyakan, 26a			2	
Lyavlyakan, 26-V			1	
Lyavlyakan, 40		1		
Lyavlyakan, 94			3	
Lyavlyakan, 322			1	
Lyavlyakan, 120-II	2			
Lyavlyakan, 120-IX	3			
Lyavlyakan, 121-I	3			
Lyavlyakan, 131-I,II		1		
Lyavlyakan, 338-I	2			
Total (quantity and %):	**52**	**18**	**19**	**9**

Tab. 12-4. Correlation of forms and mineralogical groups of slag from the Kyzyl-Kum.

Mineralogical group / Form	1 formless slag	2 flat slag	3 slug crust	4 thin slag pate
I	6 (37.5%)	5 (21.25%)	1 (6.25%)	4 (25%)
II	42 (71.19%)	6 (10.17%)	9 (15.25%)	2 (3.39%)
III	1 (20%)	1 (20%)		3 (60%)
IV	4 (66.6%)		2 (33.3%)	
VI	2 (16.67%)	2 (16.67%)	8 (66.66%)	

In the bracket: proportion of the type in mineralogical group

Tab. 12-5. Bulk (wet) chemical analyses of slag (%) from sites of the Kyzyl-Kum. The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

№	Site	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	MnO	Cu	SO_3
483	Ayakagitma 234	28.62	4.46	26.82	33.30	2.04	1.36	0.10	0.19	0.17
580	Besh Bulak 1	50.10	6.29	13.81	13.32	1.43	1.09	0.11	4.12	0.10
567	Besh Bulak 4	60.84	8.12	8.12	10.14	1.43	2.17	0.06	1.51	0.07
588	Besh Bulak 1	34.20	4.41	32.51	20.56	0.20	1.56	0.35	0.29	0.08
590	Besh Bulak 1	32.98	5.78	38.20	11.87	2.25	1.00	0.15	2.44	0.11

Tab. 12-6. Coefficients of basicity of slag from the Kyzyl-Kum.

№	Site	Coefficient of basicity	Group
483	Ayakagitma 234	1.93	basic
590	Besh Bulak 1	1.38	average
588	Besh Bulak 1	1.43	average
580	Besh Bulak 1	0.53	acid
567	Besh Bulak 4	0.32	ultra-basic

Tab. 12-7. Slags of the Kyzyl-Kum. Ratio of oxides decreasing viscosity (TiO_2, MgO, Fe_2O_3, MnO, K_2O, CaO, Na_2O) to those increasing it (SiO_2, Al_2O_3,) – coefficient Kz and coefficient of viscosity (Pa s) at the temperature of 1400°C calculated according to Bachmann et al. 1987.

№	Site	Group	Type	Material	K_z	η **1400** (Pa·s)
483	Ayakagitma 234	VII	2	slag	1.93	2.08
590	Besh Bulak 1	II	1	slag	1.45	2.94
588	Besh Bulak 1	I	1	slag	1.44	2.96
580	Besh Bulak 1	II	3	slag	0.60	7.68
567	Besh Bulak 4	II	3	slag	0.34	13.93

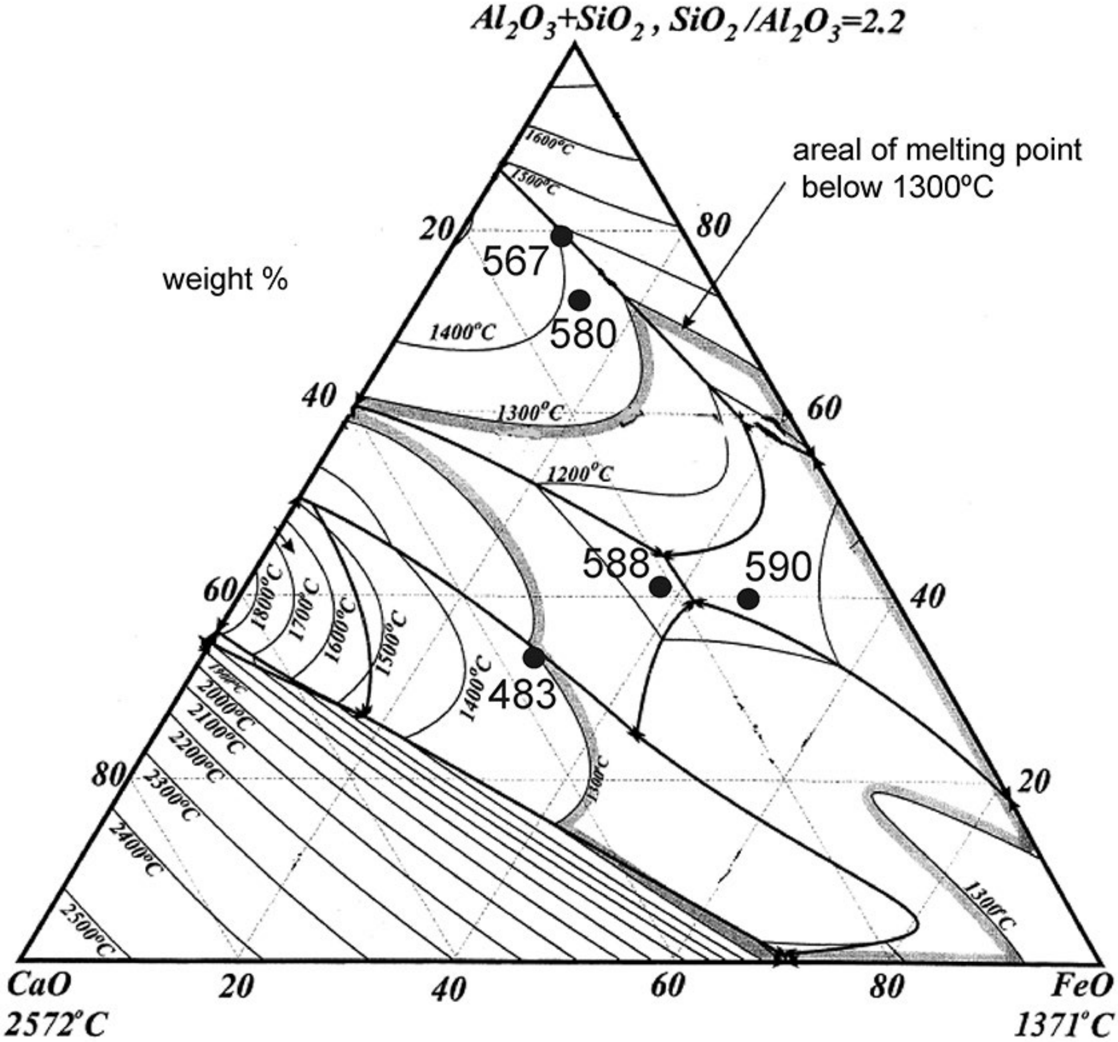


FIG. 12-8. PHASE PLOT FEO-AL2O3+SIO2-CAO FOR SLAGS FROM THE KYZYL-KUM.

Tab. 12-9. Emission spectral analyses of slag and ore from the Kyzyl-Kum (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

Area	Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge
Ayakagitma	234	slag	483	0.003	0.0015	<0.001	0.05	0.0015	0.1	<0.0005	0.00015
Ayakagitma	234	slag	484	0.007	0.002	<0.001	0.05	<0.001	0.07	<0.0005	0.00015
Ayakagitma	234	slag	486	0.007	0.0015	<0.001	0.07	<0.001	0.1	<0.0005	0.00015
Ayakagitma	10	slag	502	0.007	0.001	0.01	0.05	0.02	0.2	0.0005	0.00015
Ayakagitma	10A	slag	489	0.015	0.001	0.01	0.05	0.03	0.15	0.001	0.0003
Ayakagitma	224	slag	500	0.005	0.005	0.007	0.2	0.01	0.2	0.0005	<0.0003
Ayakagitma	239	slag	497	0.005	0.0015	0.007	0.15	0.007	0.3	0.0005	<0.0003
Ayakagitma	239	slag	495	0.005	0.002	0.007	0.1	0.007	0.2	0.0005	0.00015
Ayakagitma	10A	slag	487	0.01	0.001	0.01	0.07	0.02	0.15	0.001	0.00015
Ayakagitma	224	slag	498	0.015	0.003	0.03	0.2	0.01	0.2	0.001	<0.0003
Ayakagitma	224	slag	499	0.03	0.003	0.005	0.3	0.007	0.2	0.0005	0.00015
Besh Bulak	4	slag	576	0.005	0.0015	0.02	0.03	0.015	0.5	0.001	<0.0003
Besh Bulak	1. area 8	slag	582	0.005	0.01	0.07	0.2	0.07	0.3	0.001	<0.0003
Besh Bulak	4. accum.1	slag	565	0.005	0.0015	0.015	0.05	0.02	0.3	0.0005	<0.0003
Besh Bulak	4. accum.2	slag	574	0.005	0.001	0.02	0.03	0.02	0.3	0.001	<0.0003
Besh Bulak	4. accum.1	slag	563	0.005	0.0007	0.03	0.7	0.05	0.3	0.0005	<0.0003
Besh Bulak	2. accum.5	slag	579	0.007	0.001	0.03	0.015	0.02	0.5	0.0015	<0.0003
Besh Bulak	10. area 5	slag	548	0.007	0.002	0.05	0.02	0.05	0.2	0.0005	<0.0003
Besh Bulak	3	slag	541	0.007	0.002	0.07	0.1	0.05	0.2	0.0005	<0.0003
Besh Bulak	4. accum.1	slag	567	0.007	0.0015	0.03	0.02	0.03	0.3	0.001	<0.0003
Besh Bulak	1. area 7	slag	592	0.007	0.005	0.001	0.01	<0.001	0.05	<0.0005	0.0003
Besh Bulak	3	slag	543	0.007	0.002	0.03	0.03	0.07	0.3	0.001	0
Besh Bulak	1. area 8	slag	580	0.007	0.001	0.03	0.03	0.02	0.2	0.0005	<0.0003
Besh Bulak	1. area 8	slag	584	0.007	0.0015	0.02	0.02	0.015	0.2	0.001	<0.0003
Besh Bulak	4. accum.2	slag	572	0.007	0.001	0.03	0.02	0.015	0.2	0.001	<0.0003
Besh Bulak	4	slag	575	0.007	0.003	0.05	0.015	0.07	0.3	0.0005	<0.0003
Besh Bulak	2. accum.5	slag	577	0.007	0.002	0.01	0.03	0.02	0.15	<0.0005	0.00015
Besh Bulak	1. area 1	slag	588	0.007	0.0015	0.005	0.15	0.07	0.2	0.0005	<0.0003
Besh Bulak	1. area 7	slag	590	0.007	0.002	0.02	0.015	0.03	0.3	0.0005	<0.0003
Besh Bulak	4. accum.3	slag	569	0.01	0.0015	0.02	0.03	0.03	0.5	0.0015	<0.0003

Area	Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge
Besh Bulak	4. accum.2	slag	571	0.01	0.0015	0.02	0.03	0.015	0.2	0.001	<0.0003
Besh Bulak	10. area 5	slag	546	0.01	0.002	0.03	0.03	0.05	0.2	0.0005	<0.0003
Besh Bulak	4. accum.3	slag	570	0.01	0.0015	0.02	0.02	0.03	0.2	0.0005	<0.0003
Besh Bulak	10. area 10	ore	550	0.01	0.001	0.02	0.02	0.1	0.2	0.001	<0.0003
Besh Bulak	1. area 8	slag	581	0.01	0.002	0.03	0.015	0.03	0.3	0.001	0.00015
Besh Bulak	3	slag	542	0.01	0.002	0.05	0.05	0.05	0.2	0.0005	<0.0003
Besh Bulak	1. area 7	slag	591	0.015	0.005	0.015	0.02	0.03	0.3	0.0005	0.00015
Besh Bulak	4. accum.2	slag	573	0.015	0.003	0.03	0.02	0.05	0.2	0.001	<0.0003
Besh Bulak	1. area 8	slag	583	0.015	0.007	0.05	0.07	0.07	0.3	0.001	<0.0003
Besh Bulak	10. area 5	slag	547	0.015	0.003	0.03	0.02	0.07	0.3	0.001	<0.0003
Besh Bulak	1	ore	585	0.015	0.002	0.3	0.07	0.3	1	<0.0005	<0.0003
Besh Bulak	1. area 7	slag	589	0.02	0.007	0.03	0.02	0.05	0.5	0.001	<0.0003
Besh Bulak	3	slag	545	0.02	0.002	0.1	0.03	0.1	0.5	0.001	<0.0003
Besh Bulak	3	slag	544	0.03	0.003	0.05	0.03	0.15	0.3	0.0015	<0.0003
Besh Bulak	2. accum.1	slag	562	0.003	<0.0003	0.0015	0.05	0.007	0.1	0.0005	<0.0003
Besh Bulak		slag	555	0.015	0.003	0.05	0.07	0.07	0.3	0.0005	0.00015
Besh Bulak	2. area 1	slag	553	0.02	0.002	0.05	0.05	0.07	0.2	0.0015	<0.0003
Besh Bulak	2. accum.1	slag	560	0.02	0.002	0.05	0.05	0.05	0.2	0.001	<0.0003
Besh Bulak	2. accum.1	slag	558	0.02	0.002	0.03	0.02	0.05	0.2	0.001	<0.0003
Besh Bulak	2. area 1	slag	551	0.03	0.002	0.03	0.03	0.07	0.2	0.001	0.00015
Besh Bulak	2. accum.1	slag	557	0.03	0.002	0.05	0.02	0.07	0.2	0.001	<0.0003
Besh Bulak	2. accum.1	slag	559	0.03	0.002	0.05	0.02	0.05	0.2	0.0015	<0.0003
Besh Bulak	2. area 1	slag	556	0.05	0.005	0.03	0.02	0.07	0.2	0.0005	0.0003
Besh Bulak	2. area 1	slag	554	0.07	0.003	0.05	0.05	0.07	0.2	0.0005	<0.0003
Besh Bulak	2. area 1	slag	552	0.1	0.005	0.05	0.03	0.15	0.7	0.0015	<0.0003
Lyavlyakan	131-I.II	slag	521	0.001	0.015	0.0015	0.2	0.003	0.2	<0.0005	0.00015
Lyavlyakan	7	slag	522	0.003	0.0015	0.015	0.03	0.007	0.5	0.001	<0.0003
Lyavlyakan	26-V	slag	520	0.003	0.003	0.002	0.1	0.01	0.2	<0.0005	0.00015
Lyavlyakan	322	slag	538	0.01	0.003	0.015	0.2	0.07	0.1	0.0005	0.00015
Lyavlyakan	120-II	slag	512	0.02	0.002	0.002	0.03	0.03	0.1	<0.0005	<0.0003
Besh Bulak		ore	586	0.007	<0.0003	0.1	0.015	0.3	0.2	0.001	<0.0003

Area	Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge
Besh Bulak		ore	587	0.02	<0.0003	0.02	0.015	0.1	0.07	<0.0005	<0.0003
Ayakagitma	10	slag	504	0.007	0.0007	0.015	0.07	0.03	0.15	0.001	0.0003
Ayakagitma	17	ore	533	0.007	0.001	0.02	0.03	0.01	0.3	0.0005	0.005
Ayakagitma	10A	slag	490	0.01	0.001	0.007	0.03	0.03	0.2	<0.0005	0.0007
Ayakagitma	10	slag	503	0.015	0.0015	0.01	0.07	0.05	0.15	0.0005	0.0005
Ayakagitma	10A	slag	526	0.015	0.001	0.015	0.05	0.02	0.15	<0.0005	0.0007
Ayakagitma	10	slag	524	0.02	0.002	0.015	0.07	0.03	0.2	0.0005	0.0003
Lyavlyakan	121-I	slag	516	0.005	0.01	0.003	0.15	0.01	0.15	<0.0005	0.00015
Lyavlyakan	26a	slag	518	0.007	0.003	0.01	0.05	0.005	0.2	0.0005	<0.0003
Lyavlyakan	120-II	slag	513	0.07	0.02	0.01	0.1	0.03	0.2	0.0015	0.00015
Besh Bulak	10. area 5	ore	549	0.2	0.01	0.015	0.02	0.1	0.1	0.0005	<0.0003
Lyavlyakan	121-I	slag	517	0.002	0.005	0.003	0.1	0.007	0.2	<0.0005	0.00015
Lyavlyakan	26a	slag	519	0.015	0.01	0.007	0.07	0.01	0.2	0.0005	<0.0003
Lyavlyakan	120-IX	slag	514	0.015	0.005	0.01	0.2	0.02	0.2	0.001	0.00015
Lyavlyakan	120-IX	slag	510	0.02	0.02	0.01	0.1	0.015	0.5	0.002	0.00015
Lyavlyakan	338-I	slag	508	0.003	0.01	0.001	0.03	0.001	0.2	<0.0005	0.00015
Lyavlyakan	26	slag	511	0.01	0.005	0.003	0.05	0.015	0.15	0.0005	<0.0003
Lyavlyakan	121-I	slag	515	0.003	0.01	0.001	0.2	0.01	0.15	0.0005	0.0003
Ayakagitma	187	slag	531a	0.007	0.001	0.005	0.15	0.015	0.2	0.0005	0.00015
Lyavlyakan	338-I	slag	507	0.007	0.05	0.003	0.1	0.01	0.15	0.0005	0.00015
Ayakagitma	209	slag	491	0.015	0.003	0.0015	0.2	0.03	0.2	0.001	0.00015
Ayakagitma	209	slag	527	0.01	0.001	0.002	0.15	0.02	0.07	0.0005	0.0005
Besh Bulak	4. accum.1	slag	564	0.01	0.003	0.3	0.02	0.01	0.2	0.001	<0.0003
Lyavlyakan	40	slag	523	0.005	0.007	0.003	0.1	0.01	0.2	0.0005	0.00015
Ayakagitma	209	slag	492	0.01	0.002	0.0015	0.2	0.03	0.15	0.0005	0.0003
Ayakagitma		slag	525	0.01	0.001	0.007	0.05	0.02	0.2	0.0005	0.001
Ayakagitma	95B	slag	505	0.05	0.0015	0.03	0.02	0.07	0.3	0.002	0.00015
Lyavlyakan	94	slag	536	0.01	0.0015	0.007	0.2	0.007	0.07	0.0005	0.0003
Ayakagitma	187	slag	531	0.01	0.001	0.003	0.5	0.015	0.1	0.0005	0.0003
Ayakagitma	209	slag	528	0.007	0.001	0.003	0.3	0.02	0.1	0.0005	0.0007
Lyavlyakan	120-IX	slag	509	0.1	0.003	0.005	0.05	0.05	0.2	0.0005	0.001

Area	**Site**	**Material**	**№**	**Ni**	**Co**	**Cr**	**Mn**	**V**	**Ti**	**Sc**	**Ge**
Sensitivity of the analysis				Ni	Co	Cr	Mn	V	Ti	Sc	Ge
				0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.0003

Tab. 12-9. Emission spectral analyses of slag and ore from the Kyzyl-Kum (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.(contd.)

Area	Site	Material	№	Cu	Zn	Pb	Ag	As	Sb	Cd
Ayakagitma	234	slag	483	0.015	nd	0.0007	<0.00003	<0.01	<0.003	<0.001
Ayakagitma	234	slag	484	0.03	0.01	0.0005	<0.00003	<0.01	<0.003	<0.001
Ayakagitma	234	slag	486	0.07	0.01	0.0007	0.0015	<0.01	<0.003	<0.001
Ayakagitma	10	slag	502	0.5	0.015	0.0007	<0.00003	<0.01	<0.003	<0.001
Ayakagitma	10A	slag	489	>1	0.5	0.03	0.00003	0.005	0.05	0.001
Ayakagitma	224	slag	500	0.3	0.01	0.0007	0.00003	0.005	<0.003	<0.001
Ayakagitma	239	slag	497	0.5	0.007	0.0015	0.00003	0.005	<0.003	0.0005
Ayakagitma	239	slag	495	1	0.015	0.0015	0.00003	0.005	0.0015	<0.001
Ayakagitma	10A	slag	487	1	0.07	0.0015	<0.00003	0.005	0.007	<0.001
Ayakagitma	224	slag	498	1	0.2	0.005	0.0001	0.005	<0.003	<0.001
Ayakagitma	224	slag	499	>1	0.3	0.001	0.00015	0.005	<0.003	<0.001
Besh Bulak	4	slag	576	0.2	nd	0.0007	<0.00003	0.005	<0.003	<0.001
Besh Bulak	1. area 8	slag	582	0.3	0.005	0.0007	0.00005	0.005	<0.003	<0.001
Besh Bulak	4. accum.1	slag	565	1	0.015	0.0015	0.0002	0.005	<0.003	<0.001
Besh Bulak	4. accum.2	slag	574	0.7	0.01	0.0015	0.00005	0.005	<0.003	<0.001
Besh Bulak	4. accum.1	slag	563	0.7	0.01	0.003	0.00003	0.005	<0.003	<0.001
Besh Bulak	2. accum.5	slag	579	0.7	0.007	0.0005	<0.00003	0.005	<0.003	<0.001
Besh Bulak	10. area 5	slag	548	1	0.007	0.001	0.00003	0.005	<0.003	<0.001
Besh Bulak	3	slag	541	0.7	0.007	0.001	<0.00003	0.005	<0.003	<0.001
Besh Bulak	4. accum.1	slag	567	1	0.01	0.0015	0.0003	0.005	<0.003	<0.001
Besh Bulak	1. area 7	slag	592	0.1	0.007	0.0015	0.00003	0.005	0.0015	<0.001
Besh Bulak	3	slag	543	0.7	0.007	0.002	0.00003	0.005	<0.003	<0.001
Besh Bulak	1. area 8	slag	580	0.7	0.005	0.002	0.00005	0.005	<0.003	<0.001
Besh Bulak	1. area 8	slag	584	>1	0.015	0.002	0.00005	0.005	<0.003	<0.001
Besh Bulak	4. accum.2	slag	572	>1	0.02	0.003	0.00003	0.005	<0.003	<0.001
Besh Bulak	4	slag	575	>1	0.01	0.003	0.00003	0.005	<0.003	<0.001
Besh Bulak	2. accum.5	slag	577	>1	0.07	0.005	0.00015	0.005	<0.003	<0.001
Besh Bulak	1. area 1	slag	588	0.5	0.2	0.007	0.00003	0.005	0.003	<0.001
Besh Bulak	1. area 7	slag	590	>1	0.07	0.01	0.0003	0.005	0.02	<0.001
Besh Bulak	4. accum.3	slag	569	0.5	0.01	0.0015	0.00005	0.005	<0.003	<0.001

Area	Site	Material	№	Cu	Zn	Pb	Ag	As	Sb	Cd
Besh Bulak	4. accum.2	slag	571	>1	nd	0.0015	0.0001	0.005	<0.003	<0.001
Besh Bulak	10. area 5	slag	546	1	0.01	0.0015	0.00005	0.005	<0.003	<0.001
Besh Bulak	4. accum.3	slag	570	0.7	0.015	0.002	0.00007	0.005	<0.003	<0.001
Besh Bulak	10. area 10	ore	550	>1	0.015	0.002	0.0007	0.005	<0.003	<0.001
Besh Bulak	1. area 8	slag	581	>1	nd	0.003	0.00015	0.005	<0.003	<0.001
Besh Bulak	3	slag	542	1	0.07	0.003	0.00005	0.005	<0.003	<0.001
Besh Bulak	1. area 7	slag	591	1	0.03	0.0015	0.00003	0.005	0.003	<0.001
Besh Bulak	4. accum.2	slag	573	>1	0.015	0.003	0.00003	0.005	<0.003	0.0005
Besh Bulak	1. area 8	slag	583	>1	0.01	0.003	0.0001	0.005	<0.003	<0.001
Besh Bulak	10. area 5	slag	547	>1	0.007	0.005	0.00007	0.005	<0.003	<0.001
Besh Bulak	1	ore	585	>1	nd	0.02	<0.00003	0.005	<0.003	<0.001
Besh Bulak	1. area 7	slag	589	>1	0.02	0.002	0.0003	0.005	<0.003	<0.001
Besh Bulak	3	slag	545	1	0.007	0.003	0.00007	0.005	<0.003	<0.001
Besh Bulak	3	slag	544	>1	0.01	0.005	0.00015	0.005	<0.003	<0.001
Besh Bulak	2. accum.1	slag	562	0.3	0.05	0.003	0.0015	0.005	<0.003	<0.001
Besh Bulak		slag	555	>1	0.05	0.007	0.0002	0.005	<0.003	<0.001
Besh Bulak	2. area 1	slag	553	>1	0.015	0.003	0.00005	0.005	<0.003	<0.001
Besh Bulak	2. accum.1	slag	560	>1	0.02	0.005	0.00005	0.005	<0.003	<0.001
Besh Bulak	2. accum.1	slag	558	>1	0.02	0.02	0.00003	0.005	<0.003	<0.001
Besh Bulak	2. area 1	slag	551	>1	0.015	0.0015	0.00005	0.005	<0.003	<0.001
Besh Bulak	2. accum.1	slag	557	>1	0.015	0.002	0.00005	0.005	<0.003	<0.001
Besh Bulak	2. accum.1	slag	559	>1	0.02	0.002	0.00003	0.005	<0.003	<0.001
Besh Bulak	2. area 1	slag	556	>1	0.03	0.005	0.00003	0.005	0.005	<0.001
Besh Bulak	2. area 1	slag	554	>1	0.015	0.003	0.00005	0.005	<0.003	<0.001
Besh Bulak	2. area 1	slag	552	>1	0.01	0.007	0.00003	0.005	<0.003	<0.001
Lyavlyakan	131-I.II	slag	521	0.05	nd	0.0007	<0.00003	0.005	<0.003	<0.001
Lyavlyakan	7	slag	522	0.02	nd	0.001	0.00003	0.005	<0.003	<0.001
Lyavlyakan	26-V	slag	520	0.15	0.03	0.02	0.00003	0.005	<0.003	<0.001
Lyavlyakan	322	slag	538	0.2	0.007	0.0007	0.00005	0.005	<0.003	<0.001
Lyavlyakan	120-II	slag	512	1	0.1	0.001	0.00003	0.005	<0.003	<0.001
Besh Bulak		ore	586	>1	nd	0.003	0.00005	0.005	<0.003	<0.001

Area	Site	Material	№	Cu	Zn	Pb	Ag	As	Sb	Cd
Besh Bulak		ore	587	>1	0.03	0.002	>0.003	0.005	<0.003	<0.001
Ayakagitma	10	slag	504	1	0.3	0.01	0.00005	0.01	0.03	<0.001
Ayakagitma	17	ore	533	>1	0.007	0.02	0.003	0.01	<0.003	<0.001
Ayakagitma	10A	slag	490	1	0.7	0.02	0.00005	0.01	0.1	<0.001
Ayakagitma	10	slag	503	>1	0.5	0.02	<0.00003	0.01	0.2	0.001
Ayakagitma	10A	slag	526	>1	0.5	0.03	0.0001	0.01	0.3	0.0005
Ayakagitma	10	slag	524	>1	0.3	0.03	0.00015	0.01	0.1	<0.001
Lyavlyakan	121-I	slag	516	0.15	0.03	0.003	0.00003	0.01	<0.003	<0.001
Lyavlyakan	26a	slag	518	0.7	nd	0.0015	0.00007	0.01	<0.003	<0.001
Lyavlyakan	120-II	slag	513	>1	0.2	0.0007	0.00015	0.01	<0.003	<0.001
Besh Bulak	10. area 5	ore	549	>1	0.05	0.002	0.0015	0.015	<0.003	<0.001
Lyavlyakan	121-I	slag	517	0.2	0.015	0.005	0.00007	0.015	<0.003	<0.001
Lyavlyakan	26a	slag	519	0.5	nd	0.0015	0.00007	0.015	0.0015	<0.001
Lyavlyakan	120-IX	slag	514	0.7	0.15	0.001	0.00007	0.015	<0.003	<0.001
Lyavlyakan	120-IX	slag	510	>1	0.05	0.002	0.0001	0.015	<0.003	<0.001
Lyavlyakan	338-I	slag	508	0.3	0.01	0.001	0.0007	0.015	0.0015	<0.001
Lyavlyakan	26	slag	511	0.7	0.03	0.02	0.0003	0.02	0.0015	<0.001
Lyavlyakan	121-I	slag	515	0.5	0.3	0.015	0.00015	0.02	<0.003	<0.001
Ayakagitma	187	slag	531a	0.2	nd	0.1	0.00003	0.02	0.005	<0.001
Lyavlyakan	338-I	slag	507	1	0.03	0.003	0.0005	0.03	0.0015	<0.001
Ayakagitma	209	slag	491	1	0.5	0.03	0.0001	0.05	0.015	<0.001
Ayakagitma	209	slag	527	>1	>1	0.15	0.0001	0.07	0.01	<0.001
Besh Bulak	4. accum.1	slag	564	0.3	nd	0.0003	<0.00003	0.07	<0.003	<0.001
Lyavlyakan	40	slag	523	1	0.03	0.01	0.0003	0.07	<0.003	<0.001
Ayakagitma	209	slag	492	>1	0.5	0.02	0.00007	0.15	0.01	<0.001
Ayakagitma		slag	525	>1	0.5	0.15	0.0002	0.15	0.3	<0.001
Ayakagitma	95B	slag	505	>1	0.15	0.005	0.0003	0.2	0.03	<0.001
Lyavlyakan	94	slag	536	>1	0.1	1	0.0002	0.3	0.1	<0.001
Ayakagitma	187	slag	531	>1	0.007	0.07	0.0005	0.7	0.1	<0.001
Ayakagitma	209	slag	528	>1	>1	0.15	0.00005	1	0.1	<0.001
Lyavlyakan	120-IX	slag	509	0.7	0.7	0.01	0.0005	1	0.3	<0.001

Area	**Site**	**Material**	**№**	**Cu**	**Zn**	**Pb**	**Ag**	**As**	**Sb**	**Cd**
Sensitivity of the analysis				Cu	Zn	Pb	Ag	As	Sb	Cd
				0.001	0.003	0.0003	0.00003	0.01	0.003	0.001

Tab. 12-9. Emission spectral analyses of slag and ore from the Kyzyl-Kum (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.(contd.)

Area	**Site**	**Material**	**№**	**Bi**	**Mo**	**Ba**	**Sr**	**W**	**Sn**	**Be**
Ayakagitma	234	slag	483	<0.001	0.00015	0.07	0.1	<0.001	0.0003	0.00003
Ayakagitma	234	slag	484	<0.001	0.00015	0.03	0.05	<0.001	0.0003	<0.00003
Ayakagitma	234	slag	486	<0.001	0.00015	0.03	0.07	<0.001	0.0015	0.00003
Ayakagitma	10	slag	502	<0.001	0.001	0.2	0.03	<0.001	0.0003	0.0003
Ayakagitma	10A	slag	489	<0.001	0.003	0.3	0.1	<0.001	0.001	0.0003
Ayakagitma	224	slag	500	<0.001	0.0015	0.15	0.03	<0.001	0.0003	0.0003
Ayakagitma	239	slag	497	<0.001	0.001	0.15	0.02	<0.001	0.0005	0.0003
Ayakagitma	239	slag	495	<0.001	0.0015	0.15	0.02	<0.001	0.0003	0.0003
Ayakagitma	10A	slag	487	<0.001	0.0005	0.3	0.05	<0.001	0.0003	0.0003
Ayakagitma	224	slag	498	<0.001	0.003	0.2	0.03	<0.001	0.0015	0.0003
Ayakagitma	224	slag	499	<0.001	0.007	0.2	0.02	<0.001	0.0005	0.0003
Besh Bulak	4	slag	576	<0.001	0.002	0.15	0.05	<0.001	<0.0005	0.0002
Besh Bulak	1. area 8	slag	582	<0.001	0.002	0.3	0.1	<0.001	<0.0005	0.00015
Besh Bulak	4. accum.1	slag	565	<0.001	0.005	0.2	0.1	<0.001	0.0003	0.00015
Besh Bulak	4. accum.2	slag	574	<0.001	0.003	0.3	0.07	<0.001	<0.0005	0.00015
Besh Bulak	4. accum.1	slag	563	<0.001	0.002	0.2	0.05	<0.001	<0.0005	0.00015
Besh Bulak	2. accum.5	slag	579	<0.001	0.0005	0.5	0.1	<0.001	0.0003	0.0002
Besh Bulak	10. area 5	slag	548	<0.001	0.003	0.2	0.1	<0.001	<0.0005	0.00015
Besh Bulak	3	slag	541	<0.001	0.002	0.3	0.1	<0.001	0.0003	0.00015
Besh Bulak	4. accum.1	slag	567	<0.001	0.0015	0.3	0.05	<0.001	0.0003	0.00015
Besh Bulak	1. area 7	slag	592	<0.001	0.001	0.015	<0.01	<0.001	<0.0005	<0.00003
Besh Bulak	3	slag	543	<0.001	0.0015	0.2	0.1	<0.001	0.0003	0.00015
Besh Bulak	1. area 8	slag	580	<0.001	0.002	0.2	0.07	<0.001	0.0003	0.00015
Besh Bulak	1. area 8	slag	584	<0.001	0.003	0.5	0.1	<0.001	<0.0005	0.00015
Besh Bulak	4. accum.2	slag	572	<0.001	0.005	0.2	0.2	<0.001	<0.0005	0.0002
Besh Bulak	4	slag	575	<0.001	0.002	0.3	0.07	<0.001	0.0003	0.0002
Besh Bulak	2. accum.5	slag	577	<0.001	0.03	0.1	0.03	<0.001	<0.0005	0.0001
Besh Bulak	1. area 1	slag	588	<0.001	0.01	>3	0.03	<0.001	<0.0005	0.0002
Besh Bulak	1. area 7	slag	590	<0.001	0.005	0.2	0.05	<0.001	<0.0005	0.00015
Besh Bulak	4. accum.3	slag	569	<0.001	0.001	0.5	0.1	<0.001	<0.0005	0.0002

Area	Site	Material	№	Bi	Mo	Ba	Sr	W	Sn	Be
Besh Bulak	4. accum.2	slag	571	<0.001	0.002	0.3	0.15	<0.001	<0.0005	0.0001
Besh Bulak	10. area 5	slag	546	<0.001	0.005	0.2	0.15	<0.001	<0.0005	0.00015
Besh Bulak	4. accum.3	slag	570	<0.001	0.0015	0.2	0.05	<0.001	0.0003	0.00015
Besh Bulak	10. area 10	ore	550	<0.001	0.0003	0.1	0.015	<0.001	0.0003	0.00015
Besh Bulak	1. area 8	slag	581	<0.001	0.007	0.3	0.07	<0.001	0.0003	0.0001
Besh Bulak	3	slag	542	<0.001	0.003	0.2	0.1	<0.001	0.0003	0.00015
Besh Bulak	1. area 7	slag	591	<0.001	0.002	0.15	0.03	<0.001	<0.0005	0.0001
Besh Bulak	4. accum.2	slag	573	<0.001	0.02	0.2	0.05	<0.001	0.0003	0.00015
Besh Bulak	1. area 8	slag	583	<0.001	0.003	0.5	0.07	<0.001	<0.0005	0.0002
Besh Bulak	10. area 5	slag	547	<0.001	0.005	0.2	0.1	<0.001	0.0003	0.00015
Besh Bulak	1	ore	585	<0.001	0.002	0.7	0.05	<0.001	0.0015	0.0003
Besh Bulak	1. area 7	slag	589	<0.001	0.002	0.3	0.03	<0.001	<0.0005	0.0002
Besh Bulak	3	slag	545	<0.001	0.005	0.2	0.07	<0.001	<0.0005	0.0002
Besh Bulak	3	slag	544	<0.001	0.005	0.2	0.1	<0.001	<0.0005	0.0002
Besh Bulak	2. accum.1	slag	562	<0.001	0.00015	0.01	0.01	<0.001	0.0003	0.0001
Besh Bulak		slag	555	<0.001	0.015	0.2	0.07	<0.001	0.0005	0.00015
Besh Bulak	2. area 1	slag	553	<0.001	0.003	0.2	0.15	<0.001	0.0003	0.0002
Besh Bulak	2. accum.1	slag	560	<0.001	0.002	0.5	0.2	<0.001	0.0003	0.00015
Besh Bulak	2. accum.1	slag	558	<0.001	0.003	0.3	0.15	<0.001	0.0003	0.0002
Besh Bulak	2. area 1	slag	551	<0.001	0.002	0.3	0.15	<0.001	0.0003	0.0001
Besh Bulak	2. accum.1	slag	557	<0.001	0.005	0.3	0.15	<0.001	0.0003	0.00015
Besh Bulak	2. accum.1	slag	559	<0.001	0.005	0.5	0.2	<0.001	0.0003	0.0002
Besh Bulak	2. area 1	slag	556	<0.001	0.005	0.2	0.07	<0.001	<0.0005	0.0002
Besh Bulak	2. area 1	slag	554	<0.001	0.015	0.15	0.1	<0.001	0.0003	0.00015
Besh Bulak	2. area 1	slag	552	<0.001	0.0003	0.5	0.15	<0.001	0.0003	0.0007
Lyavlyakan	131-I.II	slag	521	<0.001	0.0001	0.1	0.03	<0.001	0.0003	0.00015
Lyavlyakan	7	slag	522	<0.001	0.0001	0.15	0.05	<0.001	0.0003	0.0002
Lyavlyakan	26-V	slag	520	<0.001	0.001	0.15	0.02	<0.001	0.001	0.0001
Lyavlyakan	322	slag	538	<0.001	0.0015	0.7	0.15	<0.001	<0.0005	0.00015
Lyavlyakan	120-II	slag	512	<0.001	0.01	0.015	0.02	<0.001	0.0003	0.0002
Besh Bulak		ore	586	<0.001	0.0003	0.3	0.015	<0.001	<0.0005	0.0002

Area	Site	Material	№	Bi	Mo	Ba	Sr	W	Sn	Be
Besh Bulak		ore	587	<0.001	<0.0001	0.1	0.01	<0.001	<0.0005	0.00007
Ayakagitma	10	slag	504	<0.001	0.0015	0.2	0.05	<0.001	0.0003	0.0003
Ayakagitma	17	ore	533	<0.001	0.001	3	0.3	<0.001	0.0003	0.00015
Ayakagitma	10A	slag	490	<0.001	0.003	0.15	0.1	<0.001	0.0003	0.0005
Ayakagitma	10	slag	503	<0.001	0.002	0.2	0.05	<0.001	0.0007	0.0002
Ayakagitma	10A	slag	526	<0.001	0.0015	0.2	0.05	<0.001	0.0015	0.0002
Ayakagitma	10	slag	524	<0.001	0.002	0.3	0.05	<0.001	0.0015	0.0002
Lyavlyakan	121-I	slag	516	<0.001	0.0007	0.5	0.01	<0.001	0.0003	0.00015
Lyavlyakan	26a	slag	518	<0.001	0.0007	0.3	0.1	<0.001	0.0003	0.00015
Lyavlyakan	120-II	slag	513	<0.001	0.005	0.03	0.02	<0.001	0.0003	0.0005
Besh Bulak	10. area 5	ore	549	<0.001	0.00015	0.15	0.01	<0.001	<0.0005	0.0001
Lyavlyakan	121-I	slag	517	<0.001	0.0007	0.5	0.07	<0.001	0.0005	0.00015
Lyavlyakan	26a	slag	519	<0.001	0.0007	0.2	0.05	<0.001	0.0003	0.00015
Lyavlyakan	120-IX	slag	514	<0.001	0.003	0.07	0.1	<0.001	0.001	0.0003
Lyavlyakan	120-IX	slag	510	<0.001	0.001	0.1	0.03	<0.001	0.0003	0.0003
Lyavlyakan	338-I	slag	508	<0.001	0.00015	0.1	0.02	<0.001	0.0005	0.00015
Lyavlyakan	26	slag	511	0.003	0.002	0.3	0.03	<0.001	0.0007	0.0002
Lyavlyakan	121-I	slag	515	<0.001	0.002	0.2	0.03	<0.001	0.0015	0.0001
Ayakagitma	187	slag	531a	<0.001	0.002	0.5	0.02	<0.001	<0.0005	0.0002
Lyavlyakan	338-I	slag	507	<0.001	0.0015	0.2	0.03	<0.001	0.001	0.00015
Ayakagitma	209	slag	491	<0.001	0.003	0.15	0.02	<0.001	<0.0005	0.0005
Ayakagitma	209	slag	527	<0.001	0.007	0.1	0.01	<0.001	<0.0005	0.00007
Besh Bulak	4. accum.1	slag	564	<0.001	0.0002	0.02	0.01	<0.001	0.0015	0.0001
Lyavlyakan	40	slag	523	<0.001	0.001	0.2	0.07	<0.001	0.001	0.00015
Ayakagitma	209	slag	492	<0.001	0.002	0.1	0.03	<0.001	<0.0005	0.0015
Ayakagitma		slag	525	0.0015	0.002	0.2	0.05	<0.001	0.001	0.0003
Ayakagitma	95B	slag	505	<0.001	0.005	1	0.5	<0.001	0.0003	0.0003
Lyavlyakan	94	slag	536	<0.001	0.0007	1	0.2	<0.001	0.0003	0.00015
Ayakagitma	187	slag	531	<0.001	0.002	0.7	0.2	<0.001	0.0015	0.00015
Ayakagitma	209	slag	528	<0.001	0.005	0.07	0.02	<0.001	<0.0005	0.0015
Lyavlyakan	120-IX	slag	509	<0.001	>0.1	0.015	0.01	<0.001	0.003	0.0002

Area	Site	Material	№	Bi	Mo	Ba	Sr	W	Sn	Be
Sensitivity of the analysis				Bi	Mo	Ba	Sr	W	Sn	Be
				0.001	0.0001	0.01	0.01	0.001	0.0005	0.00003

Tab. 12-9. Emission spectral analyses of slag and ore from the Kyzyl-Kum (%). The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.(contd.)

Area	Site	Material	№	Zr	Ga	Y	Yb
Ayakagitma	234	slag	483	0.003	0.0005	<0.001	0.00015
Ayakagitma	234	slag	484	0.003	0.0005	<0.001	0.0001
Ayakagitma	234	slag	486	0.0015	0.001	0.0015	0.0001
Ayakagitma	10	slag	502	0.007	<0.0005	0.005	0.0007
Ayakagitma	10A	slag	489	0.01	0.0005	0.007	0.0007
Ayakagitma	224	slag	500	0.01	0.001	0.007	0.0005
Ayakagitma	239	slag	497	0.007	0.0015	0.002	0.0002
Ayakagitma	239	slag	495	0.01	0.001	0.003	0.0003
Ayakagitma	10A	slag	487	0.007	0.0005	0.005	0.0005
Ayakagitma	224	slag	498	0.01	0.001	0.01	0.0007
Ayakagitma	224	slag	499	0.01	0.001	0.01	0.0005
Besh Bulak	4	slag	576	0.015	0.0015	0.005	0.0003
Besh Bulak	1. area 8	slag	582	0.01	<0.0005	0.01	0.001
Besh Bulak	4. accum.1	slag	565	0.007	0.0015	0.01	0.0005
Besh Bulak	4. accum.2	slag	574	0.015	0.001	0.007	0.0005
Besh Bulak	4. accum.1	slag	563	0.003	0.0015	0.015	0.0015
Besh Bulak	2. accum.5	slag	579	0.01	0.001	0.015	0.0015
Besh Bulak	10. area 5	slag	548	0.01	0.001	0.015	0.0007
Besh Bulak	3	slag	541	0.007	0.0005	0.015	0.0015
Besh Bulak	4. accum.1	slag	567	0.01	0.001	0.015	0.001
Besh Bulak	1. area 7	slag	592	<0.001	<0.0005	0.007	0.0007
Besh Bulak	3	slag	543	0.01	0.0005	0.015	0.001
Besh Bulak	1. area 8	slag	580	0.01	0.001	0.01	0.0007
Besh Bulak	1. area 8	slag	584	0.01	0.001	0.015	0.001
Besh Bulak	4. accum.2	slag	572	0.015	0.001	0.007	0.0007
Besh Bulak	4	slag	575	0.01	0.001	0.02	0.0015
Besh Bulak	2. accum.5	slag	577	0.003	0.0015	0.005	0.0003
Besh Bulak	1. area 1	slag	588	0.03	0.001	0.015	0.001
Besh Bulak	1. area 7	slag	590	0.015	0.0015	0.005	0.0003
Besh Bulak	4. accum.3	slag	569	0.015	0.001	0.015	0.0015

Area	Site	Material	№	Zr	Ga	Y	Yb
Besh Bulak	4. accum.2	slag	571	0.01	0.001	0.007	0.0003
Besh Bulak	10. area 5	slag	546	0.01	0.001	0.015	0.0015
Besh Bulak	4. accum.3	slag	570	0.01	0.001	0.01	0.0007
Besh Bulak	10. area 10	ore	550	0.007	0.001	0.01	0.001
Besh Bulak	1. area 8	slag	581	0.01	0.0015	0.007	0.0005
Besh Bulak	3	slag	542	0.007	0.0005	0.01	0.0015
Besh Bulak	1. area 7	slag	591	0.015	0.0015	0.003	0.0002
Besh Bulak	4. accum.2	slag	573	0.01	0.001	0.07	0.0007
Besh Bulak	1. area 8	slag	583	0.01	0.0015	0.02	0.002
Besh Bulak	10. area 5	slag	547	0.015	0.0005	0.015	0.001
Besh Bulak	1	ore	585	0.001	0.001	>0.03	>0.003
Besh Bulak	1. area 7	slag	589	0.015	0.001	0.01	0.0007
Besh Bulak	3	slag	545	0.01	0.001	0.03	0.002
Besh Bulak	3	slag	544	0.01	0.001	0.015	0.0015
Besh Bulak	2. accum.1	slag	562	0.003	0.0015	0.003	0.00015
Besh Bulak		slag	555	0.01	0.001	0.015	0.0015
Besh Bulak	2. area 1	slag	553	0.007	0.001	0.02	0.0015
Besh Bulak	2. accum.1	slag	560	0.01	0.0015	0.015	0.002
Besh Bulak	2. accum.1	slag	558	0.01	0.001	0.015	0.0015
Besh Bulak	2. area 1	slag	551	0.007	0.001	0.01	0.0015
Besh Bulak	2. accum.1	slag	557	0.01	0.001	0.015	0.0015
Besh Bulak	2. accum.1	slag	559	0.01	0.001	0.015	0.0015
Besh Bulak	2. area 1	slag	556	0.01	0.001	0.01	0.0015
Besh Bulak	2. area 1	slag	554	0.01	0.001	0.01	0.001
Besh Bulak	2. area 1	slag	552	0.015	0.001	>0.03	>0.003
Lyavlyakan	131-I.II	slag	521	0.007	<0.0005	0.001	0.0001
Lyavlyakan	7	slag	522	0.015	0.001	0.002	0.0001
Lyavlyakan	26-V	slag	520	0.01	0.001	0.001	0.0001
Lyavlyakan	322	slag	538	0.015	0.001	0.01	0.001
Lyavlyakan	120-II	slag	512	0.001	0.0005	0.005	0.0005
Besh Bulak		ore	586	nd	<0.0005	0.03	0.0015

Area	Site	Material	№	Zr	Ga	Y	Yb
Besh Bulak		ore	587	nd	<0.0005	0.005	0.0002
Ayakagitma	10	slag	504	0.005	0.0005	0.007	0.0007
Ayakagitma	17	ore	533	0.007	0.0015	0.001	<0.0001
Ayakagitma	10A	slag	490	nd	0.001	0.01	0.0007
Ayakagitma	10	slag	503	0.007	0.001	0.005	0.0005
Ayakagitma	10A	slag	526	0.007	0.001	0.005	0.0005
Ayakagitma	10	slag	524	0.01	0.0005	0.01	0.001
Lyavlyakan	121-I	slag	516	0.007	<0.0005	0.0015	0.00015
Lyavlyakan	26a	slag	518	0.01	0.001	0.001	0.0001
Lyavlyakan	120-II	slag	513	0.005	0.0005	0.015	0.0015
Besh Bulak	10. area 5	ore	549	0.01	0.0005	0.01	0.0007
Lyavlyakan	121-I	slag	517	0.01	0.001	0.0015	0.00015
Lyavlyakan	26a	slag	519	0.015	0.001	0.0015	0.0001
Lyavlyakan	120-IX	slag	514	0.01	0.001	0.02	0.0015
Lyavlyakan	120-IX	slag	510	0.01	0.0015	0.007	0.0005
Lyavlyakan	338-I	slag	508	0.01	0.001	<0.001	0.0001
Lyavlyakan	26	slag	511	0.015	0.001	0.002	0.0002
Lyavlyakan	121-I	slag	515	0.01	0.0015	0.035	0.00015
Ayakagitma	187	slag	531a	0.01	0.0005	0.002	0.0002
Lyavlyakan	338-I	slag	507	0.005	0.001	0.0015	0.00015
Ayakagitma	209	slag	491	0.01	0.001	0.005	0.0003
Ayakagitma	209	slag	527	0.01	0.0015	0.001	0.00015
Besh Bulak	4. accum.1	slag	564	0.005	<0.0005	<0.001	0.00015
Lyavlyakan	40	slag	523	0.007	0.001	0.002	0.0002
Ayakagitma	209	slag	492	0.015	0.001	0.003	0.0003
Ayakagitma		slag	525	0.01	0.0005	0.007	0.0007
Ayakagitma	95B	slag	505	0.02	0.0005	0.03	0.003
Lyavlyakan	94	slag	536	0.005	0.0005	0.003	0.0002
Ayakagitma	187	slag	531	0.007	0.001	0.002	0.0002
Ayakagitma	209	slag	528	0.015	0.0015	0.003	0.0003
Lyavlyakan	120-IX	slag	509	nd	<0.0005	0.003	0.00015

Area	**Site**	**Material**	**№**	**Zr**	**Ga**	**Y**	**Yb**
Sensitivity of the analysis				Zr	Ga	Y	Yb
				0.001	0.0005	0.001	0.0001

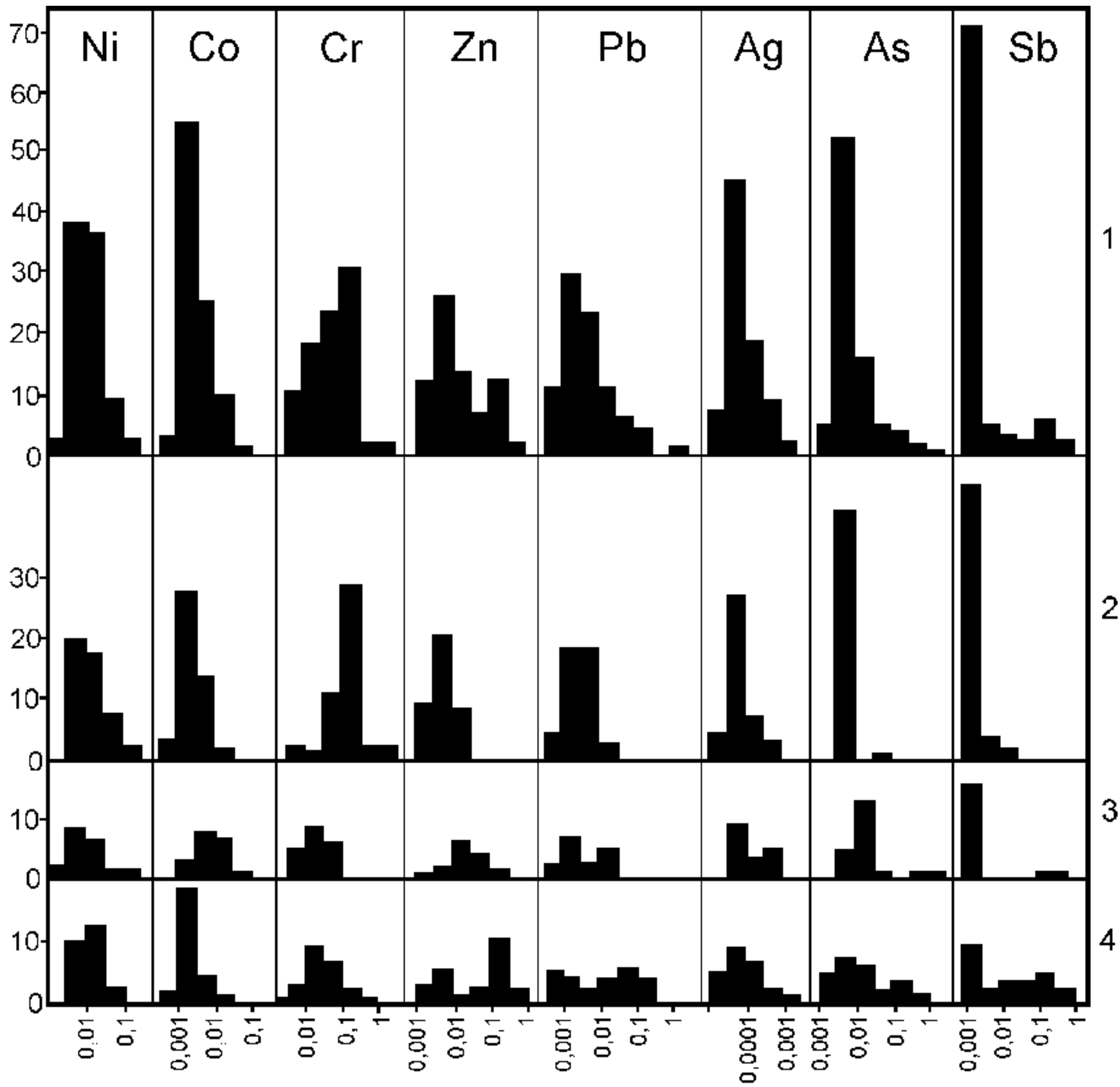


FIG. 12-10. DIAGRAMS OF DISTRIBUTION OF TRACE-ELEMENTS' CONCENTRATIONS (%) IN SLAG: 1 – COLLECTION OF THE KYZYL-KUM; 2 – BESH-BULAK; 3 – LYAVLYAKAN; 4 – AYAKAGITMA.

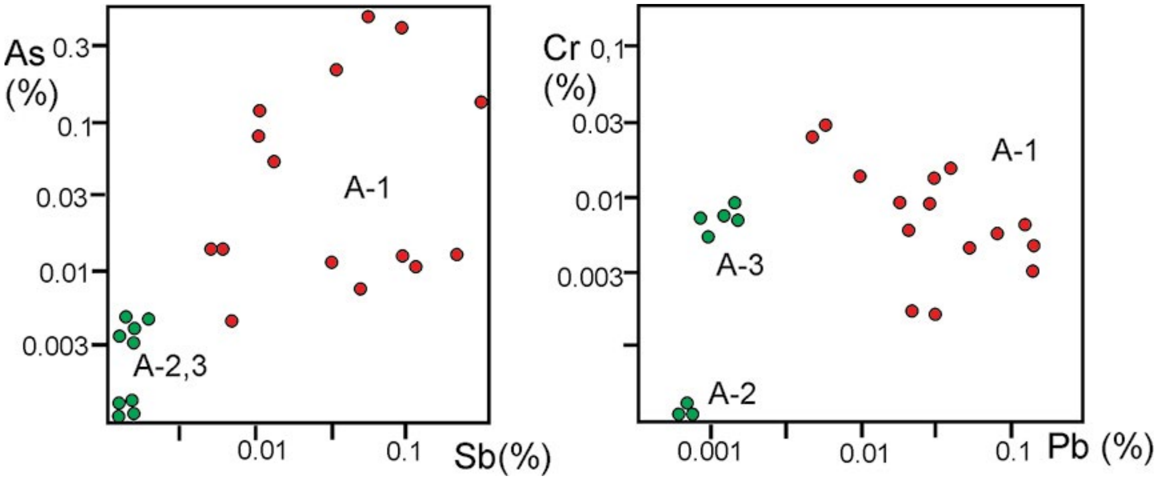


FIG. 12-11. CORRELATION OF CONCENTRATIONS: 1 – AS-SB (AYAKAGITMA); 2 – CR-PB (AYAKAGITMA) (%).

Tab. 12-12. Correlation of chemical and mineralogical groups of slag over sites in the Kyzyl-Kum.

Chemical group / **Mineralogical group**	**A-1**	**A-2**	**A-3**	**B-1**	**B-2**	**L-1**	**L-2**
I	4	1	1	4	1		3
II	5		7	28	8	6	3
III	2	1	1				
IV	1			4	1		1
VII		2		3		2	3
Total	**12**	**4**	**9**	**39**	**10**	**8**	**10**

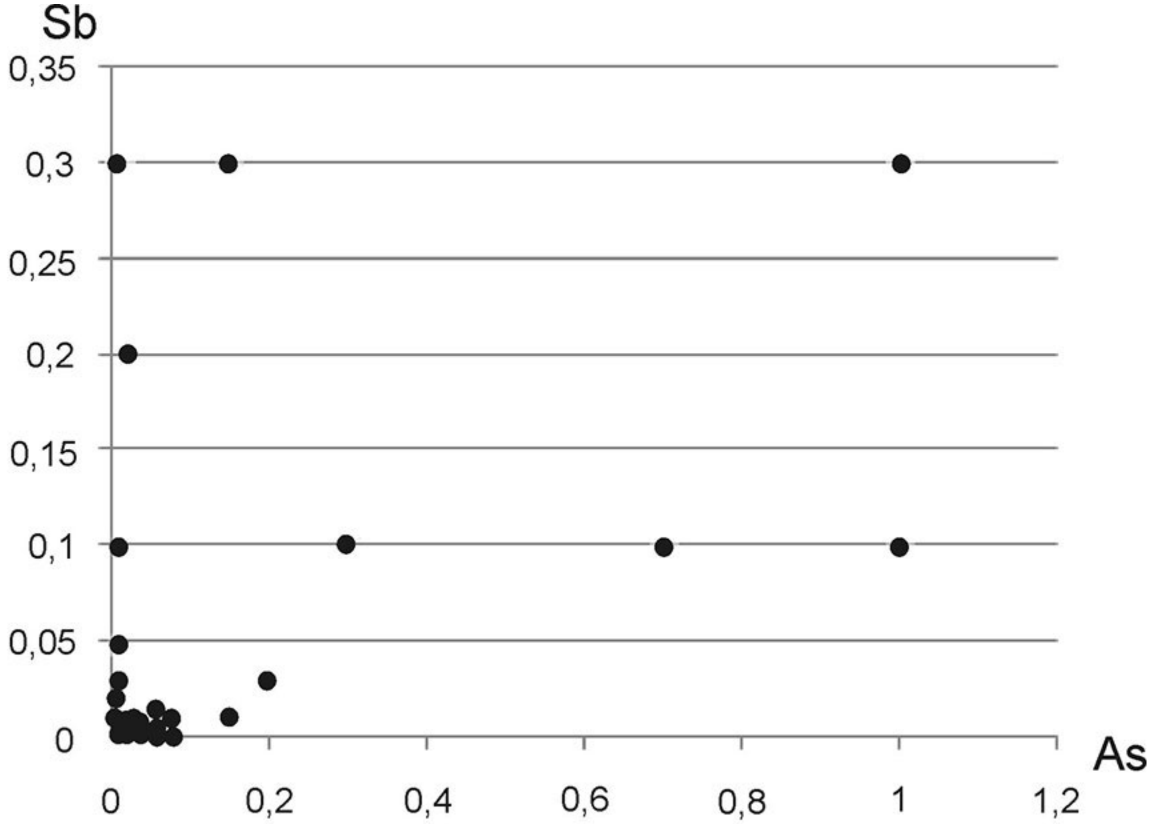


FIG. 12-13. CORRELATION OF CONCENTRATIONS AS-SB IN SLAG OF THE KYZYL-KUM (%).

Chapter 13.
The Problem of Iron in the Bronze Age of Northern Eurasia

It is obvious that technological innovations of the Late Bronze Age brought to a new qualitative jump in the metallurgical production, to the beginning of iron metallurgy. Its origins are one of the most important problems in archaeometallurgical studies. And, this problem is universal; it is very relevant in many areas. The matter is that very often iron objects are present on sites of the Bronze Age. Sometimes ones explain it by meteoric origins of this iron, sometimes scholars simply shut their eyes to its presence, believing that it was a casual penetration of a late object into the earlier layer.

In the Near East the earliest iron objects are known since 5000 BC (Sammara in Mesopotamia and Sialk in Iran). Then, in the 4th – 2nd millennia the number of iron objects gradually increased, but their number was insignificant, especially against the background of copper objects. In Anatolia iron appeared in the 3rd millennium BC. There are six iron objects from the Early Bronze Age layers of Alaca Höyük (Yalcin 1999, p. 177, 184). But we know already 74 iron objects in the Near East dated to the Late Bronze Age (Waldbaum 1980, p. 69-77). The geography of these finds also extends. They are known not only in Anatolia, but also in other regions, for example, in Colchis (Yalcin 1999, p. 177). But during all this time iron remained a rarity and was very expensive. Iron was 35-40 times more expensive than silver. Usually, ornaments and cultic objects were manufactured of this metal. Iron finds are, as a rule, connected with a prestigious context. We know from the Hittite sources a royal throne and a scepter made of iron which had been presented by 'a man from Purushanda' to the Hittite ruler Anitta. A dagger with iron blade has been found in the tomb of Tutankhamun. A dagger from the royal tomb at Alaca Höyük had a gold-covered hilt. At last, the Hittite king Hattušili III wrote to Shalmaneser about his present, an iron blade. The iron trade was widespread in Anatolia already in the period of the Assyrian trade colonies, and already then iron was precious metal. Merchants changed it for gold and silver but not for copper. 8 shekels of gold were insufficiently to exchange for 1 shekels of iron. Other texts claim that iron was 40 times more expensive than silver and its trade was strictly controlled. The last belongs already to the Hittite period when iron acted as a symbol of monarchy, and its mentions in texts are usually present in the context of mentions of the ruler[1] (Ivanov 1983, p. 91-96; Muhly 1980, p. 37, 50; Waldbaum 1980, p. 76, 76; Yalcin 1999, p. 182; Muhly *et al.* 1985, p. 73; Giorgadze 1988, p. 239). Only since the 18th century BC iron began being used widely for weapon production. One of the texts mentions 400 units of the iron weapon (Yalcin 1999, p. 182). Probably, just from this time a certain specialization in this field began as in descriptions of the Hittite festivals iron workers were mentioned, although it is unclear whether they were smelters or smiths. However there is one more sign indicating the growth of iron production. In the texts of this period gold and silver are measured in shekels, and iron and copper in minas[2] (Yalcin 1999, p. 183). The development of specialization in ironworks was promoted by one more circumstance. Iron in the antiquity was not casted; it was forged as the casting appeared at a very late stage. This operation required large skill, and among artifacts quite complicated articles are present that stimulated the appearance of the specialized blacksmiths. In Anatolia it happened in the 16th century BC when the blacksmiths started being mentioned in the texts, and in Mesopotamia it did since the 12th – 11th centuries BC (Muhly *et al.* 1985, p. 80; Giorgadze 1988, p. 242).

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[1] There is an attempt to challenge this popular belief in a relative rarity of iron objects and their high cost. So, G. Giorgadze disproves the opinion on limited use and production of iron supposing that it was used also for domestic needs. But his point of view is based mainly on data from the Boğazköy archive, richest with mentions of iron. And it is already the second half of the 2nd millennium BC (Giorgadze 1988, p. 239, 248). Calculations of mentions of various metals in written sources of the Hittite time, and the accounting of weight of objects listed in inventory lists unambiguously specifies that the share of iron among other metals was scanty, comparable only with that of gold, but incomparably smaller, than the share of silver. And it is senseless at all to compare this share with copper and bronze objects (Müller-Karpe 2000, S. 114, 115).

[2] 1 mina corresponds to 505 g, 1 shekel does to 8.4 g (Giorgadze 1988, p. 247).

In addition, up to the 12th century BC traces of smelting iron ores are lacking. The mass distribution of iron objects is dated to the same period, and they are already presented not only by ornaments and small objects, but also by relatively large weapons. Thus, the qualitative changes in the iron production took place in this period, and it is considered in some areas as the beginning of the Early Iron Age. The observation of J.D. Muhly, is very interesting, who wrote that the widespread diffusion of iron in the Near East coincided with the migration of the Dorians and the "Sea peoples" (Muhly 1980, p. 51). For example, in the cemetery of Karagunduz (11th – 10th centuries BC) already hundreds iron objects have been found including ornaments, but more often they are weapon and tools. Since the 8th century BC iron becomes the basic metal (Yalcin 1999, p. 182, 185). And, despite the early evidences on iron production in Anatolia, the contribution of the Hittite in the spreading of appropriate technologies in the late 2nd millennium BC is doubtful (Muhly *et al.* 1985, p. 82).

In Mesopotamia a large quantity of iron appears also only in the 7th century BC and the active development of the production begins since the middle of the 1st millennium BC. In Egypt in the 7th century BC Greek colonists appeared, who brought iron technologies, but for a long time the production was developing poorly because of wood deficiency. Later, in the 4th century BC, the iron production began in Nubia (Amborn 1976, S. 49-51, 57, 63, 66, 69).

In Greece the earliest iron object (a ring) is dated to the 17th century BC. Rare Mycenaean objects of the 15th – 13th centuries BC, mainly ornaments, always contain nickel that is considered as a sign of their meteoric origins, but ores with nickel are also known here, besides, in many objects of the 13th – 12th centuries BC the nickel is absent. Iron appears in large quantity in the 12th century BC, but evidences on its smelting appear only since the 9th century BC, and the rapid development is supposed in the 9th – 8th centuries BC, but evidences on this development are absent too, but after that time the technology appears in a quite developed form (Varoufakis 1982, p. 315-317).

There were similar processes in the Western Mediterranean. On sites of the Late Bronze Age in Iberia of the pre-Orientalising period (i.e. before the 8th century BC) iron with the low nickel content is occasionally present, therefore it is supposed that this iron was not of the meteoric origins and it was imported. The true iron metallurgy begins here only since the coming of the Phoenicians (Hunt Ortiz 2003, p. 356, 358).

In Central and Northern Europe in the context of the 2nd millennium BC only a few iron objects are known, and it is supposed that it was import (Pleiner 1980, p. 376).

This relative synchronism in distribution of true iron metallurgy shows that the early iron was not connected with these technologies. This situation allows us to raise a question: what was a reason of these changes and what caused so insignificant scales of iron production during previous epochs? In some works it is supposed that iron in the ancient Near East was smelted from iron ore, but smelters were not able to really control the process yet. Just it caused the high cost of this metal and its relative rarity. However the purposeful production of iron is very doubtful. Iron ores are widespread much more widely than copper ores. Therefore if the technology of iron smelting would exist, for example, in the 3rd millennium BC, it quickly enough would gain its distribution that we do not see up to the 12th century BC. It would occur for purely economic reasons. Already in the 7th century BC when technologies of iron smelting were really known, in Greece 12 kg iron cost as 6 g silver, i.e. iron was 2000 times cheaper (Muhly 1980, p. 53). Thus, in comparison with the early prices of iron the change of the ratio in prices is by 80 000 times! If there was even one chance to develop the existed technology of iron smelting, it would be done.

It is also impossible to assume a variant of manufacturing of articles from native iron which is in occurrence in the nature rather as an exception. And, in some instances the ancient iron contains nickel. The last causes interest in the light of one more hypothesis on its nature.

This hypothesis may be reduced to that this iron had meteoric origins. It as though, may be supported with Hittite and Egyptian texts where iron is designated as “metal of the sky”, and also with the analyses of ancient objects which revealed in many of them the higher nickel content, a sign of their meteoric origins (Waldbaum 1980). Meteoric iron contains 4-10% nickel, and terrestrial and metallurgical iron does less, 1-2%. It was simple to forge this iron: at low nickel concentrations the meteoric iron is easily forged with intermediate annealing only in some instances, but at high nickel concentrations hot forging is already necessary (Tylecote 1987, p. 99, 103). The last is rather important as difficulties in the ironworks are connected not so much with the problem of iron smelting, as with its subsequent forging. But at early stages there were many problems with the nickel-containing iron too. Eskimo, for example, were making small knives from meteoric iron, but could not make long articles (Coghlan 1956, p. 29).

It is necessary to take into account one more circumstance. The quantity of iron objects in the LBA of the Near East given above is not so small taking into account that iron keeps much worse than copper in archaeological layers. Besides, an absolutely insignificant share of objects of any type circulating in the ancient time gets into the archaeological collections. Therefore, have we to accept a hypothesis about the active search of meteorites in the Near East, more precisely, in some selected areas of the Near East? Metal iron is in general rare. There are less finds of the meteoric iron in Europe than in America and Siberia, and the native iron is known in large quantities only in Greenland. Do we have to think that there was another situation in the Near East? Therefore a hypothesis has been suggested that as iron appeared in the Bronze Age it was connected not with these sources but with the copper smelting, especially as there is terrestrial iron with nickel impurity (Tylecote 1987, p. 96, 98). However not all ancient objects contain the higher concentration of nickel. In particular, in one dagger from Alaca Höyük the impurity of nickel is absent that point to its terrestrial origins. Besides, the meteoric iron contains usually from 6 to 20% nickel, and its contents in all objects of this site are less than 2-3%. Therefore, all objects of this Anatolian settlement of the Early Bronze Age were made from terrestrial iron. It is supposed that it was produced from native iron or ore. It is impossible to tell something more definitely about this as there are no relevant analytical data. There is no confidence even concerning the nature of many iron objects. In particular, it is supposed that the well-known iron mace-head from Troy II is made from a piece of iron oxide (Yalcin 1999, p. 180).

In general, it is difficult to distinguish terrestrial and meteoric iron. This problem is difficult for the majority of Near Eastern objects that being rare finds are of great museum value and are inaccessible for the analyses. However rare analyses, for example, of the objects from the same Alaca Höyük (2nd millennium BC) have shown presence of slag inclusions; therefore they could be produced from ore. But there is no confidence also in this case as these inclusions could appear in the process of forging. Similar inclusions have been also found in objects from Boğazköy (there are also two finds of slag), and also from some other sites that allowed to assume the iron ore smelting since the 14th century BC, therefore the iron production sharply increased. Written sources mention, for example, an iron basin (or a vessel) weighing 90 minas (45 kg) (Yalcin 1999, p. 181, 182, 184). The first reliable data on extracting iron from iron ore come from the second half of the 2nd millennium BC, but finds of furnaces and slag of this time are absent. The earliest slag is found in the archaic settlement of Miletus (Yalcin 1999, p. 185; Muhly *et al.* 1985, p. 80).

However, the connection of even higher concentrations of nickel with meteorites is not unconditional. Mycenaean iron objects contain from 1-5 to 10-77% nickel. And, a corresponding deposit is situated on Euboea Island. Therefore iron cannot be called “meteoric” basing on presence of this impurity only (Muhly *et al.* 1985, p. 74).

There is one more curious fact. As a rule, Anatolian iron contains a little nickel. Its content in iron of Mesopotamia and Egypt is more. For example, one object from Gerzeh dated to 3500 BC contains 7.5% nickel. Therefore it is quite probable that it has the meteoric origins (Yalcin 1999, p. 184).

In Egypt the early finds of iron usually contain nickel. Studies of the early set of tube-shaped beads from Gerzeh (3300-3200 BC) have shown that they were forged from meteoric iron (Rehren *et al.* 2013; Jonson *et al.* 2013). But earlier analyses showed copper impurity and smaller quantity of nickel in this iron. The problem is that these objects are completely oxidized and just this oxide was analyzed which has another content of nickel and the copper inclusions, passed into it from a copper harpoon found nearby (Jonson *et al.* 2013). Therefore the old analyses are not quite reliable.

Therefore it is hard to say whether other similar finds from the early context were of the meteoric or metallurgical origins. One of such finds is a cult object for the opening of the mouth ritual in the temple of Menkaure in Giza, the mid-3rd millennium BC, where nickel in iron is absent, but there is copper impurity. Such iron is present also in sites relating to the period of the 6th dynasty (2423-2263 BC). The quantity of iron objects increases in the Amarna period (14th century BC). Nevertheless, sometimes it is supposed that technologies of iron smelting in Egypt were unknown as there are even no reliable terms connected with the iron production. And the presence of iron may be explained by contacts with Asia Minor (Amborn 1976, S. 49-51, 57). Nevertheless, the iron metalworking existed in Egypt early enough. Already in Tutankhamun's tomb 19 iron objects have been found, and judging from their typology they were obviously made in Egypt (Snodgrass 1980, p. 365).

The traditional connection of iron production with Anatolia and lower nickel concentration in the Anatolian iron are not, apparently, casual. The matter is that the iron smelted from ore in some instances can contain nickel. Piaskovski (1988)[3] believes that river sands of Northern Anatolia with high nickel content could be a source of iron smelted from ore, and the iron of the Chalybes described by Aristotle originated from there (Yalcin 1999, p. 184). The iron of the Chalybes looked like silver and was not oxidized. These people probably specialized on the iron production. The written sources emphasize that they were not engaged in agriculture and did not graze cattle (Kuparadze *et al.* 2008, p. 249, 250). The Chalybes and their iron had been described in the Hellenistic source "De mirabilibus auscultationibus", and, apparently, this source is attributed to Aristotle mistakenly. But it must be kept in mind that Piaskovski's opinion that this iron had to contain considerable impurity of nickel is based not on analytical data, but on parallels with iron objects in Europe dated to the 1st millennium BC (Muhly *et al.* 1985, p. 74).

The connection of iron production with Anatolia is emphasized also by that in Anatolia of the Hittite period iron was often used for household articles while in other areas of the Near East its used was limited by decorative and prestigious objects. If to judge from texts found in Mari, iron was produced in Anatolia (Muhly *et al.* 1985, p. 73, 75). Written sources of the Old Assyrian period mention Cappadocia as an area from where iron was imported to Babylonia (Reiter 1999, p. 168).

Besides, there are clear descriptions indicating artificial production of iron and large complexity of this process. In particular, the letter of Hattusilis III to Shalmanaser contains: "As for good iron about which you wrote to me, there is no good iron in my storehouse in Kizzuwatna. I wrote to you that now is bad time for production of good iron. I have given orders and they are smelting good iron, but up until now they have not finished. When they have finished I will send it to you. Meanwhile I am sending to you an iron blade (a dagger?)". From this fragment it also follows that iron was produced not in the capital, and its production was under control of the ruler. It is not excluded that he demanded that all made iron was handed over (Yalcin 1999, p. 183).

For this reason the majority of scholars assume a considerable part of the meteoritic iron among the ancient objects in the Near East, but suppose that there was some technology of extracting iron from iron ores, whose nature is unclear now (Waldbaum 1980, p. 80, 88). Charles believes that ancient iron was extracted as a result

[3] The opinion of this author is given from another publication (Yalcin 1999).

of smelting copper ores with the use of iron-containing fluxes. As the temperatures increased and the balance of CO/CO_2 changed, the production of iron also grew (Charles 1980, p. 166; Charles 1992, p. 24, 25).

From the above given correspondence of Hattusilis and Shalmanaser it is clear that there was some “good iron”, and probably this is not the matter of its quality only. It is possible though not confirmed reliably that the Hittites mean steel as this “good iron”. From the texts it is possible to understand that they knew the carbonized iron. Together with the cuneiform term AN.BAR there was a term AN.BAR.SIG. Another designation for steel (*habalkinu*) is known from the Amarna tablets. In the letter of the Mittanian king Tushratta to the pharaoh Amenhotep III (1413-1375 BC) daggers from iron and steel are distinguished. Probably only since the Hittite time there are first evidences on the meteoric iron which actually absent in earlier archaeological sources. Probably the term AN.BAR designated terrestrial iron, and AN.BAR.GE_6 did the meteoric one. However, the term “iron of the sky” not always designated the meteoric iron as the sky can be described in texts as iron, for example “the iron sky”. Thus, it is a question of the color. There was, probably, a distinction of metallurgical and meteoric iron, good and white iron, and it is absolutely unclear what was understood under the last term (Yalcin 1999, p. 183, 184). At the same time, there were designations for the iron taken from the furnace: AN.BAR ŠA GUNNI. In one text AN.BAR ŠA GUNNI and AN.BAR.SIG_5 are distinguished, the latter means “good, pure iron” (Giorgadze 1988, p. 244). Another text mentions 22 pieces of iron taken directly from the furnace. Giorgadze agrees with the majority of scholars considering AN.BAR as the term for designation of terrestrial iron, and AN.BAR.GE_6 as the term for meteoric iron. The last term means more likely “black iron” but it is often meet with the term AN.BAR nepišaš (“sky iron”), therefore its consideration as meteoric is probably true[4]. But if the specification is absent and the term AN.BAR (“iron”) is used, the text means the terrestrial iron (Giorgadze 1988, p. 243, 244). Distinction of “good iron” (or steel?) and “iron from the furnace” as though specifies that the first was not produced at direct smelting of ore, although in this case only its quality could be meant. “Black iron” was worse than “pure iron”, but it was better than “iron” (Giorgadze 1988, p. 245).

There is one more paradox. If to be based on the texts where AN.BAR is the terrestrial iron and AN.BAR.GE6 means the meteoric iron, the smelted was known earlier, but it is only a theoretical opportunity. This distinction is present already in the epos about Lugalbanda. The epos reflects events of the Early Dynastic 2 period but it reached us in texts of the Old Babylon period, therefore in this case it can be only the reflection of later situation (Muhly *et al.* 1985, p. 75). At the same time, we may assume that the use of meteoric iron became possible because metallurgists were already familiar with metallurgical iron. One more fact can testify well this assumption. In Mesopotamia only two artifacts from the context of the 3rd millennium BC in Uruk and Ur of the ED2 period contain nickel. Therefore it is supposed that this iron could be meteoric. Other things of this time contain no nickel and made probably from the terrestrial smelted iron. Contrary to it, Russian scholar A.A. Vaiman believed that the term AN designated the meteoric iron, and AN.BAR was already a later modification specifying the beginning of smelting (Muhly *et al.* 1985, p. 75). But even it demonstrate the early knowledge of iron metallurgy in the Near East.

Steel appeared since the 2nd millennium BC but technology of its production is also unclear. Nevertheless, since 1200 BC the steel widely spread in many areas (Muhly *et al.* 1985, p. 81). According to ancient Greeks, inventors of steel were the Chalybes living in the south-east of the Black Sea and having various relations with the Hittites, Mitannians and Urarteans. Steel, in principle, can be produced in two ways: it was possible to smelt it from ore and also to carbonize iron and quench it quickly. In the 1st millennium BC both of these ways were used (Yalcin 1999, by p. 185). Later, since the end of this millennium and in the Middle Ages in Iran, India and Central Asia for production of steel two ways were used: Damascus (alloying in a crucible of high-carbonaceous and low-carbonaceous iron and manufacturing of steel with a characteristic Damascus

[4] The same comparison can be made also on later Abkhazian sources which supports this version (see Ardzinba 1988, p. 270, 271).

pattern) and Indian (heating of iron with an organic material and slow cooling) (Feuerbach *et al.* 1998). However it is very doubtful that any of these ways was used in Anatolia in antiquity.

There are very limited analytical data confirming the presence of early metallurgical iron in the Eastern Mediterranean (Muhly *et al.* 1985, p. 76, 78, 79).

One studied sample have been found in Boğazköy in Anatolia. It is supposed that it is speiss (metal arsenide) as there is a layer of iron sulfide and iron arsenide in the sample, with inclusions of silicate slag. Muhly and coauthors reconstructed process as follows. A smelter used arsenopyrite or another mineral containing iron, sulfur and arsenic for the smelting. As a result of smelting iron on the bottom formed, and iron sulfide with arsenic did above it. The studied phase should be even above being covered with slag. The studied material could not be malleable. In North-Western Turkey there is an iron deposit with higher contents of arsenic. However it is remote from Boğazköy, and I am not sure that this field can be considered as a source of this smelting. The second find from Boğazköy is an axe handle with perlite inclusions. At slow cooling perlite is formed and contains also a phase with carbon. The edge of the axe is more carbonized. But it is possible it everything was caused by the longer duration of forging operations that led to this effect, and we should not see signs of purposeful process of steel production here. From Alaca Höyük three things have been studied. The first is presented by a point. The ferrite structure with perlite inclusions is recorded in the metal. There are small inclusions of slag. All these signs are typical of the blast-furnace iron. An object of iron and arsenic has been found in Tiryns in the layer of the Late Helladic III period. But its size is small, and Kilian believes that it is the speiss too, instead of the metal produced for manufacturing of articles. From these data Muhly and coauthors drew the following conclusions. Ancient metallurgists smelted iron probably from arsenopyrite. The sample of speiss shows that Hittites could not control the smelting process normally. They had no sufficient skills and were not familiar with the normal carburizing.

More disputable data on early metallurgy of iron come from the Western Mediterranean. It is supposed that already in the Middle Bronze Age of Iberia there were attempts to smelt iron ore (settlements of El Trastejon and Solana del Castillo de Alange) as wüstite and fayalite have been found in slag of this period (Hunt Ortiz, 2003, p. 334). But these minerals are characteristic also of smelting of copper ores, in particular chalcopyrite. Therefore this ground is insignificant although the low content of copper (32 and 126 ppm) is really strange for copper smelting. However slag is heterogeneous, probably additional analyses are necessary.

However some authors believes that despite the presence of a series of iron objects in Iberia in the early 1st millennium BC, even during this period traces of smelting of iron ore are absent. Iron was imported from the Eastern Mediterranean but the articles were manufactured in Iberia, which is demonstrated by local forms of these objects. Smelting of ores appears together with the Phoenician colonies in the 8th century BC in the Orientalising period which is marked by slag finds. But slags of three settlements are different from this slag (Cerro del Villar, La Fonteta, Los Castillejos de Alcorrín). These slags and metal inclusions of these slags contain high contents of copper, arsenic and nickel. The authors also point to the identity of microstructures of this slag and microstructures of slag of iron smelting; therefore they explain it by origins from some polymetallic deposit. And similar slags are known in other areas of Spain and in Tuscany (Renzi *et al.* 2013, p. 179, 180, 184, 185). This case can be explained by the Ural material which will be discussed below.

Summing up the said above it is necessary to note that judging from the written sources and analytical data meteoric iron was known in the Near East. At the same time, the metallurgical iron smelted in furnaces was also used. The last had different quality, and we can even assume the knowledge of steel. Some terms are unclear, for example "white iron". But it must be kept in mind that in different texts different terms could be used for designation of the same type of production. Therefore it is essentially possible to speak about the knowledge of meteoric and metallurgical iron and steel. The conclusion about an aspiration to produce iron from arsenopyrite seems to me doubtful but we may discuss a possibility of the use of sulfide minerals containing iron and arsenic.

There is one more paradox in data of written sources. Some sources of the boundary of 3rd /2nd millennium BC allow us to assume that iron was a slag when copper was smelted (Ivanov 1983, p. 108).

However, not so much it as the logic of development of metallurgy forces to look for roots of production of the first iron objects in copper metallurgy. This assumption is based on that the copper ores often contain iron. Therefore according to some scientists the first iron objects were received incidentally from copper ore (Yalcin 1999, p. 185).

Samples of the Late Bronze Age slag of Northern Eurasia help to understand the essence of this technology. We have seen that there were many essential technological changes at this time. First of all, temperatures reached in the course of smelting sharply grew: the limit of 1300-1400 ºC became rather typical, but it is possible to assume also the temperature about 1500 ºC. Besides, at this time in many cultures active use of chalcopyrite began that is expressed in the appearance of the 6th mineralogical group. And metallurgical iron has been identified in many slags.

The studied slags of this mineralogical group very clearly indicate the nature of metallurgical reactions happened at the smelting of chalcopyrite. At the first stage it disintegrated into copper and iron sulfides. Having a low melting point the copper sulfides fused and separated from ore. The iron sulfides in process of burning out of sulfur and enrichment with oxygen turned into wüstite (FeO). And, the melting point of this new mineral sharply decreases that leads to appearance of fused structures which disintegrate in some cases into the fussed dendrites. In case of preservation of the reducing atmosphere, wüstite could turn into iron although not all it inclusions as its considerable part interacting with silicate components forms the fayalite slag. Thus, the quantity of iron produced in such smelting depends not only on the atmosphere, but also on the ratio of acid and basic oxides in the furnace charge.

As a result, conditions under which it was possible to produce some quantity of the reduced iron were created. Sometimes it led to alloys of copper with iron containing various proportions of these two components. It is reflected in the slag microstructure by inclusions of small prills of metal having optical characteristics, intermediate between those of copper and iron. E.N. Chernykh who analyzed metal of the Sosnovaya Maza hoard wrote about the use of copper containing considerable impurity of iron and smelted from chalcopyrite (Chernykh 1970, p. 19).

Excavation of furnaces at Mitterberg (Austria) allowed a conclusion to be drawn that since the Middle Bronze Age (that corresponds to the Late Bronze Age in the east) metallurgists smelted chalcopyrite. And, on the surface of rough copper a layer enriched with iron was formed (Preßlinger, Eibner 1987, S. 237-239).

In addition to this, some slags contain inclusions of the metal iron presented by molten prills too. The last does not mean at all that during the smelting the melting of iron was reached. Most likely, iron was reduced from the wüstite prills having the lower melting temperature. The second explanation is iron carburizing that sharply reduced the temperature of its melting.

Sample 66 from the settlement of Verkhnyaya Alabuga in the Tobol Basin is most remarkable. It is presented by a piece of reduced iron having dendritic anisotropic[5] structure (Fig. 11-22.). The formation of this structure was connected apparently with smelting of chalcopyrite. Chemical analysis has demonstrated the prevalence of pure iron with copper impurity, silicates and some other components (Tab. 11-19., Tab. 11-23.). The subsequent use of this iron required its further refining.

[5] Iron, as well as other metals, is isotropic but its polished sections demonstrate sometimes the effect of anisotropy.

Study of this sample by R. Schwab at the Institute of Archaeometallurgy of the Bergakademie Freiberg has shown that the iron is carbonized, and we may speak therefore about steel (Fig. 13-1.). Thus, the conditions for the iron carburizing could be sometimes created, and it was not a process of intentional steel production.

In small quantity the inclusion of reduced iron have been found in many samples of the Late Bronze Age: on several sites of the Ayakagitma and Besh-Bulak depressions in the south of Central Asia, on the settlements of Ust-Kenetay and Kara-Tyube in Eastern Kazakhstan, Korshunovo, Verkhnyaya Alabuga and Vishnyovka in Western Siberia, Novokizganovo, Yukalekulevo, Baygildino, Novobaryatino, Aitovo and Verkhnebikkuzino in Bashkiria, Shigonskoye and Popovo Ozero in the Volga region, Mosolovka on the Don, and Akshuben in the Kama region. It is remarkable that these finds are more often located in the northernmost part of the studied region where the smelting of chalcopyrite has been identified (Fig. 13-2.). Possibly, this explanation is also true for the Iberian slags discussed above.

Thus, in the Late Bronze Age in Northern Eurasia there were conditions for receiving iron as a by-product as a result of smelting of the sulfide copper ore that should stimulate searches of evidences of the use of this iron. There are some facts in favor of this. Many years ago B.N. Grakov noted the presence of iron artifacts in the Late Bronze Age layers (Grakov 1958, p. 8, 9). It is especially important that the iron artifacts are known also on settlements containing slags with iron inclusions, for example, the Mosolovka settlement (Fig. 13-3.) (Pryakhin 1996, p. 55). It seems to be very probable that there were also other similar finds but either the fact of their presence out of a customary context confused excavators, or their stratigraphical position was not too accurate. There are already many iron objects, mainly knives and daggers, in the Belozerka culture of the North Pontic area. In general, in the Late Bronze Age dozens objects are known in the Timber-Grave and Sabatinovka cultures and 33 objects in cultures of the Final Bronze Age from which 25 objects have been found on sites of the Belozerka and Bondarikha cultures. These finds are localized mostly in the Don area. It is supposed that it were already the first attempts of bloomery production (Koryakova *et al.* 2011, p. 11). Sometimes it is assumed that it was not the local production, and these articles were imported from the Balkan-Danube area (Nikitenko, 1998).

I think that in the case with Belozerka and Bondarikha cultures of the end of the Bronze Age we may speak about essentially different technological schemes of the iron production based on smelting of proper iron ores (we will discuss it in the following chapter). But earlier complexes can reflect the extraction of iron as a by-product when smelting copper ore. In the Donets Basin on the settlement of Pilipchatino 1 an iron ingot has been found in the layer of the 14th – 12th centuries BC near copper-smelting hearth. Its weight is 0.4 kg and it contains higher content of copper that is explained by the smelting of sulfide copper ore and a deviation from the temperature mode in a situation of a very long smelting (Tatarinov 1986, p. 36; 2003, p. 197).

All told about the situation in Northern Eurasia substantially reflects also that in the Near East. Probably a part of iron in the Near East was made really from meteorites. The etymology of terms for iron designation ("iron of the sky" of the Egyptians and "black iron of the sky" of the Hittites[6]) indicates it (Waldbaum 1980, p. 79) if color of the metal was not the cause of these terms. At the same time, the acceptance of nickel impurity as a marker for the meteoric iron (that is peculiar to very many Near Eastern objects) should be recognized as insufficiently reasonable. The nickel-containing iron could be made also at the smelting of copper ore. Theoretically it is, at first sight, impossible as in the Ni-Cu-Fe system the nickel passes completely into copper. However in more complicated systems with arsenic impurity the nickel can be shared between iron and copper. Besides, it is necessary to take into account that in metallurgical production individual chemical processes can be divided in space and time. Therefore the system Ni-Cu-Fe could not exist in its pure form. There are also experimental confirmations to it. In some cases nickel was shared equally between iron and copper (Tylecote 1981, p. 48).

[6] Above we have stated that it could reflect also the color characteristics. In general it was typical of ancient designations of metals (see Ivanov 1983).

The alloying of copper with arsenic took place in Anatolia and the Transcaucasia since the 4th millennium BC. On materials of the Sintashta metallurgy it is clearly visible that the alloying was carried out at the stage of ore smelting by some arsenic mineral with the high nickel content. The last component was necessary to keep arsenic in copper. And it was the only possibility to alloy copper with arsenic.

Therefore we may to assume the same way of alloying also in the Middle East. In this case the ratio of iron artifacts with nickel and without it does not indicate a ratio of meteoric and metallurgical iron; it indicates the ratio of alloyed and unalloyed metal; besides the iron without nickel could be a result of the complete passage of nickel into copper. The use of nickel-containing bronzes in the Near East is well known. The higher concentrations of nickel in ancient iron of this region are accompanied in some instances by higher concentrations of arsenic (Piaskowski, 1991, tab. 1). It should also remember that, as long as we discuss the smelting of chalcopyrite, sulfide copper ores are often strongly polluted with various impurities including arsenic and nickel.

There are also other evidences of the iron produced from the copper ores in the Near East. There is copper impurity in the most ancient iron objects, for example, in objects from Tepecik the copper content is 6.12 and 2.19% (Yener *et al.* 1994, p. 383).

In the large mining center at Timna in the south of Palestine the copper and iron coproduction at copper ore smelting in furnaces of the 14th – 12th centuries BC has been revealed. This conclusion is checked by means of studies of lead isotopes in both copper and iron objects (Gale *et al.* 1990, p. 182-191).

In Alalakhe (15th century BC) a copper alloy with iron has been found (Wertime 1980, p. 15).

The carried out by Muhly and Maddin on the Cyprus experiments with chalcopyrite smelting without use of fluxes resulted in some quantity of metal iron in slag (Wertime 1980, p. 16). Tylecote's experiments with oxidized copper ores containing a significant quantity of iron oxides were also very successful (Tylecote 1980, p. 188, 189).

Raw materials for iron production are of special interest. In the old Assyrian texts the term *amutum* designated iron smelted from ore. The raw material for it was a*ši'um*. It is supposed that it was some iron ore but not hematite as it was objects of the trade. Rather this term designated some metal (Muhly 1980, p. 35, 36). It is possible to assume that it was iron, a product of the smelting of chalcopyrite requiring additional treatment.

The capabilities to produce iron from chalcopyrite existed in the Near East long ago. On the Cyprus the use of sulfides began in the mid-4th millennium BC and by the end of this millennium it spread quite widely. Since the same time arsenic alloys were also known (Zwicker 1987, S. 194, 199). Earlier single iron objects could be made partly from meteoric iron, partly from the iron smelted from copper ores with additions of iron-rich fluxes. Though for this period we cannot also exclude episodic use of sulfide ores in smelting operations.

Certainly, this way of iron production could not provide stable results. A basic opportunity for this was given by two obligatory factors: existence of the reducing conditions in the furnace which was promoted by sulfide ores (burning sulfur takes away the surplus oxygen), and prevalence of iron oxides over silicates. Otherwise wüstite and silicates formed fayalite. Only the superfluous wüstite in case of the reducing atmosphere could turn into iron. All this explains the rarity and high cost of this metal, and also the existence of mentions of bad and good iron. In the presence of unreduced oxides or sulfur in iron, the iron lost its malleability although its visual characteristics not very differed. It is not excluded that directly in the furnace the conditions also could be created for limited steel production.

On this background finds of the most ancient iron objects in Eastern Europe from Pit-Grave barrows of the Orenburg area dated to the 3rd millennium BC are of special interest. They are presented by a chisel, bimetallic adze with a handle from copper and a working end from iron, and a disc-shaped article. Investigations of these objects under microscope have allowed a conclusion to be drawn that they were made of meteoric iron (Terekhova *et al.* 1997, p. 33-39). In the total, 24 objects from the meteoric iron are found in the Pit-Grave complexes of the Early Bronze Age and 21 objects in the synchronous Afanasievo complexes in Southern Siberia. One object comes from the Catakomb burial of the Middle Bronze Age but in this case a possibility is assumed that it is the bloomer iron (Koryakova *et al.* 2011, p. 11). The conclusion about the meteoric origins of the early iron completely corresponds to all said above as in the Orenburg area the copper mineralization is connected with copper sandstones which contain no primary sulfides. The mineralization is presented here almost exclusively by oxidized ores whose smelting could not result in the reduced iron. In particular it could not be made in this early period. Probably the Afanasievo metallurgy was also based on the oxidized ores.

Thus, the most part of the earliest iron objects in the Near East and Eastern Europe (excepting objects of the Pit-Grave culture) including those containing nickel impurity was not of meteoric but of metallurgical origins. There are serious bases to claim that iron for their production was received, mainly, as by-product when smelting copper ores, above all, the sulfides. Sometimes it could be produced due to reduction of iron fluxes but then the reducing atmosphere was necessary, and in the case of smelting of oxidized ores it was impossible at all. This instability of iron production caused its rarity and high cost. The increasing mining of sulfide ores also led to the gradual growth of quantity of iron articles. However it is impossible to speak about the beginning of iron metallurgy on this basis.

Some scholars are confused by a passage from the Hittite correspondence about the bad time for iron production. Therefore it is supposed that there was some special technology, unclear to modern researchers. However it can be explained by a simple circumstance: seasonality of works on copper mines. It is not excluded that in winter time in the Anatolian mountains the mining works were stopped. Besides, in the majority of areas of the world with transition to smelting of sulfide ores the smelting process was transferred from settlements to ore deposits. Partly it was connected with the evaporation of suffocating sulfuric gas. Therefore the smelting process could also have the seasonal nature.

Thus, the essential technological changes which happened in the Volga-Ural metallurgy at the beginning of the Late Bronze Age were stimulated by impulses from the Near East. These impulses introduced the primary knowledge of production, forging and use of iron. But whether it is possible to connect the technology of chalcopyrite smelting and the production of iron as the by-product with the subsequent true iron metallurgy and smelting of iron ores? Probably no, as the subsequent iron production was based on oxidized ores. In Africa, for example, various iron oxides were always used for it (Amborn 1976, S. 4). But the above described technology was built on smelting of the sulfide ores. Thus, they are different chemical processes. And we have seen that in the majority of areas where only the oxidized ore was smelted, the smelting technology was badly sustained, and it led to the oxidizing atmosphere and the formation of cuprite. In these conditions it was impossible to produce iron, and iron is absent in slags smelted from these ores. Metallurgists already were able to achieve the necessary temperatures, but could not create in the furnace the needed balance of CO/CO_2 for iron smelting. This means that the development of technology in the Late Bronze Age prepared the appearance of iron metallurgy: knowledge of iron in many areas, emergence of skills of its forging, ability to reach high temperatures. But some additional innovations in the field of smelting of the oxidized ores were necessary which resulted in ability to smelt them in conditions of the reducing atmosphere. Therefore it is not excluded that these innovations appeared in those areas where oxidized ores were smelted.

And in this regard it is interesting that at the end the Bronze Age in the east the already discussed bloc of cultures formed: Karasuk, Irmen, Begazi-Dandybay. And we see there the return to smelting of the oxidized ores. And, these cultures had the Near Eastern origins, and arose after the appearance of iron metallurgy in the Near East. In this regard the facts given by A.Kh. Margulan are very interesting. On some settlements of the Begazi-Dandybay culture (Karkaraly III (Suukbulak), Shortandy-Bulak) pieces of sorted iron ore, iron slag, iron arrowheads similar to the bronze prototypes of this culture have been found. On two other settlements (Tagibaybulak in the Bayanaul area and Samembet in the Karkaralinsk area) an iron hook and a fragment of iron needle are found. From this a conclusion is drawn that the initial stage of iron smelting in Central Kazakhstan should be dated to the pre-Scythian time (Margulan 2001, p. 73).

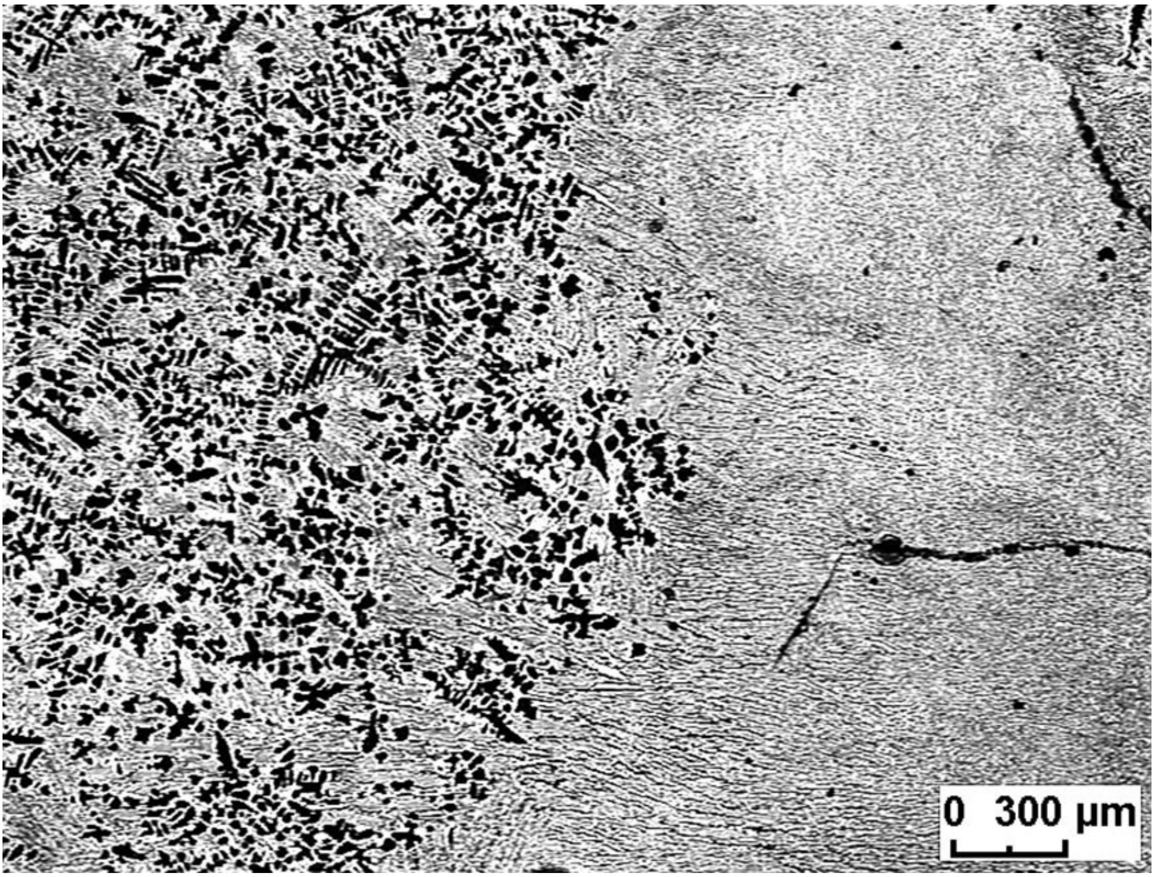

Fig. 13-1. Carburized inclusions in iron (sample 66) from the settlement of Verkhnyaya Alabuga.

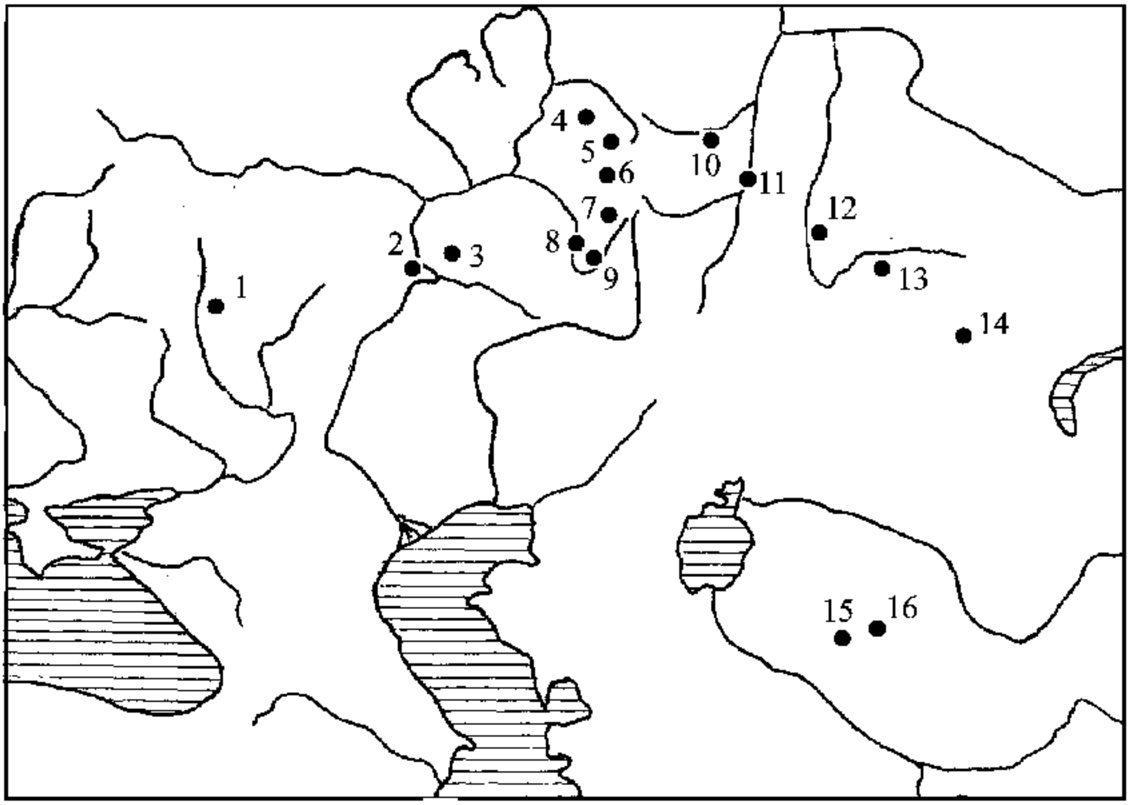

Fig. 13-2. Finds of the copper slag with iron inclusions: 1 – Mosolovka, 2 – Shigonskoe, 3 – Popovo Ozero, 4 – Novokizganovo, 5 – Yukalekulevo, 6 – Baigildino, 7 – Novobaryatino, 8 – Aitovo, 9 – Verkhnebikkuzino, 10 – Korshunovo, 11 – Verkhnyaya Alabuga, 12 – Vishnyovka, 13 – Ust-Kenetay, 14 – Kara-Tyube, 15 – Besh-Bulak, 16 – Ayakagitma.

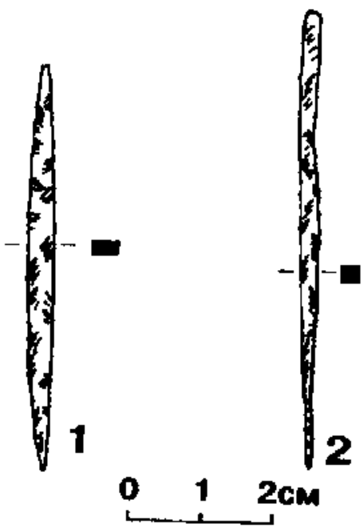

Fig. 13-3. Iron artifacts from the Mosolovka settlement (after Pryakhin 1996).

Chapter 14.
Metallurgical Production in the Early Iron Age

Study of metallurgical production in Northern Eurasia in the Early Iron Age is not a problem of this work; therefore very limited quantity of samples has been studied with the single aim: to outline the most general features of the way of development of metallurgy after the end of the Bronze Age. However even this limited analysis brought us to a series of complicated problems whose decision requires, unfortunately, the analysis of a large number of materials.

In this period the next drastic change in the system of production in Northern Eurasia occurred, as well as reorganization of territorial division of the production. It was caused by sharply increased contrast between the steppe and forest cultures in comparison with the Bronze Age. After the penetration of new tribes into the steppe zone and spreading of nomadic way of life the metallurgical production in the steppe disappeared for a certain time. It is not excluded that this impression is false, and it is difficult to date the ancient mining works on the ore deposits, and already for the Late Bronze Age we have seen the tendency to transfer the production closer to mines. Besides, the areas of mines in the steppe zone are studied extremely poorly. Nevertheless, if this production even existed, it was probably very depressed. Indirectly it is testified by a rapid growth of production in the mining and metallurgical centers of the forest and mountain regions of the Urals and Altai. In any case, in the Urals scholars are inclined to explain the increase in production of the Itkul metallurgical center by that it produced metal for the nomads. And, these deliveries were not limited to metal; they manufactured finished articles. The best evidence of it is the abundance of casting moulds on the Itkul settlements (Beltikova 1993, p. 100; 1993a).

In the forest Transurals at the beginning of the Early Iron Age the Itkul culture formed. The culture is dated to the 7th – 3rd centuries BC (see Beltikova 1993, p. 95; Tairov 2000). Traditionally scholars connect its origins with the previous Mezhovka culture of the Late Bronze Age. However there is no serious base of this idea. We have practically no possibility for dating of the Mezhovka complexes even to the late 2nd millennium BC (Grigoriev 2000b, p. 391, 392). Apparently a hypothesis is more justified that the entire suite of cultures of the Early Iron Age of Western Siberia and the Western Urals formed as a result of an eastern impulse at the end of the Bronze Age (Akishev 1973; Grigoriev 1999, p. 289-291; Itina, Yablonskii 2001, p. 108; Botalov 2003; Tairov 2003, p. 46). And, the situation was not limited to this single impulse. The formation of steppe cultures of the Early Iron Age in the 7th century BC was a complicated process caused by migrations from Central Asia and influence of this population to the north that had impact also on the Itkul culture. It was expressed in the formation in the Ural and Kazakhstan steppes of the Tasmola family of cultures. But at the end of the 6th – the beginning of the 5th centuries BC this process was intensified by groups of the Scythians from Eastern Europe and also two waves of Asian nomads from the Aral area and Eastern Turkestan (Northern and North-Western China) (Tairov, Gutsalov 2006, p. 312-315).

To some extent these processes are confirmed also by studies of metallurgical production.

Copper metallurgy

Copper metallurgy is an important part of metallurgical production of the Early Iron Age. For this research those limited analyses of copper slags which have been done are extremely important for the reason that they allow use to trace tendencies of further development of metallurgical production in the territory which was occupied earlier by the Eurasian Metallurgical Province. Besides, the iron metallurgy did not appear in a vacuum. It was the successor of metallurgy of copper. And the understanding of the technological development of copper production allows us to understand how the iron metallurgy arose.

Copper metallurgy of the Early Iron Age in the Altai and Southern Siberia

Sample 791 from the settlement of Ostrovnoe III belongs certainly to the slags smelted from copper ore. By the way, spectral analysis of this sample has also shown the high content of copper (Tab. 14-1.). It is impossible to determine the nature of ore bearing rock basing on this sample as single nonmetallic inclusions can be connected with the furnace lining. The used ore was oxidized, mainly malachite. However, the smelting was carried out in the reducing atmosphere that allowed copper to be reduced and well separate from slag.

The rate of cooling was apparently rather high, therefore crystallization practically did not occur (Fig. 14-I..1,2). Smelting temperature was probably low as an unfused grain of cuprite is noted, but it is obviously not enough for sure judgments on this subject. It is not excluded that this concrete sample of slag was formed in a peripheral part of the furnace, and this explains all its characteristics.

In the second sample from the same settlement (No. 790) copper components have not been found, but there are inclusions of metal iron. But it is a very porous sample with limited number of any inclusions (except for rare needles of fayalite and rare small dendrites of magnetite crystallizing from slag). Most likely, it is a fragment of slagged lining of walls or bottom of the furnace.

Other slags of this settlement investigated by means of spectral analysis have detected the presence of about 1% copper. Probably all slags of this settlement belong to the smelting of copper ore. Exception is sample 788 investigated by means of spectral analysis. It contains much less copper (0.015%). However in this case there are no bases for statements that the slag was smelted from iron ores as the sample also can be a fragment of furnace lining.

Thus, for this epoch in the Altai we practically have no data for reasonable judgments about the nature of smelting of copper ores. It is possible to speak only about the preservation of tradition of the preferred use of oxidized ores with possible additions of secondary sulfides.

More numerous data on smelting during in the Early Iron Age have obtained for the Minusinsk Depression (Sunchugashev 1975). The copper-smelting places are found here near the mines. They are well visible due the large slag heaps. It is supposed that smelting was carried out in crucibles which were placed over a deep (up to 15 cm) hearth with the sizes 40×50×15cm – 30×40×15cm. Nearby small pits for slag tapping are situated. Each smelting operation gave up to 300 g copper. More complicated deep furnace consisted of two parts of the late Tagar culture is also investigated. One of the parts was used for installation of bellows (Sunchugashev 1975, p. 93, 94). The same technology of crucible smelting is reconstructed also for Tuva. It allowed smelters to carry out smelting in one furnace changing crucibles, and relieved of need to take it to pieces and build again as it was doing 200-300 years later in iron production (Sunchugashev 1975, p. 115). The last is confirmed also by our experimental works. The excavator of these sites Sunchugashev believed that in the Minusinsk Depression only oxidized ore was smelted. The smelting temperature exceeded 1000 ºC. However it was not the upper limit of the temperature possibilities of the Tagar metallurgists. According to the analysis of Tagar knives they were cast at the temperature of 1350 ºC (Sunchugashev 1975, p. 117).

In addition to copper in the Tagar time rare lead articles were also known, and also considerable impurity of lead has been found in the copper cauldrons; it was necessary for castability of the metal (Sunchugashev 1975, p. 107, 109, 114, 147).

Thus, at the transition to the Early Iron Age we see no clear technological innovations in the region, but it is not excluded that the reason of it is in scarcity of the information only.

However there are essential changes in alloys. Against the absolute domination of arsenic alloys in the Final Bronze Age the tradition of alloying with tin revives and wins in the Early Iron Age. This process covers the whole Western Siberia and the south of Middle Siberia (Sunchugashev 1975; p. 146; Grishin 1975, p. 68; Bobrov 2002a, p. 159; Bobrov *et al.* 1997, p. 171; Troitskaya, Galibin 1983). Even in the taiga areas to the north from Krasnoyarsk where in the Karasuk period pure copper dominated, in the Scythian time the tin alloy spreads (up to 80% of objects) (Khavrin 2006). It is interesting that in the Altai and in Tuva at the early Scythian stage tin bronze dominated, and then their quantity is reduced (Khavrin 2005).

Exception for the early stage is perhaps one, but extremely important complex of metal of the barrow Arzhan where alloys with arsenic sharply prevail (Pyatkin 1983). But it is a royal barrow, and finds in it can reflect not only local production. In Scythian time alloys with arsenic are widespread in the Western Transbaikalia (culture of Tiled Graves) (Minyaev 1983, fig. 8), therefore import of metal from this region is not excluded.

Nevertheless, the tendency of distribution of tin alloys in Southern Siberia is more significant. It is hard to say, with what the renewal of this tradition was connected. It would be apparently a mistake to draw a conclusion that this revival was connected with western centers of the EAMP as there by the end of the Bronze Age archaeological sites practically disappeared in the steppe zone. Besides, the EAMP even in the Bronze Age was supplied with tin from the Altai; therefore the reasons of the new revival of tin alloys should be looked for in the east. In this sense it is interesting that exactly in the Eastern Transbaikalia on the Onon River copper and tin mines are present. The last were exploited in the Bronze Age and in the Early Iron Age because in artifacts of the Karasuk and Tagar time of the area the part of tin is very high (Grishin 1975, p. 67, 68). In metal of the Xiongnu in the Ordos desert the domination of tin is also present, unlike the metal of the Xiongnu in Southern Siberia (Minyaev 1983, fig. 7) that points to rather stable tradition of tin alloys in the eastern areas close to China.

Describing the disappearance of tin alloys in the Central Asian Metallurgical Province of the Bronze Age we have discussed the preservation of this tradition in China. And, in this area the overwhelming domination of tin alloys remains also after this, in the Early Iron Age (the periods of Spring and Autumn, 771-476 BC and Warring States Kingdoms, 476-221 BC). The only noted dynamics here is the increase of the part of lead alloys (Wang, Mei 2009, p. 383). Actually, we see also the same to the north where there are alloys with lead in the Tagar culture too.

Therefore it is not excluded that the subsequent revival of alloys with tin was connected with eastern impulses as exactly in the east they remained in the very spacious area. But before systematic studies this assumption about eastern roots of the tin bronzes distribution can be considered only as a hypothesis although it quite corresponds to the context of distribution of the nomadic culture and types of artifact from the east to the west.

Copper metallurgy of the Early Iron Age in the Southern Transurals

Itkul furnaces for copper smelting

The Itkul culture was probably one of the most metal producing centers of the area. Traces of metallurgical production and a series of furnaces have been found on many Itkul sites (Fig. 14-2.). At the beginning of studies of the Itkul culture on the Petrogrom Hill 18 furnaces were studied. The assumption was done that these furnaces were of open type, and they were used for uninterrupted smelting of ore with periodic addition of furnace charge and tapping of slag and metal (Bers 2004, p. 6; Beltikova, Morozov 2004, p. 7). The following studies have shown that many Itkul sites were points of specialized metal production with a complicated arrangement of furnaces and surrounding working places. In addition to the furnaces there are places for preparation of ore, pits of unclear functions (probably for storing charcoal or ore), deep and surface places with burnt soil and clay lining on which various remains of metallurgical production have been found. It is supposed that these places were used for metalworking (Beltikova 1988, p. 108, 109). We have not seen similar complicated arrangement of working space in the Sintashta culture of the Middle Bronze Age where specialized production was absent but we see it on the fortified settlement of Shaiginskoe left by the Jurchens, an obviously specialized center of production. A part of pits there served for wastes, another one did for raw materials and fuel storage (Lenkov 1974, p. 31).

Besides the metallurgical furnaces on the Petrogrom Hill, a set of other constructions of this type have been revealed and described on the Itkul sites (Malyi Vishnyovyi Island, fortified settlement of Itkul I, Dumnaya Mountain) (Beltikova 1986, p. 67, 68; 1988, p. 107; 1993, p. 101; Beltikova, Stoyanov 1984, p. 134-138). Unfortunately, preliminary publications of these materials not always give a chance to understand their constructive features, and furthermore, the functional distinctions (Fig. 14-2.). Probably in the future a detailed report and classification of the Itkul furnaces will appear. In general, the furnaces are divided into single-sectioned and two-sectioned. The second section is considered as a shallow pit for slag tapping. Such an assumption is done however for furnaces with the bottom divided by a low partition. Additional argument in favor of this possibility is so-called furnaces of open type on the Petrogrom Hill.

Similar pits for slag tapping are known in later time nearby the ironwork furnaces on the settlements of the Jurchens (Lenkov 1974, p. 31). However in the Itkul culture in some cases this shallow pit moves down towards the furnace and such its device could not promote the tapping of slag, but it was convenient for installation of double-sectioned bellows. As our experimental works have shown, the tuyere has to be directed to the lower part of the furnace. Being connected with the upper section of the double-sectioned bellows, the construction has to provide space for the bottom section in the pulled apart state. Therefore the furnaces consisting of two parts probably reflect existence of the double-sectioned bellows. But it cannot be a final conclusion as our studies of Itkul slag assume also a possibility of its partial tapping. But the analyzed slag is not connected with concrete furnaces. Therefore most likely the existence of different type of furnaces indicates both of these possibilities (Beltikova, Stoyanov 1984, p. 142), but only future studies can make this conclusion more accurate.

The sizes of the smelting parts were small; they vary in limits of 0.7-1m. The furnaces are slightly deep although some furnaces are deep in soil up to 50 cm. Thickness of walls of the furnaces is 20 cm, and their reconstructed height is 40-50cm. Remains of stone walls are present close to some furnaces although often the walls were made of clay. The clay remains of the collapsed vault are also found. In a furnace on the island of Malyi Vishnyovyi a small drain goes away from the center of the smelting part (Beltikova 1988, p. 107). Therefore it is not excluded that copper nevertheless was partly removed from the furnace in the course of smelting although this option seems to me doubtful. It is possible that this furnace simply coincided with a tectonic crack in the granite basis. Such cracks are rather typical in the area.

Around the furnaces many remains of metallurgical production have been found: fragments of burnt furnace lining, small ore crumb and malachite pieces, stone tools for crushing and grinding ore, small metal ingots and drops, slag pieces, clay for lining, birch bark, fragments of pressure-blowing tuyeres casting moulds, and burnt bones (Bers 2004, p. 6; Beltikova 1986, p. 68, 76; 1988, p. 107; Beltikova, Stoyanov 1984, p. 134-138). On the island of Malyi Vishnyovyi ore is not revealed but many stone tools have been found, and one pestle has traces of work with a green mineral, probably, malachite. However this settlement was specialized in metalworking (Beltikova 1988, p. 110, 116). On the fortified settlement of Itkul I also iron smelting is supposed on the basis of finds of slag and hematite (Beltikova 1986, p. 68) but, as it will be shown below, copper ore from this settlement was in iron-rich ore bearing rocks, and the presence of slag not always allows us to judge about a type of metal that had been smelted. Therefore, most likely, the found hematite marks the enrichment of copper ore on the settlement. A fact of use of animal bones as a flux is interesting too, because it has been demonstrated for Sintashta metallurgy. It is remarkable that only oxidized ores have been found around the places of copper smelting.

The ore crushing was made here, and it is established that ore was crushed to a powdery state. Sources of ore of the Itkul time are not determined reliably yet. There are many small veins with malachite, azurite, and chrysocolla near the fortified settlement of Itkul, and in the distance of 30-40 km the mine of Gumyoshki is located (Beltikova 1986, p. 76). This mine contains copper-skarn ores, mainly malachite. There are numerous ancient open pits and mines. On the settlement of Dumnaya Mountain probably the ore from the Gumyoshki mine was smelted. However this conclusion has some problems: the ores from the Gumyoshki mine and Dumnaya have different concentrations of lead (Chernykh 1970, p. 45, 46). It is not excluded that the mine of Polevskoi was an important ore source. Russian industrialists found an ancient pit up to 25.6 m[1] in depth there. It indicates huge scales of mining works.

Copper smelting slag of the Itkul culture

Unfortunately, the studied material is not very representative and is limited to 21 samples from three smelting centers: Dumnaya Mountain (5 samples), Palatki I (6 samples) and Itkul (10 samples). In addition to this, 65 samples of copper-smelting slag and one sample of ore have been analyzed by means of the spectral analysis: Dumnaya Mountain (30 samples) and Itkul (36 samples).

The most part of the analyzed material is presented by dense shapeless slag with small or large pores and fused surfaces.

In all slag samples from three Itkul sites the fayalite crystallization is presented in the form either of the small densely located prisms, or needles and nuclei of crystallization (Fig. 14-I.3-6., Fig. 14-II.1-4,6; Fig. 14-III.1). The contents of fayalite are great, up to 40-60%. In many parts of the slag the crystallization did not occur at all although the glass matrix judging from its color has the fayalite composition. Possibly, there were enough components for formation of fayalite but the high speed of crystallization prevented formation of larger crystals.

The quantity and forms of crystals of magnetite slightly differ on individual sites. So, in slag from the Dumnaya Mountain magnetite is presented by small particles and nuclei of crystallization, octahedra, skeletons, and rarer by dendrites. The most part of magnetite had crystallized from molten slag. Its contents vary in the interval of 3-5%. Slag of Palatki I shows a similar situation, but it contains more magnetite, and is noticeable that a part of the magnetite was formed due to disintegration of larger grains of an iron oxide, and there are molten inclusions of copper sulfide between the magnetite particles that demonstrates the connection of ore with iron containing rocks. And, in samples of this site the fused particles of wüstite and fused skeletons of magnetite are present which were formed probably as a result of oxidation of the wüstite. Slag of the fortified settlement of Itkul is in general similar, but the content of magnetite in the majority of samples is much higher fluctuating from 5 to 30%. Only in three samples the magnetite content in the form of thin rash is very small (samples 116, 118, 121). The formation of magnetite at the edges of globules of copper and copper sulfide has been identified. Magnetite is formed from molten slag and by disintegration of larger grains of iron containing rock. Lattice structures including fused lattice and dendritic structures of wüstite are present, in some instances they keep the borders of primary grains. Possibly, these cases demonstrate smelting of chalcopyrite.

Quartz in samples of all sites is present usually as an exception, in the form of fine grains. But they could quite come from the furnace lining. Slightly better they are presented in two samples where reduced particles

[1] I am thankful to E. Rukosuyev who has provided me with this information. Unfortunately, these mines did not remain.

of copper are also found in the quartz (samples 131 from the Dumnaya Mountain and 118 from the settlement of Itkul). In general, it is possible to speak rather with confidence that most likely ores from iron-rich rocks were used in the smelting.

Copper minerals in slag from the Dumnaya Mountain and the settlement of Palatki I are presented by cuprite and malachite grains, but there are also prills of copper sulfide, copper sulfide filling cracks (the last specifies that the slag solidified at a temperature above the melting point of the sulfide). In some instances the sulfide forms borders round pores and a grain with the reduced copper inside. Associations of sulfide, cuprite, copper and magnetite are present. In one case sulfide is surrounded with a magnetite border. But in some cases associations of sulfide and malachite are also found. All this specifies that minerals from the oxidation zone of a deposit in iron-rich rocks were smelted, mainly malachite and secondary sulfides (covellite and chalcocite). Prills of chalcocite are recorded in some samples. Copper was sometimes reduced directly from the sulfide, and the copper was not always molten. Malachite after reduction forms initially cuprite, and already then copper. On the average prills of cuprite are larger than those of copper that specifies that the cuprite was formed in the course of smelting, instead of as a result of secondary oxidation in the cultural layer. But the content of cuprite is not too large. In two samples from Itkul and Palatki I (samples 114 and 143) needles of delafossite have been found.

Copper is presented by prills of different sizes. Its losses are insignificant. An area filled with accumulation of copper prills with a clear border is found. Possibly some mineral was smelted. Sometimes glass is tinted in red color by small copper inclusions. Sulfide inclusions are present in some large copper prills. Therefore the copper probably required refinement. Usually losses of copper are insignificant, no more than 1-2% although in one samples from Palatki I many copper prills and their large accumulations are recorded (5-10%).

Many slags contain single prills or particles of a white metal, apparently, iron.

Technology of copper smelting in the Transurals

Proceeding from the analysis of slag, it is possible to conclude that copper ore was mined in the zone of oxidation of sulfide deposits, and it was presented mainly by malachite, cuprite and secondary sulfide minerals (covellite and chalcocite). The latter were used, apparently, rather widely that promoted creation of the reducing conditions in the furnace. As a matter of fact, Itkul metallurgists smelted an ideal for ancient production ore mix allowing them to reduce malachite by the sulfide ores. It was caused by a good presence of these ores in the area of Itkul culture. At the same time, in some cases it is possible to say that chalcopyrite was smelted although it was not the main ore of the Itkul metallurgy. Apparently, in different smelting operations the balance of sulfide and oxidized ores varied; therefore also the smelting atmosphere was slightly different being mainly reducing. It led to that the slag contains a limited quantity of reduced iron although its inclusions are very rare in comparison with the slag of the forest and forest-steppe areas of the Late Bronze Age. Ore was prepared near the smelting places and grinded to a powdery state.

Blasting was carried out by means of pressure-blowing bellows. The location of many smelting sites on hills is not at all a confirmation of the widespread myth that it was doing for the purpose of use of natural draft of wind. Technologically it would be a difficult task, and taking into account the existence of bellows marked by finds of tuyeres it was absolutely senseless. The location on the hills and mountains could be caused by many reasons: problems of defense, proximity of ore sources, cult reasons, but only not the aspiration to use wind (Beltikova, Stoyanov 1984, p. 142). Actually, this conclusion is absolutely lawful and obvious to any who tried to work with the bellows at least once. No wind is capable to create such pressure of air in the furnace.

Iron oxides were the gangue that was making possible to do easily rather free-running slag. Any evidence on use of fluxes is absent now. Therefore the source of silicate components necessary for formation of fayalite slag is unclear. It is not excluded that it was present in the gangue. Crushed bones of animals were an additional fluxing component.

Apparently, the furnace charge was loaded directly into the furnace. Pieces of crucibles are found near the Itkul smelting paces, but the most part of them has small sizes (90-100 cm^3) and they were used probably in metalworking. But large crucibles in the form of dishes 30 cm in diameter are also present. One of such crucibles has been investigated by the petrographic analysis and a conclusion has been drawn that it served for melting of crude copper (Beltikova 1986, p. 68). However it is not excluded that similar crucibles were placed on the furnace bottom protecting it from metal and slag. It saved from need to re-build the furnace after each smelting. In some furnaces on the bottom small holes are found. It is accepted that they served for placing crucible (Beltikova, Stoyanov 1984, p. 138). But this was possible only in case of metalworking. In Africa such holes are widespread in ancient and modern iron-smelting furnaces. These holes served in ritual purposes to put medicines (herbs) in them (Schmidt 1997, p. 239-240, 242, 247). But it is too remote and improbable parallel.

The smelting temperature reached the melting points of copper, cuprite, chalcocite, fayalite, and wüstite. But the melting point of magnetite was not reached. Rare cases of the fused magnetite are explained apparently by oxidation of wüstite. Thus, the temperature was within about 1300 ºC that was, as a whole, a standard for ancient metallurgy. Sometimes it reached 1360 ºC (molten in some cases wüstite). Petrographic research of samples of the fallen furnace cover has allowed a conclusion to be drawn that temperatures were not less than 1000-1200 ºC, and studying of a crucible revealed the temperature of 1200-1300 ºC (Beltikova 1986, p. 68) that quite corresponds to the result received in the analysis of slag. The matter is that near the cover the temperature should be lower than in the bottom part of the furnace where the blasting was directed.

Thus, we see an interesting situation: at rather high temperatures and mainly oxidized character of ore ancient metallurgists could keep the reducing atmosphere in the furnace. It cannot be explained by any single factor; probably there was a combination of various factors based on experience saved up for millennia: presence of some quantity of sulfides, blasting mode, construction of the furnace, basic composition of furnace charge, that in total led to this result.

Solidification of the slag happened at various speed, but mainly quickly. It is possible to assume that the slag was partly tapped, which provided the presence of slags demonstrating different speed of cooling. But it is impossible to judge it surely at this stage of studies.

At the same time, during the smelting the slag was very fluid that allowed copper to separate quite well and led to absolutely insignificant losses of metal.

Chemical analyses of slag and ore

An attempt to divide the Itkul slags on the basis of spectral analysis by means of Brookhaven Date Handling Programs has been done, however it has not leaded to some certain results. Samples from only two sites (Dumnaya and Itkul) have been analyzed. On this basis four clusters have been distinguished which have included samples from both smelting centers, only cluster 4 is presented by samples from Itkul (Tab. 14-3.). Attempts to find any dependence on the basis of studying of individual trace-elements were unsuccessful too. Possibly this picture is explained by that metallurgists in the Itkul time used arbitrary ore mixes. But there is no opportunity to make conclusions about ore sources basing on these data.

Conclusions on the Itkul metallurgy of copper

A traditional opinion of scholars is that the Itkul metallurgy was a result of accumulation of former Late Bronze Age traditions of the Cherkaskul, Mezhovka, Barkhatov and Sargari cultures (Beltikova 1993, p. 100). However in my opinion we see a drastic break from traditions of Mezhovka metallurgy in which sulfide ores were used much more widely. To a certain extent it is possible to speak about an inexplicable technological regress. But Itkul metallurgy was apparently comparable with traditions of metallurgical production of eastern metallurgical centers of this period and the Final Bronze Age. Probably, types of alloy of the Itkul metallurgists had also the same eastern roots, and they did not succeed the earlier traditions of the EAMP. Above we have already discussed the spreading in Western Siberia of alloys with tin that looks as a drastic break from the former tradition of arsenic alloys. In the Itkul culture the pure copper absolutely dominated, its part was 90% of the entire metal. The part of tin bronzes was only 10%. However it is not an indicator of any other technological tradition and was connected with deficiency of the alloying component (Beltikova 1993, p. 98, 101). Therefore the assumption is most probable that the development of metallurgy in the Transurals in the Early Iron Age was influenced from the east. It is necessary to add to it also that tin in noticeable concentrations is absent in slag, and the alloying was made according to principle 'metal with metal' that was typical already since the Late Bronze Age.

Western Urals in the Early Iron Age

In the Early Iron Age scholars (Kuzminykh, 1983) distinguish two metallurgical centers of the Middle Volga and Western Urals: Ananyino and Akkozino. The first center succeeded traditions of metalworking of the Prikazanskaya culture, and the second one did those of the Late Bronze Age tribes with textile ceramics. In this period the following groups of copper are characteristic of metallurgy of the area: VK, antimony-arsenic alloys (56%, from which 83% coincide with tin bronzes), VU (23% from which 70% coincide with tin bronzes), MP, copper sandstones (5% of objects from which only 4% coincide with tin bronzes), EU (6% and 34% are alloyed with tin) and objects which have not been related to any group (7% and 76% are alloyed with tin). There are some distinctions in dynamics of the development between separate centers. The Akkozino center which is considered as metalworking was based on metal imported from the east. In comparison with the Late Bronze Age Prikazanskaya culture it demonstrates a little reduced part of the VK and VU groups of metal, absence of the MP group, and the proportion of artifacts alloyed with tin drastically grows that was not characteristic of the Prikazanskaya center. In the Ananyino center on the Middle Volga the ore smelting was not practiced, and in the Kama area the copper sandstones were smelted. Nevertheless, the imported VK and VU groups of eastern origins were the main raw basis. The center succeeded to the Prikazanskaya traditions where the part of the VK copper was 70%, and this copper dominated also at an early stage of the Ananyino center, but the Ananyino metal was alloyed with tin to a greater extent than Prikazanskaya one (Kuzminykh 1983, p. 11, 157, 167-172).

Nevertheless all this raise some questions about the formation and functioning of the Akkozino and Ananyino centers. The increase in the proportion of objects alloyed with tin, in principle, corresponds to the tendency of restoration of the role of this alloy in the east in comparison with metallurgy of the Final Bronze Age. However conclusions about the eastern roots of the most part of metal in general require probably some correction, at least, for the Ananyino metallurgy. Above all, it is necessary to pay attention that the proportion of tin bronzes here is higher than that in Itkul metallurgy. Thus, this copper could not come from the Transurals in the form of ingots. It is difficult to discuss ore sources of the steppe and forest-steppe in Kazakhstan and Siberia in view of absence of data on copper metallurgy in these areas. It is possible to assume, of course, separate imports of copper from the Transurals and tin from the east making a detour to the south of the Transurals, but a set of chemico-metallurgical groups contradicts to it. In the regional metal the VK group obviously dominated. As we have discussed earlier, this group was a result apparently of smelting of the primary sulfide ores that was characteristic of the forest and forest-steppe zones of the

Urals and neighboring areas. A part of this group is connected with the arsenic-antimony alloying. However all this was not characteristic of the Itkul metallurgy where a mix of secondary sulfides and oxidized ores was smelted. Therefore, the metal was of local Cisural origins, and this conclusion corresponds to the use of primary ores in the Late Bronze Age of the area.

Copper-smelting slag in the Early Iron Age of the Western Urals

Unfortunately, there are few samples of slag from this area in the analyzed series, and many samples have not been very reliable dated.

First of all, it is a sample from the Skorodum settlement found in a dwelling of the Late Bronze Age – the beginning of the Early Iron Age (Zbrueva 1952). According to S.V. Kuzminykh, it is possible to distinguish two phases within the Ananyino center: the first one: since the mid-8th – late 6th centuries BC and the second: since the late 6th – 4th centuries BC. Judging from the present of rare imports of the Caucasian articles, on the first phase the connections with the local Late Bronze Age metallurgy and the Caucasus were essential. Within the second phase the connections with the east (south of Central Asia, Kazakhstan, Western Siberia and the Altai) became more important. Materials of the Skorodum settlement belong to the first phase (Kuzminykh 1983, p. 171, 178). Therefore this sample just reflects apparently this postulated connection of local metallurgy of the Late Bronze Age and Early Iron Age as was shown in its microstructure (Fig. 14-III.2,3).

The sample is presented by dense heavy slag with a small quantity of pores of the average size. In some places of the slag the quantity of pores is more, and crystallization here did not occur. Slag is saturated with prismatic skeletons and large prisms of fayalite with magnetite particles between them, although it is not everywhere. In some places fayalite is presented by thin skeletal prisms and needles, but usually by completely formed prisms. There are places with large fused dendrites of wüstite which form in some instances lattice structures. The prismatic and polygonal crystals of fayalite were formed after them. There are small single prills of copper, quartz grains, and very rare fine grains of chromite, one of which is surrounded with the magnetite border.

Probably, the slag was smelted from chalcopyrite. It is impossible to identify the ore bearing rock as the grains of quartz could origin from furnace lining. The smelting atmosphere was reducing, the slag cooled down slowly, apparently, directly in the furnace. It is difficult to determine smelting temperatures basing on the single sample. Possibly, they exceeded 1200 ºC, and judging from the fused wüstite they reached 1360 ºC.

Two samples have been found by A.V. Schmidt in 1925 on the cemetery of Turbino I of the Seima-Turbino type. The top horizon of this burial ground was presented by the Ananyino-Glyadenovskaya layer of the Early Iron Age (Chernykh, Kuzminykh 1989, p. 18). One sample (No. 317) is presented by dense heavy shapeless iron-rich slag with metal luster. The main inclusions in it are large polygonal, prismatic, needle and long skeletal crystals of fayalite, and also fused large dendrites and lattice structures of wüstite (Fig. 14-III.4,5). There are also small dendrites of the magnetite which had crystallized from molten slag. Metal inclusions are presented by few small prills and fused particles of iron. The iron was obviously formed by replacement of wüstite and repeats its shape. In some cases the molten inclusions of copper sulfide and its rare large deformed globules have been detected. One such globule is surrounded with the magnetite border.

Another sample (No. 318) is presented by a thick slag crust formed on a roundish bottom of a furnace, crucible or in a shallow hole. The slag is dense and rich in iron with inclusions of light rock. It has a zonal structure (Fig. 14-III.6; Fig. 14-IV.). The lower part consists of ceramic mass. The fayalite crystallization occurred in it worse, and quantity of wüstite is less. In the upper part large octahedra, skeletons and dendrites of wüstite are typical. In some instances they grow from molten slag, in others they disintegrate from larger grains. Lattice structures of fused wüstite with accurately outlined borders of primary grain are also found. Therefore, they were formed from pieces of some iron mineral. Judging from the size it was crashed up to the pieces of 1.5-2mm, may be rather larger. There are also the extended needles and skeletal prisms of fayalite. Copper prills are rare. Occasionally the fused small particles of iron are present. There are many small grains of quartz, but it could come from the furnace lining, instead of the gangue. Small rare grains of chromite have been found too. The reason of distinctions in the fayalite crystallization in the upper and lower parts of the slag was probably not in distinctions in the speed of slag cooling. Most likely, in the lower part of slag there were no components for formation of fayalite. Slag in this part was formed mostly as a result of slagging of the lining of bottom. Probably, the distinctions of the microstructure of different samples are caused also by that they formed in different zones of the furnace. As a matter of fact, this slag is similar to that we have seen before in the Mezhovska series.

Some samples were only examined visually or investigated by means of spectral analysis. From the settlement of Polovinnoe I dated to the 3rd – 1st centuries BC (excavation of A.F. Melnichuk, N.V. Soboleva) four samples have been examined. One of them (No. 160) is presented by a slag flat cake whose form points to low viscosity of the slag; the second sample (No. 162) is slag with ceramic crust, therefore, smelting was carried out on a lining of furnace bottom, and two samples (No. 163, 164) are pieces of ceramic slag. These samples have not been analyzed, but, in general, they do not contradict the analyzed series.

Similar slag has been found also on the fortified settlement of Zuyevskoye (No. 444). It is a piece of elongated curved heavy slag. One its surface is tuberous and fused. The second surface is presented by slagged clay. The samples of slag (No. 150) and ore (No. 161) are taken from the collection of Zaosinovo V. The slag from the Zuyevskoye settlement and ore from Zaosinovo have been analyzed by the spectral analysis (Tab. 14-1.). In both cases the low contents of all impurities and lack of arsenic and antimony are indicative. Therefore, most likely, the smelted ore could not result in production of copper of the VK group. In both cases high concentrations of titan (0.5%) are evident, but it is hard to say about their reasons.

Technology of copper smelting

Thus, judging from the studied samples, the main smelted ore was sulfide, probably chalcopyrite. The smelting was carried out directly in the furnace in conditions of the reducing atmosphere at temperatures exceeding obviously 1300 ºC. By analogy with slags of the Late Bronze Age it is possible to assume even higher temperatures but while the analytical base for such a conclusion is limited. The furnace cooled down relatively slowly. The faster crystallization near the bottom of the furnace was caused only by composition of slag in this place. The losses of copper were very small; the smelting was quite perfect. In general, the slag corresponds to that from the settlement of Skorodum. This technology does not correspond to the Itkul technology, but had direct connection with technology of the Late Bronze Age of the area.

A series of samples from Bashkiria from the settlements of Kurmantau-5 and Biktimirovo of the Kara-Abyz culture located in the central part of the area, and also from the settlement of Ulak-6 and the Olotau mine (the Irendyk Ridge in the Baymak area) has been studied too[2]. The last settlement is remarkable because it is located in the south-east of the area in the steppe zone and contains materials of nomads of the early Saka time. Contrary to it, the Kara-Abyz culture is considered as a result of coming of the Ananyino people from the north and influence of the Gafuri culture from the east (from the forest-steppe Transurals).

A part of samples from the settlements of Biktimirovo and Ulak-6 was connected with iron smelting. Samples 2233-2236 from Kurmantau-5 and 2340-2342, 2345-2348 from Biktimirovo are related to copper slags.

[2] Materials are kindly presented by N.S. Saveliev and V.V. Ovsyannikov.

These are small shapeless and heavy pieces with slagged surface and inclusions of oxidized copper. After preparation of probes it became clear that all of them are slagged copper ingots. Therefore the only real task was an attempt to find out whether are these slagged drops and ingots a result of smelting of ore or melting of metal to check the fact of ore smelting in this zone. From two samples of the Biktimirovo settlement (2341 and 2347) mainly slagged surface of the metal has been taken for the analysis. It is visible in the copper contents (0.2 and 0.6%) in these probes (Tab. 14-1.). A series of statistical procedures has been carried out which have demonstrated that in comparison with copper the distribution of impurities in these samples more corresponds to ore slag. But regularities of transition of trace-elements into slag are quite obvious in statistically reliable series. For single samples any factors are possible. Therefore it is possible to assume that the population of the Kara-Abyz culture practiced the smelting of copper ore, but strict proofs are absent. It is possible to speak with confidence about the metalworking only.

Problem of origins of iron metallurgy

As it has been discussed in the previous chapter, metallurgy of iron was certainly connected with the development of copper metallurgy. Slags of the Late Bronze and the Early Iron Age contain iron inclusions. But, as a rule, they are present in those slags which smelted from chalcopyrite. And this connection of extraction of iron as a by-product from sulfide copper ores with proper metallurgy of iron calls into question. The matter is that the latter was based on smelting of oxidized iron ores and, correspondingly, on the reducing processes. Therefore from the point of view of chemistry of the processes it is more lawful to look for roots of iron metallurgy in an area where smelters mastered a successful reduction of the oxidized copper ores actively using iron oxides, either as fluxes, or they got to furnace charge as the gangue.

A stimulus to this transition is unclear too. It is usually considered to be the case that the reason was in wider distribution of iron ores, but these ideas do not work on the Cyprus where copper deposits are presented very well, as well as in many other areas. But the direct transition from the smelting of copper ores is also doubtful. A purposeful production of iron in this way is impossible: it requires very specific conditions which cannot be reached at permanent routine work of smelters. And volumes of iron produced in this way were insignificant. A direct transfer of experience of the smelting and subsequent forging of copper was also impossible (Maddin 1982, p. 303).

Physical and chemical principles of the archaic iron production

There is a series of differences of metallurgy of copper from iron metallurgy. Some of them are visible at a superficial glance, without going into in the chemistry of the process. At the discussion of problems of copper smelting, we were constantly talking about the molten copper, frequently about the viscous slag from which it was necessary to extract small copper ingots. Iron smelting is different. Metallurgists produced solid iron from which they tried to melt slag (Tylecote 1987, p. 114). Unlike copper, iron is characterized by its refractoriness. Its melting point is 1534 °C. But in addition to this iron is chemically more active, it has different valence and returns the bound oxygen only in the presence of large volume of carbon monoxide. Therefore problem of its smelting is, mainly, in creation of a furnace which allows to reach high temperatures and to form the reducing atmosphere (Schmidt 1997, p. 110). The furnace has to contain a larger quantity of charcoal. Reduction of wüstite (FeO) requires more carbon oxides than the copper reduction, and iron reduction is even more. And blasting has to be not too intensive providing, however, a high temperature (Wagner 1993, p. 48). Judging from ethnographic data from Togo, sometimes 90% of volumes of the furnace were filled with charcoal, that made possible to produce not only iron, but also steel (Hahn 1997, S. 136).

Iron reduction in the furnace begins already at a temperature of 500 °C, but more intensively it passes at 900-1000 °C. In practice higher temperatures are necessary, but not for the iron reduction, but to separate slag (Amborn 1976, S. 17, 18). The situations are known (from ethnographic smelting in Burkina Faso and Mali in the Niger Bend) when smelting rather pure ore was carried out at low temperatures, 900-1000 °C, but the smelting duration was very long, 3-7 days (Martinelli 2004, p. 178). The matter is that the direct reduction of iron and receiving of sponge iron and pellets without melting of gangue is probable also at low temperatures to 1100 ºC excluding melting and agglomeration. Carbon monoxide acts in this process as a reducing agent. But the continuous regeneration of iron requires a long time. Therefore in these conditions the process proceeds very slowly. Besides, the quantity of the forming carbon monoxide is insignificant (it is perfectly illustrated by an example of the low-temperature smelting in Burkina Faso and Mali given above which lasted several days). Only at a temperature more than 1000 ºC in the conditions of large modern furnaces the gas phase contains already up to 99% CO. However, for getting a bloom (caked mass of sponge iron) higher temperatures with slag formation are necessary (Metallurgy 1986, p. 61-63).

Temperature should not be excessively high as at high temperature (1600 °C, for example) there will be melting of iron and then also its oxidation. But there is also the smallest extreme, about 1200 °C, otherwise formation of liquid slag will not occur and metal will not separate from it. A typical bloomery slag contains wüstite and SiO_2, small impurity of hematite and magnetite (Schmidt 1997, p. 101).

At first sight, the chemistry of process is rather simple. But in the case of iron there are, nevertheless, some features influencing the course of smelting. The process of reduction itself, as well as in the case with copper ore, is carried out by carbon monoxide. Therefore here conditions for its formation are needed, and these conditions as well as the following processes with ore drastically differ in different types of furnaces. Two types of the furnace for iron smelting are known from archaeological sites: bowl-shaped (in a shallow pit covered with a cupola) and shaft-furnaces (with high walls). The first type of furnace is similar to that we have seen in copper metallurgy. There is a simple formation of carbon monoxide and reduction of iron in such furnaces. And, a part of iron passes into slag (Tylecote 1987, p. 152). In this case the process is not so different than the process of smelting of copper ore, but the quality of blooms is lower, the reducing conditions are not so good, and the productivity of the furnace is low.

In the shaft-furnaces the processes are different. They are based on gradual movement of products from the top part to the bottom. But conditions in different parts of the furnace are various. Near a tuyere, or in the lower part of the furnace, the carbon monoxide is not produced in a sufficient volume; its mix with carbon dioxide dominates, therefore the conditions here are less reducing than above. In the top part of the furnace at first dehydration and disintegration of carbonates take place, and then reactions with oxides and metal. The carbon monoxide reacts with the oxidized ore, and iron oxides of ore turn into wüstite (FeO). The latter is very important component as iron is reduced from it. But already at a temperature of 1175 °C it combines with silicates and forms fluid fayalite slag. There is a certain paradox in it: this slag is necessary for a successful smelting, but its formation reduces a proportion of the final product, a situation which we did not face at discussion of copper metallurgy. At high temperature both fayalite and wüstite melt and gradually start sinking down. And, already in the top part of the furnace some quantity of iron can be formed which being in a solid state, remains in the top part of the furnace (Schmidt 1997, p. 120-124, 133). But there can be also new metamorphoses with the iron. Reacting with carbon the iron forms Fe_3C, but even at smaller carbon contents the temperature of its melting becomes lower. Iron with the carbon content of 4.3% melts at a temperature of 1147 °C (unlike pure iron whose melting point is 1534 °C). And such molten iron could be produced always and everywhere, but ones began to use it only in China. There is an inverse relationship: in case of the less quantity of carbon in iron the temperature of its melting is higher. And specifics of the following process depend on this balance of the temperature and the content of carbon. Therefore there is a division: solid pure iron remains above, steel is below, and the molten iron which has absorbed larger quantity of carbon sinks to the bottom of the furnace. Naturally, such division does not occur fully, and the presence of this molten iron promotes association of iron in large blooms with small slag inclusions. The carbonized molten iron falling down gets to more oxidizing conditions where its part is reduced losing carbon, and another part is oxidized and, reacting with silicates, forms the fayalite slag. A part of the sinking wüstite (in case of a lack of silicates) can be reduced into iron, and can remain in slag in the form of oxide. As a result, in different parts of the furnace there are different processes and various products form. In principle, the large contents of wüstite in slag mean the partial loss of the final product, and it characterizes many early smelting operations. It can be caused by that the wüstite was in reducing conditions during an insufficient time or the sunken down iron was insufficiently carbonized as wüstite helps to avoid the carburization losing oxygen and being reduced into iron. Under other conditions if wüstite with the carbonized iron have not reacted or in the bottom part of the furnace the conditions were reducing, the larger quantity of steel could be produced (Tylecote 1980a, p. 209; Tylecote 1987, p. 152; Childs 1996, p. 299). The most part of slag accumulates in the same bottom part of the furnace. Smelters could voluntarily or according to their technological tradition to transform the process: to add silicates, and more iron will go to slag, but the slag will be fluid, or to increase the balance of charcoal to ore producing more iron and even steel (Rehren *et al.* 2007, p. 214, 216).

The final product of the ancient bloomery production in the shaft-furnace was bloomery iron and some quantity of steel which due to presence of molten components (carbonized iron and slag) were combined into a bloom. These blooms (and they are not so obligatory a single big bloom) it was necessary to forge in a hot state to remove inclusions of charcoal and slag, uniting them in larger blooms. The second reason of this forging was the need to make metal more solid (Fluzin 2004, p. 71). In the course of this operation additional losses of iron occur. Above we have seen that a lot of iron remains in slag in the form of fayalite and wüstite. Usually slag contains 40-50% iron. But, taking into account the volume of slag, the losses can be rather large. The large (2.5-3 m in height) shaft-furnaces of the Banjeri people in Western Africa were loaded with 55 kg ores, 183 kg charcoal and 15 kg firewood. After the smelting it was withdrawn from the furnace 29 kg slag, 14 kg iron and 5 kg unburned charcoal (Goucher, Herbert 1996, p. 50).

Ethnographic data on iron making in India supply us with detailed information on the following losses after forging the blooms. In Madras from the bloom weighing 11 pounds ones produced after the forging 6, sometimes 3 pounds of iron. Partly it occurs due to removal of slag and other inclusions, but the iron also can be slagged and broken away when forging. Therefore in the bloomery production it is possible to use only the richest deposits (Craddock 2003, p. 233). Proceeding from the above-stated figures, using the archaic bloomery technologies from 55 kg ores it was possible to produce 3.8-7.6kg of finished blooms. There are also slightly lesser figures. In Kamar Joda in India ones placed 30 pounds of ore and as much charcoal in the bowl-shaped furnace receiving at the end 2 pounds of iron (Chakrabarti 1992, p. 138).

Ones tried to forge the blooms right after their extraction from the furnace, but, in case of cooling, their additional heating was also necessary. It is recorded also by ethnographers in India (Chakrabarti 1992, p. 135). Naturally, it was made already in other furnaces. In oppidum Michelsberg (the Early Iron Age in Germany) the heating of blooms was carried out in open hearths (Pleiner 1980, p. 400). In North-Western Tanzania small furnaces for heating and agglomeration of the blooms dated to the 1st millennium BC are found (Schmidt, Childs, 1996, p. 213). But they were not the forge hearths which are more open. In Tanzania the Fipa people had two types of constructions: those for agglomeration of blooms, their heating and removal of slag (with height of walls to 40 cm) and open hearths for the following forging (Barndon 1996, p. 63).

The whole process of smelting is directly connected with the following forging technologies. In essence, here we deal with the same system situation which we have seen in technologies of the Bronze Age. The matter is that iron is unique metal which can be alloyed with carbon, and it changes properties drastically. If the carbon content does not exceed 0.008%, this is pure iron, ferrite. This iron is well malleable, but it is too soft. In case of high carbon contents (to 1.7%) we deal with steel which is also malleable, but with the higher carbon content the iron already easily melts and becomes fragile. The bloomery iron can be presented by non-carbonized ferrite or low-carbonized steel (Amborn 1976, S. 15; Wertime 1980, p. 6; Schmidt 1997, p. 101). The production of some quantity of steel is a quite normal variation of the bloomery process noted in Europe as for the Early Iron Age as for the early Middle Ages (Killick 1996, p. 259, 260).

And a number of next difficulties are connected with it. Just the difficulty of the working with iron was the cause of the slow spreading of this technology (Waldbaum 1980, p. 87). Below we will see that iron making technologies start spreading early enough, in the 13th – 11th centuries BC in different areas of the world, but it did not lead to that the iron became dominating metal. Its rapid distribution happens a bit later.

It is connected with one peculiar properties of iron but if former properties can be still somehow connected with copper metallurgy, this has with copper nothing in common. The matter is that the properties bronze are much better than those of iron in pure its form. Bronze is rather strong, well malleable, it can be cast. Iron yields to it in all respects if not to subject it to a special processing. Iron starts prevailing over bronze only after the carburizing, a process which could not be transferred directly from the bronze metalworking where this effect is absent. It is possible to learn it only by practical way, after a long work with iron. Some blooms can already contain some quantity of carbon. The superficial carburizing and hardening occurs to iron already after hot forging under a charcoal layer. But iron (in this case steel) obtains its outstanding properties after a long heating with charcoal. Such iron (perlite) consists of two phases: soft and malleable iron (ferrite) and strong and fragile iron carbide (cementite). Just their variations provide properties of the metal. But if to cool this metal quickly after the heat treating, it will be transformed into martensite which is stronger than perlite, but is more fragile (Wheeler, Maddin 1980, p. 118, 119, 121, 124; Maddin 1982, p. 303, 304). Different variants of processing make possible to produce iron of various quality and for various purposes. Therefore the presence of carbon in iron without evidence of hardening is not indicative; it is often present in blooms of the Mediterranean in the same contents as in modern steels (Snodgrass 1980, p. 338).

This hardening could be done after forging operations, but sometimes also before them. In India ones produced steel in a rather simple way: they placed small pieces of iron with charcoal or tree branches in a crucible, and covered them with leaves. A crucible was sealed with clay and put in a furnace. After this smelters filled the furnace with charcoal and heated several hours. Sometimes they extracted iron and cooled it right away (Tylecote 1980a, p. 214; Chakrabarti 1992, p. 144).

There are also other elements which change properties of iron. First of all, it is phosphorus which reduces the melting point of iron, but also gives undesirable properties in the process of forging. Iron with small contents of phosphorus becomes even stronger than the carbonized iron, but it makes it fragile. It is possible to treat it by hot forging only, as in case of cold forging cracks can appear. Decrease of melting temperature makes it possible to form blooms of the large sizes. But the forging provokes a set of unpredictable problems, and it was necessary to work with this metal very carefully. Therefore in antiquity ones did not alloy iron with phosphorus. Phosphorus could be present in both ore and coal, but in the course of smelting its most part evaporated (Schmidt 1997, p. 126, 127; Childs 1996, p. 299, 301, 309, 311). Therefore the main way of hardening of iron was its carburization.

People mastered this important process, carburization, between 12th and 10th centuries BC in the Eastern Mediterranean, but still in the 9th century BC they manufactured the articles carbonized on the surface (Wheeler, Maddin 1980, p. 116; Maddin 1982, p. 311). Thus, the carburizing was carried out in the course of special forging operations. In Homer’s description iron becomes stronger after cooling in water. But it is possible only for steel which, therefore, in the Homer’s time (8th century BC) already existed (Muhly 1980, p. 52). Along with it both bloomer iron and bloomer steel were used. In the Scythian time in Eastern Europe everywhere the noticeable role was played by objects from soft irregularly carbonized (bloomery) steel (Terekhova *et al.* 1997, p. 48-72). The same situation was everywhere (Pleiner 1980, p. 388).

Iron making furnaces of the Old World

Before to start the description of furnaces found in Northern Eurasia, we turn to evidences on furnaces of other areas that will allow us to estimate the character of constructions and to determine how we can identify the furnaces with iron making.

If to speak about basic types of furnaces for the iron making, there are three: bowl-shaped, shaft and dome furnaces. However, the first type with shallow depression of the bottom is distinguished conditionally as archaeological data not always can reliably reconstruct the height and form of walls and covering. Therefore it is not excluded that it is a variant of a shaft or dome furnace with the deep bottom. Bowl-shaped and dome furnaces could work only with artificial blasting from bellows. In the early furnaces slag was not tapped, it sank on the bottom. It is supposed that for its extraction the furnace could be partly destroyed, and temperatures possible in such furnaces were about 1150 °C. Development of this type of furnaces is expressed in invention of pits for slag tapping (Tylecote 1980a, p. 210, 212). Such dome furnaces with slag tapping are found in Central Europe. Their diameter was 1 m, and the height was to 1-2m (Pleiner 1980, p. 399). The same type is found in Nigeria on sites of the 8th century BC. There the furnaces with the diameter of 0.85-1.25m were connected by a channel with slag pits. The reached temperatures varied in the limit of 1155-1455 °C (Ekafor 2004, p. 44). In furnaces of this type it was difficult to form the reducing conditions therefore their slags contain a lot of wüstite.

However, the highest furnaces of this series probably cannot be related to the dome furnaces, they can be considered as shaft-furnaces. For example, on the settlement of Mühlbach, in Mitterberg in Austria, eight furnaces are investigated, 1-1.5m high, with the internal diameter of 50-60cm (Herdits 2003, p. 71, 72). As the height of the walls here is much more than the diameter, the furnaces can be considered as the shaft-furnaces. In Nigeria (Taruga) the constructions were developing in the same direction. Here the shaft-furnaces without slag tapping have been found, 1-2m in height, dated to the 5th – 3rd centuries BC (Jemkur 2004, p. 39). Similar furnaces of the 4th – 3rd BC centuries have been found in the Nok culture in Nigeria (van der Merwe 1980, p. 479). These furnaces had already less problems with creation of the reducing atmosphere. For this purpose the furnace has to be high, with the height twice more than the diameter (Schmidt 1997, p. 172). In Africa this tendency gradually developed in production in high furnaces with natural draft and air heating, production of high-carbon blooms which lost the carbon in the course of forging. Therefore here it is possible to speak about a certain typological lone of the furnaces: bowl-shaped, low shaft-furnaces without a slag pit, low shaft-furnaces with a hole for slag tapping and extraction of blooms, high shaft-furnaces with natural draft (van der Merwe, 1980, p. 486, 489). This line, in general, can be considered as essentially generic, but it is not strict. Different types can be present in one area. In the Gulf of Guinea the shaft-furnaces, bowl-shaped and dome furnaces are archaeologically known, for example. There are also furnaces with slag tapping (De Maret, Rhiry 1996, p. 33). It is not excluded that it was connected with that the smelting in these furnaces gives iron with different properties. As it is possible to judge from ethnographic data in India, as a result of smelting in the shaft-furnace ones produced a mix of iron and steel, and in the bowl-shaped furnace it was possible to make rather pure iron, without sulfur, carbon and other impurity (Chakrabarti 1992, p. 138). It is quite explainable, as the content of carbon in a shaft-furnace is much higher. Therefore, in principle, the coexistence of these two types of furnaces in the neighboring territories was possible, but it depended on traditions of the following forging of metal.

In Europe it is more difficult to reconstruct the dynamics of development of furnaces because many early data are very disputable. For the earliest period of emergence of iron in Europe (Hallstatt) we know many mentions of iron smelting, but real evidences are scanty. Those furnaces that are mentioned are large pits which served more likely for ore roasting (Pleiner 1980, p. 386). In South-Eastern Germany already at the beginning of the Early Iron Age two types of furnaces are noted: shaft-furnaces with the built-in pit for slag under the heating chamber (slag pit shaft furnace), and dome furnaces (Gassmann *et al.* 2005, p. 85). In

Austria (the end of the Hallstatt D period, about 500 BC) on the settlement of Waschenberg nine hearths with slagged clay lining have been found, with the diameter and the depth of 30-40cm. Nearby slag and blooms are found that is evidence the ore smelting. The same small furnaces existed in the Celtic time when there are much more evidences. In Britain these furnaces have a deep to 20cm bottom, the diameter of 25-35cm, but the height of walls is unclear. In such furnaces it was difficult to separate iron from slag (Pleiner 1980, p. 386, 397). But, because of the small diameter if it was a dome furnace, its reaction zone would be insignificant, and in such a furnace it would be impossible to reduce iron. Therefore it is very probable that the walls were rather high, and it was a variant of shaft-furnaces with the deepened bottom for slag. For example, in some areas of India (according to ethnographic data) the smelting operations were carried out in furnaces with a diameter of only 1 foot having deep bottom and walls up to 2 feet high. The smelting in it made possible to produce very pure iron, but it was not very productive (Chakrabarti 1992, p. 138).

Very often it is difficult to understand a type of furnaces. For example, in Iberia, in the Malaga Province on the settlement of Morro de Mezquitilla, furnaces have been investigated with a diameter of 0.4-0.5m (and one even has an external diameter of 1.4 m), but the walls have remained only up to the height of 0.55 m (Renzi *et al.* 2013, p. 180). Therefore it is difficult to tell to what type these furnaces belong, but more likely to the shaft-furnaces.

In ancient Europe the bottom of the shaft-furnaces with slag pit was covered with twigs, and ore and charcoal layers were placed above. The twigs did not permit the furnace charge to sink right away, and their burning created enough carbon below. Slag flew down where it accumulated together with charcoal; the blooms remained higher at the level of a tuyere. It is supposed that this type of furnaces originated in Bohemia, Lesser Poland and Thuringia (Pleiner 1980, p. 398). After filling the pit with slag the furnace was built in a new place (Tylecote 1987, p. 154). In principle, it should be fixed archaeologically well that is perfectly confirmed by a lot of African materials.

This placement of small twigs or grass in the bottom part of furnaces is well studied by ethnographers in Africa. In this case the grass gives abundance of coal, and slag flowing down through it (containing both fayalite and wüstite), actively reacts with it, and in this bottom part of the furnace not only the iron reduction occurs, but also its carburizing. If iron has taken 2.4% carbon, in some places even molten iron occurs (Schmidt, Avery 1996, p. 179). It is rather traditional way, as in slags of the first half of the 1st millennium AD in North-Western Tanzania imprints of leaves or rush are present in some instances. In one of furnaces of this time iron was carburized up to 1% as a result of a long heating at the temperature of 800-850 °C (Schmidt, Childs 1996, p. 219, 220). Thus, in this case there was always a formation of steel in the lower part of the furnace. The aspiration to lift the reaction zone above the tuyere level to accumulate slag in the lower part of the furnace is sometimes fixed. It was possible to do also without the deepened bottom. Metallurgists of the Fipa people in South-Western Tanzania filled the furnace with ore and charcoal layers, and put wet logs below (Barndon 1996, p. 63; Childs 1996, p. 285). The result in this case was the same, as in case of the deep bottom.

According to Tylecote, the main types of furnaces in Europe were dome and shaft-furnaces with the slag pits below. The shaft-furnaces appeared in Anatolia about 1000 BC, and soon after that began to spread to the west. Then an idea appears to construct below a pit, the reservoir for slag. These furnaces are widespread in France and Britain (in some instances they have an absolutely insignificant diameter). Dome furnaces and close to them bowl-shaped furnaces are present in Germany and in different areas of Northern Europe coexisting with the shaft-furnaces. Possibly, it led him to the idea that this type of furnaces could spread from Anatolia together with the shaft-furnaces, but a separate way through the Caucasus is also possible (Tylecote 1987, p. 156-158, 167-173, 176).

But the Roman provincial shaft-furnaces became the peak in development of iron-making furnaces in Europe (Pleiner 1980, p. 399). In the Roman period even in Nubia ones tapped slag from rather small furnaces 1m in height and with internal diameter of 50cm (van der Merwe 1980, p. 474).

In the majority of the areas of Africa the ethnographically fixed furnaces belong to the shaft type, and the principle of their work has been studied very well. Height of these furnaces reached 2 m, and sometimes even 3 m. Diameter of the furnaces fluctuated in limits of the 80-140cm. Such height made possible to create a large reaction zone and to carry out the successful reduction of iron; steel was often the by-product (Goucher, Herbert 1996, p. 46; Schmidt 1997, p. 173, 175; Hahn 1997, S. 107; Barndon 1996, p. 62). Most often the blasting in such furnaces was carried out without bellows. Into the basis of the furnace 8-12 tuyeres were inserted. Because in the furnace hot gas rose up, the furnace involved air from outside and air came through the tuyeres. It is less effective than the blasting by bellows, but one person could cope with this work. Ones regulated the intake of air by wooden stoppers covered with wet clay. It allowed them to reach temperature of 1000 °C and even higher, 1200-1300 °C (Hahn 1997, S. 107, 134, 135; De Maret, Rhiry 1996, p. 33; Goucher, Herbert 1996, p. 46, 48). But a high furnace or presence of a high flue was necessary for this. Without them it was difficult to surpass the temperature of 850 °C (Tylecote 1987, p. 181).

However this was purely African phenomenon. In the majority of cases in other areas the height of furnaces was less, and the blasting was carried out by means of bellows. It was the case everywhere in India. And, bellows for large furnaces were made from a bovine skin, and for small ones did from that of sheep. Here during the same epoch we see considerable variability and types of furnaces and methods of treatment with slag. The slag was either tapped from time to time or upon completion of the smelting or remained in the furnace until the end of the smelting. Openings for extraction of iron and slag were situated below. And the height of furnaces fluctuated from 2 to 7 feet (Chakrabarti 1992, p. 130-140).

This is the general historical and technological background allowing us to consider materials of Northern Eurasia.

Iron metallurgy in the Donets Basin

It is very probable that metallurgy of iron in the Donets Basin began its development as far back as the Final Bronze Age within the Belozerka, Belogrudovka and Bondarikha cultures of the 11th – 9th centuries BC. We remember from the previous chapter that there was earlier here also the knowledge of iron smelted from sulfide copper ores.

On the settlement of Uman of the Belogrudovka culture a slagged bloom has been found (Pankov 1982, p. 201). On the settlement of Limanskoye Lake of the Bondarikha culture pieces of oxidized iron ore, limonite, and also an iron-making hearth (Fig. 14-4.) are found. The hearth had the size of 2.1×0.8m and consisted of three deep (0.33-0.42m) parts. In its filling some remains of the production are found: pieces of slagged lining, slags, a flat iron cake with a diameter of 8 cm and a thickness of 4 cm,[3] with convex bottom and a round hollow on the upper surface; iron rod 2.5 cm long and 2-3mm thick; pieces of a clay tuyere. Finds of iron are known also on other settlements of this culture (Tatarinov 1980, 1986).

There is a later analogy to this type of furnaces in the Celtic oppidum of Michelsberg. It was a trench 186 cm long and 80 cm wide (Pleiner 1980, p. 400).

Probably, these long constructions were necessary to increase the reaction zone and to create the reducing atmosphere, but this type was less effective than the shaft-furnaces.

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[3] As the specific weight of iron is 7.8 g/cm^3, the gross weight of this piece of iron is about 1570 g.

Another type of furnaces of the first quarter of the 1st millennium BC is found on the settlement of Lyutezh in the Kiev area. In general 14 furnaces have been investigated there, with a diameter of 0.5m and the height of 0.7-0.8m (Pankov 1982, p. 203). In this case it is obviously the shaft-furnaces. This type of furnaces was more progressive, but it does not mean that exactly this type became a technological standard. For the subsequent Scythian period we know few reliable furnaces, some of the known can be dated to later time. But on the Sharpovka fortified settlement of the 6th – 5th centuries BC an oval furnace is investigated, with the height of walls of 0.2-0.25 m, i.e. it is the same type that we have seen on the Limannoye Lake (Pankov 1982, p. 202).

In this region 25 iron objects of this time are known which repeat forms of bronze prototypes. At their production hot forging and sometimes welding were applied, there are traces of carburization. By the end of the 9th century BC the quantity of objects grows, they are known in the North Caucasus, North Pontic area and on the Middle Volga. Since the 8th – 7th centuries BC the cementation was known. It is supposed that this production was based on two traditions: Eastern European (production of the low-quality iron) and Eastern Mediterranean (cementation and production of steel) (Koryakova *et al.* 2011, p. 11, 12; Erlikh 2011, p. 46). Thus, it is supposed that the technology of ore smelting was a local development, and its subsequent improvement was a southern borrowing. But we see that it was absolutely synchronous with stages of development of iron production in the Eastern Mediterranean. The transition from smelting of copper ores to smelting of iron ores was not so simple. Therefore the primary impulse from the south is also more probable. It is possible that the technology of cementation was borrowed. But this transition is simpler. The surface carburizing occurs already in the process of forging. Nevertheless, in this case it is possible to agree with the Eastern Mediterranean influence as the south of Eastern Europe was connected through the Caucasus with more developed iron making centers. And the diffusion of technological improvements was simply inevitable. In Transcaucasia the steel production appeared in the 10th century BC, and in the North-Western Caucasus it did later, in the 8th century BC, but, first of all in the foothill centers connected with Transcaucasia (Erlikh 2011, p. 46). It is difficult to connect these impulses with a concrete area of the Middle East. In Iran, in Hasanlu, there are bimetallic objects appearing in the Caucasus, there is also many iron objects although their production from ore is not recorded here (Pigott 1989, p. 71, 74).

It is supposed that from here technologies of iron making got in the 8th – 7th centuries BC to the north, into the Volga and Kama areas, where they were adopted by tribes of the Ananyino culture. A part of this iron was obviously southern import, but for another part its local production is supposed (Koryakova *et al.* 2011, p. 12). The southern parallels in technology of metalworking and types of artifacts (in particular bimetallic objects) allowed a conclusion to be drawn about a migration from the North Caucasus with which also masters came (Terekhova *et al.* 2007, p. 77). It is impossible to disagree with it. Above we have considered unfortunately rare samples of copper slag of this culture. Ore smelting here succeeded former traditions of the Late Bronze Age of the area and, in principle, it was possible here to produce a limited quantity of iron. But the true production of iron does not follow directly from this technological scheme. And, if the diffusion of forging technology through many areas is admissible (if it is demonstrated, instead of it is declared), the emergence of ore smelting without the coming of masters was hardly possible.

However a question remains: how far these influences extended to the east where local origins of this production are not also excluded. We may assume even some Middle Eastern impulses to the east, but any serious base for such a conclusion while are absent. This assumption can be built only on a hypothesis of the Middle Eastern origins of the Karasuk-Irmen cultural bloc, the late Irmen impulses to the west and on the presence of traces of iron smelting in the Begazi-Dandybay complexes which we have discussed earlier.

Unfortunately, analytical materials available today do not allow us to do any conclusions about it. The series of analyzed slag documenting this process are very limited.

At first sight it seems to be justified to connect the emergence of iron with further development of tradition of smelting of primary sulfides characterizing metallurgy of the Urals during the Late Bronze Age. However, as it follows from very limited, but indicative analyses of slag of the Final Bronze Age, by the beginning of the Early Iron Age there was a universal transition to the oxidized ores and secondary sulfides. And this tradition is succeeded in the majority of cultures of Northern Eurasia of the Early Iron Age. It is very remarkable that at least in the Urals the iron metallurgy arises not just since the beginning of the Early Iron Age. Therefore, as well as the use of meteoric iron, the tradition of chalcopyrite smelting and the production of a small quantity of metal iron as a by-product apparently did not lead to the emergence of metallurgy of iron, although it promoted the knowledge of iron and development of skills of its forging and use. Taking into account the small volume of the analyzed slag of the Final Bronze Age and the Early Iron Age, this conclusion cannot be considered as a definitive, it is only an impression. Some hypotheses appear only with the research of slags of the iron smelting.

Metallurgy of iron in the Transurals

Furnaces

Unfortunately, furnaces connected with metallurgy of iron are not reliably documented in the Transurals. It is considered that they had a design identical to furnaces for copper ore smelting and it is assumed that they were surface furnaces with a pit for slag (Beltikova 1993, p. 101, 104). At first sight, such furnaces really exist. In the course of our works on the fortified settlement of Guseva Gora[4] on the lake of Great Nanoga a series of furnaces has been found. The settlement is located on the mountainous island towering over the lake. A top part of the island is surrounded with a ditch and bank with dwelling constructions inside. There are materials of the Itkul culture and a large quantity of metallurgical slag from iron making on the slopes. Traces of copper smelting on the settlement have not been found. Two furnaces are close to the discussed type (Fig. 14-5.1,2).

The first of them (Fig. 14-5.1) had a rectangular shape and the sizes of 2×1.15m. In the south-eastern part on the upper level of the contour a piece of burnt lining with a cylindrical impression about 9 cm in the diameter has been found. Probably, it was a fragment of basis of a chimney. Below pieces of burnt soil and ashen layers are present. But in the north-western part the lining of the bottom 4 cm thick is only dried, but not burnt, i.e., it was exposed to light thermal impact. This part is deepened to 25 cm from the level of virgin soil. The south-eastern part rises by a small step, and in the center a burnt spot 25 cm thick is recorded, i.e., the highest temperature was exactly here. But the furnace had a common covering over both parts that provided its firing in both parts and drying of the bottom in the north-west. The covering (perhaps, dome-shaped) collapsed having blocked everything. This common covering provided the temperature in both parts, drying and firing of the lining in the north-west, although the burning took place only in the south-east.

The second furnace (Fig. 14-5.2) was found in the form of a long depression with the rounded corners and it also consisted of two parts. The south-eastern part had the sizes 70×65cm, its edges are strongly burnt here from the top. In the filling pieces of burnt collapsed walls or an arch, burned stones with the size of 5-15cm have been found. Below the walls slightly widen forming a small arch of virgin soil. They are strongly burnt and covered with a lining layer of clay with small stones. The north-western part had the sizes 80×50cm, and the burnt soil is absent here. In the center the bottom of this part was at the level of the furnace bottom, to the north and south small elevated areas are situated.

In principle, it is possible to try to consider these constructions as smelting furnaces with a shallow slag pit in the north-western part. But both of these furnaces are situated inside the dwellings. However, and for the

[4] The works have been carried out by A.G. Gavrilyuk, S.A. Grigoriev, A.M. Naumov, and Yu.V. Vasina.

early European iron making the furnaces in dwellings are known. Especially it is characteristic of northern areas (Pleiner 1980, p. 401; Tylecote 1987, p. 171). Secondly, near the furnaces nothing has been found indicating the metallurgical production. Therefore, most likely, they were ordinary household stoves.

But two other furnaces were absolutely definitely connected with the production of iron as nearby and inside them slags and blooms (Fig. 14-5.3,4) are found. Around these furnaces a large number of burnt pieces of walls lay.

Both furnaces stood on the edge of clay platforms. Before their construction ones removed soil and put a layer of the humus brought from below from the shore of the lake (as it did not contain inclusions of small stones) which was rammed and covered with a clay layer 10-20cm thick. In the basis of one of the platforms animal bones lay. Ethnographic parallels to it exist. In Tanzania (Fipa people) where the smelting process was ritualized, at construction of a furnace a sacrifice was practiced, and bones of a lion could be embedded into the furnace (Barndon 1996, p. 65-67). But some rational explanations are more lawful. Possibly in our case the bones played a role of armature.

The width of the clay platforms was 1.5-1.7m, and the length did 2.5-3m. On the platforms pieces of the wooden planks lying in the cross direction are found, probably the remains of a shed. The shed was, probably, rather permanent, made of logs as post poles are not revealed around it, and at the edges of one of the platforms several stones have been found, some of which are rather large, to 50 cm. Some stones covered the planks of the shed, i.e., they pressed the covering of the shed. Such stones for certain would not hold out on an easy covering from the rush.

Purpose of these platforms is not quite clearly. Their analogs are known in iron making furnaces of the Roman time which were put on the edge of clay platforms, nearby pits for slag were situated, and all this structure served for slag tapping (Tylecote 1980a, p. 217, fig. 7.12.a). But, as we will see from the analysis of microstructures of the slag, it was not tapped. Therefore the closest analog is the discussed above clay platforms of the Late Bronze settlement of Gorny in the Orenburg area where slag was not tapped too. It served for comfortable work only.

When constructing one furnace (Fig. 14-5.3) ones dug in the clay platform a small ring ditch 1m in the diameter, 15-20cm in the width, and 3-4cm in the depth. Along its external edge stakes with the diameter of 5 cm to the depth of 5 cm were piled. They were tied up and from the inside plastered with clay and covered with wet fabric. As a result, imprints of these stakes and fabric have remained on the fragments of walls. The covering with wet fabric was carried out to provide uniform drying of the furnace and to avoid cracks in its walls. Respectively, the furnaces were cylindrical and were erected in one step, instead of a step-by-step plastering of clay layers. In parallel with the construction of walls ones plastered the bottom of furnaces. When constructing the second furnace (Fig. 14-5.4) a ring base of humus was made, but the other technology was the same.

Such careful preparing of the furnace walls is explained by need to prevent their slagging in conditions of long smelting at high temperatures. It was probably a standard operation at the construction of iron making furnaces. In Africa smelters were diligently smoothing walls, and then burned down grass inside to accelerate the drying. The bottom of furnaces was covered with a sand layer to protect it from slag impact (Goucher, Herbert 1996, p. 46, 47), but the last operation is not recorded in the Urals.

One furnace had a smelting chamber of 60×40cm, the smelting chamber in the second one was 60×55cm. In the lower part of the wall faced to the edge of platform, an opening (in both furnaces) have been found. Probably they served for air supply and extraction of smelting products from the furnace. Walls and bottom of the furnaces were burnt. Fragments of the burnt walls were collected, and it allowed us to estimate the size of the construction. Its initial height was 1.5 m. In one of the furnaces two large pieces of slag and in remains of the collapsed walls two blooms have been revealed.

The combination of the furnace with the specially prepared platform, the presence of the shed specifies that the furnace served a long time. Furnaces in some areas of Africa after each smelting were destroyed (Schmidt 1997, p. 100-102). But probably if a smelting complex was situated on a settlement, it was relatively long-term construction. Judging from the presence of openings in the bottom part, the extraction of smelting products was carried out through them. Naturally, the furnace was charged from above. It allowed smelters in the course of smelting to do additional charging of the furnace with charcoal and ore as it took place sometimes in Africa (Amborn 1976, S. 27), but we have no clear evidence confirming it here.

Thus, these two excavated furnaces are reliably connected with smelting of iron ore, and their design allows us to understand how it was possible to reach the reducing atmosphere using the oxidized ores and keeping the high temperature. As the blasting was carried out from below, and the furnace charge filled the entire furnace, air passed a large distance through the furnace charge that led to the intensive generation of carbon monoxide and created the reducing conditions. Possibly, just this transition from the dome furnaces to the high cylindrical ones (shaft-furnace) allowed iron metallurgy to defeat finally. Somewhere it could be realized also in another way, but the general principle was the same everywhere: the space of the smelting chamber should be sufficient for the generation of carbon monoxide. At the same time, as we have seen, similar furnaces do not mark the earliest stage in the development of iron making furnaces although technologically these furnaces are inferior to more developed furnaces with slag tapping or with the slag pit under the smelting chamber.

Slag

A small series of the iron making slag has been selected for the analysis from ancient settlements near Ozyorsk (Fig. 14-6.). It is the foothill forest zone in the north of the Southern Transurals, abounding with lakes and with numerous small deposits of both copper and iron ores. In total for the analysis it has been selected 9 samples of slag from the fortified settlements of Irtyash II, Uzhovoy Island and Kirety 1 on the lake Irtyash, and from the fortified settlement of Guseva Gora on the lake Great Nanoga.

On the settlement of Irtyash II materials of the second half of the 6th – 4th centuries BC (Itkul and Gamayun cultures) have been found. Therefore slags from this settlement definitely belong to the Early Iron Age.

Slags from the settlements of Uzhovoy Island and Kirety 1 belong to the Middle Ages (Petrogrom culture of the 10th – 12th centuries AD).

On the settlement of Guseva Gora the Itkul materials of the Early Iron Age and medieval of the 10th – 13th centuries AD are presented. This settlement is the richest with slags. Large its pieces with diameters to 30cm lie in large numbers at the bottom of the hill on which the site is situated.

Owing to so small sampling and chronological uncertainty of samples from Guseva Gora, the result of research of these slags is not able to solve any particular questions of metallurgy of this region during various periods of the late antiquity. Our research of these samples is caused only by aspiration to present the most general tendencies of the subsequent development of metallurgical production in Northern Eurasia that will allow in the future the ways of these studies to be outlined.

All analyzed slags from the Irtyash Lake area are very similar. These are pieces of crushed larger slags typical of this area. The slag was obviously crushed for metal extraction. Slag is heavy and dense, its surfaces are fused.

The smelting was carried out with charcoal. There are its inclusions and imprints in the slag.

Rather pure iron ores were used in the smelting. Impurity of the gangue are, practically, absent. In some instances there are very small grains of quartz, but they could get to the slag from furnace lining. Therefore it is impossible to determine the nature of the ore bearing rocks. There was also a silicate component in the furnace charge as the slag contains a lot of fayalite crystals whose formation is impossible without this component. Against the background that it was, certainly, the iron smelting, the presence of small and rare chalcopyrite inclusions in slag of the Irtyash settlement is intriguing. In some samples spectral analysis (Tab. 14-1.) has identified a higher copper content slags (0.2-0.7%) than in the case for usual iron making slags. Such contents are present also often if we deal with re-melting of copper. It is not excluded that the iron ore had been extracted on some copper deposit or on an iron deposit in which chalcopyrite was the incidental mineral. It is impossible to determine it more precisely on the basis of the limited number of analyses. It is also impossible to distinguish chemical groups of slag basing on only seven spectral analyses. We can only outline some difference in contents of individual trace-elements. So, two samples (2209, 2210) from Guseva Gora and one from Uzhovoy Island contain more manganese than other samples. In the same samples the contents of titan, scandium, beryllium, and yttrium are higher, and that of zinc is slightly lower. Therefore it is not excluded that these slags were smelted from similar ores.

Samples from the settlements of Irtyash II and one of the samples from Guseva Gora (2208) are chemically identical too. Therefore it is also not excluded that they were smelted from ores of one source.

For two samples the bulk chemical analysis has been made (Tab. 14-7.). The high content of iron oxides and a significant quantity of silicates in the slag of iron smelting is not surprising. The small contents of calcium and potassium attract attention, and this (maybe only in this concrete case) does not point to the use of calcite or bones as fluxes. The high concentrations of alumina (5-6%) can be explained by its presence either in the ore, or in the lining. As a matter of fact, the chemical composition of slag is close to that we have seen in many slags of copper smelting where in some cases the iron content can be also very high. Only the low copper content differs this slag sharply in comparison with that of copper smelting. It is a standard situation for slags of the iron making (Tylecote 1980a, p. 223).

The plenty of iron oxides promoted good crystallization in the slag and its low viscosity (Tab. 14-8.). Respectively, the basicity coefficient in these slags based on their chemical composition is very high and the analyzed samples belong to the ultrabasic group (Tab. 14-9.).

Standard petrochemical re-calculations of the chemical compositions have given no possibility to reconstruct the ore base (Tab. 14-10.).

Pyroxenes in slags by these calculations have not been determined. The silicate component is presented exclusively by olivine, and, in the high contents (75.4 and 76.5%). Prevalence of Fe-rich olivine (fayalite) over magnesian ones is overwhelming, and the part of magnetite is high. In small quantity corundum has been revealed, and anorthite is present. However its calculated values in slag can be explained by furnace lining and ashes.

Thus, the calculations have demonstrated only smelting of iron ores and do not give a chance for more detailed judgments about the character of the deposit. It is possible to assume only that sample 2207 from Guseva Gora and sample 2212 from Uzhovoy Island were smelted from ore of a single field as calculated their standard mineral compositions are, almost, identical.

In the majority of samples fayalite crystallized rather well (Fig. 14-V.; Fig. 14-VI.1,2) that demonstrates the low rate of slag cooling. In some samples its crystallization occurs quicker, but it can be explained by that a peripheral part of slag is analyzed. Besides, above we have discussed that in shaft-furnaces different processes can take place at different levels. To all appearances, the slag cooled directly in the furnace, it was not tapped. Usually the crystals of fayalite have various orientations. Therefore, there was no definite direction of crystallization, and there was no part of the furnace in which temperatures were much lower. It conflicts with the opinion of G.V. Beltikova who believes that slag from the furnaces was tapped (Beltikova 1993, p. 104). For the later epochs (the Shaiginsk fortified settlement of the Jurchens, 12th century AD) it has been assumed that iron ore was smelted in crucibles and then slag was poured from them. A reason of this opinion is based on the absence of slag, ore and waste in furnaces (Lenkov, 1974, p. 98). However, this assumption is insufficiently proved even for this case, and in the case of the Itkul metallurgy it is impossible at all to speak about the slag tapping.

A widespread component in the slag is wüstite. Its main part formed due to reduction of some iron mineral. As a result, the wüstite melts after its formation. But a part of wüstite is formed due to crystallization from slag, forming the large fused dendrites. Apparently, in the interval of crystallization between fayalite and wüstite (1205-1360 °C) slag cooled down very slowly. Probably, the time of smelting was also rather long as without continuation of blasting the temperature would fall very quickly.

The suggested temperature limit is confirmed also by the calculations of temperature made on the basis of the bulk chemical analysis of slag (Fig. 14-11.). Slag of this composition melts at a temperature below 1300 °C.

The smelting atmosphere was reducing. There are particles of the reduced iron in slag. They are sometimes fused, but not molten. They are reduced from wüstite or directly from some hydroxide inside its grains.

Slag from the fortified settlement of Dolmatovo in the Tobol area is similar (Fig. 14-V.); it apparently reflects smelting of the oxidized ore, probably iron hydroxides. The smelting was carried out in a furnace at a high temperature of 1205-1400 °C. The slag was cooling slowly and a long time that allowed fayalite and wüstite to crystallize well. Presence of iron prills, probably, does not specify that the iron was actually molten. Rather, it was molten wüstite reduced subsequently into iron. But it is not also excluded that a part of iron was carburized that lowered its melting point.

A slag sample from the Nizhny Tagil district in the north of the Middle Urals, in principle, shows a situation close to that which is shown by slags from settlements of the Irtyash area. In this case it is possible to assume the use of ores connected with quartz rocks. However the slag cooled faster. But it is the single sample which cannot reflect the situation on the site.

Four samples of slag got to the studied collection from the south, from the Biktimirovo settlement of Kara-Abyz culture of Bashkiria. Two of them (No. 2343, 2344) are absolutely small shapeless lumps of dense slag. The third (No. 2350) is slightly larger and heavier, but also of very small size. And only one piece of heavy slag (No. 2349) was slightly more (3×4cm). One its surface is rather flat and, probably, was formed on the furnace bottom, but it has no traces of clay lining. Another surface is rough. Two not very informative but very important samples have been found on the early Sarmatian settlement of Ulak-6 in South-Eastern Bashkiria. These are small (2 and 2.5 cm) pieces of light porous slag. The first (2338) has fused surfaces of dark gray color; and surfaces of the second (2339) are of brown color and not fused.

The spectral analysis has demonstrated (Tab. 14-1.) that the content of copper in all these samples is extremely insignificant, only in one from the Biktimirovo settlement it reaches 0.05%. Therefore we deal with iron making.

A number of trace-elements (Ag, As, Zn, Co, Ni) show a small difference between slags of these sites. Other elements (Mn, Ba, Pb, Ti, V, Sn, Cr, Sb) have higher concentrations in slag from Ulak-6. In slag of the

Biktimirovo settlement the contents of Mo is higher. Therefore these slags were obviously smelted from ore of various sources (that is quite natural to iron melting), but it is impossible to add something new about it.

One bulk chemical analysis of sample of slag of the Biktimirovo settlement has been done (Tab. 14-12.). In the slag of the settlement iron oxides considerably prevail over silicon oxide. Together with other components, it gives very high coefficient of basicity (2) calculated from the chemical composition, therefore this slag relates to the basic group. It is also the reason of low viscosity of the slag, only 2.02 Pa·s, that is slightly higher than the viscosity of slag from the Uzhovoy Island and Guseva Gora (1.28 and 1.33 Pa·s). Nevertheless, the slag was obviously fluid. A small quantity of alumina (5.38%) can be partly connected with the fused lining of the furnace, but a part of it could contain also in ore. Relatively high content of CaO (8.92%) indicates probably the fluxing with calcite. A small impurity of potassium oxide is probably caused by its transition to slag from ashes. Sulfur contains in smaller concentration than it can be detected by the analysis. Respectively, most likely, the oxidized iron ore with impurity of silicate gangue was used in the smelting.

Mineralogical studies of slag from the settlement of Ulak-6 (No. 2338) under microscope have shown that it is saturated with pores, and crystallization in it occurred very poorly. There are small needle-shaped and prismatic nuclei of fayalite crystallization in some places (Fig. 14-VI.3), as well as very small crystallizing dendrites of magnetite. Magnetite inclusions are so small that the total quantity of magnetite is absolutely insignificant. From metal inclusions one prill of iron has been identified.

Similar slag structures are typical of slagged crucibles and furnace lining. There was obviously no enough iron components in the slag. It is possible to assume that the slag was formed as a result of fusion of walls of the furnace at the iron making. When smelting the copper ore, and the lining fuses, the copper content in ceramic slags can be very low too. Therefore a serious justification requires larger fragments, large analytical series and a larger set of the analytical methods. Nevertheless, it is more probable that it is slag of the iron production. If so, it is not excluded that on the periphery of the nomadic world there were some groups practicing this production.

More definite results have been received from the analysis of two samples of the Biktimirovo settlement (2349, 2350) (Fig. 14-VI.-4-6; Fig. 14-VII.; Fig. 14-VIII..1,2). One of the main inclusions in the slag are large fused dendritic and lattice structures of wüstite, some of which keep borders of primary ore grains, probably iron oxide. In some instances molten inclusions of wüstite in small cracks in the slag matrix are present.

The second leading component in this slag is crystals of fayalite. In the studied samples they are slightly different. In sample 2349 the fayalite is presented by prismatic and polygonal forms between which small needle crystals grow. In the second sample it is more amorphous and smaller polygonal and prismatic crystals, and in some instances long skeletal crystals. The contents of wüstite and fayalite is approximately identical, together they fill in both samples up to 80% of the polished sections. Therefore in the second sample the weaker crystallization of fayalite was caused not at all by deficiency of iron components, but the higher speed of cooling of either slag or this concrete fragment of slag.

Occasionally in both samples the fused particles of iron are present, in some cases rather large. In sample 2350 large areas are filed with these molten inclusions.

Thus, the oxidized iron ore probably from quartz rocks was smelted. Of course, a possibility of use of a quartz containing flux is not excluded, but it is impossible to confirm or disprove this situation without a serial comparison of chemical compositions of initial ore and slag.

If to recognize that there are few unmolten inclusions in the slag, the bulk chemical composition can be used for calculation of melting temperature of this slag. Thanks to the basic composition it occurs at a temperature over 1200 ˚C (Tab. 14-12.; Fig. 14-11.). But for the fluidity of this slag higher temperatures are necessary. Taking into account that wüstite in the slag is molten, we may to assume the temperatures about 1360-1370 ˚C. The molten iron is not evidence of higher temperatures as it was reduced from the molten wüstite.

Then the temperature decreased gradually, and the fayalite crystallized. At temperatures below 1200 ˚C the slag solidified. Possibly it was the cause of that the large polygonal forms of fayalite did not grow in both samples, despite the basic composition of the slag.

Despite the oxidized character of ore and obviously high temperatures, the smelting was carried out in the reducing conditions. The only acceptable explanation for it is the optimal design of the furnace. A shaft-furnace is most probable, by analogy to the find in Guseva Gore. Actually, other parameters of the smelting were also, almost, identical.

Technology of iron making in the Urals

Thus, the technology of iron smelting practicing in the Urals was the follows. Ones placed iron hydroxides in the shaft-furnace together with charcoal layers. It is impossible also to exclude the presence of some quantity of sulfide minerals, for example, pyrite. It could promote the keeping of the reducing atmosphere. However such an opportunity is testified only by rare microscopic inclusions of chalcopyrite in slag of the Irtyash settlement. If they did not get into slag by accident, it is not excluded that we face very interesting phenomenon of extraction of iron ore on a copper-ore deposit. Most likely, on the same deposit both iron and copper ores could be mined.

Probably, the silicate component in slag can indicate the use of corresponding fluxes, but it also could get to the smelting together with ore, therefore we have no strict bases to assume the use of fluxes. But it is a standard situation for early metallurgy of iron. If to take pure iron ore, it was enough to reduce it by charcoal. Certainly, ore often contains impurity which can be removed together with slag. But the most widespread impurities are silicates which form optimal fayalite slag together with iron oxides. Studying of smelting places of the Early Iron Age of Italy in Baratti gulf in Populonia has resulted in a conclusion that smelting was carried out without fluxes (Pleiner 1980, p. 386). The same has been determined also for the Nok culture in Nigeria, the 4th – 3rd centuries BC (van der Merwe 1980, p. 479). It is sometimes difficult to prove the use of fluxes on the base of archaeological evidence, but later ethnographic data confirm it everywhere. Fluxes were not used in India in the 19th century (Chakrabarti 1992, p. 143). We have no evidence from Africa about the use of fluxes in the iron making too. Only ashes were used there as a flux. Therefore the African metallurgists specially selected trees for charcoal with higher contents of calcium as ashes were a natural flux doing slag fluid (Amborn 1976, S. 10, 11; Childs 1996, p. 286; Schmidt 1997, p. 104, 115).

The smelting temperature reached 1205-1400 °C and was in this interval a long time. The smelting was carried out a rather long time, and then the temperature gradually decreased. Such high temperatures demand a special discussion as in metallurgy there is an axiom that a possible temperature limit when blasting by cold air is 1300 °C. As we have seen, this limit was overcome in the Late Bronze Age. However there it was promoted by smelting of sulfide ores (exothermic reaction of combustion of sulfur and possibility of intensive blasting). Certainly, the results of development of metallurgy in the Late Bronze Age affected the temperature opportunities in the Early Iron Age. By this time there were already constructions and linings, capable to keep temperature in the furnace. Studies of ethnographic smelting of the Haya people in Tanzania show that the lining was carried out from refractory clay; otherwise it would be slagged (Childs 1996, p. 312). But the problem of the blasting with cold air remains, as sulfides were not used in smelting any more. The process was based on the oxidized ores.

The maintenance of high temperatures when smelting the oxidized ores is really a problem if the blasting is carried out by the cold air. In Africa in both an archaeological and ethnographic context long tuyeres are known. It is typical, for example, for the Haya people in North-Western Tanzania. These tuyeres were in focus of a fierce discussion because on the basis of experimental works an assumption was done that their length promoted air heating. In the course of smelting the temperature on the surface of the tuyere was 1250 °C, and at the exit from the tuyere air heated up to 600 °C. At such heating of air it is possible to heat up the furnace to 1870 °C (Avery, Schmidt 1996; Schmidt, Avery 1996, p. 175, 177; Schmidt, Avery 1996a; Schmidt 1997, p. 50, 104, 117, 119). As studying of slags of the Early Iron Age of the region revealed the temperature of 1300-1400 °C, and in some cases 1500-1700 °C, it is supposed that this tradition of the use of long fire-resistant tuyeres began 2000 years ago, and it arose in South-Eastern Niger where iron production is noted since the mid-1st millennium BC (Schmidt, Childs 1996, p. 187, 224, 225, 229). Opponents of this hypothesis claimed that even in case of such a long tuyere the temperature of air in it can increase no more than to 22 °C that is not important for essential change of temperature in the furnace (the latter can be only 10 °C higher). In a small furnace it is possible to reach the temperature of 1600 °C using cod air, and all experimental measurements are incorrect (Rehder 1996, p. 235-239; Killick 1996, p. 249, 253-257).

As a matter of fact, both opinions are based on very thorough arguments and calculations. But a wide distribution of the long tuyeres is an actual fact, and there was some reason of their necessity. Tuyeres of 1.4 m long are known also in the period of Han dynasty in China and in archaic metallurgy of India in the 19th century (Tylecote 1980a, p. 215; Chakrabarti 1992, p. 136). On the other hand, it is really difficult to imagine the heating of air if it goes through a tuyere under pressure. It cannot be considerable and influence essentially on the change of a temperature mode in the furnace. In Europe and Northern Eurasia similar tuyeres are unknown; nevertheless, our materials demonstrate possibility of the high temperatures exceeding the theoretically admissible. Possibly, the reason is that the sizes of furnaces were small. Besides, it was more significant and large-scale than heating inside the tuyeres, the heating of the gases passing through the furnace charge, which were reflecting from particles of the furnace charge and furnace walls.

After the furnace cooled slag and reduced iron were extracted for what the slag was crushed.

In general, for the Urals during the period of late antiquity it is possible to draw the following preliminary conclusions on technologies of smelting of iron ores. Hydroxides were used as raw materials. Unfortunately, we have no evidence on preparation of ore for smelting. Tools for ore crushing and places of its roasting have not been found on settlements. Possibly, these operations were carried out, but in other place, nearby the mines. Their need is quite obvious that numerous researches in other areas confirm. So, in Africa the crushing of ore and its roasting in heaps on firewood are everywhere ethnographically recorded. Sometimes this roasting was made in pits or special furnaces, sometimes (Haya people) ore could be put on the periphery of the furnace and roasted in parallel with another smelting (Schmidt 1997, p. 59, 103, 178; Schmidt, Avery 1996, p. 179; Childs 1996, p. 286). The crushing of ore was obligatory also in India; the roasting was sometimes also applied (Chakrabarti 1992, p. 139). Crushing of ore was necessary for its best reaction, and the optimal size of ore pieces depended on length of the reaction zone. So experiments with iron ore have demonstrated that pieces of ore less than 3mm are reduced easily in the furnace 1 m high; for smelting of pieces about 2 cm^3 the height of the furnace has to reach already 2.2 m (Childs 1996, p. 289). For example, in Tanzania ancient and modern furnaces of the Haya people have a long reaction zone, these are high furnaces under which a pit was also dug out. Therefore pieces of ore were rather great (Schmidt 1997, p. 145).

Correspondently, if to be based on the furnaces found in the Transurals, the ore had to be crashed up very small (less than 1 cm^3) pieces; and it was more convenient to do it on settlements, but while such finds are absent.

Temperatures were very high. Slag cooled down relatively slow and was not tapped. It is possible to assume that initially the emergence of metallurgy of iron was somehow connected with development of copper metallurgy. It is remarkable that exactly the earliest slags from the Irtyash settlement was smelted from ore probably extracted on a sulfide copper deposit. It is necessary to remind that the analyzed slags of copper smelting of the Itkul culture were smelted from ore extracted from iron containing rocks. But, most likely, it is a question of accident, instead of a technological connection. In the south-east of China, in the Wu kingdom, for example, all copper fields were located on the larger deposits of iron ores (Wagner 1993, p. 127). For certain such cases can be found also in other areas.

Metallurgy of iron in the Altai

Some slag samples from the Altai have been included in the studied collection too. There are only several Early Iron Age samples relating to smelting of iron ore from the settlements of Malyi Ganbinsky Kordon 1 and Partizanskaya Katushka which have been analyzed under microscope.

Materials from the settlement of Malyi Ganbinsky Kordon 1 are dated to the 3rd – 2nd centuries BC, and those from Partizanskaya Katushka are dated to the 6th – 2nd centuries BC. On the last settlement a rectangular hearth from slate tiles with clay lining (the size is 140×60 cm) is investigated, that was apparently connected with metallurgical production (Shulga 1998, p. 148, 149).

As we see, the slag collection from the Altai settlements of the Early Iron Age is very limited that, especially against the background of its heterogeneity, does not allow us to do reliable conclusions about metallurgical production of this period. The situation is complicated also by that slags of copper production in case of a complete smelting of ore and separation of metal can be the same as the slags of iron making. So, these slags can quite contain inclusions of metal iron that is characteristic already of many slags of the Bronze Age.

The studied slags (Fig. 14-VIII.3-6) contain a significant quantity of fused grains and dendrites of wüstite forming lattice structures in some instances. Therefore, the temperature reached the melting point of wüstite (1360 °C). There are small densely located prisms of fayalite in one sample (779). Probably, from the temperature of 1205 °C the slag cooled down rather quickly. Copper components are absent in it. But single prills of iron have been found.

Spectral analysis of these samples (Tab. 14-1.) has revealed low contents of copper. However, it is remarkable that samples from these settlements demonstrate the low concentrations of all other trace-elements, in comparison with samples from Ostrovnoe connected with copper smelting. Apparently, this is explained by the fact that in case of smelting of copper ore the furnace charge contained both oxidized minerals and fahlores, and in the iron making its hydroxides were used.

Ways of distribution of iron production

Thus, for serious discussion of the metallurgical production in the Early Iron Age we have obviously not enough evidence although it is possible to discuss some tendencies as a hypothesis. It is not excluded that early stages of iron production were connected with mining of iron ores on the copper-ore fields. In principle, it quite corresponds to the tendency revealed for the Late Bronze Age. However, as we have seen analyzing materials of the Final Bronze Age, in this period former traditions of the forest-steppe zone of the EAMP (smelting of primary sulfides) were rejected, and metallurgists started to smelt the oxidized ores. The use of the oxidized iron ores remains subsequently also in the Middle Ages. On the fortified settlement of Shelomok in the middle part of the Tobol area smelters used sideritic ores which were crushed for pieces to 5cm, roasted and crushed again to a powdery state. Marsh marl was used as a flux (Maloletko *et al.* 1983, p. 118, 127-128). According to studies of the fortified settlement of Shaiginskoe left by the Jurchens, 12th century

AD, hematite was smelted (Lenkov 1974, p. 94). It, as we have seen, was characteristic also of the African metallurgy.

In the period of the Early Iron Age in copper metallurgy a mix of the oxidized ores and secondary sulfides was used. But the metallurgy of iron was based on smelting of oxidized ores. In case of a direct transition to smelting of these ores according to the former technological scheme metallurgists would have problems with creation in the furnace of the reducing atmosphere needed for iron production. Therefore there some additional improvements of heating constructions and air supply system had to take place to solve this problem. Unfortunately, while information clearing up this question is absent. There is little reliable evidence on furnaces for iron production in this period. In the later time (the Jurchens) iron making furnaces were larger: 2.2-3m long, the width of the back wall was 2 m, and the width of the front wall was 1.4 m. However it was already a complicated high-organized production (Lenkov 1974, p. 94). The furnace of the Guseva Gora settlement was rather high, therefore the air from the bottom passed up through the furnace charge layer that led to generation of carbon monoxide and creation of the reducing atmosphere. Possibly, it was possible to realize this principle also in the long furnaces, but it was less convenient. Probably, the progress which led to iron metallurgy moved in the direction of creation of high shaft-furnaces that is distinctly shown everywhere.

Taking into account the outlined eastern connections which led to the restoration of tin alloys, preservation in the east of the traditions of smelting of oxidized ore, it is possible to assume that these improvements occurred there, but materials of the Sayan Mountains and Mongolia have not been included in the research. Unfortunately, I have also no data on technology of ore smelting in China at the end of the Bronze Age. Possibly, in different areas of the country it was different. One fact is interesting: in the area of Tonglushan in the Hubei Province a shaft-furnace is excavated which is dated to about 9th century BC. Near it pieces of malachite are found, and iron oxides were used as a flux (Wagner 1993, p. 47). The shaft-furnaces have an advantage over ordinary dome furnaces: gases in them overcome larger distance and pass through the furnace charge layer that promotes creation of the carbon monoxide and the reducing atmosphere. It made possible to smelt the oxidized ores more successfully. Thus, in the east, within the Central Asian Metallurgical Province, at the end of the Bronze Age we see the preservation of dominating tin alloys and development of technologies allowing the reducing atmosphere in the furnace to be created. It is not excluded that these impulses were carried out from there, but while we have not enough evidence. And, it should be rather east areas bordering in the south on the civilization of the Huang He Basin, as in Xinjiang (see chapter 11) the use of arsenic alloys remains at this time.

The high smelting temperatures reconstructed on the basis of slag analyses also quite correspond to the latest analytical data on iron metallurgy. The matter is that within this process it is not enough to reduce iron and to form the blooms consisting of iron and slag inclusions. The formation of slag at low temperatures is impossible.

High temperatures were necessary also for the subsequent forging of iron. Experiments on forging of blooms from medieval Novgorod have shown that the bloom for the forging has to be heated up to the temperature of 1400-1450 ºC. At lower temperatures the blooms disintegrate. In the course of the same experiments in a hearth it was possible to reach temperatures of 1400-1450 ºC (Terekhova *et al.* 1997, p. 11, 12, 17). Thus, from the point of view of the temperature mode the emergence of iron metallurgy was a united process. We have seen that during the Late Bronze Age the temperature jump was connected partly with the transition to smelting of sulfides that caused exothermic reaction of combustion of sulfur. However in parallel apparently there was a process of improvement of bellows. It is not excluded that the bellows appeared close to modern forge bellows. Construction of furnaces was improved too.

Thus, in general, the tendency of origins and development of iron metallurgy looks as follows. With the appearance of the metallurgical processes based on slag reactions and smelting of copper sulfides, in the Near

East conditions occurred to produce a limited quantity of iron as an accompanying product when smelting copper ore. It had a casual character, and metallurgists were not able to control the process. Distribution of this innovation in Northern Eurasia in the Late Bronze Age led to the appearance of the first iron objects here. It is necessary to take into account that the earliest iron objects of Northern Eurasia are found in burials of the Pit-Grave culture. However they were made from meteoric iron (as well as a part of articles of the Near East) and do not reflect the process of formation of iron metallurgy. It is not excluded that just the knowledge of meteoric iron was a stimulus which led to the use of iron pieces taken from slags of copper smelting. However it is doubtful that any analytical evidence confirming this assumption will be found. In Northern Eurasia it could not happen as during this period exclusively oxidized ores were smelted here in the oxidizing conditions that did make possible to produce the metal iron incidentally. It is not excluded that the purposeful extraction of iron from ores was also connected originally with mining of sulfide copper-ore fields, and at the first stages the ores containing sulfide minerals were preferable. Available analytical data do not allow us to speak about that how universal this tendency was and whether it was actually. Now it may be considered only as a hypothesis. Only subsequently, after development of blasting technology and improvement of balance of CO/CO_2 the transition to smelting of oxidized iron ores happened. But it is difficult to tell about the ways of spread of this innovation in Eurasia.

African metallurgy is an important example of it. Copper production in Western Africa began about 2200 BC. Some authors doubt so early date, but on sites of the period of 1500-900 BC the metallurgy of copper is quite definitely detected (Holl 2000, p. 13; 2009, p. 431; Bisson 2000, p. 89). And, judging from copper-ore mines, archaeological and ethnographic data, and despite the long period of development, the production of copper was based on smelting of exclusively oxidized ores, mainly, malachite (Bisson 2000, p. 90, 91, 97). This stability or stagnation of technology is not quite explainable against the background of development in other areas and against the subsequent rapid development of iron metallurgy in Africa. But it does not mean that metallurgical technologies were not improved at all. Moreover, it is not excluded that exactly this stability of copper technology was base for the rapid development of iron making on the African continent. As it has been already discussed above, for developing of iron ore smelting it was necessary to achieve and keep a high temperature at preservation of reducing atmosphere, despite the use of oxidized ores. Any intensification of blasting leads to the oxidizing conditions. Use of sulfides as in the case with copper ore, results in deterioration of properties of iron, and this problem cannot be solved by refinement as it took place with copper. There was a single way: improvement of constructions of furnace. And this process really took place. Early African furnaces of copper smelting are very varied in the form therefore it is supposed that it was a result of trials and errors, instead of borrowings from a single source. Later furnaces (3000-1000 years ago) are uniform, as a rule, these are cylindrical constructions. Continuations of the tradition and transition from late copper-smelting furnaces to iron-smelting furnaces are visible rather distinctly. Such purely ritual details as the holes for medicines, widespread in many African iron-making furnaces remain sometimes even up to the ethnographic time (Holl 2000, p. 38; 2009, p. 431, 434). In Congo (Yeke people) smelting of copper was carried out in furnaces with the diameter of 1 m and the height of 1.75m (Bisson 2000, p. 96) and it is close to that we see in the Urals. Invention of shaft-furnaces led to that the gases passed through the furnace charge long enough that allowed to create a high temperature at the preservation of reducing atmosphere.

This situation confirms that although the early knowledge to iron was connected with smelting of sulfide copper ore, but smelting of the oxidized copper ores led to development of technology of iron ores smelting. And it is unclear where exactly it occurred.

In scientific literature an idea was claimed long ago that iron metallurgy appeared in the Near East, more likely in Anatolia, and exactly from there it spread across Europe, although nobody has provided this idea with strong evidence (Pleiner 1980, p. 378-380; Muhly 1980, p. 51; Tylecote 1987, p. 162). The provided arguments are based on the chronology only. In the previous chapter it has been discussed that in the 2nd millennium BC iron objects in Europe were extremely rare. Their quantity on the Balkans was slightly more that is well explained by traditional contacts with the east. Iron is steadily present in the Eastern Mediterranean since the 12th century BC. Therefore the Early Iron Age begins here from this time (Waldbaum 1980, p. 82). Probably, exactly since this time we may date the transition from use of meteoritic iron and the metal received as the by-product of copper ore smelting to smelting of true iron ores. But chronologically it coincides with the movement of “Sea People” started on the European continent and swept over the whole Eastern Mediterranean (Muhly 1980, p. 51; Snodgrass 1980, p. 356). This movement had its continuation even in North Africa. Therefore it is still early to put an end in the question where the iron smelting originated for the first time. On the one hand, these migrating people could bring a just now arisen idea of iron smelting, and in the Eastern Mediterranean it was quickly adapted because of the higher level of social and economic development and various other social and economic reasons. On the other hand, the migrations could cause destructive processes in the region, break former commercial and productive relations, and this served as a stimulus for the rapid development of the new technology which has arisen by that moment in the Near East. A clear solution of this problem while cannot exist. As an example it is possible to give a situation on the Cyprus. Muhly provides biblical descriptions of the Philistine smiths and assumes that exactly from Palestine iron got to the Cyprus, and from there to Greece (Muhly 1980, p. 51). But on the Cyprus iron appeared since the 12th – 11th centuries BC, and originally it often had the Aegean forms and was accompanied by the Aegean ceramics that has allowed a conclusion to be drawn that this technology came from the Aegean area (Snodgrass 1982, p. 293). It is necessary to remember that just the Philistines, apparently, were this alien component. And the possibilities of iron knowledge existed in Europe as in the Late Bronze Age the chalcopyrite smelting appeared there, and the accompanied it limited iron production was from time to time inevitable. Nevertheless, the tribes occupying before Western Anatolia were the main component in this movement. Therefore today the theory about the Anatolian homeland of iron metallurgy looks more preferable.

There are no also doubts that the further distribution of iron was carried out from the Eastern Mediterranean that is confirmed by chronology of this distribution. Prevalence of iron over bronze began here only in the 10th – 9th centuries BC (Waldbaum 1980, p. 85; Snodgrass 1980, p. 357). Above we have discussed that exactly by this time ones seized the iron carburizing, and only by the 8th century BC it is possible to speak about the stabile production of steel. Just it made sensible the mass production of iron. And from now it starts spreading actively. At first it occurs in Central and Southern Europe, and then in Western Europe. In England iron appears only since 500 BC. In Northern Europe it occurs earlier, but in noticeable quantities iron articles are present there late enough (Pleiner 1980, p. 379, 380). And only this vector of distribution indicates the distribution from the Eastern Mediterranean. But it marks the distribution based on the beginning of steel production, and it does not testify at all that in the same region there was a technology of smelting of iron ore although it is the most probable version.

To the east, in Northern Eurasia, there is no clarity in this question too. We can assume that a technological impulse came here from the Near East or the Caucasus. Possibly, for the Donets Basin it is the most acceptable explanation.

It is possible to assume that in the Urals and Altai the iron metallurgy arose independently basing on its earlier extraction in the course of smelting of sulfide copper ores and the transition to smelting of the oxidized ores at the end of the Bronze Age. In this case it is difficult to solve this problem logically without large analytical series, as it was necessary to take one small step between these two technologies, therefore independent emergence of a similar technology in various remote areas is quite probable. However a question remains: whether these processes in the Urals and in Altai were connected with each other? If to proceed from the logic of cultural genesis in the region, it is possible to assume the impulse from the east. However it took place at the very beginning of the Early Iron Age, and the emergence of iron metallurgy in the forest Transurals occurred much later, in the 5th century BC that is after the emergence of this technology in the Ananyino culture. Taking into account the obvious connections between the Ananyino and Itkul cultures a conclusion about distribution of this production from the Western Urals to the Transurals arises. But comparison of slags from the Western Urals an the Transurals clears up nothing in this question.

To the east, in the Sargat culture of the south of Western Siberia, a large quantity of iron appears even later, in the 3rd century BC, and in the Bolsherechie culture of the Upper Ob area in the 5th – 3rd centuries BC that confirms this vector of relations too. But the Itkul knives are made from low-quality bloomer iron, and the needles are from steel (Beltikova 1993, p. 98; Koryakova *et al.* 2011, p. 13, 14). The last obviously specifies that the bloomery iron was used, and the technology of steel production was absent. It was possible to produce some quantity of steel, quite sufficient for manufacturing of needles, even within the bloomery production. Therefore it causes the bewilderment why the technology of steel manufacturing which could be easier distributed, did not come to the Transurals together with technology of ore smelting? Nevertheless, this vector of relations is confirmed also by characteristic of the Ananyino culture bimetallic articles. But in this case it is possible to raise the second question: from where the iron came to the nomads of the Transurals at the very beginning of the Early Iron Age, as these tribes were obviously of eastern origins? May be it, nevertheless, was known among the peripheral nomadic groups as it is probably shown by the slag from the settlement of Uvak-6?

It is impossible also to exclude that the technology already existed and came from the east, but it was not widespread rather widely. It is necessary also to remember that at the end of 6th – the beginning of the 5th century BC nomads from Eastern Europe, Southern Kazakhstan and Central Asia penetrated to the Transurals. Therefore the problem can be solved by only a special research in which considerable series of ore and slag of the Final Bronze Age and the Early Iron Age will be involved.

For the time present, the general dynamics of the spreading of iron metallurgy in the east looks as follows. In end of the previous chapter we have discussed that at the end of the Bronze Age a group of cultures (Begazi-Dandybay, Irmen, Karasuk, and Elovka) appeared in Kazakhstan, Southern Siberia and Central Asia. These cultures originated after impulses from the Middle East and they contain some traces of iron making. In this connection A.H. Margulan wrote about the appearance of iron metallurgy in the pre-Scythian time being based on materials of the Begazi-Dandybay culture (Margulan 2001, p. 73). In Western Siberia in the Late Bronze Age single iron objects are known in the Elovka culture, and in the late Irmen complexes (Linevo cemetery, the 8th – 7th centuries BC) already a large series of iron objects is known (Koryakova *et al.* 2011, p. 14). And, in Western Siberia where no copper field is present, it was obviously the bloomery iron. Therefore, here the technologies of iron production were rather developed already by the beginning of the Early Iron Age, i.e., earlier than they appeared in the Transurals. But the evidences testifying it are limited: the coming at the beginning of the Early Iron Age from the east of the technology of smelting of oxidized copper ores and, correspondently, the ability to keep high temperatures in conditions of the reducing atmosphere, and also eastern impulses which had impact on formation of Ural cultures. But, I will repeat, for a final decision of the question large series of the analyzed slag of this epoch are needed.

As a result, it is possible to assume that technologies of iron can get into Central Asia in the last third of the 2nd millennium BC from the Middle East although, at the beginning, they did not gain here an essential development. But subsequently exactly from here this technology was distributed to the west up to the Transurals. It does not conflict with a general picture of distribution of this production in the neighboring areas.

In Western and Central Iran in the mid-2nd millennium BC the Gray Ware culture formed which is considered already as a culture of the Early Iron Age. However originally (1450/1350-1100 BC) iron objects in it are very rare. In the second period (1100-800 BC) the iron is already present on many sites, and since the third period (800-550 BC) it becomes really widespread. In Hasanlu, for example, about 2000 articles have been found, the majority from which is dated to about 800 BC. The same occurs also in neighboring Urartu. Steel appears at the same time that explains the rapid adaptation of the new technology. It was not a very developed production yet. Analyses of the artifacts from Hasanlu have demonstrated that more often it was something average between rough iron and low irregularly carburized steel. There was no steady ability to produce the steel (Pigott 1980, p. 418, 420, 421, 431, 499; 1989, p. 67, 76; 2004; 2009, p. 375, 377). All this repeats a situation in the Near East; therefore it is quite probable that the distribution of technology started exactly there.

To the east, in India, iron spread some later, but in general at the same time. Almost everywhere (in the north-west, in Balochistan, on the Deccan Plateau, in megaliths of the Southern India) it appears in the early 1st millennium BC. There are small exceptions, for example, the earliest iron in Gujarat is dated since 500 BC, but it is caused by a small volume of excavation of this period in the area. Studies of the iron demonstrate that it was mainly bloomery iron (ferrite), but there is also carburized metal, and a mix of ferrite with steel that could be a result of the bloomery production. But sometimes the surface of artifacts was carburized by means of a long high-temperature heating. Importance of iron is emphasized by that it is mentioned as an obligatory attribute of gods of the Rigveda (Chakrabarti 1992, p. 37, 40-47, 50-55, 60, 67, 68, 78, 80, 86-98). Possibly, the emergence of steel promoted the rapid distribution of iron here.

This southern background does not contradict a possibility of so early penetration of iron metallurgy to Kazakhstan and Central Asia. But, as we see, to the south iron does not become the widely used metal prior to the purposeful production of steel.

It is not excluded that the emergence of iron making technologies in Central Asia by the end of the Bronze Age made impact on their distribution to the south. In China the first rare finds of iron are dated to the 12th – 11th centuries BC; and it is supposed that this iron was of meteoric origins (Needham 1980, p. 512, 515, 539; Wagner 1993, p. 95), although the emergence of the Karasuk tribes on northern borders of China assumes also option that this iron was of metallurgical origins. But systematic production of iron begins here since the 7th /6th century BC, and since the 5th century BC it gets also into Indochina (Needham 1980, p. 513, 515, 539). However, it is not excluded that the first iron was present in Thailand slightly earlier, during 700-500 BC (Pigott 1996, p. 89). Possibly, the mass production in China begins also only since this time, and here at once were making both bloomery iron and cast iron that was caused by the developed bronze-casting technologies (Wagner 1993, p. 66, 146). This means that in the north the iron making technologies arose earlier and could therefore have a forming impact.

It contradicts an early hypothesis that iron in China appeared about 600 BC, probably, from the Middle East (Tylecote 1980a, p. 214), but it corresponds to the current ideas of Chinese scholars who believe that the iron metallurgy was introduced to China either by Scythians through Xinjiang or from the Western Asia (Wei 2006, p. 17; Wu 2006, p. 20, 21). The earliest metallurgical iron of China is dated to the 10th century BC, and it has been found really in Xinjiang (Pigott 1996, p. 89).

There is, however, an opinion that in the Scythian barrows of Tuva in Southern Siberia the iron of the 7th century BC was probably imported from Eastern Zhou (Semenov 2011, p. 75). The last is not essential in this case as in the royal barrows the artifacts brought from far away could be placed, and it has no relation to origins of the production. But the absence of iron in the earlier Scythian complexes indicates something too. Whether means it that in Central Asia the production dies away?

Subsequently the Chinese metallurgy develops absolutely independently, and develops promptly. Initially steel was produced here in crucibles. But very soon ones began to make cast carburized iron from which relatively large articles were cast. Possibly, it was connected with the previous high level of the bronze-casting production (Tylecote 1980a, p. 215, 216; Wertime 1980, p. 3, 4).

This problem of an external stimulus for development of iron metallurgy is actual everywhere. It is very indicative on the African continent. Here long ago a typical for different fields of archeology opposition existed of trans-cultural diffusion and autochthonous development. Earlier an opinion was accepted that everywhere in Africa the transition to smelting of iron was realized without the stage of copper metallurgy, directly from the stone industry. But gradually the evidences appeared testifying that there was copper metallurgy already in the 1st millennium BC everywhere in Western Africa (Jemkur 2004, p. 34, 37).

At any discussion about the correctness of chronology of iron metallurgy in Africa, it is impossible to discuss the transition to iron smelting from the Stone Age for technological reasons (skills of maintenance of high temperatures, heat-resistant linings, forging, reducing atmosphere, etc.). But there are many data on the early emergence of metallurgy of copper. In the chapter on the Eneolithic the data were provided that in North Africa the first copper objects and copper metallurgy started appearing already during this period and, judging from typology of some artifacts, it was stimulated from the Iberian Peninsula. To the south, in Niger, there are radiocarbon dates for the copper metallurgy within the 3rd millennium BC. It is worth doubting, but a series of dates of the 2nd millennium BC is quite reliable (Holl 1997, p. 18, 21; Holl 2000, p. 13; Bocoum 2004, p. 100, 102). Early dates of the copper metallurgy in the Nile valley demand no discussion at all. Therefore, in principle, the problem is, whether the iron metallurgy arose here on the basis of local development of copper metallurgy or it was introduced.

For North-Eastern Africa it is possible to answer this question quite unambiguously. As well as everywhere in the Eastern Mediterranean, about 900 BC iron hardening and steel appeared in Egypt. But smelting of iron ore was carried out since the 7th – 6th centuries BC, and it was stimulated at first by the Assyrians, but the connection with the Greek colonization is more evident (Amborn 1976, S. 47, 80-81; Snodgrass 1980, p. 365; van der Merwe 1980, p. 471). From here the iron metallurgy penetrated to the south along the Nile, into the Meroe Kingdom, where the first iron artifacts probably imported are known in a context of the 8th century BC, and the iron metallurgy appeared at the end of the 6th century BC, but absolutely reliable in the 5th century BC, and, in the large volumes (van der Merwe 1980, p. 472, 473; Jemkur 2004, p. 34, 35). Correspondently, all this quite keeps within the tendency that took place everywhere in the Eastern Mediterranean and is explained by the external stimulus.

For Western Africa such certainty is absent because of a weak study and ambiguity of radiocarbon dates. Some dates from the Termit Massif in Niger refer the iron metallurgy to 2000 BC that is much earlier than in Anatolia and have allowed an assumption that a single center of iron origins did not exist (Fluzin 2004, p. 66). Moreover, some former dates of iron finds in the layers dated to 2780 BC and the mid-3rd millennium BC have provoked an idea that iron got to Egypt from Western Africa (Maes-Diop 2004, p. 189-191). But reliably the iron in Niger is present since the 1st millennium BC, and a metallurgical furnace for iron smelting is dated only since 760 BC (Holl 1997, p. 22; Holl 2000, p. 14). And in general in this area the sites connected with metallurgy give the dates between the 17th and 9th centuries BC (Holl 2009, p. 417, 419). But the early dates are rare, and a question remains: how correctly they indicate just the connection with iron metallurgy?

There is one more aspect of the problem. Furnaces for copper smelting in Niger are divided into two periods: the Copper Age I (4000-3000 BP or about 2545-1200 BC) and the Copper Age II (3000-1000 BP or 1200 BC – 1000 AD). Early furnaces are very various; therefore it is supposed that it indicates the local development (trials and errors). Furnaces of the late period are uniform, they are cylindrical. The earliest iron making furnaces of the area are dated to the 8th – 7th centuries BC. They are cylindrical, and it is considered as a continuation of tradition from copper furnaces of the late period (Holl 2009, p. 431, 434).

To the south, in Nigeria, metallurgy of iron is presented in the Nok culture. There are a lot of problems with its dating, and some scholars doubt the early dates as it is the arid zone where old trees could be used

(Bocoum 2004, p. 98). Besides, very often the analyzed samples have been collected from the surface, without excavation, that causes many questions (Quechon 2004, p. 109-118). Therefore the early dates in Nigeria are considered to be wrong, and now for the Nok culture the dates since the 10th – 9th centuries BC are accepted (Maes-Diop 2004, p. 191). But, if to speak not about the culture, but about the dating of sites where the earliest iron production of the Nok culture is recorded, it is Taruga dated to about 2500 BP (the 7th – 6th centuries BC) (Aremu 2004, p. 149). There are also slightly earlier dates (the 8th century BC) for iron metallurgy in Nigeria (Ekafor 2004, p. 43). It is not excluded that the emergence of the metallurgy was stimulated there by impulses from the north as the formation of this culture was connected with coming of northern tribes.

Thus, it is obvious that the early dates of the iron making in Africa are wrong. May be the old theory that this technology was distributed from Carthage is right? This theory really existed. Iron was known in the Phoenician colonies, Phoenicians traded with the Berbers, and those with more southern areas, and the technology was also delivered along these caravan paths (van der Merwe 1980, p. 477). But in Carthage the iron metallurgy is dated since the 8th – 7th centuries BC that is synchronous or even later than in some parts of Africa where it is possible to trace its gradual development (Holl 2009, p. 426).

To the south, in Central Africa, the dates of iron production are within the late 2nd – early 1st milennium BC (Holl 1997, p. 22; De Maret, Rhiry 1996, p. 31; Essomba 2004, p. 148; Maes-Diop 2004, p. 191, 192), although some chronological problems are present here too.

To the east, in the area of the Great African Lakes and Tanzania, the dates of emergence of the iron production are within the interval of 900-500 BC. But lately the early dates (about 1450 BC for the Great Lakes and 1740 BC for Tanzania) have appeared there (Holl 1997, p. 22; 2000, p. 15).

In the late 1st millennium BC – early 1st millennium AD the iron production spread to South Africa that is usually explained by migrations of the Bantu people from the Gulf of Guinea although evidences about it are scanty (van der Merwe 1980, p. 478, 482; Maes-Diop 2004, p. 192). From Nigeria and Cameroon the Bantu languages spread in the early 1st millennium BC to the area of the Great Lakes that in general corresponds to the reliably dated traces of metallurgy here, and then to the south. At the same time the iron metallurgy appeared there too. But then in South Africa also the copper metallurgy appeared (Miller 2003, p. 102). Therefore the distribution of metallurgy here was connected with migratory processes. But the problem is that the proto-Bantu were not metallurgists, judging from linguistic data. They mastered metallurgy somewhere on the road (De Maret, Rhiry 1996, p. 34, 36). It is not excluded that it took place exactly near the Great Lakes as some languages (Egyptian, Sudanese and Bantu) have the same word for iron designation (Maes-Diop 2004, p. 192).

In general, as we see, there are few data in Africa both archaeological and linguistic, and many scholars incline to that an independent formation of iron in two centers in the east and west is more probable, without influence from the north (Müller B. 1997, S. 81, 82).

Unfortunately, single early dates in many areas raise doubts. The problem is not only in standard troubles of the radiocarbon analysis, probes from the surface, lack of large series, but also in the ambiguity of the context of many probes. How the earliest from them are connected with the production of iron?

But there are obvious things. The distribution of iron in the southern part of Africa was caused by migratory processes from the north, and it was a later phenomenon. It is possible to say the same about the areas of the Gulf of Guinea including the whole Nigeria. There are no doubts also in borrowing of this technology in Sudan.

There is a problem of emergence of iron metallurgy in North-Eastern Niger. Carthaginian influences can be ignored for chronological reasons. But in the last third of the 2nd millennium BC North Africa was penetrated by people from the Eastern Mediterranean where iron was already well known. Therefore it is not excluded that the idea of iron smelting was introduced by them and then spread to the south long before Carthage. Above, discussing technological capabilities of transition from smelting of copper ore to smelting of iron, we have said that in Africa such conditions were present as there was the ability to create the reducing atmosphere at smelting of the oxidized copper ore. But radiocarbon dates are not enough to tell accurately whether the idea of iron smelting was borrowed, being put in an appropriate technological context, or it arose independently from this appropriate context. Typological comparisons and cultural studies are necessary.

Socio-economic reasons and technological conditions of development of iron making

In the Early Iron Age of Northern Eurasia there were some processes, radically different from the processes and relations during the Bronze Age. Traditionally it is supposed that exactly the production centers located in the forest and mountainous areas supplied the steppe. Possibly, it also was substantially so, but it is a hypothesis which is not based yet on serious studies. The emergence of iron metallurgy led to the further development of territorial specialization in Northern Eurasia. If since the beginning of the Early Iron Age the production starts being displaced in the production centers of the forest-mountainous zone surrounding the steppe, to the areas of copper mines, with the appearance of iron the production extends territorially within the forest zone, but, at the same time, a specialization in production of this or that metal appears caused by the geographical factor. For areas of Western Siberia remote from copper-ore sources it is quite explainable. However in some centers specializing in copper production, iron was not produced although possibilities for this existed (Beltikova 1993, p. 98, 105). At the same time, as we see on the example of settlements near Ozyorsk with sources of copper ore nearby, even they specialized in iron making. Thus, the factor of specialization first determined by geographical factors becomes connected with social and economic factors, and also with certain traditions. And, as the Itkul materials demonstrate, just the specialized metallurgical centers arose, and some of them probably were seasonal although they were surrounded by massive fortifications. If this assumption will be confirmed, a question will be open: who kept these settlements during the periods when metallurgical operations were not practiced there, and what systems of social relations supported this system? In general, this period generates many questions. And meanwhile we have no sufficient information for answers.

Motives of the wide distribution of iron are also a very complicated problem. Actually, for more developed stages of the production when the high-quality steel appeared, they are obvious: high quality of articles and possibility of mass production. For this reason we see the rapid distribution of iron after the work with steel was mastered. At earlier stages the reason could be others. It is supposed that there was a shortage of bronze at the end of the Bronze Age in the Eastern Mediterranean as there were few sources of tin, and the use of metal grew (Muhly 1980, p. 47). It could be really so because of destruction of the system connected with the movement of “Sea People” this situation was aggravated, and a part of metal should be replaced with iron of low quality (Medvedskaya 2011, p. 9). Work with this metal allowed to smiths to improve technologies and to achieve in the course of time the ability to produce the qualitative metal. The same variant is suggested for Northern Eurasia where destruction of cultural system of the Late Bronze Age led to dissolution of the traditional deliveries of tin and stimulated the transition to iron (Kushtan 2011). But in this case it is possible to doubt a similar conclusion as at the beginning of the Early Iron Age in Northern Eurasia just the restoration of tin supply took place. Therefore it is necessary to look for other motives.

For many militarized societies including nomadic societies of Northern Eurasia, a possibility to manufacture the better weapon was important. Sometimes a possibility to manufacture tools was the main stimulus. As an example it is possible to give a situation in the Wu Kingdom, in South-Eastern China, where exactly low cost of iron agricultural tools was the cause of development of iron making (Wagner 1993, p. 97, 144). In

Iran it was promoted by expansion of Assyria and Urartu (Pigott 1989, p. 69). These reasons everywhere were own. But there were also technological peculiarities. As we have seen the iron smelting is rather difficult technological process. It is closely connected with the subsequent problems of forging. Therefore the transition to this technology was a difficult complex transformation which was difficult to be borrowed without contacts and a training process. If it was the transfer of this technology over a large distance, instead of a slow diffusion during some centuries, more often we must suppose migrations or very intense contacts. In Africa it is visible rather well, irrespective of the problem of primary emergence of this technology in Niger.

But for its assimilation a technological readiness was also necessary in the form of ability to maintain the high temperature and reducing atmosphere in conditions of smelting of the oxidized ores. As we have seen, this condition is kept in Africa thanks to what the rather rapid distribution of iron production took place there. The metallurgists who traditionally smelted oxidized copper ores here and created the shaft-furnaces were ready to it. We observe the same in Northern Eurasia where in many areas of the Asian zone by the time of emergence of iron the copper smelting was based on the oxidized ores too. It was a surmountable obstacle, but its overcoming depended on the training process too.

In my opinion, in the above-stated sketch the following is important. Irrespective of various social and economic conditions, of ore base and very different traditions of previous copper metallurgy, the production of iron spread in one rather narrow time interval over huge spaces of Eurasia. Therefore it does not come to mind almost to anybody to discuss independent origins of metallurgy of iron in different areas. And, as we have seen, very frequent it was connected with migrations.

But concrete processes of the transition to the Early Iron Age here do not look rather distinctly yet, and can present to us many surprises in the future.

Tab. 14-1. Emission spectral analyses of slag (%) from sites of the Early Iron Age. The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Itkul	slag	39	0.005	0.003	0.007	0.07	0.015	0.3	0.0015	0.0003	>1
Itkul	ore	40	0.003	0.001	0.007	0.1	0.02	0.2	0.002	0.00015	>>1
Zuevskoe	slag	444	0.015	0.002	0.02	0.03	0.01	0.5	0.0015	<0.0003	0.02
Zaosinovo	ore	161	0.002	0.0015	0.001	0.3	0.02	0.5	0.001	0.00015	0.02
Dumnaya	slag	606	0.0007	0.0007	0.003	0.2	0.001	0.05	<0.0005	0.001	>>1
Dumnaya	slag	607	0.003	0.002	0.001	0.1	0.003	0.05	<0.0005	0.003	>1
Dumnaya	slag	608	0.002	0.001	0.001	0.1	0.005	0.1	0.0005	0.0015	>1
Dumnaya	slag	609	0.002	<0.0003	0.0015	0.05	0.003	0.07	<0.0005	0.001	>1
Dumnaya	slag	610	0.001	0.002	0.002	0.3	0.007	0.1	<0.0005	0.0003	0.7
Dumnaya	slag	611	0.0015	0.001	0.0015	0.07	0.007	0.2	0.0015	0.0015	>1
Dumnaya	slag	612	0.003	0.003	0.005	0.05	0.015	0.3	0.0015	0.0007	>>1
Dumnaya	slag	613	0.0015	<0.0003	0.002	0.07	0.03	0.03	0.0005	0.0015	1
Dumnaya	slag	614	0.005	0.015	0.005	0.05	0.01	0.2	0.002	0.0007	>1
Dumnaya	slag	615	0.003	0.0015	0.0015	0.1	0.0015	0.1	0.0005	0.001	>1
Dumnaya	slag	616	0.0015	0.005	0.0015	0.3	0.003	0.1	<0.0005	0.0007	1
Dumnaya	slag	617	0.001	<0.0003	0.0015	0.2	0.003	0.1	0.0005	0.0003	>1
Dumnaya	slag	618	0.005	0.003	0.015	0.07	0.01	0.3	0.0015	0.0003	1
Dumnaya	slag	619	0.002	0.0015	0.002	0.1	0.007	0.1	0.0005	0.0007	>1
Dumnaya	slag	620	0.005	0.002	0.007	0.1	0.007	0.2	0.0015	0.0007	1
Dumnaya	slag	621	0.0015	0.002	0.001	0.2	0.007	0.15	<0.0005	0.0007	0.7
Dumnaya	slag	622	0.005	0.005	0.005	0.1	0.0015	0.2	<0.0005	0.0007	>>1
Dumnaya	slag	623	0.005	0.002	0.003	0.1	0.003	0.15	0.0005	0.002	>>1
Dumnaya	slag	624	0.003	0.003	0.005	0.07	0.01	0.2	0.0015	0.0005	>1
Dumnaya	slag	625	0.0015	0.0007	0.001	0.2	0.003	0.15	0.0005	0.001	>1
Dumnaya	slag	626	0.005	0.003	0.003	0.2	0.003	0.15	0.0005	0.001	>1
Dumnaya	slag	627	0.0015	0.001	0.002	0.3	0.003	0.15	0.0005	0.0015	>1
Dumnaya	slag	628	0.002	0.002	0.0015	0.1	0.0015	0.07	<0.0005	0.003	>1
Dumnaya	slag	630	0.0015	0.002	0.003	0.1	0.005	0.15	0.0005	0.0003	0.5
Dumnaya	slag	631	0.005	0.002	0.0015	0.1	0.007	0.15	0.001	0.002	>1
Dumnaya	slag	632	0.003	0.0015	0.015	0.1	0.01	0.3	0.0015	0.00015	>1
Dumnaya	slag	633	0.001	0.0015	0.002	0.15	0.002	0.07	0.0005	0.001	>1

Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Dumnaya	slag	634	0.0015	0.001	0.0015	0.15	0.005	0.07	0.0005	0.002	1
Dumnaya	slag	635	0.003	0.003	0.01	0.1	0.015	0.5	0.0015	0.0015	>>1
Dumnaya	slag	636	0.005	0.003	0.005	0.1	0.01	0.2	0.0015	0.0007	>1
Itkul	slag	637	0.002	0.0015	0.0015	0.15	0.003	0.1	0.0005	0.002	1
Itkul	slag	638	0.005	0.007	0.007	0.15	0.01	0.3	0.0015	0.0007	>1
Itkul	slag	639	0.007	0.02	0.005	0.2	0.01	0.2	0.0005	0.0015	>>1
Itkul	slag	640	0.0007	0.0005	0.001	0.1	0.007	0.07	<0.0005	0.0007	1
Itkul	slag	641	0.003	0.001	0.005	0.2	0.007	0.2	0.0015	0.002	>1
Itkul	slag	642	0.0015	0.0003	0.001	0.15	0.01	0.1	0.0005	0.0003	0.7
Itkul	slag	643	0.005	0.0015	0.005	0.15	0.005	0.1	0.0005	0.002	>1
Itkul	slag	644	0.002	<0.0003	0.0015	0.15	0.007	0.07	<0.0005	0.005	>1
Itkul	slag	645	0.003	0.0003	0.002	0.1	0.01	0.1	0.001	0.0005	1
Itkul	slag	646	0.002	0.0007	0.0015	0.1	0.003	0.07	<0.0005	0.003	>1
Itkul	slag	647	0.05	0.02	0.007	1	0.007	0.15	0.0005	0.0007	>1
Itkul	slag	648	0.002	<0.0003	0.0015	0.15	0.003	0.05	<0.0005	0.0015	>1
Itkul	slag	649	0.0015	0.0003	0.001	0.07	0.0015	0.03	<0.0005	0.0007	1
Itkul	slag	650	0.003	0.0007	0.0015	0.1	0.005	0.1	0.0005	0.002	>1
Itkul	slag	651	0.002	0.001	0.0015	0.15	0.003	0.1	<0.0005	0.0015	>1
Itkul	slag	652	0.003	0.0015	0.001	0.15	0.005	0.07	<0.0005	0.003	>1
Itkul	slag	653	0.001	0.001	0.002	0.1	0.005	0.1	<0.0005	0.002	>1
Itkul	slag	654	0.005	0.003	0.002	0.2	0.005	0.1	0.0005	0.002	>1
Itkul	slag	655	0.003	0.0015	0.005	0.05	0.003	0.1	0.0005	0.001	>1
Itkul	slag	656	0.0015	0.0005	0.005	0.1	0.007	0.15	0.0005	0.0003	1
Itkul	slag	657	0.002	0.0007	0.002	0.1	0.0015	0.07	0.0005	0.003	>1
Itkul	slag	658	0.003	0.001	0.002	0.1	0.007	0.2	0.0005	0.0003	1
Itkul	slag	659	0.005	0.02	0.005	0.2	0.01	0.2	0.0005	0.0015	>1
Itkul	slag	660	0.02	0.002	0.02	0.1	0.015	0.5	0.0015	<0.0003	0.5
Itkul	slag	661	0.001	0.0003	0.0015	0.3	0.005	0.15	0.001	0.0015	>1
Itkul	slag	663	0.002	0.001	0.0015	0.15	0.005	0.1	0.0005	0.002	>1
Itkul	slag	664	0.002	0.003	0.005	0.1	0.01	0.15	0.0005	0.0015	>1
Itkul	slag	665	0.015	0.003	0.02	0.2	0.007	0.5	0.0015	0.002	1
Itkul	slag	666	0.003	0.003	0.003	0.3	0.01	0.15	0.0005	0.0007	>1
Itkul	slag	667	0.005	0.01	0.02	0.15	0.01	0.2	0.0015	0.001	>>1

Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Itkul	slag	668	0.007	0.002	0.01	0.07	0.007	0.15	0.001	0.0005	>1
Itkul	slag	669	0.007	0.002	0.015	0.1	0.01	0.15	0.001	0.0005	>1
Itkul	slag	670	0.003	0.0015	0.005	0.05	0.01	0.2	0.001	0.0015	>1
Itkul	slag	671	0.002	<0.0003	0.002	0.07	0.003	0.1	0.0005	0.005	1
Malyi Ganbinsky Kordon	slag	779	0.003	0.0015	0.007	0.15	0.0015	0.2	0.0005	0.00015	0.1
Partizanskaya Katushka	slag	781	0.005	0.003	0.001	0.05	<0.001	0.07	<0.0005	0.00015	0.2
Ostrovnoe 3	slag	788	0.0015	0.0005	0.002	0.2	0.01	0.2	<0.0005	<0.0003	0.015
Ostrovnoe 3	slag	789	0.007	0.0015	0.015	0.05	0.015	0.5	0.002	<0.0003	0.7
Ostrovnoe 3	slag	790	0.005	0.0015	0.015	0.07	0.01	0.7	0.0015	<0.0003	0.7
Ostrovnoe 3	slag	791	0.007	0.05	0.01	0.1	0.007	0.5	0.0015	0.00015	>1
Ostrovnoe 3	slag	792	0.005	0.0015	0.01	0.1	0.007	0.3	0.001	<0.0003	1
Dolmatovo	slag	2033	0.02	0.003	0.005	0.1	0.003	0.02	<0.0005	<0.0003	0.05
Dolmatovo	slag	2034	0.015	0.003	0.07	0.15	0.007	0.5	0.0005	<0.0003	0.07
Guseva Gora	slag	2208	0.015	0.001	0.003	0.5	0.003	0.05	<0.0005	<0.0003	0.02
Irtyash II	slag	2211	0.007	< 0.001	0.003	0.5	0.002	0.05	<0.0005	<0.0003	0.02
Kirety 1	slag	2213	0.002	< 0.001	0.015	0.3	0.01	0.05	<0.0005	<0.0003	0.01
Irtyash II	slag	2214	0.015	< 0.001	0.003	0.15	0.002	0.05	<0.0005	<0.0003	0.7
Uzhovoy Island	slag	2215	0.02	0.002	0.02	0.2	0.01	0.3	0.001	<0.0003	0.015
Guseva Gora	slag	2209	0.0005	<0.0003	0.005	>1	0.005	0.15	0.0005	<0.0003	0.015
Guseva Gora	slag	2210	0.0005	<0.0003	0.01	>1	0.01	0.2	0.0005	<0.0003	0.005
Dolmatovo	slag	2033	0.015	0.0015	0.015	0.15	0.0015	0.1	<0.0005	<0.0003	0.03
Kurmantau-5	copper	2233	0.02	0.003	0.01	0.05	<0.001	0.05	nd	nd	>>1
Kurmantau-5	copper	2234	0.015	0.007	0.003	0.3	0.003	0.1	nd	nd	>>1
Kurmantau-5	copper	2235	0.007	0.003	0.007	0.07	<0.001	0.05	nd	nd	>>1
Kurmantau-5	copper	2236	0.03	0.003	0.007	0.05	<0.001	0.05	nd	nd	>>1
Olotau mine	ore	2336	0.015	0.005	0.01	0.05	0.02	0.3	nd	nd	>1
Olotau mine	ore	2337	0.001	<0.0003	0.005	0.03	0.01	0.05	nd	nd	>>1
Ulak-6	slag	2338	0.007	0.002	0.1	0.07	0.015	0.3	nd	nd	0.03
Ulak-6	slag	2339	0.01	0.003	0.03	0.06	0.01	0.2	nd	nd	0.015
Biktimirovo	copper	2340	0.007	<0.0003	0.01	0.06	<0.001	0.01	nd	nd	>>1
Biktimirovo	copper	2341	0.01	0.0005	0.001	0.03	0.01	0.015	nd	nd	0.6
Biktimirovo	copper	2342	0.007	<0.0003	0.01	0.06	<0.001	0.01	nd	nd	>>1

Site	Material	№	Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
Biktimirovo	slag	2343	0.007	<0.0003	0.007	0.005	<0.001	0.02	nd	nd	0.03
Biktimirovo	slag	2344	0.007	0.001	0.007	0.01	0.0015	0.015	nd	nd	0.05
Biktimirovo	copper	2345	0.007	0.009	0.007	0.2	<0.001	0.3	nd	nd	>>1
Biktimirovo	copper	2346	0.005	<0.0003	0.007	0.06	<0.001	0.03	nd	nd	>>1
Biktimirovo	copper	2347	0.005	0.002	<0.001	0.05	0.003	0.01	nd	nd	0.2
Biktimirovo	copper	2348	0.007	<0.0003	0.01	0.06	<0.001	0.015	nd	nd	>1
Biktimirovo	slag	2349	0.007	0.002	0.01	0.015	<0.001	0.01	nd	nd	0.03
Biktimirovo	slag	2350	0.007	0.0015	0.003	0.015	0.0015	0.01	nd	nd	0.02
Sensitivity of the analysis			Ni	Co	Cr	Mn	V	Ti	Sc	Ge	Cu
			0.0005	0.0003	0.001	0.003	0.001	0.005	0.0005	0.0003	0.001

Tab. 14-1. Emission spectral analyses of slag (%) from sites of the Early Iron Age. The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.(contd.)

Site	Material	№	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
Itkul	slag	39	0.1	0.015	0.00007	<0.01	<0.003	<0.001	<0.001	0.00015	0.02
Itkul	ore	40	0.1	0.005	0.00007	0.01	0.0015	<0.001	<0.001	0.0001	0.015
Zuevskoe	slag	444	0.007	0.001	0.00003	0.005	<0.003	<0.001	<0.001	0.00015	0.1
Zaosinovo	ore	161	0.015	0.0007	0.00003	<0.01	<0.003	<0.001	<0.001	0.00015	0.015
Dumnaya	slag	606	0.015	0.0007	0.003	0.005	<0.003	<0.001	<0.001	0.0001	0.01
Dumnaya	slag	607	0.07	0.001	0.0015	0.005	<0.003	<0.001	<0.001	0.0001	0.01
Dumnaya	slag	608	0.015	0.003	0.00005	0.005	<0.003	<0.001	<0.001	0.0001	0.01
Dumnaya	slag	609	0.05	0.001	0.0005	0.005	<0.003	<0.001	<0.001	0.0001	0.01
Dumnaya	slag	610	0.1	0.0007	0.00005	0.005	<0.003	<0.001	<0.001	0.0001	0.02
Dumnaya	slag	611	0.02	0.005	0.0003	0.005	<0.003	<0.001	<0.001	0.00015	0.02
Dumnaya	slag	612	0.03	0.01	0.003	0.005	<0.003	<0.001	<0.001	0.0001	0.03
Dumnaya	slag	613	0.05	0.0007	<0.00003	<0.01	<0.003	<0.001	<0.001	0.0001	0.01
Dumnaya	slag	614	0.1	0.007	0.00003	<0.01	<0.003	<0.001	<0.001	0.00015	0.015
Dumnaya	slag	615	0.03	0.0007	0.0002	0.005	<0.003	<0.001	<0.001	0.0001	0.015
Dumnaya	slag	616	0.15	0.001	0.00015	<0.01	<0.003	<0.001	<0.001	0.0001	0.01
Dumnaya	slag	617	0.03	0.0005	0.0005	0.005	<0.003	<0.001	<0.001	0.0001	0.01
Dumnaya	slag	618	0.07	0.007	<0.00003	0.005	<0.003	<0.001	<0.001	0.00015	0.05
Dumnaya	slag	619	0.015	0.0003	0.00007	0.005	<0.003	<0.001	<0.001	0.00015	0.03
Dumnaya	slag	620	0.15	0.005	0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.02
Dumnaya	slag	621	0.07	0.002	0.0002	<0.01	<0.003	<0.001	<0.001	0.00015	0.01
Dumnaya	slag	622	0.07	0.002	0.001	<0.01	<0.003	<0.001	<0.001	0.0015	0.03
Dumnaya	slag	623	0.15	0.015	0.0002	0.02	0.0015	<0.001	<0.001	0.00015	0.015
Dumnaya	slag	624	0.03	0.0007	0.0005	0.005	<0.003	<0.001	<0.001	0.0005	0.02
Dumnaya	slag	625	0.1	0.005	0.00005	0.005	<0.003	<0.001	<0.001	0.0001	0.03
Dumnaya	slag	626	0.05	0.005	0.0015	0.015	<0.003	<0.001	<0.001	0.0001	0.03
Dumnaya	slag	627	0.1	0.003	0.0001	0.005	<0.003	<0.001	<0.001	0.00015	0.03
Dumnaya	slag	628	0.1	0.002	0.0015	0.005	<0.003	<0.001	<0.001	0.0001	0.015
Dumnaya	slag	630	nd	0.0003	<0.00003	<0.01	<0.003	<0.001	<0.001	0.0001	0.02
Dumnaya	slag	631	0.15	0.015	0.00007	0.005	<0.003	<0.001	<0.001	0.0003	0.015
Dumnaya	slag	632	0.15	0.005	0.00003	0.005	<0.003	<0.001	<0.001	0.0001	0.02
Dumnaya	slag	633	0.07	0.005	0.00015	0.005	<0.003	<0.001	<0.001	0.0007	0.015

Site	Material	№	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
Dumnaya	slag	634	0.07	0.001	0.001	0.01	<0.003	<0.001	<0.001	0.00015	0.02
Dumnaya	slag	635	0.1	0.015	0.00003	0.005	<0.003	<0.001	0.003	0.0002	0.03
Dumnaya	slag	636	0.1	0.005	<0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.02
Itkul	slag	637	0.07	0.0007	0.0001	<0.01	<0.003	<0.001	<0.001	0.0002	0.1
Itkul	slag	638	0.05	0.007	0.0001	0.01	<0.003	<0.001	<0.001	0.0002	0.1
Itkul	slag	639	0.15	0.007	0.0002	0.03	<0.003	<0.001	0.002	0.00015	0.07
Itkul	slag	640	0.05	0.0007	0.00003	<0.01	<0.003	<0.001	<0.001	0.0001	0.1
Itkul	slag	641	0.15	0.007	0.002	0.015	0.003	<0.001	<0.001	0.0001	0.3
Itkul	slag	642	0.03	0.0005	0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.3
Itkul	slag	643	0.2	0.002	0.0015	0.005	0.0015	<0.001	<0.001	0.0003	0.03
Itkul	slag	644	0.1	0.0015	0.0002	0.005	<0.003	<0.001	<0.001	0.00015	0.15
Itkul	slag	645	0.02	0.0007	0.00015	0.005	<0.003	<0.001	<0.001	0.0002	0.15
Itkul	slag	646	0.3	0.007	0.0015	0.01	<0.003	<0.001	<0.001	0.0007	0.1
Itkul	slag	647	0.1	0.007	0.0007	0.005	<0.003	<0.001	<0.001	0.00015	0.1
Itkul	slag	648	0.1	0.0007	0.0002	<0.01	<0.003	<0.001	<0.001	0.0001	0.05
Itkul	slag	649	0.03	0.0005	0.0002	<0.01	<0.003	<0.001	<0.001	0.0001	0.02
Itkul	slag	650	0.2	0.007	0.0007	0.015	<0.003	<0.001	<0.001	0.0003	0.05
Itkul	slag	651	0.1	0.002	0.00003	0.01	<0.003	<0.001	<0.001	0.00015	0.2
Itkul	slag	652	0.15	0.003	0.0002	0.01	0.0015	<0.001	<0.001	0.0002	0.1
Itkul	slag	653	0.1	0.002	0.0002	0.005	<0.003	<0.001	<0.001	0.0001	0.1
Itkul	slag	654	0.15	0.002	0.0003	0.02	0.0015	<0.001	<0.001	0.00015	0.07
Itkul	slag	655	0.15	0.002	0.0003	<0.01	<0.003	<0.001	<0.001	0.0002	0.03
Itkul	slag	656	nd	0.0005	0.00015	0.005	<0.003	<0.001	<0.001	0.00015	0.15
Itkul	slag	657	0.2	0.0005	0.0005	0.01	0.0015	<0.001	<0.001	0.0001	0.03
Itkul	slag	658	nd	0.003	0.00005	0.005	<0.003	<0.001	<0.001	0.0001	0.02
Itkul	slag	659	0.2	0.007	0.0005	0.03	<0.003	<0.001	0.002	0.00015	0.07
Itkul	slag	660	0.01	0.003	0.00015	0.005	<0.003	<0.001	<0.001	0.00015	0.1
Itkul	slag	661	0.07	0.0015	0.00005	0.01	<0.003	<0.001	<0.001	0.0001	0.1
Itkul	slag	663	0.2	0.002	0.0002	0.01	<0.003	<0.001	<0.001	0.0001	0.07
Itkul	slag	664	0.15	0.007	0.0002	0.005	<0.003	<0.001	<0.001	0.0001	0.03
Itkul	slag	665	0.02	0.001	0.00015	0.01	<0.003	<0.001	<0.001	0.0001	0.5
Itkul	slag	666	0.1	0.007	0.0002	0.01	<0.003	<0.001	<0.001	0.0007	0.07
Itkul	slag	667	0.15	0.01	0.0005	0.03	<0.003	<0.001	0.0015	0.00015	0.1

Site	Material	№	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
Itkul	slag	668	0.03	0.007	0.0002	0.005	<0.003	<0.001	<0.001	0.0002	0.02
Itkul	slag	669	0.05	0.007	0.0005	0.005	<0.003	<0.001	<0.001	0.0002	0.05
Itkul	slag	670	0.15	0.02	0.00015	0.005	0.0015	<0.001	<0.001	0.00015	0.02
Itkul	slag	671	0.15	0.0015	0.0001	0.015	<0.003	<0.001	<0.001	0.0001	0.03
Malyi Ganbinsky Kordon	slag	779	0.015	0.0015	0.00015	0.005	<0.003	<0.001	<0.001	0.0002	0.1
Partizanskaya Katushka	slag	781	0.015	0.001	0.00007	0.005	<0.003	<0.001	<0.001	0.0003	0.015
Ostrovnoe 3	slag	788	0.01	0.0015	0.00005	0.005	<0.003	<0.001	<0.001	0.00015	0.15
Ostrovnoe 3	slag	789	0.007	0.01	0.0015	0.1	0.02	<0.001	<0.001	0.0001	0.1
Ostrovnoe 3	slag	790	0.007	0.002	0.0001	0.01	0.0015	<0.001	<0.001	0.00015	0.15
Ostrovnoe 3	slag	791	0.015	0.02	0.0015	0.05	0.0015	<0.001	<0.001	0.0001	0.1
Ostrovnoe 3	slag	792	0.007	0.003	0.0015	0.02	0.005	<0.001	<0.001	0.0001	0.1
Dolmatovo	slag	2033	0.01	0.0015	0.0003	0.005	<0.003	<0.001	<0.001	0.001	0.02
Dolmatovo	slag	2034	0.01	0.0015	0.00005	0.005	<0.003	<0.001	<0.001	0.0005	0.1
Guseva Gora	slag	2208	0.03	< 0.003	<0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.015
Irtyash II	slag	2211	0.03	< 0.003	0.000003	0.005	<0.003	<0.001	<0.001	0.0003	0.015
Kirety 1	slag	2213	0.02	< 0.003	0.000003	0.005	<0.003	<0.001	<0.001	0.0003	0.015
Irtyash II	slag	2214	0.1	< 0.003	0.0003	0.005	<0.003	<0.001	<0.001	0.0005	0.04
Uzhovoy Island	slag	2215	0.02	0.003	<0.00003	0.005	<0.003	<0.001	<0.001	0.0005	0.06
Guseva Gora	slag	2209	0.01	< 0.003	0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.015
Guseva Gora	slag	2210	0.01	< 0.003	0.00003	0.005	<0.003	<0.001	<0.001	0.0003	0.03
Dolmatovo	slag	2033	0.015	< 0.003	0.000003	0.01	<0.003	<0.001	<0.001	0.0015	0.02
Kurmantau-5	copper	2233	0.02	0.5	>>0.003	0.1	0.07	nd	0.015	nd	0.015
Kurmantau-5	copper	2234	0.02	0.15	>0.003	0.05	0.015	nd	0.005	nd	0.03
Kurmantau-5	copper	2235	0.007	0.1	>0.003	0.1	0.003	nd	<0.001	nd	0.015
Kurmantau-5	copper	2236	0.01	0.07	>0.003	0.07	0.02	nd	0.015	nd	0.01
Olotau mine	ore	2336	0.015	0.003	>0.003	0.007	<0.003	nd	<0.001	nd	0.03
Olotau mine	ore	2337	0.007	0.0015	>0.003	0.015	<0.003	nd	<0.001	nd	0.015
Ulak-6	slag	2338	0.01	0.002	0.00007	0.007	0.0015	nd	<0.001	0.0007	0.15
Ulak-6	slag	2339	0.01	0.002	0.00007	0.005	0.0015	nd	<0.001	0.0007	0.1
Biktimirovo	copper	2340	0.005	0.05	>0.003	0.015	0.005	nd	0.005	nd	0.015

Site	Material	№	Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
Biktimirovo	copper	2341	0.015	0.0015	0.0003	0.01	<0.003	nd	<0.001	0.0005	0.15
Biktimirovo	copper	2342	0.01	0.3	>0.003	0.07	0.015	nd	0.01	nd	< 0.01
Biktimirovo	slag	2343	0.007	0.0005	0.00005	0.01	<0.003	nd	<0.001	0.002	0.01
Biktimirovo	slag	2344	0.007	0.001	0.00005	0.01	<0.003	nd	<0.001	0.0005	0.01
Biktimirovo	copper	2345	0.02	>1	>0.003	0.07	0.03	nd	>0.03	nd	0.015
Biktimirovo	copper	2346	0.01	0.05	>0.003	0.015	0.005	nd	0.007	nd	0.015
Biktimirovo	copper	2347	0.01	0.0015	0.0003	0.01	<0.003	nd	<0.001	0.0007	0.1
Biktimirovo	copper	2348	0.007	0.02	>0.003	>1	0.15	nd	0.01	nd	0.03
Biktimirovo	slag	2349	0.01	0.0005	0.00005	0.005	<0.003	nd	<0.001	0.002	0.01
Biktimirovo	slag	2350	0.007	< 0.003	0.00005	0.007	<0.003	nd	<0.001	0.003	0.015
Sensitivity of the analysis			Zn	Pb	Ag	As	Sb	Cd	Bi	Mo	Ba
			0.003	0.0003	0.00003	0.01	0.003	0.001	0.001	0.0001	0.01

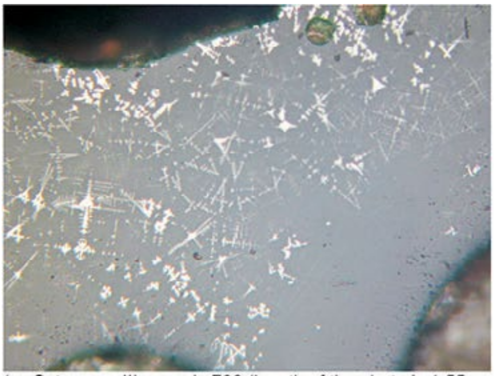
Tab. 14-1. Emission spectral analyses of slag (%) from sites of the Early Iron Age. The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.(contd.)

Site	Material	№	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Itkul	slag	39	0.015	<0.001	0.0005	0.0002	nd	0.001	0.015	0.001
Itkul	ore	40	0.01	<0.001	<0.0005	0.0001	nd	0.001	0.003	0.00015
Zuevskoe	slag	444	0.03	<0.001	0.0003	0.0002	0.02	0.0015	0.003	0.0002
Zaosinovo	ore	161	0.01	<0.001	0.0007	0.00003	0.003	0.001	<0.001	0.0001
Dumnaya	slag	606	0.01	<0.001	0.0015	<0.00003	nd	0.001	<0.001	<0.0001
Dumnaya	slag	607	0.01	<0.001	0.0015	<0.00003	nd	0.0015	<0.001	<0.0001
Dumnaya	slag	608	0.01	<0.001	0.0005	0.00003	nd	0.0005	<0.001	0.0001
Dumnaya	slag	609	0.01	<0.001	0.001	<0.00003	nd	0.001	<0.001	0.0001
Dumnaya	slag	610	0.01	<0.001	0.0005	0.00003	nd	0.0005	0.0015	0.00015
Dumnaya	slag	611	0.015	<0.001	0.001	0.0001	nd	0.0015	0.005	0.0007
Dumnaya	slag	612	0.015	<0.001	0.0007	0.00015	0.01	0.002	0.005	0.0002
Dumnaya	slag	613	0.01	<0.001	0.003	0.00003	nd	0.0005	0.001	0.00015
Dumnaya	slag	614	0.015	<0.001	0.0003	0.00015	0.007	0.001	0.005	0.0005
Dumnaya	slag	615	0.01	<0.001	0.001	0.00003	nd	0.001	0.0015	0.00015
Dumnaya	slag	616	0.01	<0.001	0.0007	<0.00003	nd	0.001	0.001	0.0001
Dumnaya	slag	617	0.01	<0.001	0.0003	0.00003	nd	0.0005	0.001	0.00015
Dumnaya	slag	618	0.01	<0.001	0.0005	0.0002	0.005	0.0015	0.01	0.0007
Dumnaya	slag	619	0.01	<0.001	0.0005	<0.00003	nd	0.001	0.002	0.00015
Dumnaya	slag	620	0.01	<0.001	0.0005	0.00015	nd	0.001	0.007	0.0005
Dumnaya	slag	621	0.01	<0.001	0.0005	0.00003	0.001	0.0005	0.001	0.00015
Dumnaya	slag	622	0.01	<0.001	0.003	0.00005	0.007	0.0005	0.01	0.001
Dumnaya	slag	623	0.01	<0.001	0.0015	0.00007	0.0015	0.001	0.0015	0.00015
Dumnaya	slag	624	0.015	<0.001	0.001	0.00005	0.005	0.0015	0.015	0.0015
Dumnaya	slag	625	0.01	<0.001	0.0003	0.00005	nd	0.001	0.0015	0.00015
Dumnaya	slag	626	0.015	<0.001	0.002	0.00003	nd	0.001	0.001	0.0001
Dumnaya	slag	627	0.01	<0.001	0.0015	0.00005	nd	0.0015	0.001	0.00015
Dumnaya	slag	628	0.01	<0.001	0.0015	<0.00003	nd	0.002	0.0015	0.00015
Dumnaya	slag	630	0.015	<0.001	0.0003	0.00003	nd	0.0005	0.002	0.0003
Dumnaya	slag	631	0.01	<0.001	0.001	0.00007	nd	0.0015	0.003	0.0002
Dumnaya	slag	632	0.015	<0.001	0.0003	0.00015	0.005	0.0015	0.003	0.0003
Dumnaya	slag	633	0.015	<0.001	0.0015	<0.00003	nd	0.001	0.0015	0.0003

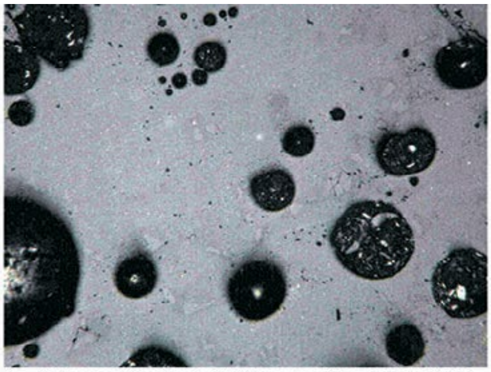
Site	Material	№	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Dumnaya	slag	634	0.015	<0.001	0.001	0.00003	nd	0.0015	0.001	0.00015
Dumnaya	slag	635	0.01	<0.001	0.0005	0.00015	0.005	0.002	0.005	0.0002
Dumnaya	slag	636	0.01	<0.001	0.0005	0.00007	nd	0.0015	0.003	0.0002
Itkul	slag	637	0.015	<0.001	0.0015	<0.00003	0.003	0.0015	0.003	0.0002
Itkul	slag	638	0.03	<0.001	0.002	0.0002	0.015	0.0015	0.015	0.001
Itkul	slag	639	0.015	<0.001	0.002	0.0001	0.01	0.0015	0.01	0.0007
Itkul	slag	640	0.015	<0.001	0.0015	<0.00003	nd	0.001	0.001	0.0002
Itkul	slag	641	0.02	<0.001	0.003	0.0001	0.007	0.0015	0.002	0.0001
Itkul	slag	642	0.01	<0.001	0.0005	0.00003	0.0015	0.001	0.001	0.0001
Itkul	slag	643	0.015	<0.001	0.0015	0.00003	nd	0.0015	0.001	0.0002
Itkul	slag	644	0.01	<0.001	0.01	0.00003	nd	0.0015	0.001	0.00015
Itkul	slag	645	0.015	<0.001	0.001	0.00003	nd	0.001	0.002	0.0002
Itkul	slag	646	0.015	<0.001	0.003	<0.00003	nd	0.0015	0.001	0.0001
Itkul	slag	647	<0.01	<0.001	0.001	0.00007	0.005	0.001	0.002	0.0002
Itkul	slag	648	0.01	<0.001	0.002	0.00003	nd	0.0015	<0.001	0.0001
Itkul	slag	649	0.01	<0.001	0.001	0.00003	nd	0.001	<0.001	0.0001
Itkul	slag	650	0.01	<0.001	0.005	<0.00003	nd	0.0015	0.0015	0.00015
Itkul	slag	651	0.01	<0.001	0.005	<0.00003	0.0015	0.0015	0.002	0.0002
Itkul	slag	652	0.01	<0.001	0.005	0.00003	nd	0.0015	0.001	0.00015
Itkul	slag	653	0.01	<0.001	0.003	0.00003	nd	0.001	0.0015	0.00015
Itkul	slag	654	0.01	<0.001	0.005	0.00007	nd	0.0015	0.001	0.0001
Itkul	slag	655	0.01	<0.001	0.0007	0.00003	nd	0.0005	0.001	0.0001
Itkul	slag	656	0.015	<0.001	0.0003	0.00003	nd	0.001	0.0015	0.0001
Itkul	slag	657	0.01	<0.001	0.003	<0.00003	nd	0.0015	0.001	0.0001
Itkul	slag	658	0.01	<0.001	0.0005	0.00005	nd	0.001	0.003	0.0002
Itkul	slag	659	0.01	<0.001	0.005	0.00007	nd	0.0015	0.007	0.0005
Itkul	slag	660	0.03	<0.001	0.0003	0.0002	0.015	0.0015	0.003	0.0002
Itkul	slag	661	0.01	<0.001	0.005	0.00005	nd	0.0015	0.003	0.0002
Itkul	slag	663	0.01	<0.001	0.003	0.00003	0.003	0.0015	0.0015	0.00015
Itkul	slag	664	0.015	<0.001	0.0007	0.00003	nd	0.001	0.007	0.0003
Itkul	slag	665	0.03	<0.001	0.01	0.0002	0.015	0.0015	0.002	0.0001
Itkul	slag	666	0.015	<0.001	0.003	0.00015	nd	0.0015	0.007	0.0005
Itkul	slag	667	0.02	<0.001	0.007	0.0002	0.007	0.002	0.01	0.0007

Site	Material	№	Sr	W	Sn	Be	Zr	Ga	Y	Yb
Itkul	slag	668	0.015	<0.001	0.002	0.00007	0.005	0.0015	0.007	0.0003
Itkul	slag	669	0.015	<0.001	0.002	0.0001	0.005	0.0015	0.005	0.0005
Itkul	slag	670	0.01	<0.001	0.0015	0.00007	nd	0.001	0.003	0.0002
Itkul	slag	671	0.01	<0.001	0.007	<0.00003	nd	0.003	0.0015	0.0003
Malyi Ganbinsky Kordon	slag	779	0.02	<0.001	0.002	0.0001	0.01	0.001	0.001	0.00015
Partizanskaya Katushka	slag	781	0.01	<0.001	<0.0005	<0.00003	0.001	0.0005	<0.001	0.0001
Ostrovnoe 3	slag	788	0.01	<0.001	<0.0005	0.00015	0.005	0.0005	0.0015	0.00015
Ostrovnoe 3	slag	789	0.03	0.001	0.01	0.0003	0.02	0.0015	0.003	0.00015
Ostrovnoe 3	slag	790	0.03	0.001	0.0005	0.0003	0.03	0.001	0.003	0.00015
Ostrovnoe 3	slag	791	0.03	<0.001	0.007	0.0002	0.02	0.005	0.002	0.0001
Ostrovnoe 3	slag	792	0.03	<0.001	0.015	0.0002	0.015	0.001	0.0015	0.0001
Dolmatovo	slag	2033	0.01	<0.001	0.003	<0.00003	0.003	<0.0005	<0.001	<0.0001
Dolmatovo	slag	2034	0.02	0.001	0.0005	0.00015	0.015	0.001	0.0015	0.0015
Guseva Gora	slag	2208	0.01	<0.001	<0.0005	0.00003	0.0015	0.001	<0.001	<0.0001
Irtyash II	slag	2211	0.01	<0.001	<0.0005	0.00003	0.0015	0.0005	<0.001	<0.0001
Kirety 1	slag	2213	0.01	<0.001	<0.0005	0.00003	0.0015	0.0005	<0.001	<0.0001
Irtyash II	slag	2214	0.01	<0.001	<0.0005	0.00003	0.0015	0.0005	<0.001	<0.0001
Uzhovoy Island	slag	2215	0.02	<0.001	<0.0005	0.0002	0.0015	0.0015	0.009	0.0003
Guseva Gora	slag	2209	0.01	<0.001	<0.0005	0.0001	0.01	0.001	0.003	0.0003
Guseva Gora	slag	2210	0.01	<0.001	<0.0005	0.0003	0.005	0.0005	0.007	0.0007
Dolmatovo	slag	2033	0.01	<0.001	0.0003	<0.00003	0.005	0.001	<0.001	<0.0001
Kurmantau-5	copper	2233	nd	nd	>0.3	nd	nd	nd	nd	nd
Kurmantau-5	copper	2234	nd	nd	>0.3	nd	nd	nd	nd	nd
Kurmantau-5	copper	2235	nd	nd	0.03	nd	nd	nd	nd	nd
Kurmantau-5	copper	2236	nd	nd	>0.3	nd	nd	nd	nd	nd
Olotau mine	ore	2336	nd	nd	0.01	nd	nd	nd	nd	nd
Olotau mine	ore	2337	nd	nd	0.0001	nd	nd	nd	nd	nd
Ulak-6	slag	2338	nd	nd	0.0005	nd	nd	nd	nd	nd
Ulak-6	slag	2339	nd	nd	0.0005	nd	nd	nd	nd	nd
Biktimirovo	copper	2340	nd	nd	0.1	nd	nd	nd	nd	nd

Site	**Material**	**№**	**Sr**	**W**	**Sn**	**Be**	**Zr**	**Ga**	**Y**	**Yb**
Biktimirovo	copper	2341	nd	nd	0.02	nd	nd	nd	nd	nd
Biktimirovo	copper	2342	nd	nd	0.3	nd	nd	nd	nd	nd
Biktimirovo	slag	2343	nd	nd	<0.0005	nd	nd	nd	nd	nd
Biktimirovo	slag	2344	nd	nd	<0.0005	nd	nd	nd	nd	nd
Biktimirovo	copper	2345	nd	nd	>0.3	nd	nd	nd	nd	nd
Biktimirovo	copper	2346	nd	nd	0.05	nd	nd	nd	nd	nd
Biktimirovo	copper	2347	nd	nd	0.015	nd	nd	nd	nd	nd
Biktimirovo	copper	2348	nd	nd	0.01	nd	nd	nd	nd	nd
Biktimirovo	slag	2349	nd	nd	0.0005	nd	nd	nd	nd	nd
Biktimirovo	slag	2350	nd	nd	<0.0005	nd	nd	nd	nd	nd
Sensitivity of the analysis			Sr	W	Sn	Be	Zr	Ga	Y	Yb
			0.01	0.001	0.0005	0.00003	0.001	0.0005	0.001	0.0001

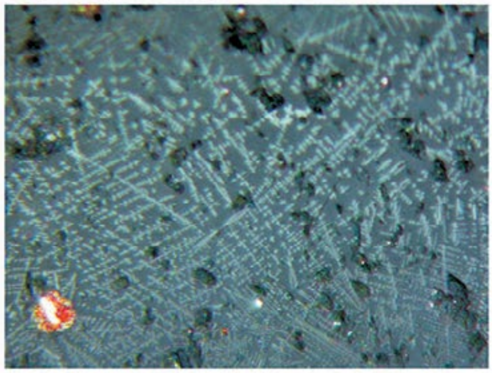


1 – Ostrovnoe III, sample 790 (length of the photo is 1.55 mm), small dendrites of magnetite.

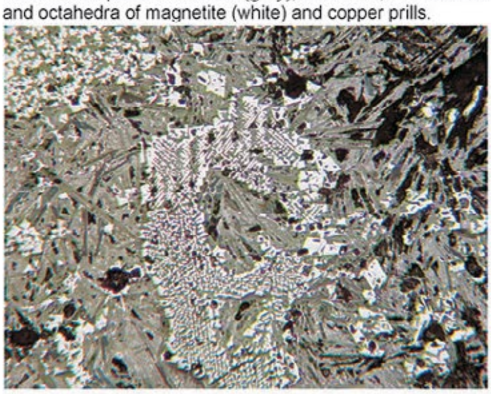


2 – Ostrovnoe III, sample 790 (length of the photo is 1.55 mm), small pores in the glass matrix.

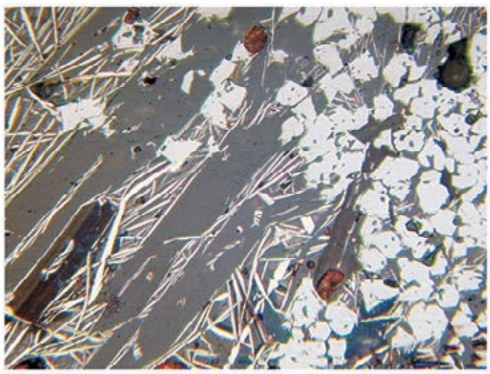
3 – Itkul I, sample 109 (length of the photo is 0.54 mm), badly visible small prisms of olivine (grey), skeletons, small dendrites and octahedra of magnetite (white) and copper prills.



4 – Itkul I, sample 111 (length of the photo is 0.54 mm), smal dendrites of magnetite and copper prills in the glass matrix.

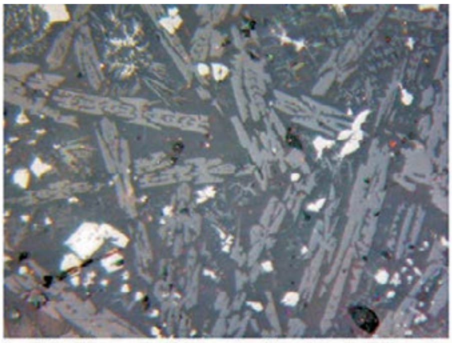


5 – Itkul I, sample 114 (length of the photo is 1.55 mm), needle-shaped and small prismatic crystals of olivine (grey), octahedra of magnetite and lattice fused structure of magnetite saved the border of a primary grain.

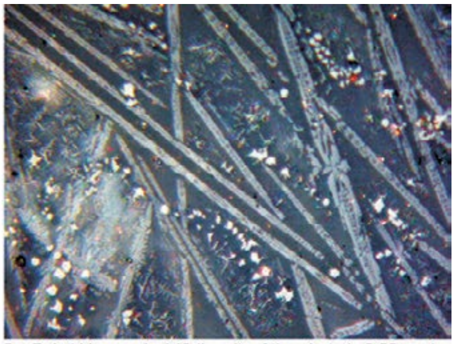


6 – Itkul I, sample 114 (length of the photo is 0.54 mm), octahedra of magnetite, needles of delafossite and copper prills in the glass matrix.

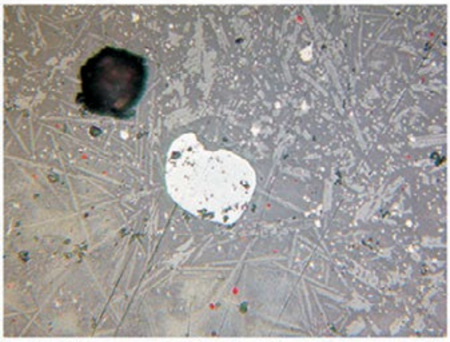
Fig. 14-I. Microstructures of copper smelting slag of the Early Iron Age, reflected light: 1 – Ostrovnoe III, sample 790 (length of the photo is 1.55 mm), small dendrites of magnetite; 2 – Ostrovnoe III, sample 790 (length of the photo is 1.55 mm), small pores in the glass matrix; 3 – Itkul I, sample 109 (length of the photo is 0.54 mm), badly visible small prisms of olivine (grey), skeletons, small dendrites and octahedra of magnetite (white) and copper prills; 4 – Itkul I, sample 111 (length of the photo is 0.54 mm), small dendrites of magnetite and copper prills in the glass matrix; 5 – Itkul I, sample 114 (length of the photo is 1.55 mm), needle-shaped and small prismatic crystals of olivine (grey), octahedra of magnetite and lattice fused structure of magnetite saved the border of a primary grain; 6 – Itkul I, sample 114 (length of the photo is 0.54 mm), octahedra of magnetite, needles of delafossite and copper prills in the glass matrix.



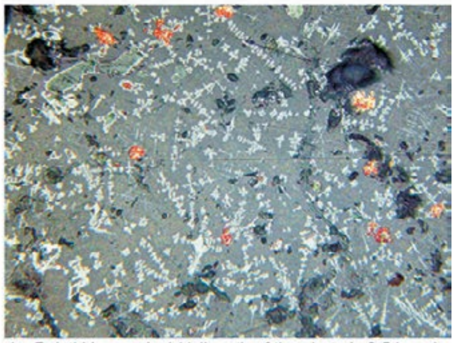
1 – Palatki I, sample 139 (length of the photo is 0.22 mm), long skeletal prisms of olivine (light grey), small octahedra and particles of magnetite (white), pores (black), copper prills.



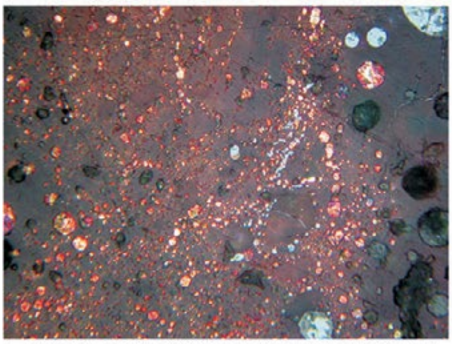
2 – Palatki I, sample 140 (length of the photo is 0.22 mm), long needles of olivine, small octahedra of magnetite and small copper prills.



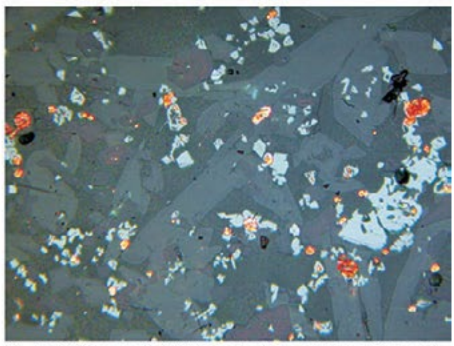
3 – Palatki I, sample 140 (length of the photo is 0.54 mm), needles and small prisms of olivine (light grey), chromite grain (in the center), small magnetite crystals and copper prills.



4 – Palatki I, sample 141 (length of the photo is 0.54 mm), skeletons of magnetite and copper prills, particles of malachite (green).

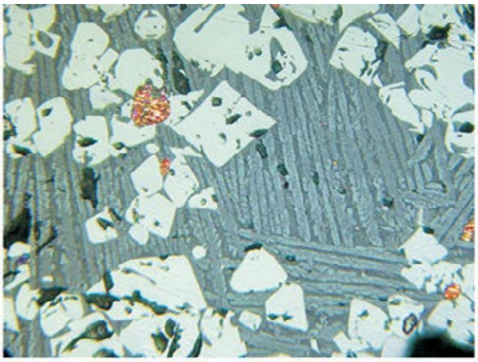


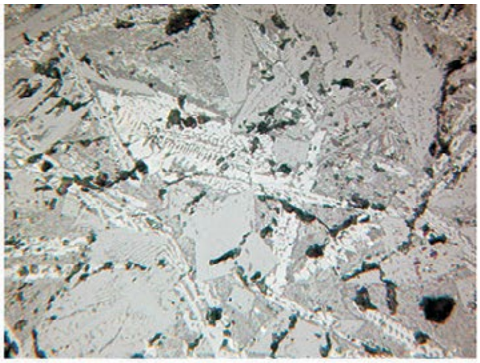
5 – Palatki I, sample 141 (length of the photo is 0.54 mm), small copper prills and larger globules of cuprite (light blue), fused particles of malachite (greenish).

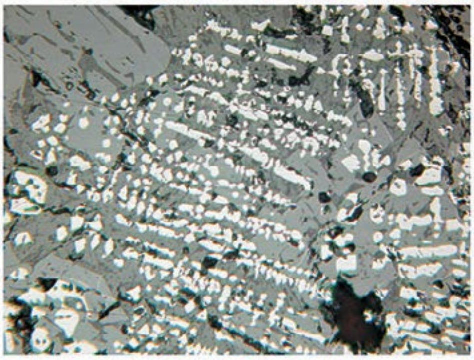


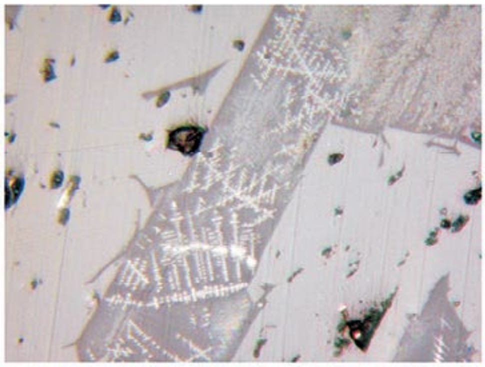
6 – Palatki I, sample 143 (length of the photo is 0.54 mm), prismatic crystals of olivine (grey), octahedra of magnetite and copper prills.

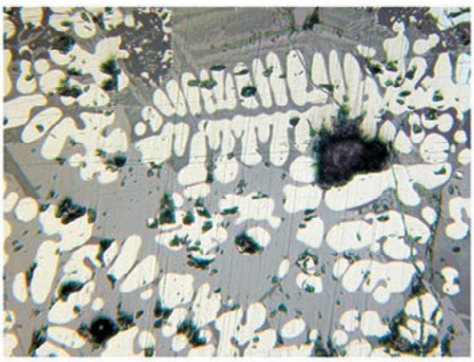
Fig. 14-II. Microstructures of copper smelting slag of the Early Iron Age, reflected light: 1 – Palatki I, sample 139 (length of the photo is 0.22 mm), long skeletal prisms of olivine (light grey), small octahedra and particles of magnetite (white), pores (black), copper prills; 2 – Palatki I, sample 140 (length of the photo is 0.22 mm), long needles of olivine, small octahedra of magnetite and small copper prills; 3 – Palatki I, sample 140 (length of the photo is 0.54 mm), needles and small prisms of olivine (light grey), chromite grain (in the center), small magnetite crystals and copper prills; 4 – Palatki I, sample 141 (length of the photo is 0.54 mm), skeletons of magnetite and copper prills, particles of malachite (green); 5 – Palatki I, sample 141 (length of the photo is 0.54 mm), small copper prills and larger globules of cuprite (light blue), fused particles of malachite (greenish); 6 – Palatki I, sample 143 (length of the photo is 0.54 mm), prismatic crystals of olivine (grey), octahedra of magnetite and copper prills.


1 – Palatki I, sample 145 (length of the photo is 0.54 mm), long needles of olivine, large octahedra of magnetite and copper prills.


2 – Skorodum, sample 149 (length of the photo is 0.54 mm), prismatic crystals of olivine.


3 – Skorodum, sample 149 (length of the photo is 0.54 mm), prismatic crystals of olivine and lattice structures of wüstite.


4 – Turbino I, sample 317 (length of the photo is 0.22 mm), polygonal crystals of olivine and small dendrites of magnetite.


5 – Turbino I, sample 317 (length of the photo is 0.22 mm), polygonal crystals of olivine (light grey) in the glass matrix (dark grey) and fused large dendrites of wüstite (white).

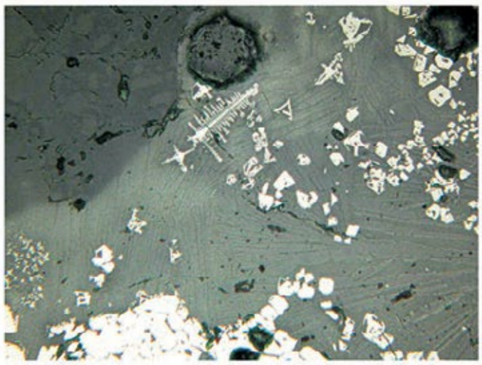
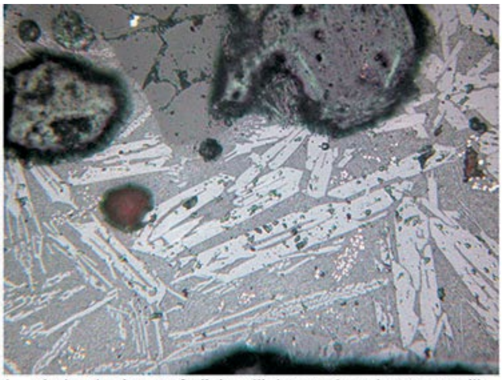
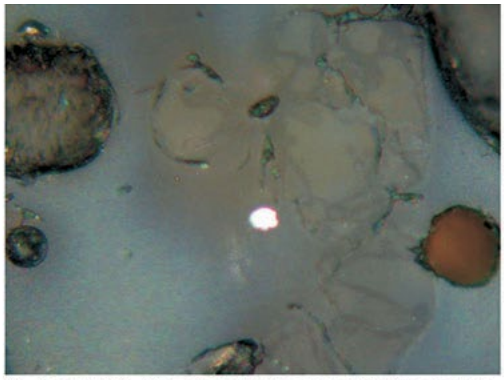

6 – Turbino I, sample 318 (length of the photo is 0.22 mm), long skeletal prisms of olivine (greenish-grey), dendrites, skeletons and particles of magnetite (white), grain of quartz (dark grey).

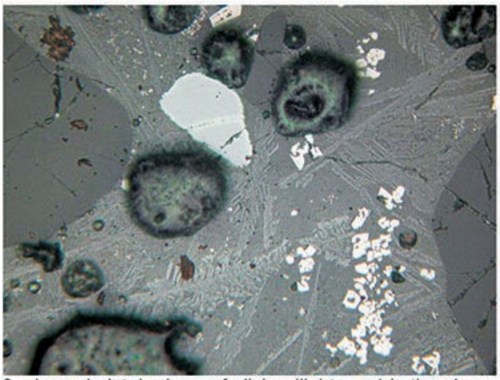
Fig. 14-III. Microstructures of copper smelting slag of the Early Iron Age, reflected light: 1 – Palatki I, sample 145 (length of the photo is 0.54 mm), long needles of olivine, large octahedra of magnetite and copper prills; 2 – Skorodum, sample 149 (length of the photo is 0.54 mm), prismatic crystals of olivine; 3 – Skorodum, sample 149 (length of the photo is 0.54 mm), prismatic crystals of olivine and lattice structures of wüstite; 4 – Turbino I, sample 317 (length of the photo is 0.22 mm), polygonal crystals of olivine and small dendrites of magnetite; 5 – Turbino I, sample 317 (length of the photo is 0.22 mm), polygonal crystals of olivine (light grey) in the glass matrix (dark grey) and fused large dendrites of wüstite (white); 6 – Turbino I, sample 318 (length of the photo is 0.22 mm), long skeletal prisms of olivine (greenish-grey), dendrites, skeletons and particles of magnetite (white), grain of quartz (dark grey).



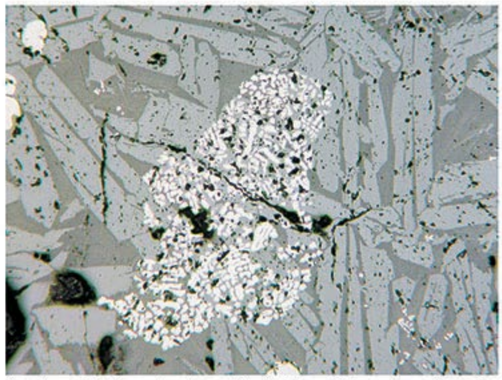
1 – skeletal prisms of olivine (light grey) and copper prills in the glass matrix (grey), quartz grain (dark grey above) with inclusion of a malachite grain and a particle of iron (length of the photo is 0.22 mm).



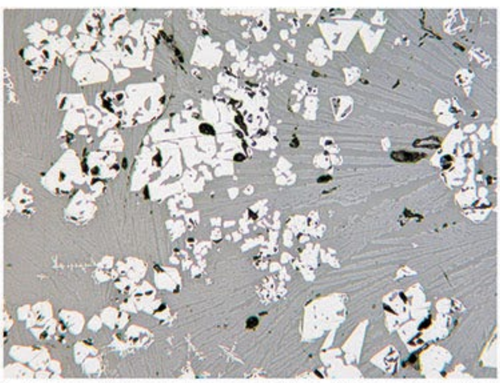
2 – fused grain of quartz and a copper prill in the porous glass (length of the photo is 0.22 mm).



3 – long skeletal prisms of olivine (light grey) in the glass matrix (grey), grains of quartz (dark grey), a grain of chro-mite (grey with a white magnetite border), octahedra of magnetite (white) and pores (length of the photo is 0.22 mm).



4 – fused lattice structure of wüstite with borders of a pri-mary grain, long prismatic crystals of olivine (light grey) (length of the photo is 0.54 mm).



5 –large particles and small dendrites of magnetite (white), long skeletal crystals of olivine (light grey) in the glass matrix (grey) (length of the photo is 1.55 mm).

Fig. 14-IV. Microstructures of copper smelting slag of the Early Iron Age, reflected light (Turbino I, sample 318): 1 – skeletal prisms of olivine (light grey) and copper prills in the glass matrix (grey), quartz grain (dark grey above) with inclusion of a malachite grain and a particle of iron (length of the photo is 0.22 mm); 2 – fused grain of quartz and a copper prill in the porous glass (length of the photo is 0.22 mm); 3 – long skeletal prisms of olivine (light grey) in the glass matrix (grey), grains of quartz (dark grey), a grain of chromite (grey with a white magnetite border), octahedra of magnetite (white) and pores (length of the photo is 0.22 mm); 4 – fused lattice structure of wüstite with borders of a primary grain, long prismatic crystals of olivine (light grey) (length of the photo is 0.54 mm); 5 –large particles and small dendrites of magnetite (white), long skeletal crystals of olivine (light grey) in the glass matrix (grey) (length of the photo is 1.55 mm).

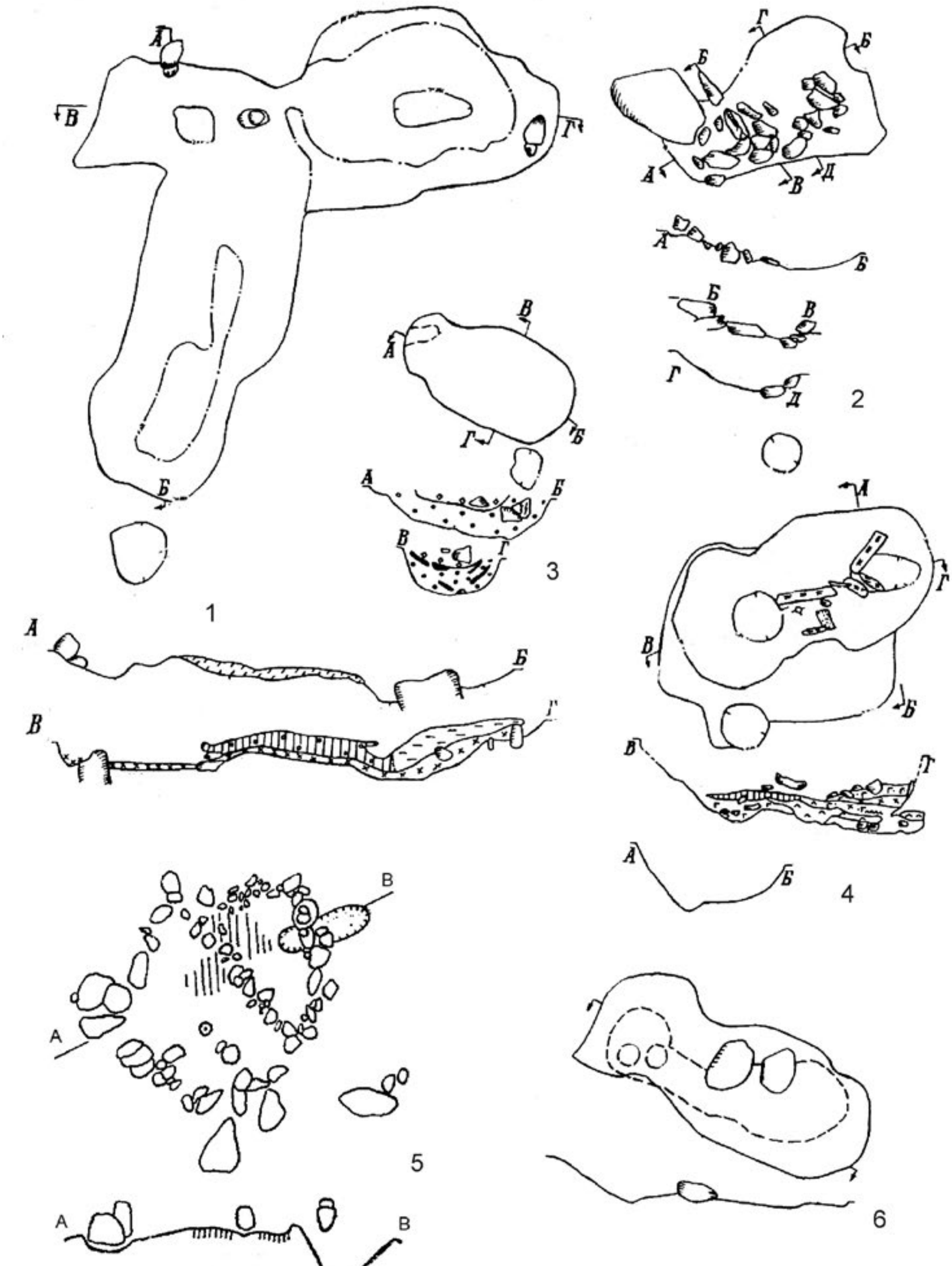


Fig. 14-2. Furnaces of the Itkul culture (after Beltikova): 1-4,6 – Dumnaya Mountain, 5 – Malyi Vishnyovyi Island.

Tab. 14-3. Clusters of slag of the Itkul culture based on the emission spectral analyses.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Dumnaya	13	3	13	1
Itkul	4	10	5	16

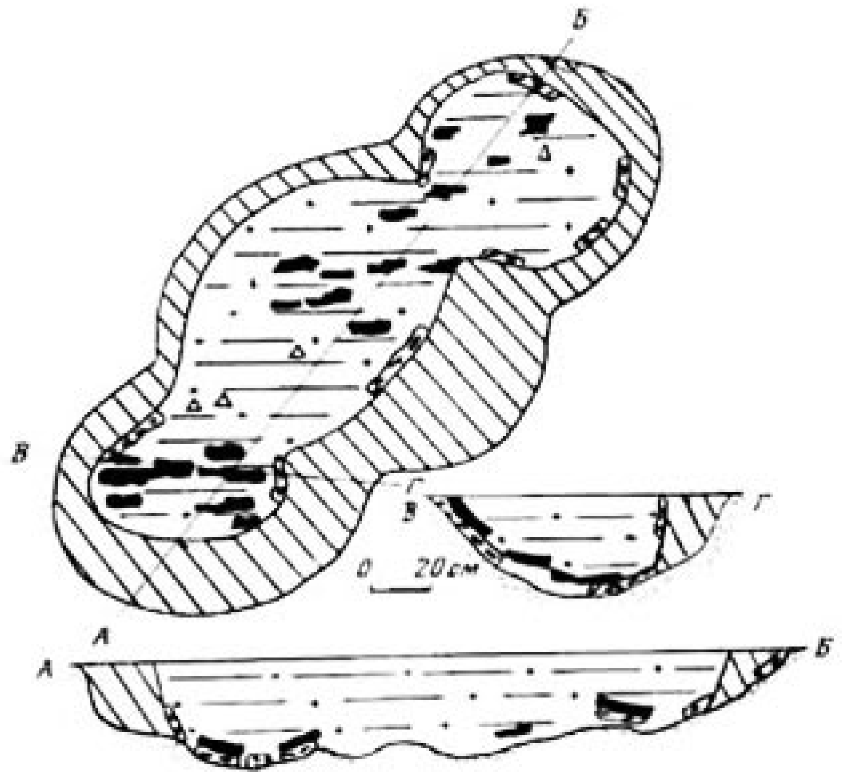


FIG. 14-4. FURNACE FROM THE SETTLEMENT OF LIMANSKOYE LAKE (AFTER TATARINOV 1980).

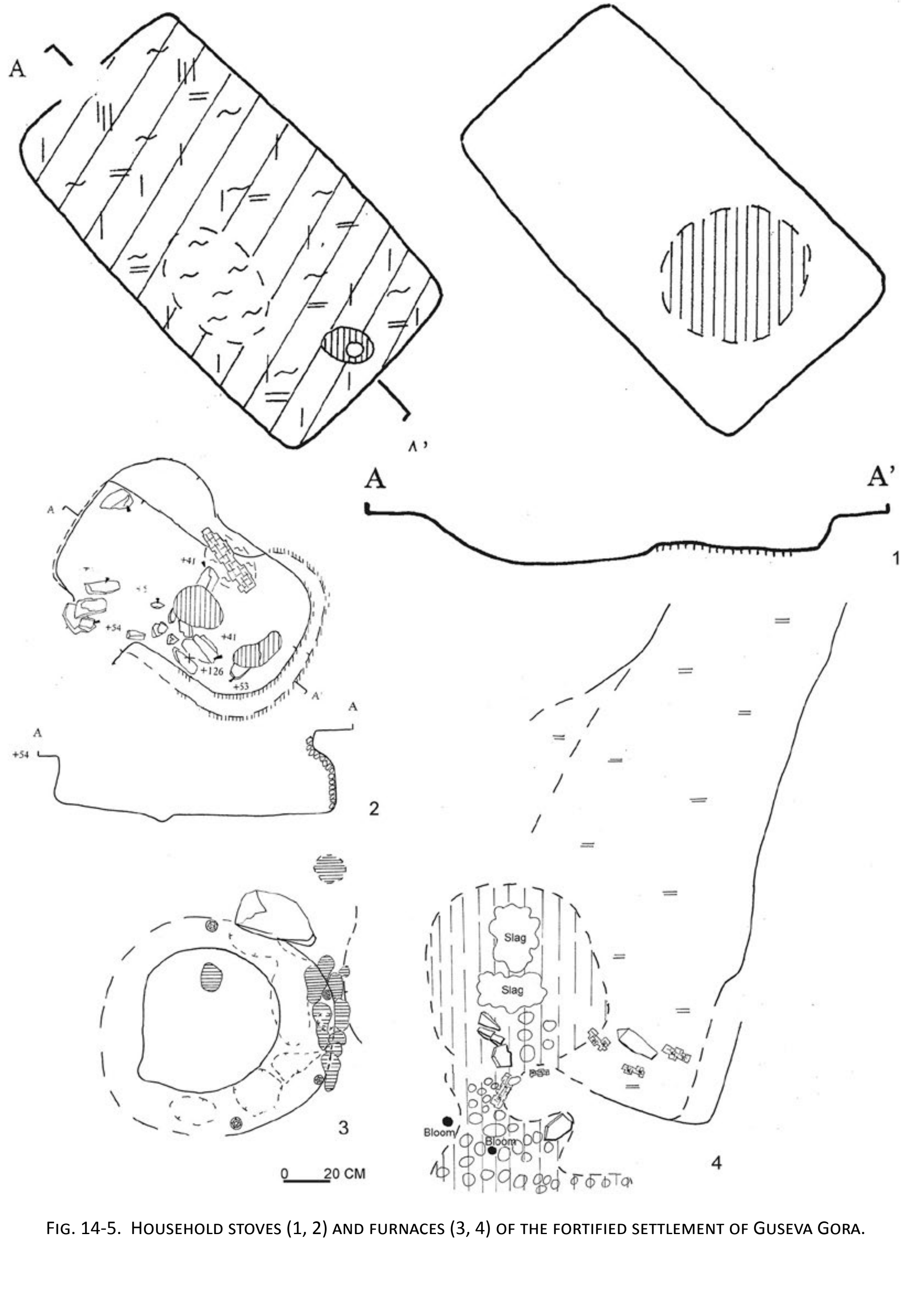


Fig. 14-5. Household stoves (1, 2) and furnaces (3, 4) of the fortified settlement of Guseva Gora.

Fig. 14-6. Forms of slag of iron smelting from the Ozyorsk area in the Southern Transurals: 1 – Guseva Gora, sample 2207; 2 – Guseva Gora, sample 2208; 3 – Guseva Gora, sample 2209; 4 – Guseva Gora, sample 2210; 5 – Irtyash II, sample 2211; 6 – Uzhovoy Island, sample 2212; 7 – Kirety, sample 2213; 8 – Irtyash II, sample 2214; 9 – Uzhovoy Island, sample 2215; 10 – Guseva Gora, from surface.

Tab. 14-7. Bulk chemical analyses (%) of slag of iron making. The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

Sample	Site	Material	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	Al_2O_3	SiO_2
2207	Guseva Gora	slag	73.15	2.24	0.31	1.73	0.10	0.47	6.09	22.22
2212	Uzhovoy Island	slag	72.34	3.00	1.02	1.73	0.04	0.47	5.35	22.44

Tab. 14-8. Ratio of oxides decreasing viscosity (TiO_2, MgO, Fe_2O_3, MnO, K_2O, CaO, Na_2O) to those increasing it (SiO_2, Al_2O_3,) – coefficient Kz and coefficient of viscosity (Pa s) at the temperature of 1400ºC calculated according to Bachmann et al. 1987.

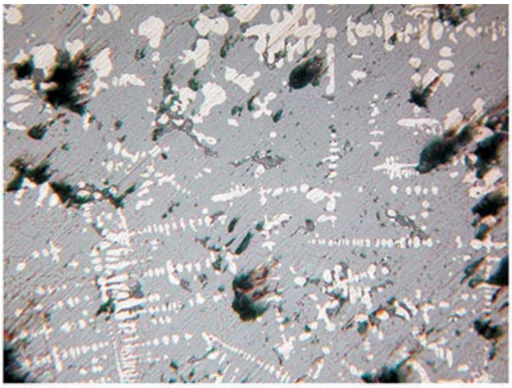
№	Site	Material	K_z	η **1400** (Pa·s)
2207	Guseva Gora	slag	2.76	1.33
2212	Uzhovoy Island	slag	2.83	1.28

Tab. 14-9. Coefficients of basicity of slag of iron making.

Sample	Site	Basicity	Group
2207	Guseva Gora	2.76	ultra-basic
2212	Uzhovoy Island	2.83	ultra-basic

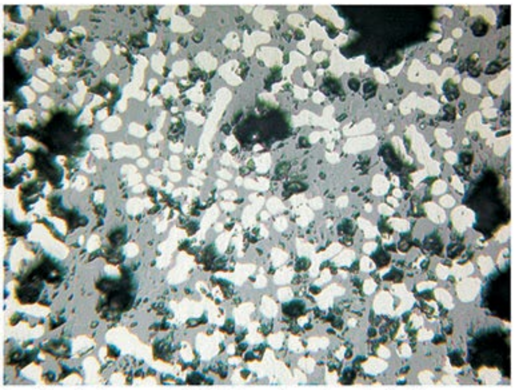
Tab. 14-10. Standard petrochemical re-calculations of the chemical compositions of slag and ore dome by means of the Minpet program.

Sample	Site	Corundum	Anorthite	Olivine	Ol. (Fo)	Ol. (Fa)	Magnetite
2207	Guseva Gora	2.43	8.58	75.40	0.54	74.87	16.45
2212	Uzhovoy Island	1.69	8.56	76.50	1.77	74.74	16.42

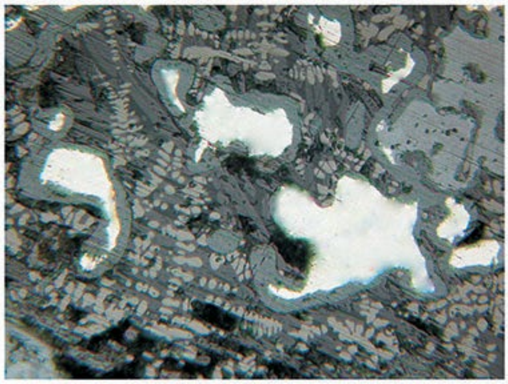


1 – Guseva Gora, sample 2207, fused dendrites of wüstite.

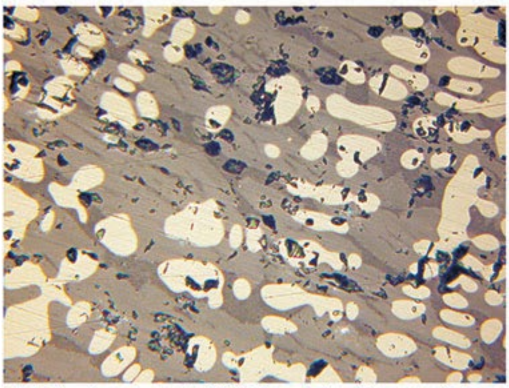
2 – Guseva Gora, sample 2210, skeletal and long prismatic crystals of fayalite.



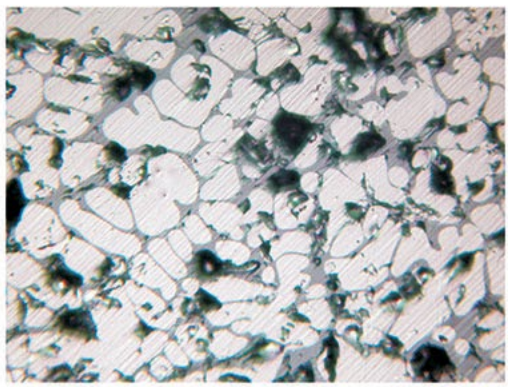
3 – Irtyash II, sample 2211, fused grains of wüstite.



4 – Irtyash II, sample 2214, fused dendrites of wüstite and inclusions of iron surrounded with hydroxides.

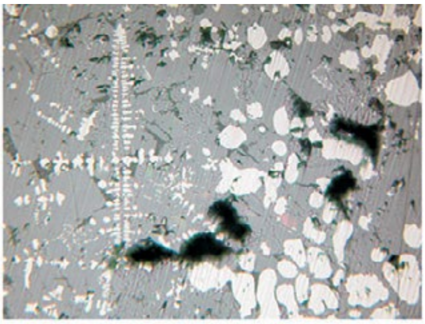


5 – Dolmatovo, sample 2033, fused dendrites of wüstite and prismatic crystals of fayalite.

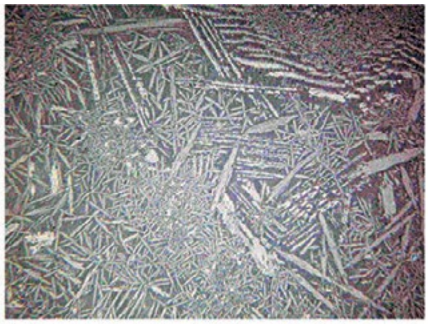


6 – Kirety, sample 2213, fused inclusions of wüstite.

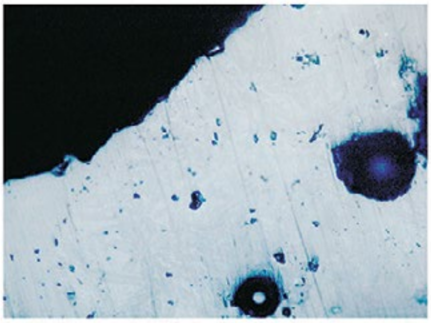
Fig. 14-V. Microstructures of slag of the Early Iron Age (length of the photos is 0.54 mm): 1 – Guseva Gora, sample 2207, fused dendrites of wüstite; 2 – Guseva Gora, sample 2210, skeletal and long prismatic crystals of fayalite; 3 – Irtyash II, sample 2211, fused grains of wüstite; 4 – Irtyash II, sample 2214, fused dendrites of wüstite and inclusions of iron surrounded with hydroxides; 5 – Dolmatovo, sample 2033, fused dendrites of wüstite and prismatic crystals of fayalite; 6 – Kirety, sample 2213, fused inclusions of wüstite.



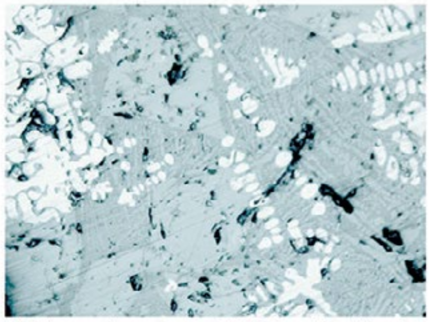
1 – Uzhovoy Island, sample 2212, dense polygonal crystals of fayalite (light grey background), dendrites and fused grains of wüstite (white).



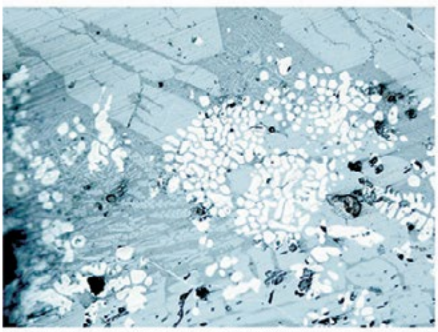
2 – Uzhovoy Island, sample 2215, needle-shaped crystals of fayalite.



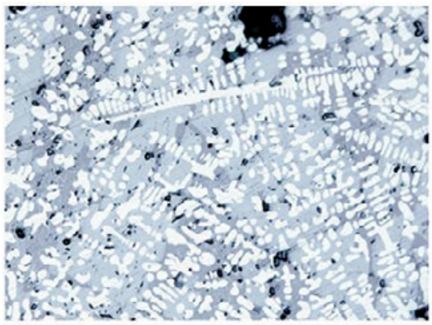
3 – Ulak-6, sample 2338. Small nuclei of fayalite crystallization in the porous glass.



Biktimirovo settlement, sample 2349: fused dendrites of wüstite (white) and molten disintegrating grain of wüstite formed from another iron oxide (on the left), polygonal and needle-shaped crystals of fayalite \(light grey) in the glass (dark grey matrix) with small pores (black).



5 – Biktimirovo settlement, sample 2349: fused particles of wüstite saved the form of a primary ore grain, prismatic and thin skeletal crystals of fayalite (light grey) in the glass (dark grey matrix) with small pores (black).



6 – Biktimirovo settlement, sample 2349: fused dendrites of wüstite (white) against the background of prismatic crystals of fayalite (light grey) in the glass (dark grey matrix) with small pores (black).

Fig. 14-VI. Microstructures of slag of the Early Iron Age (length of the photos is 0.54 mm): 1 – Uzhovoy Island, sample 2212, dense polygonal crystals of fayalite (light grey background), dendrites and fused grains of wüstite (white); 2 – Uzhovoy Island, sample 2215, needle-shaped crystals of fayalite; 3 – Ulak-6, sample 2338. Small nuclei of fayalite crystallization in the porous glass; 4 – Biktimirovo settlement, sample 2349: fused dendrites of wüstite (white) and molten disintegrating grain of wüstite formed from another iron oxide (on the left), polygonal and needle-shaped crystals of fayalite (light grey) in the glass (dark grey matrix) with small pores (black); 5 – Biktimirovo settlement, sample 2349: fused particles of wüstite saved the form of a primary ore grain, prismatic and thin skeletal crystals of fayalite (light grey) in the glass (dark grey matrix) with small pores (black); 6 – Biktimirovo settlement, sample 2349: fused dendrites of wüstite (white) against the background of prismatic crystals of fayalite (light grey) in the glass (dark grey matrix) with small pores (black).

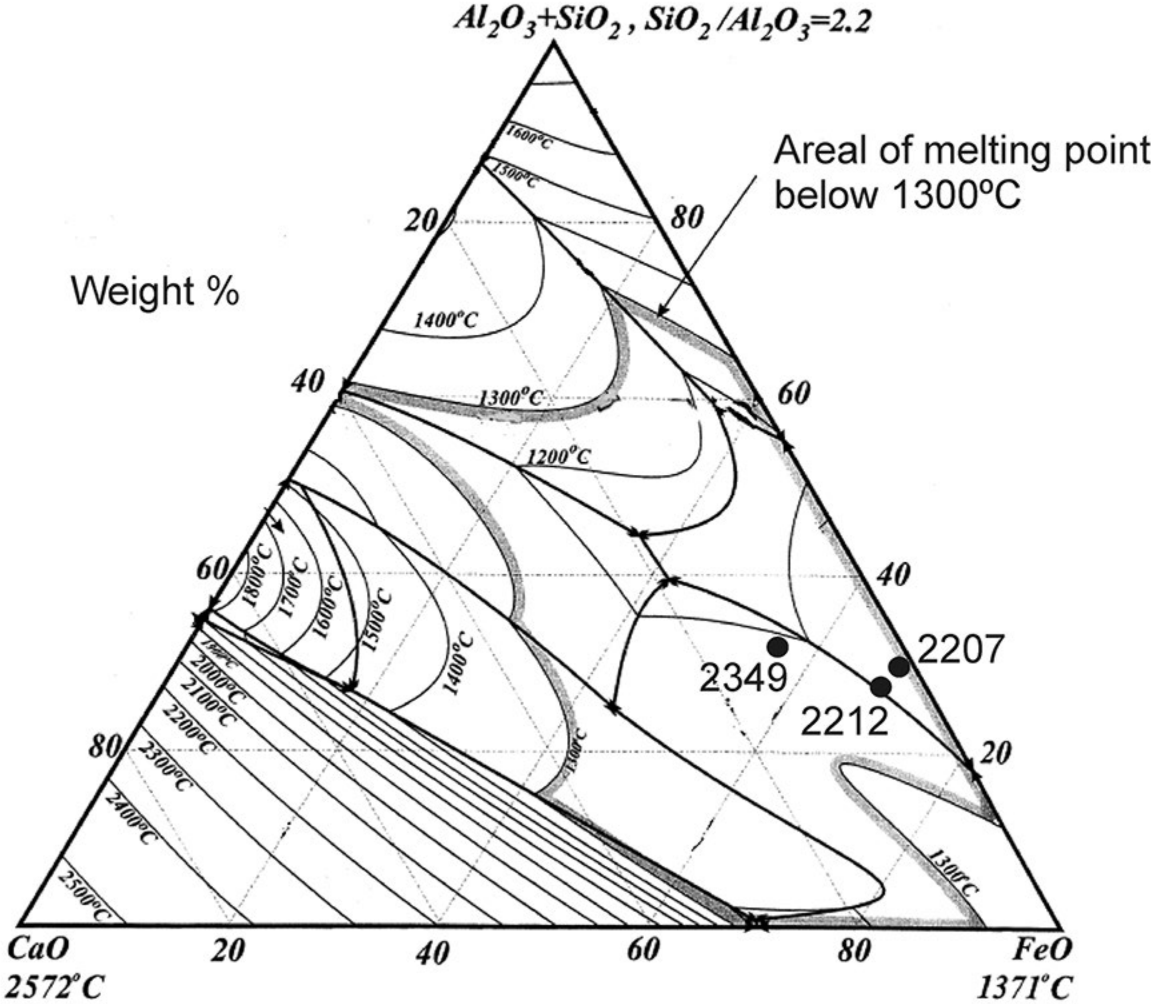
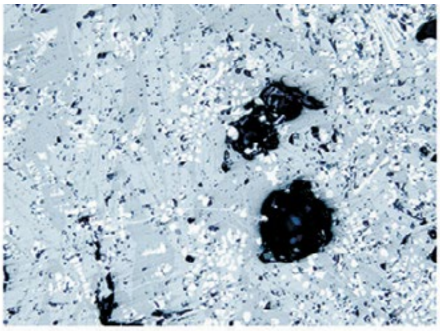


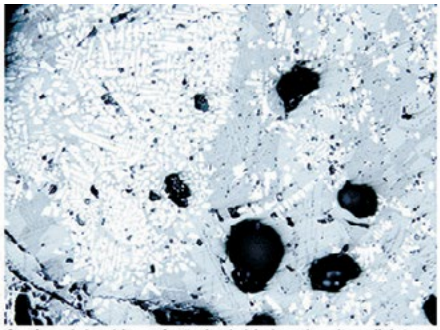
Fig. 14-11. Phase plot of FeO-Al2O3+SiO2-CaO for slag from the settlements of Guseva Gora (2207), Uzhovoy Island (2212) and Biktimirovo settlement (sample 2349).

Tab. 14-12. Bulk chemical analysis of slag from the Biktimirovo settlement (%).The analyses have been done in the Chemical laboratory of the Chelyabinsk geological expedition.

№	SiO_2	TiO_2	Al_2O_3	FeO	CaO	K_2O	S	Cu	CuO	Total
2349	23.00	0.25	5.38	47.11	8.92	1.67	<0.05	0.03	0.04	86.36

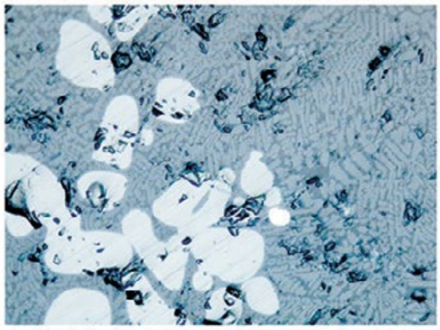


1 – fused dendrites of wüstite (white) against the background of prismatic crystals of fayalite (light grey) in glass (dark grey matrix) with small pores (black).

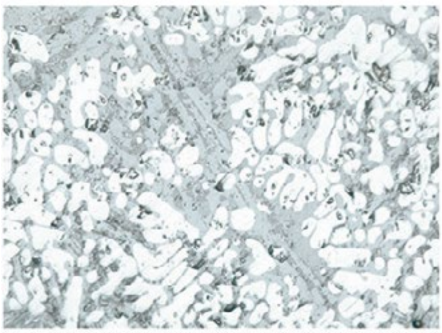


2 – fused dendrites of wüstite (white) and molten disintegrating grain of wüstite formed from another iron oxide (on the left), polygonal and needle-shaped crystals of fayalite (light grey) in glass (dark grey matrix) with small pores (black).

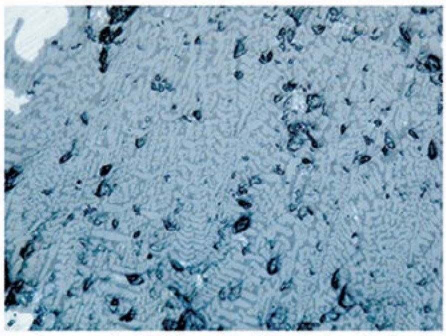
3 – lattice structure of fused dendrites of wüstite (white) saved border of a primary ore grain, long prismatic and needle-shaped crystals of fayalite (light grey) in the dark grey glass with pores (black).



4 – fused dendrites of wüstite (light grey) in glass (dark grey matrix) filled with dense small skeletal crystals of fayalite (grey), fused particle of iron (white).

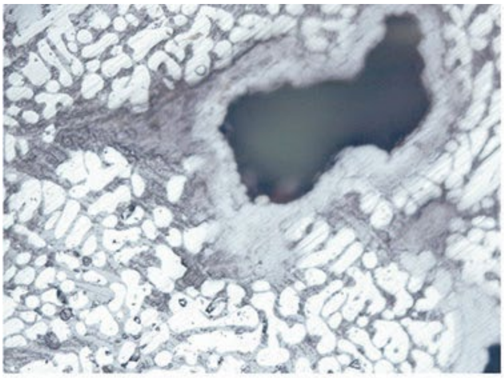


5 – fused grains of wüstite (white) against the background of long prismatic and needle-shaped crystals of fayalite (grey) in the glass matrix (dark grey).

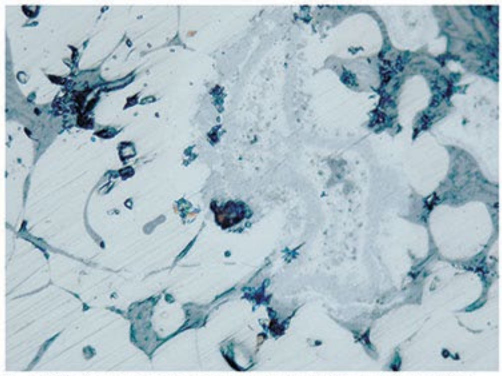


6 – dense small skeletal crystals of fayalite (grey) in the dark grey glass, fused grain of wüstite (light grey).

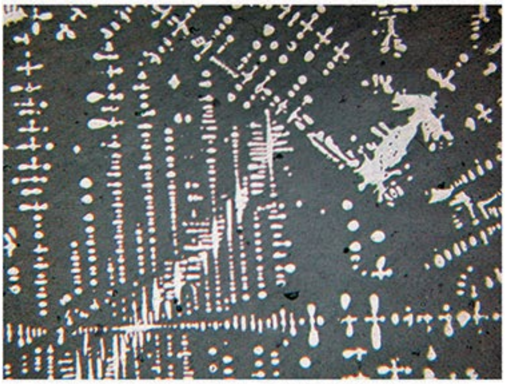
FIG. 14-VII. MICROSTRUCTURES OF SLAG OF THE BIKTIMIROVO SETTLEMENT, SAMPLE 2349 (LENGTH OF THE PHOTOS IS 0.54 MM): 1 – FUSED DENDRITES OF WÜSTITE (WHITE) AGAINST THE BACKGROUND OF PRISMATIC CRYSTALS OF FAYALITE (LIGHT GREY) IN GLASS (DARK GREY MATRIX) WITH SMALL PORES (BLACK); 2 – FUSED DENDRITES OF WÜSTITE (WHITE) AND MOLTEN DISINTEGRATING GRAIN OF WÜSTITE FORMED FROM ANOTHER IRON OXIDE (ON THE LEFT), POLYGONAL AND NEEDLE-SHAPED CRYSTALS OF FAYALITE (LIGHT GREY) IN GLASS (DARK GREY MATRIX) WITH SMALL PORES (BLACK); 3 – LATTICE STRUCTURE OF FUSED DENDRITES OF WÜSTITE (WHITE) SAVED BORDER OF A PRIMARY ORE GRAIN, LONG PRISMATIC AND NEEDLE-SHAPED CRYSTALS OF FAYALITE (LIGHT GREY) IN THE DARK GREY GLASS WITH PORES (BLACK). 4 – FUSED DENDRITES OF WÜSTITE (LIGHT GREY) IN GLASS (DARK GREY MATRIX) FILLED WITH DENSE SMALL SKELETAL CRYSTALS OF FAYALITE (GREY), FUSED PARTICLE OF IRON (WHITE); 5 – FUSED GRAINS OF WÜSTITE (WHITE) AGAINST THE BACKGROUND OF LONG PRISMATIC AND NEEDLE-SHAPED CRYSTALS OF FAYALITE (GREY) IN THE GLASS MATRIX (DARK GREY); 6 – DENSE SMALL SKELETAL CRYSTALS OF FAYALITE (GREY) IN THE DARK GREY GLASS, FUSED GRAIN OF WÜSTITE (LIGHT GREY).



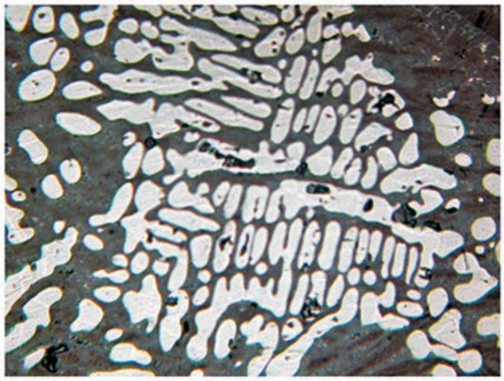
Biktimirovo settlement, sample 2350, formation of molten lattice structures of wüstite (white) round a pore surrounded with iron oxide.



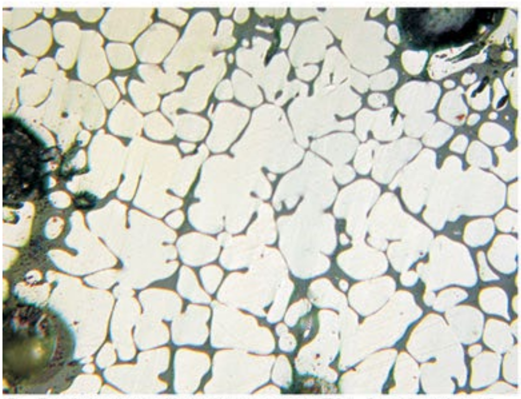
2 – Biktimirovo settlement, sample 2350, malting of iron oxide and formation of molten structures of wüstite.



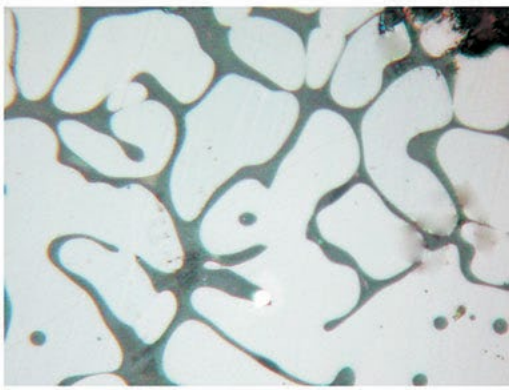
3 – Malyi Ganbinsky Kordon, sample 779, dendrites of wüstite.



4 – Malyi Ganbinsky Kordon, sample 779, fused lattice structures of wüstite.



5 – Partizanskaya Katushka, sample 781, fused grains of wüstite.



6 – Partizanskaya Katushka, sample 781, fused grains of wüstite (length of the photo is 0.22 mm).

FIG. 14-VIII. MICROSTRUCTURES OF SLAG OF THE EARLY IRON AGE (LENGTH OF THE PHOTOS IS 0.54 MM): 1 – BIKTIMIROVO SETTLEMENT, SAMPLE 2350, FORMATION OF MOLTEN LATTICE STRUCTURES OF WÜSTITE (WHITE) ROUND A PORE SURROUNDED WITH IRON OXIDE; 2 – BIKTIMIROVO SETTLEMENT, SAMPLE 2350, MALTING OF IRON OXIDE AND FORMATION OF MOLTEN STRUCTURES OF WÜSTITE. 3 – MALYI GANBINSKY KORDON, SAMPLE 779, DENDRITES OF WÜSTITE; 4 – MALYI GANBINSKY KORDON, SAMPLE 779, FUSED LATTICE STRUCTURES OF WÜSTITE; 5 – PARTIZANSKAYA KATUSHKA, SAMPLE 781, FUSED GRAINS OF WÜSTITE; 6 – PARTIZANSKAYA KATUSHKA, SAMPLE 781, FUSED GRAINS OF WÜSTITE (LENGTH OF THE PHOTO IS 0.22 MM).

Conclusions

As it has been discussed on pages of this book, the development of metallurgy passed several successive stages: from use of natural copper to smelting of copper sulfides and iron production. And all these changes had geological grounds: the upper part of deposits contains native copper and copper oxides, with secondary and then primary copper sulfides below. This means that in process of mining a transition to the next technological stage took place. It is not fully true for any particular deposit and mining area, because there could become apparent many distinctive features, but this regularity is absolutely true within frameworks of vast areas. But this changing of the ore base demanded also more complicated technological operations: from cold forging to high-temperature smelting, from crucibles to furnaces, to control on temperature and many other smelting conditions (Strahm, Hauptmann 2009, p. 122, 123). Therefore, at first sight, this logic of development could be presented anywhere because this chain of ores in the deposits is universal. However, many authors suppose that there was a diffusion of this production from the Near East because we have no other area with evidences of its local development (Strahm, Hauptmann 2009, p. 125).

We have also seen that the main forming impulses for development of metallurgy in Northern Eurasia in the Bronze Age came exactly from the Near East. It is very old problem in archaeometallurgy. This discussion has been started by T. Wertime who supposed that metallurgy was invented only once and extended then from a single center and C. Renfrew who believed that there were independent centers of emergence of this production everywhere (Roberts *et al*. 2009, p. 1012).

But this chain of ores in the deposits is not always accompanied by the same logic of the technological development from smelting of copper oxides to secondary and then primary sulfides. For example, in Africa copper metallurgy appeared in the 3rd – 2nd millennia BC, but up to the ethnographical period it was based on smelting of malachite (Holl 2000, p. 13, 2009, p. 431; Bisson 2000, p. 89-91, 97). Therefore, the transition to other ores and technologies is not always based on the logic of their bedding in the deposits and the technological logic. If it was so, we would see a set of independent origins and lines of development of the production across Eurasia. But it is not so. Usually the development was a result of borrowings. It is well visible from history of the spreading of metallurgical production.

The earliest knowledge of copper occurred in Anatolia and Northern Mesopotamia. The first copper objects made by cold forging are dated there to the 8th – 7th millennia BC. The hot forging and casting appeared about 6000 BC, and the first copper smelted from ore is dated to about 5000 BC. Perhaps, from this area the use of native copper was distributed to Western Iran, although in this instance to be more precise we must discuss the unity of technological processes in broader area because the ore smelting appeared in Iran in the 5th millennium BC, contemporary to its appearance in Anatolia.

On the Balkans the first copper occurred at the end of the Neolithic period (Fig. 15-1.). Because during the whole Neolithic the Balkan Peninsula was closely connected with Anatolia we may assume that knowledge of metal came to the Balkans from there, as well as many other Anatolian inventions. In Anatolia the ore smelting started only since the late 6th – early 5th millennia BC. Thus, initially the use of native copper was distributed. In the 5th millennium BC a very developed Eneolithic production arose in the Northern Balkans that gradually was distributed throughout South-Eastern and Central Europe. The Balkan production, with its plenty of massive tools could not be based on native copper; metallurgists smelted most likely ores, although it cannot be confirmed yet by slag finds. In this case it is impossible to answer a question where it was a local development or it was stimulated by some additional impulses from Anatolia. Before the beginning of this period it was almost the united Balkan-Anatolian cultural complex. Therefore it is more correct to speak about the formation of ore smelting in the Balkan-Anatolian region. Use of the pure oxidized ore on the

Balkans is probably symptomatic. The neolitization of the Balkans was carried out from Anatolia; possibly, skills of mining, knowledge of metal, probably (at the end of the Neolithic period) smelting of the oxidized ore were transferred at this time. In this period arsenic copper was also not as widespread in Anatolia as in the following time, although single casual objects are not excluded.

Some later, in the mid-5th millennium, the metallurgical production was distributed from the Eastern Mediterranean to the west, to Iberia, and then, in the late 4th millennium BC, from Iberia to North Africa. In the same millennium metallurgy appeared on the Corsica and in North-Western Italy, and from this area it did in Southern France. At the beginning of this millennium we see the spreading of metallurgy from the Balkans to Middle Europe, where one later impulse from the south-west penetrated, from France and Swiss. As a result, in the mid-4th millennium BC metallurgy was mastered everywhere in Middle Europe.

Shortly before the mid-4th millennium BC some processes took place in Anatolia and Central Europe. As a result, we see the both Central European and Anatolian (through Eastern Europe) impulses to the Balkans. The Anatolian ones brought to appearance of arsenic alloys in South-Eastern Europe.

In Northern Eurasia the first copper objects are dated to the 5th millennium BC. Just in this period we see distribution of traditions of forging and casting from the Balkans to the Dnieper area and, probably, to the Volga River. Some Eneolithic cultures of Eastern Europe demonstrate copper objects repeating Balkan types and chemically close to those in the Balkans. They had been made by similar but slightly degraded technology which shows their local production. It happened within the final formation of the Balkan-Carpathian metallurgical province of the Eneolithic period.

Some later, in the 4th millennium BC, situation in Central Europe changed, and the Balkan-Carpathian province disintegrated. In this millennium metallurgy originated in Karelia, but it was presented only by forging of native copper. In this instance we may admit borrowing of knowledge about metal, however, a local origin of this primitive technology is not excluded. At the same time impulses from Central Europe reached the Urals and copper production arose there. It is not excluded that there was one more impulse from Anatolia, but it is too poorly proofed by materials. Various technological traditions were present in this production: smelting of both oxidized and sulfide ores including chalcopyrite, attempts to alloy with arsenic and even with tin. Smelting was carried out in complicated furnaces. At the same time, there was also a very archaic crucible smelting of oxidized ores. And it is absolutely unclear how these traditions were blended together. But metallurgy did not gain here a serious development; it degraded. First, it was not demanded in economy of hunters and fishers. In the beginning this tradition was supported by the stratified society created in the early Eneolithic, but subsequently, in process of leveling of this society, metallurgy degraded to extremely primitive forms.

In the late 4th millennium BC the Circumpontic Metallurgical Province formed, extending over vast areas of the Near East, the Caucasus, Eastern Europe and the Balkans. Chronologically it covered the next millennium and two archaeological epochs: Early and Middle Bronze Age. In the late 4th millennium BC the Maikop culture of the Northern Caucasus formed (Fig. 15-2.). Its arsenic alloys with nickel admixtures demonstrate Near Eastern origins. Slag of this culture is absent, but most probably this alloying could be realized by addition of arsenic minerals to copper oxides.

After this the ore smelting appeared in the Southern Urals, in the Pit-Grave culture. Its metal artifacts have an undoubted Circumpontic background and probable connections with the Northern Caucasus, although it is unknown where here the ore smelting came from. The arsenic alloys were absent here, as well as slag. Technology was probably very archaic being based on copper oxides from sandstones and crucible smelting. But we cannot say now what it was: either regress of Caucasian technologies or borrowing from local Eneolithic metallurgy. Besides, we do not know what will Pit-Grave slags and furnaces show if they will be anywhere found.

In the 3rd millennium BC metallurgy penetrated to the British Isles. In Northern Eurasia we have no evidence about smelting in this period, albeit there is a lot of metal in burials of the Pit-Grave and Catacomb cultures. A single known ore source of this time was deposits in the Ural sandstones, above all the Kargaly mines, but other deposits of this area too. We see no serious technological transformations. But in the west, in the southern part of Eastern Europe, many metal objects were alloyed with arsenic, so they were not connected with the Southern Urals. It was especially typical of the Catacomb culture. It is improbable that this metal was of Transcaucasian origins, but other data are completely absent today. Therefore even attempts to discuss this problem are completely insensible.

In the late 3rd – early 2nd millennia BC, at the end of the Middle Bronze Age, a burst of metallurgical production started in Northern Eurasia (Fig. 15-3.). Its first place was the Sintashta culture in the Southern Urals where metallurgy penetrated from the Near East. This production was based on smelting copper oxides (with additions of secondary sulfides) from ultra-basic rock, as well as on alloying copper with arsenic minerals on the ore smelting stage. There was a gradual expansion of the ore base and the use of more widespread ores from quartz rocks. At the same time in the Western Urals people of the Abashevo culture saved a very archaic technology of crucible smelting of very pure oxidized ore, succeeding probably to the Eneolithic production. But the Sintashta technology penetrated here, and it was the basis of a further technological development of the production in the area.

In the 3rd millennium BC the south of Central Asia (Uzbekistan, Turkmenistan) was influenced by metallurgical production from Iran (Fig. 15-2.). Initially a very archaic crucible ore smelting occurred here. It is not excluded that such a tradition appeared also in the north, in the Sayan-Altai region (Afanasievo culture). But here the source of this production was the Pit-Grave metallurgy of the Urals. Probably, some technological changes took place here in the Middle Bronze Age connected with the Late Afanasievo and Okunev cultures, which was expressed in the appearance of first alloys, but there is no trustworthy evidence about smelting technologies of this period in Southern Siberia. Most probably, just from this area impulses to the south-east, to China, emanated which resulted in origins of metallurgy there, but it is impossible to confirm this supposition by concrete materials now. It is based exclusively on the chronological correspondence.

In the second half of the 3rd millennium BC in the south of Central Asia (Kyzyl-Kum desert) metallurgists started to smelt chalcopyrite. After this the technology appeared to the north, in the Altai. It was still weakly expressed in the Elunino culture where a mix from copper oxides and sulfides was smelted, but the first tin alloys were already known. It is difficult to connect these innovations with any particular area of the Middle East, but initial Anatolian roots of the tin alloys and the smelting of chalcopyrite are undoubted (Fig. 15-3.).

At the transition to the Late Bronze Age, in the first half of the 2nd millennium BC, with the formation of the Timber-Grave culture in Eastern Europe and Petrovka and Alakul cultures in the Urals and Kazakhstan, metallurgical production was distributed over large territory. The process had been started at the end of the Middle Bronze Age by penetration of Sintashta traditions to the north (the forest-steppe Transurals) and the east (the western part of Northern Kazakhstan), but soon they were distributed wider and transformed. We see the transition from smelting ores from the ultra-basic rocks to ores from quartz, which is quite explainable in view of their richness and wider distribution. But this resulted in longer smelting process, higher temperatures and oxidizing conditions which made impossible to save arsenic in metal in case of its addition on the ore smelting stage. This created preconditions for the following technological changes connected with eastern impulses.

The traditions of smelting of sulfides and tin alloys appeared first in the Altai and penetrated west through the forest-steppe area. Archaeologically these processes are expressed in the appearance of the Seima-Turbino and Fyodorovka metallurgy. New traditions of alloys penetrated also to the steppe area inhabited by the Timber-Grave and Alakul people, but previous smelting traditions going back to Sintashta culture remained there. All this leaded to the final formation of the Eurasian Metallurgical Province (EAMP), although the process was started since the Sintashta metallurgy.

More successfully these new technologies penetrated west, first to Central Europe, and then to Atlantic Europe, although in Britain a local origin of tin alloys is not excluded. The second vector of impulses from the Sayan-Altai area was directed to the south-east, so we see the wide distribution of tin alloys and Seima-Turbino types of weapons in China. At last, steppe people brought their smelting technologies to the south of Central Asia, which is visible on materials from the Kyzyl-Kum desert.

In the Final Bronze Age, at the beginning of the second half of the 2nd millennium BC, steppe area saved its previous technological traditions. But in some places, especially in Southern Siberia and Central Asia, new technological features appeared, stimulated from the Middle East, but it is impossible to determine any concrete area (Fig. 15-4.). In the north-eastern part of the EAMP metallurgists returned to smelting of copper oxides or their mix with sulfides as well as to the arsenic alloys. Possibly, it was accompanied by technology of iron smelting. But the latter was in a latent state up to the appearance of steel because non-carbonized iron yields to bronze. As a result, a new Central Asian Metallurgical Province (CAMP) arose there, which had drastically different characteristics in comparison with the EAMP. It influenced to the south (and a part of China was included in it) and partly to the west. In the west it leaded to distribution of arsenic alloys and degrading of the former tradition of tin alloys. The latter remained in the east of the province only. Perhaps, it was influenced by developed production that had been formed in China where tin alloys dominated.

The most powerful influence from Central Asia to the west took place at the beginning of the Early Iron Age. It resulted in the renewal of tin alloys, transition to smelting copper oxides and their mix with sulfides, introduction of iron metallurgy. The last technology had been appeared first in Anatolia, and in the Final Bronze Age it started move eastwards, to Iran, India, Central Asia and China. A northern direction is also probable: through the Caucasus to the Don and then to the Middle Volga and Kama areas. To the west the technology was distributed through Central Europe and Mediterranean. The last way was probably a stimulus of rise of iron metallurgy in Northern Africa and its gradual victorious movement to the south of the continent. There are some questions with the origins of iron metallurgy in the Eastern Urals. It was partly stimulated from the Kama area, but eastern impulses are not excluded.

Above we have touched upon only questions of ore smelting and partly alloys. They were interacting processes, but there are also many problems of metalworking and mining. And all this was not only a distribution of the complex of metallurgical technologies. They were accompanied by other changes of material culture.

One of the most important features of cultural genesis in ancient Northern Eurasia was a pulsatile character of cultural processes, with sudden significant cultural transformations of similar type on vast territories. The majority of scholars are inclined to explain this with different reasons, being based on an idea of autochthonic development of these areas. In my opinion, this region was always subjected to long-distance migrations which were the basic reason of these transformations. It is especially obvious in metallurgical production, which being very complicated excludes borrowings without a training process. It is possible to borrow knowledge of metal. But it can provoke only the use of native copper and its forging by means of very simple technologies as it was the case in Karelia in the Eneolithic period. For some instances we may admit the distribution of metalworking technologies from any population to their neighbors and gradual diffusion in such a way through large distances. Such case probably took place in the Eneolithic when metalworking technologies spread from the Northern Balkans across the south of Eastern Europe, and this process was accompanied by their gradual primitivization that is quite logical at similar process.

But very often we see distribution of ore smelting technologies, which was impossible through areas were ore deposits were lacking. Moreover, particular elements of any metallurgical complex were closely interconnected. Any type of raw material (types of ore and gangue) dictated definite smelting technologies. The latter were connected with types of alloying and through them with the metalworking technologies. The latter were the base of types of metal artifacts. So, it is a very complicated complex that cannot be gathered from several different isolated pieces. Therefore a sudden appearance of this complex without a possibility to trace back its gradual creating has to set thinking, at least. In my opinion, it allows to put a problem of a migratory character of these innovations, especially if we can trace previous phases of this technological development in others, even very remote areas.

Basing on analyzes of materials from Northern Eurasia it is possible to draw a conclusion that in development of metallurgical production here internal impulses dominated. But sometimes striking changes stimulated from outside took place in the region. At the beginning metallurgy of the Balkan-Carpathian Metallurgical Province (the most development area of the period) was the main stimulus, although there were some Anatolian impulses.

Then, during the whole Bronze Age, the main stimulating center was in the south-eastern part of the Circumpontic Province, and even after its disintegration the Near East was continuing to influence metallurgical developments in the north. Only at the transition to the Early Iron Age some area of the Central Asian Metallurgical Province started to play this role.

All this perfectly illustrates the accepted by many archaeometallurgists opinion that only migrating experts could transfer metallurgical technologies. And, the distribution of technologies cannot be considered separately from a sociocultural network and other traditions (see e.g. Roberts *et al*. 2009, p. 1016-1019; Roberts 2009, p. 135, 136). And in Northern Eurasia we see that processes of distribution of technologies and other cultural traditions coincided rather precisely. But there is also one more coincidence. The directions of distribution of cultural traditions in the Eurasian Bronze Age coincided with the directions of distribution of Indo-European languages from the Near East (Gamkrelidze, Ivanov 1984; Grigoriev 1999, 2002)[1].

It follows from this that bearers of these languages acted also as the main distributors of advanced metallurgical technologies over Eurasia. Of course it does not mean that exactly they were developers of these technologies. Different peoples of the Near East took part in their development and, above all, the people lived in Anatolia. In the antiquity the most part of metallurgical innovations was created exactly there. As a matter of fact, the reasons of it are quite obvious. As well as many other parts of culture of any society, metallurgy is very traditional and inertial. Probably, it is even more traditional than all other as it is a rather complicated system consisting of a complex of different operations, and this complex cannot be collected of pieces from different incomparable parts. Therefore without an essential need the changes here are improbable. From time to time such needs arise and cause the technological transformations. But in Anatolia there was a strong stimulus to the continuous development which forced to improve and expand the production all the time.

The high level of both economy and society in the Near East was a basis of the development of metallurgy in Anatolia. But this indisputable motive for development of the production was repeatedly intensified by the existence near Anatolia of poor in resources but roughly developing Mesopotamia. It provided the immense market for the Anatolian metallurgy. For example, demand for silver was stimulated with the need to provide Mesopotamian trade and exchange. Therefore native minerals and silver ores were insufficient. It led to

[1] Similarly, other scholars have noted the coincidence of the time and direction of distribution of arsenic alloys in Iran with migrations of the Proto-Elamites (Thornton, Lamberg-Karlovsky 2004, p. 267).

development of technology of silver extraction from lead ores. This trade stimulated also the mining of gold in the neighboring and even remote areas. The last studies have shown that a part of the Mesopotamian gold of the Bronze Age was got in Armenia (Kunze *et al*. 2011, p. 20).

Thus, the distribution of metallurgical technologies not always was a pure process of distribution of technology. Usually it happened with migrating collectives which knew these technologies. Naturally, these migrations were not aimed at all to spread anywhere a new technology or other cultural achievements. It always was a forced process connected with either natural or political reasons. And popular conversations about the "wandering masters" are based on nothing, except for understanding that it was impossible to spread metallurgy without training and on the unwillingness to acknowledge a possibility of large-scale migrations. However, it will be possible to discuss the idea of the "wandering masters" only after at least any attempt to give minimal facts in favor of it will appear.

But I would not like that there was an impression that Eurasia is obliged to the distribution of metallurgical technologies exclusively to the Indo-Europeans. In some instances it was really so. But in in the other ones we do not see behind a distribution of a particular culture of any strict compliance in the model of migration of bearers of the Indo-European languages. A striking example to it is the earliest penetration of metallurgy from the Eastern Mediterranean to the west and its assimilation in the megalithic cultures of Atlantic and Northern Europe. In my opinion (Grigoriev 2010b) it was connected with migrations of people speaking, mainly, languages of the Dene-Caucasian family of languages. In South Africa above all the Bantu people acted as bearers of metallurgical traditions. It is possible to find also a number of other examples. But it was always concrete people who distributed this tradition, sometimes over a large distance.

But after any tradition had been introduced to a new area, new, already local processes began. A part of them was connected with available ore base which could be unusual or improper for this tradition that resulted in any small technological transformation. The influence was made also by contacts with local technological traditions, especially in case of adaptation of the new technology by local masters.

A significant role was played also by a type of economy and social structures in the new place. So, having appeared in the Urals in quite developed forms metallurgy degrades. Possibly, this degradation goes after the degradation of the society which at first showed an unexpectedly complicated level, most vividly expressed in the megalithic building, but then everything becomes simpler. Among hunters and fishers these social structures could not be stable, and metallurgy initially did not play any noticeable role in this society.

The situation gradually starts changing in the Bronze Age when metallurgical production of Northern Eurasia exists in conditions of productive economy and becoming more and more complicated social structures. Certainly, it was not a cornerstone in the formation of these structures; rather these social structures and economic forms had impact on the nature of metallurgical production. But, being a part of this complicated system, the metallurgy influenced the other parts.

A new peculiarity was also that the more complicated production was integrated into these more complicated social systems. Production of the Eneolithic period of Northern Eurasia directed its efforts to small volumes and it was based, mainly, on very simple technologies and use of unalloyed copper. Presence of skillful masters and ore sources nearby was the only condition for this production. But in the Bronze Age the production becomes complicated. For the Sintashta culture of the Middle Bronze Age II this complication did not reach yet the level when specialization was required. But there was a problem with arsenic alloys and suitable ore sources, some of which were common for the entire Sintashta culture. Therefore the use of these sources had some forms of social or intercommunal regulations.

The situation gradually becomes complicated in the Late Bronze Age. It was connected also with more complicated casting and forging technologies that demanded emergence of the corresponding specialization. Metallurgical production extends everywhere, but it is presented not on all settlements. Therefore there is a need of metal supply from the mining centers.

A specialization of different settlements and even of larger mining areas appeared. It took place, of course, not everywhere. And it existed in some social structures whose forms are not very clear yet.

The transition to new alloys with tin was also an important factor, which was mined and produced in Central and Eastern Kazakhstan and was delivered far to the west. Naturally, something had to be delivered in the opposite direction. It created the whole system of the trade and exchange relations. Therefore, from now metallurgy already makes some impact on the social and economic systems within which it existed.

At last, in the Early Iron Age we see the following growth in the level of specialization, because both mining and metallurgical production were transferred, mainly, to the periphery of the region. It cannot be considered as further development of the ‘natural’ process of specialization. There was a concrete historical reason: the transition to nomadic economy in the steppes that stimulated the development of settled metallurgical centers on the periphery.

These are the most general conclusions, and I would not like to summarize here particular conclusions drawn for separate problems as they probably need to be transformed greatly in the future. It is more pertinent here, in conclusion, once again to stop on the thought which is already stated in the Introduction. This work cannot pretend to be a description of metallurgy in Northern Eurasia as it cannot be made within one research. The problem of the work was to show possible research ways, methods and approaches to studying of ancient ore smelting, and to give a general picture of development of technologies in this huge space. In the work only some knots are studied with the use of large quantity of materials. Beyond their limits there are blank spots. But I want to hope that this book will form the base for gradual filling of these spots and if once it happens, its task will be solved.

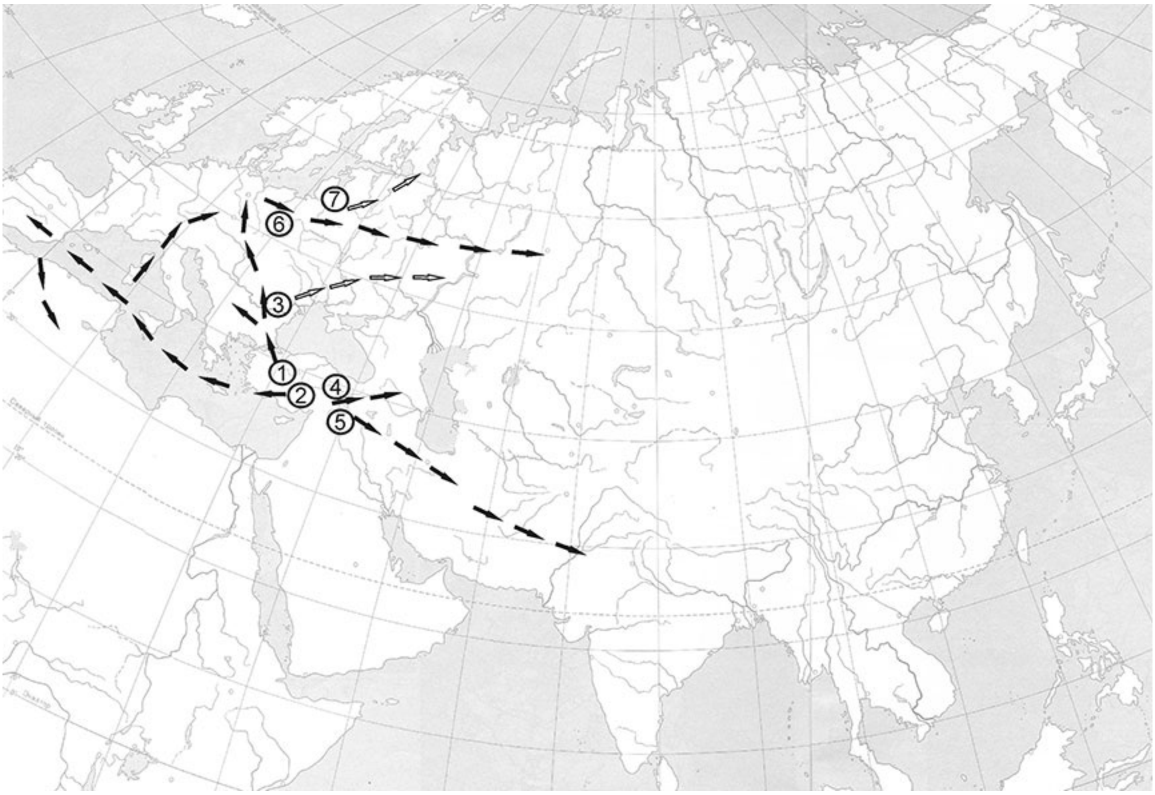


Fig. 15-1. Distribution of copper metallurgy in the Eneolithic: 1 – penetration of copper metallurgy from Anatolia to the Balkans in the late 6th – early 5th millennia BC and then, in the late 5th – early 4th millennia BC to Central Europe; 2 – penetration of copper metallurgy in the 5th millennium BC from the Eastern to Western Mediterranean; 3 – distribution of metalworking from the Balkans to the south of Eastern Europe in the 5th millennium BC; 4 – penetration of copper metallurgy to the Transcaucasia in the 5th millennium BC; 5 – distribution of copper production into Iran in the 6th – 4th millennia BC; 6 – distribution of metal production from Central and Northern Europe to the Urals in the 4th millennium BC; 7 – distribution of metal-working into Karelia in the 4th millennium BC.

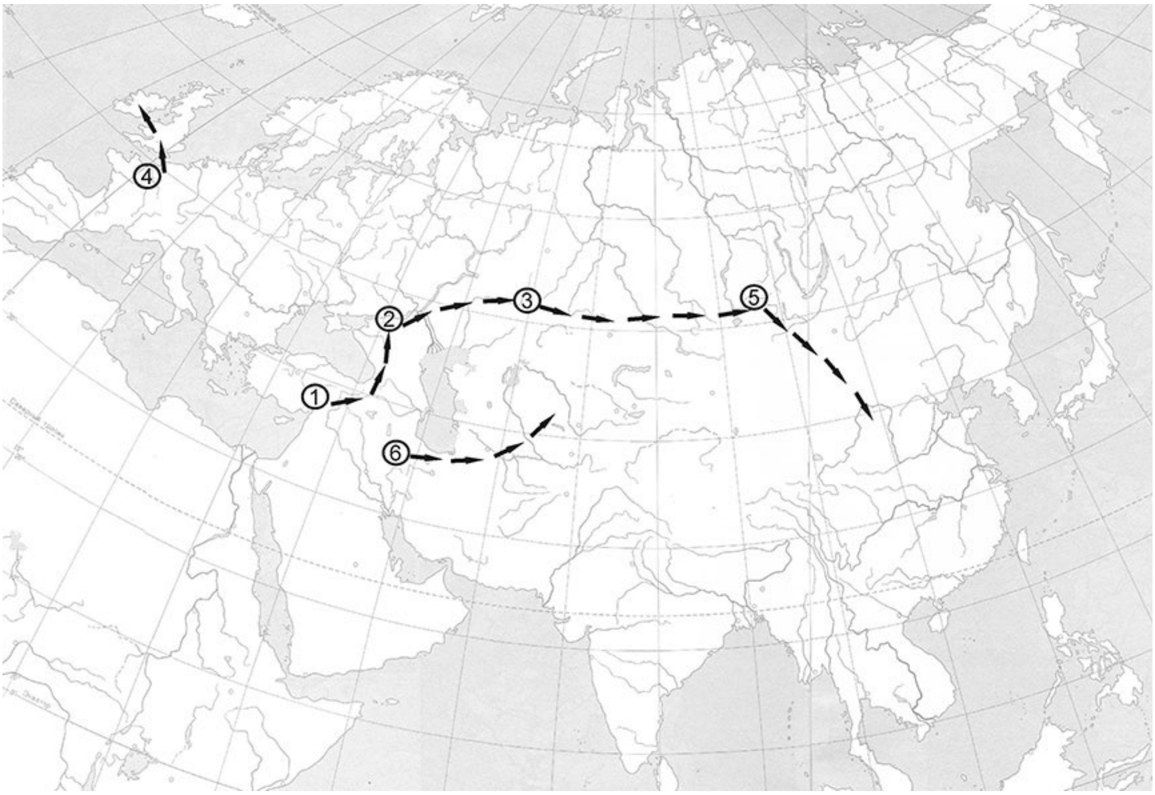


Fig. 15-2. Distribution of metallurgy in the EBA-MBA: 1 – formation of Maikop metallurgy in the Northern Caucasus as a result of the Near Eastern impulse in the late 4th millennium BC; 2 – influence of Maikop metallurgy on formation of Pit-Grave metallurgy in the Urals in the early 3rd millennium BC; 3 – influence of Pit-Grave metallurgy on formation of Afanasievo production in the Sayan-Altai region; 4 – continental impulses and formation of metallurgy in the British isles in the 3rd millennium BC; 5 – probable Afanasievo and Okunev influences on formation of metallurgy in China; 6 – distribution of technologies from Iran to the south of Central Asia.

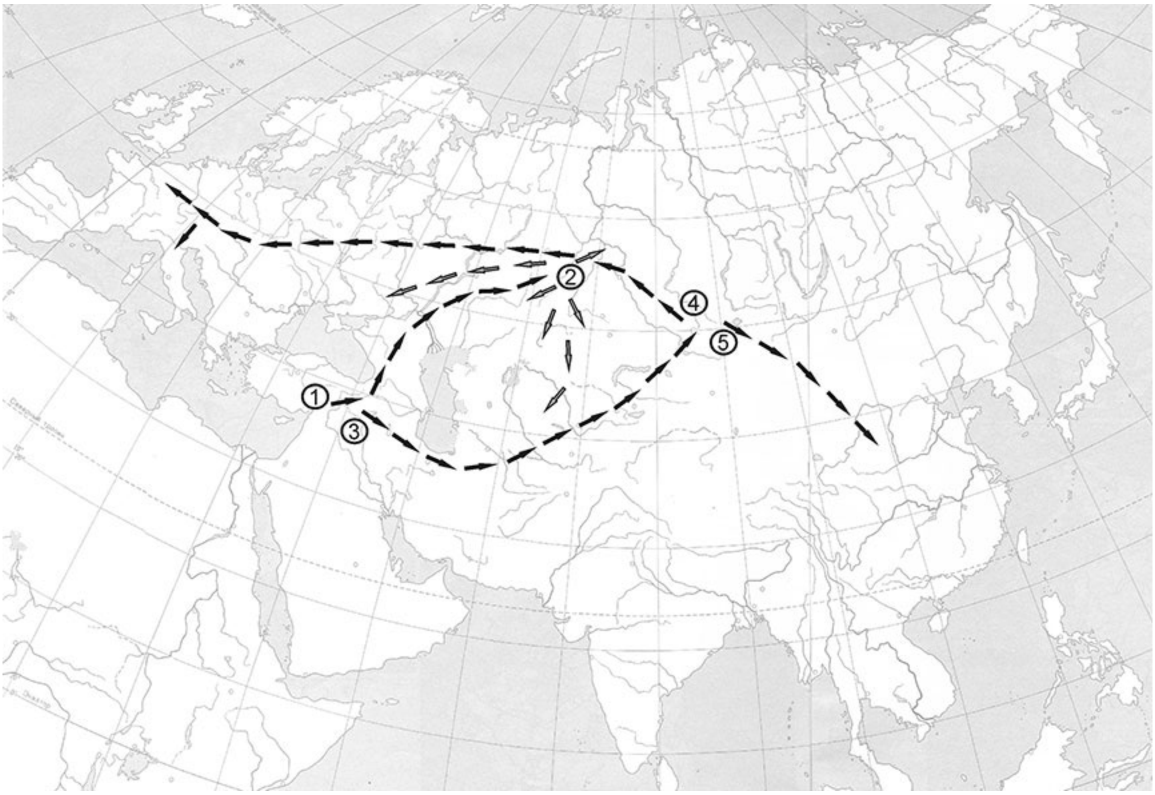


Fig. 15-3. Distribution of new technologies at the end of the MBA and in the LBA (late 3rd – early 2nd millennium BC): 1 – formation of Sintashta metallurgy as a result of the Near Eastern impulse; 2 – distribution of Sintashta traditions to Kazakhstan, the forest-steppe Transurals, the Western Urals and Eastern Europe (grey arrows); 3 – movement of traditions of tin alloys and sulfide ores smelting and formation of Seima-Turbino and Elunino production; 4 – further penetration of these traditions to the Urals and Europe; 5 – distribution of Seima-Turbino traditions to China.

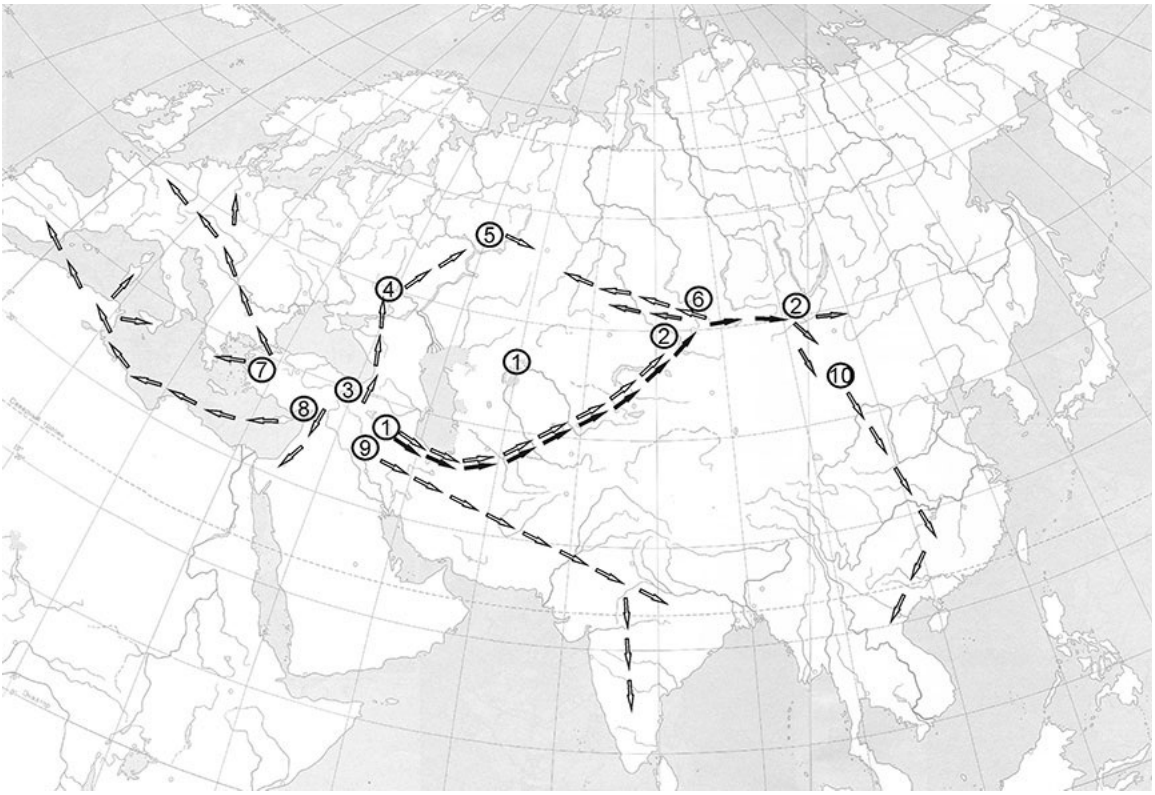


Fig. 15-4. Distributions of copper (black arrows) and iron (white arrows) technologies at the end of the Bronze Age – beginning of the Early Iron Age: 1 – penetration of copper oxide smelting, arsenic alloys and iron making to Southern Siberia and Central Asia in the last quarter of the 2nd millennium BC; 2 – influence of these traditions in neighboring areas (grey arrows); 3 – penetration of iron making to the Caucasus and south of Eastern Europe in the last quarter of the 2nd millennium BC; 4 – Caucasian impulses and formation of Ananyino iron making in the first half of the 1st millennium BC; 5 – Ananyino influence on formation of iron production in the Urals in the mid-1st millennium BC; 6 – impulses from Central Asia, appearance of iron in the steppe Urals and possible influence on its appearance in the forest area in the 8th – 7th centuries BC; 7 – distribution of iron metallurgy from Anatolia to Central Europe in the last quarter of the 2nd millennium BC; 8 – distribution of iron metallurgy from the Eastern to Western Mediterranean in the last quarter of the 2nd millennium BC; 9 – distribution of iron metallurgy through Iran to India in the last quarter of the 2nd millennium BC and the first half of the 1st millennium BC; 10 – distribution of iron production in Eastern Asia in the 1st millennium BC.

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