TephroArchaeology in the North Pacific

edited by

Gina L. BARNES

SODA Tsutomu

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Cover Illustration:
Alaid Volcano viewed from Shumshu Island, northern Kurils off the tip of Kamchatka.
Photo: B. Fitzhugh 2016

Dedicated to

ARAI Fusao & MACHIDA Hiroshi
who together paved the way for
TephroArchaeology in the North Pacific

"In Japan, they've got some very very good preservation, but there are some tremendously compelling things…. We need to know about this; they're doing really really good work." Payson Sheets

"The data in Japan is so incredibly rich and the archaeology is so fantastic that there is huge potential here within one cultural area for us all to get together and map out some of these differences. I think it could set a standard for us who have much less data to compare." Robin Torrence

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Preface

TephroArchaeology Becomings

The way volcanic eruptions affect human life has become a widespread topic of archaeological research. I owe special gratitude to Payson Sheets, Robin Torrence, and Felix Riede for introducing me to this field of study beyond Japan. Their publications together with those of many other colleagues have provided a rich array of assessments of human interaction with volcanoes from the modern era into deep time (e.g. Sheets & Grayson 1979; Torrence & Grattan 2002; Grattan 2006; Grattan & Torrence 2007; Riede 2015, 2016). These works segue into those from the Earth Sciences by geologists becoming more interested in the effects of volcanic eruptions on human society (e.g. Chester 1993; Cashman & Giodorno 2008; Cronin, Nemeth & Neall 2008; Donovan 2010; Lockwood & Hazlett 2010). Many works deal broadly with many kinds of disasters (e.g. Cooper & Sheets 2012; Mata-Prelló et al. 2012; Stewart & Gill 2017), but in this volume, we will restrict ourselves particularly to examining human responses to volcanic eruptions and specifically in the North Pacific.

This book is mainly the product of a Forum on TephroArchaeology, organized by Gina Barnes and SODA Tsutomu[1] for the 2016 meeting of the World Archaeology Congress (WAC8) in Kyoto. It was followed by a similar Forum on Archaeological Volcanology at the 2017 Society for American Archaeology (SAA) meeting in Vancouver, organized by Felix Riede, Gina Barnes, and Payson Sheets. For a discussion of these forum titles, their meanings and suitabilities, please see the Introduction (Chapter 1). Most of the chapters herein were first presented at the WAC8 Forum, but other timely papers were included to widen the scope of the volume; discussion from the SAA Forum formed a major framework for the presentations herein. We thank the editors of the WAC One World Archaeology Series for allowing this publication not to be included in their series, as they have first right of refusal for volumes based on WAC conference papers.

Due to the WAC8 Forum being held in Japan with mainly Japanese participants, the volume is naturally geared to the practice of tephroarchaeology in that country, though what is presented here barely scratches the surface of the work being done there. The remit of the Forum was to concentrate on the methods and techniques of excavating in tephra. Unsolicited comments by Payson Sheets and Robin Torrence, taken from SAA and WAC8 Forum discussions respectively with their permission, shine a light on the potential significance of the Japanese data to worldwide tephroarchaeology. SODA Tsutomu reports on the history of tephroarchaeology in Japan where the term originates (Chapter 2); KUWAHATA Mitsuhiro comments on the measurement of volcanic disasters by tephra depth (Chapter 3) and also writes on eruption effects on medieval agriculture in southern Kyushu (Chapter 12). The Towada eruption of 915 AD is covered from different angles by MURAKAMI Yoshinao and KOBAYASHI Masashi (Chapter 6) and MARUYAMA Kōji (Chapter 8), dealing with lahar-buried villages and population movements respectively. With Chapter 9, HORAGUCHI Masashi reviews Gunma Prefecture tephroarchaeology, setting the stage for detailed excavation reports on the tephra-preserved Kanai settlements by SUGIYAMA Hidehiro (Chapter 10) and agricultural reconstruction efforts in Chapter 11 by SAKAGUCHI Hajime. The agricultural theme is continued by Gina BARNES in Chapter 13 on tephrogenic soils and their potential, and Chapter 14 by NOTO Takeshi and Gina BARNES presents an overview of Japanese agriculture and cultivation recovery techniques in Gunma.

WAC8 Forum topics, however, were not exclusively limited to Japan: participants broadened this regional focus, with Gerry OETELAAR's Chapter 4 investigating landscape change on the Northern Great Plains of North America, and with Torill Christine LINDSTRØM's Chapter 15 dealing with psychological behaviour in the face of volcanic eruptions, drawn from several examples around the world. It is unfortunate that

[1] Soda's surname appears with a macron (Sōda) in this volume when indicating a publication in Japanese.

Ezra Zubrow's WAC8 Forum presentation on Kamchatka, and the southern Kyushu data presented by MAGOME Ryodo and MORISAKI Kazuki, could not be included here. Keith PRATT's paper on Mt Paektu eruptions (Chapter 7) was first given at the Association for Korean Studies in Europe (AKSE) conference in April 2017 for a panel on the sociology of Mt Paektu; it appears here by invitation. Chapter 5 by Ben FITZHUGH, Caroline FUNK and Jody BOURGEOIS is a welcome addition, growing out of interaction at the SAA Forum; dealing with the Kuril and Aleutian arcs, it justifies the chosen title for the volume. MACHIDA Hiroshi's contribution (Appendix E) is a translation by Gina BARNES of a chapter published in the *Atlas of Tephra in and around Japan* (Machida & Arai 1992, 2003, 2011; hereafter, the *Atlas of Tephra*), included here by invitation. Machida's co-author, ARAI Fusao, is now deceased, but he would have been glad to be included as he was involved with archaeology from early on (cf. Arai 1971). The Introduction and Appendices A–D by Gina BARNES are additions to round out the volume methodologically, providing crucial geographical and geological information for archaeologists new to the field; cross-references among all the appendices and other chapters have been added editorially with the authors' permission.

This volume is also designed to bring Japanese work on volcanic disaster studies to the English-speaking world. Until now, only two people have had a voice in this discussion: SHIMOYAMA Satoru, who very unfortunately passed away prematurely, and MACHIDA Hiroshi, who continues his valuable research after retirement. Shimoyama's work (1999, 2002a,b) has continued to influence volcanic disaster studies on an international scale as well as within Japan. In addition to sharing the research area of southern Kyushu with Shimoyama, KUWAHATA Mitsuhiro continues that methodological involvement in disaster archaeology. Machida is a tephrochronologist who has consistently published in English from 1980 (Machida 1980), contributing to one of the first collations on tephrochronology deriving from the NATO Advanced Study Institute symposium (Self & Sparks 1981; Machida 1981). By 1984, he had begun exploring tephrochronology for archaeological use within Japan (Machida 1984), including prehistoric data in relevant sections of the *Atlas of Tephra*. In the early 1990s, he collaborated with Robin Torrence in archaeological work in Papua New Guinea (Machida 1996), and he has continued his concern with archaeology in Japan (Machida 2000; Machida 2002; Machida & Sugiyama 2002). In 2011 he was honoured with a commemorative volume of *Quaternary International* (Lowe et al. 2011).

The impact that Shimoyama and Machida have had on the field is due primarily to their ability to work in English. This is not a trivial comment, as the major wall (*kabe*) between Japanese and worldwide archaeology is the language barrier. Most local Japanese archaeologists do not speak or read English, and in turn how many of us speak or read Japanese? The archaeological literature in Japan is voluminous. In its heyday (1970s and '80s), 40 shelf feet of archaeological reports were being produced by prefectural archaeological units every year (see Barnes 1990 for reasons why). Public archaeologists work to an annual schedule tied by construction contract deadlines; they have little time for extra research and little leeway to make their discoveries known to the wider world, or even read about world archaeology. Of course, there is a cohort of Japanese archaeologists that interacts internationally – two cohorts, in fact: one that studies non-Japanese archaeology of various foreign countries, and the other that writes about Japanese archaeology in English. The latter tend to be few and far between as well as theoretically oriented, while the archaeological papers on Japan in this volume come directly from the excavators themselves. They reveal the wealth of data, extraordinary methodologies and discoveries, and valuable comparative materials for the general field of TephroArchaeology.

For several Japanese archaeologists represented in this volume, this is their first publication in the English language. Kuwahata, Maruyama, Kobayashi, Sugiyama, Murakami, Horaguchi, and Sakaguchi all work or have worked in archaeological units and present knowledge gleaned from or inspired by their local excavations. The reader will notice that their chapters are entirely localized, with few citations of theory or even problem-orientation. This is bottom-up archaeology, defining the problems as they are met, and solving them along the way. Nevertheless, this inductive approach is very fruitful, and the detail of work presented here is astounding, with several unprecedented discoveries: Who would have thought to identify the direction of pyroclastic flow from rock impact traces? Or estimate eruption timings from footprint overlays? Or deduct seasonality of tephra fallout from the preserved stage of the agricultural cycle? All such findings require attention to minute detail and rigorous care in excavation.

Several of the Japanese chapters contain discussions of methodology. These are given without reference to developments in the field elsewhere precisely because of the language barrier. Many of their observations form independent confirmation of what researchers in other countries have also concluded from their archaeological volcanology studies. It is heartening to know that archaeologists around the world can come to the same conclusions, and it is good to have Japanese archaeologists speak in their own voices. Activities of tephroarchaeologists in Japan continue, with a large panel having been offered at the November 2017 regional meetings of the Japan Archaeological Association organized by Kuwahata. Researchers from around Japan contributed their findings and insights to his panel entitled "New Developments in TephroArchaeology". The papers are now available in the special issue of *Archaeology Quarterly* (*Kikan Kōkogaku* 146, February 2019), in Japanese with English table of contents on p. 117.

Except for Kuwahata, who submitted his two manuscripts in English, the translation and editing of the Japanese chapters have been carried out by myself. Many of the authors have sufficient reading ability to double-check these efforts, and for those with little confidence in their English skills, I hope this exercise has improved them. It takes enormous effort and good will on both sides to produce a final product, and I would like to thank all authors for their patience and cooperation, both in preparation for the Forum and during the editing process. I hope they are pleased with their debut on the international stage and will continue to think of publishing internationally. Many thanks are due the international authors who agreed to have their work published in this volume and who bore with me through a long editing process.

In closing, I would like to add a personal acknowledgement to the Department of Earth Sciences at Durham University, which has generously supported an affiliation that allows off-site access to scientific journals. Without such access, this research – for my own contributions and in editing others – would have been impossible. I am eternally grateful and hope that this book is useful to the field.

Gina L. Barnes (GLB) Durham, February 2019

Special thanks to David W. Hughes, who has worked his usual magic in proof-reading the volume.

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Stylistic Notes

- All Asian names occur surname first; when the whole name is given, the surname is in small capitals. Non-Asian names linked with Asian names (e.g. as co-authors) also have the surname in small caps.
- East Asian terms in chapters are given characters in the Glossary.
- Measurements are given in metric; mm = millimetre, cm = centimetre, m = metres, km = kilometres, dm = diameter
- Korean names are given in McCune-Reischauer transliteration, with South Korean government alternatives in parentheses.
- Macrons are eliminated from the names of the main Japanese islands (properly Kyūshū, Honshū, and Hokkaidō).
- BC/AD are used instead of BCE/CE; the former are more visually distinct, and the latter do not avoid the issue that year 0 (the birth of Christ) is used as the watershed – a meaningless year in East Asian history: nothing 'in common' about it.
- Figure sources are given at the end of each chapter rather than in captions.
- Figures are cross-referenced throughout the volume in the format 'Chapter number: Figure number'.
- Spelling is British or English according to author/translator preference.
- Multiple references to edited volumes in bibliographies are referred to the editor(s) entry.
- The bibliography style is unique to this volume.
- NASA = National Aeronautics and Space Administration.
- Author/editor entries in bibliographies are limited to three persons, plus et al.
- 4th-level sub-headings are not listed in the Table of Contents.

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Recurrent Abbreviations (exclusive of bibliographies)

- # = number
- aDNA = ancient DNA
- b. = born
- BCE or bc = uncalibrated ^{14}C dates given in the Smithsonian's Global Volcanism Program
- BP, bp = lit. before present:
  - bp *sensu stricto* = uncalibrated radiocarbon date; before present = 1950
  - BP *sensu stricto* = calibrated or true calendar date, calendar years before present
- ca. = circa, 'about'

- cal. = radiocarbon date calibrated by wiggle-matching to dendrochronological date
- CBS = Changbaishan volcano
- ^{14}C = radiocarbon, carbon isotope 14
- ch. = chapter
- CVL = Commission on Volcanic Lakes
- DPRK = Democratic People's Republic of Korea = North Korea
- DRE = Dense Rock Equivalent
- EDMA = Energy Dispersive (X-ray) Micro-analysis
- EPMA = Electron Probe Micro-Analysis
- est. = estimated
- GARF = Gunma Archaeological Research Foundation
- GSC = Geological Survey of Canada
- HPD = Highest Posterior Density (used in radiocarbon calibrations)
- IAVCEI = International Association of Volcanology and Chemistry of the Earth's Interior
- IWGCL = International Working Group on Crater Lakes
- JAA = Japanese Archaeological Association
- JMA = Japan Meteorological Agency
- ka (used in science publications), see kya
- Kor. = pronunciation in the Korean language
- kya = thousand years ago
- Kyōi = Kyōiku Iinkai = Board of Education
- LIP = Large Igneous Provinces
- Maibun = Research Institute for Buried Cultural Properties
- ME = Millennium Eruption (of Mt Paektu)
- ML = 'local magnitude', the original Richter scale for measuring earthquake strength; includes Mb (body-wave magnitude), Ms (surface-wave magnitude), and Mw (moment magnitude)
- msl (metres above sea level)
- Mt = mountain (-shan in Chinese, e.g. Changbaishan; -san in Japanese and Korean, e.g. Paektu-san)
- mya = million years ago
- Nabunken = Nara Research Institute for Cultural Properties
- n.d. = no publication date given
- NSF = National Science Foundation, USA
- PDC = pyroclastic density current = pyroclastic flows & surges
- pH = lit. 'potential of Hydrogen': a measure of relative acidity or alkalinity of a substance
- PI = Principal Investigator
- PRC = People's Republic of China
- r. = reigned
- SAA = Society for American Archaeology
- uncal. = uncalibrated radiocarbon date
- 'unpg.' in citations means 'unpaginated', becoming more common in online materials and difficult for quotation attribution
- USGS = United States Geological Survey
- VEI = Volcano Explosivity Index
- WAC = World Archaeology Congress

Tephra abbreviations (references to volcanoes in Index II)

- A-Ito (Ito pumice), see Aira
- As-A, As-B, As-C (Asama tephra), see Asama
- Aso-4 tephra, see Aso
- AT (Aira-Tanzawa volcanic ash), see Aira
- B-Tm (Baekdu–Tomakomai tephra), see Paektu
- FA = Hr-FA
- FP = Hr-FP
- Hk-TP (Hakone-Tokyo pumice), see Hakone
- Hr-FA (Futatsudake Ash), see Haruna
- Hr-FP (Futatsudake Pumise), see Haruna
- K-Ah (Akahoya tephra), see Kikai
- K-Ky (Kōya pyroclastic surge), see Kikai
- Km-11, Km-12, Km(gr), see Kaimondake
- KS1 eruption, see Ksudach
- Ku-a, Ku-b (Kumakura ash), see Kumakura
- On-Pm I (Ontake pumice I), see Ontake
- To-a (Towada-a ash), see Towada

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Introduction to TephroArchaeology

Gina L. BARNES *

An Archaeological Sub-discipline in Japan

'TephroArchaeology' [1] is a translation of the Japanese word *kazanbai kōkogaku* (lit. volcanic ash archaeology), referring to a sub-discipline of archaeology that has developed in Japan in the last few decades. The Japanese term was coined by archaeologist SHINTŌ Kōichi and developed by geologist ARAI Fusao. The historiography of the field's development within Japan is written by SODA Tsutomu (Chapter 2), who translated the term into English as 'tephroarchaeology'. That Japan should take the lead in formalizing such an archaeological sub-discipline is not surprising, given the geographical prominence of volcanoes in that country. Active volcanoes in Japan account for 10% of the world's total, up to 110 in number depending on the source reference and definition.

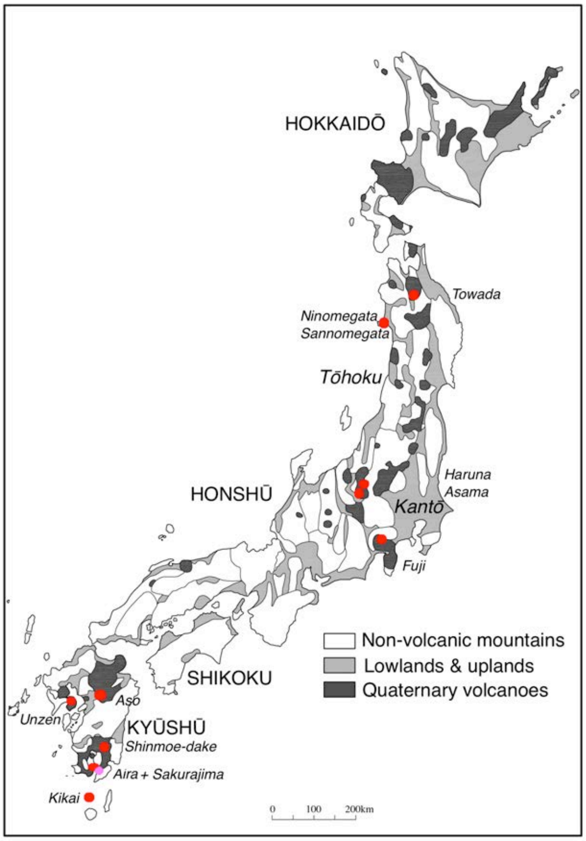

FIGURE 1 VOLCANIC FOOTPRINTS IN JAPAN
Volcanoes mentioned in this chapter are red/pink

In Japan, the definition of 'active volcano' has been modified through time. The first list of active volcanoes was made by the Committee for Predicting Volcanic Activity, formed in 1974 of university specialists and government workers in hazard prevention (Nakata 2005). At that time, 66 volcanoes were recorded as active within the last thousand years. The list was revised in 1999 (active within two thousand years), and in 2003 (active within ten thousand years) (Yamasato 2005). By 2006, 108 volcanoes were listed as active during the last 10,000 years (Aizawa 2006), and the current list (JMA 2013) has 111 entries. This list does not include volcanoes that erupted prior to the Holocene; earlier volcanoes are considered 'inactive' or even eroded, but their products still exist in the landscape and have formed important sources of stone for artefact and architectural use from prehistoric into modern times. Moreover, eruptions prior to the 10 kya cut-off point for Active Volcanoes, such as Aira at 30,000 years ago, have been very disruptive to prehistoric life and should not be ignored.

[1] It is idiosyncratically capitalized here to visually distinguish it from other sub-disciplines: 'tephrochronology' and 'tephrostratigraphy'.

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TephroArchaeology is only one of several sub-disciplines to have developed in Japan in the last 40 years. Three of them can be considered under what I call 'Tectonic Archaeology': those that deal with direct effects of being located in a tectonically active subduction zone region. These are TephroArchaeology, Earthquake Archaeology (*jishin kōkogaku*), and Tsunami Archaeology (*tsunami kōkogaku*).[2] The focus of TephroArchaeology on volcanic ash has been conditioned by the fact that although active volcanoes have a relatively small footprint in the Japanese landscape (Figure 1), every inch of the archipelago has been subject to tephra cover of varying quantities (Machida 1980: 29). However, some areas have been more affected than others due to the clustered distribution of the volcanoes. In particular, archaeologists in Kagoshima and Miyazaki Prefectures[3] in southern Kyushu (Shimoyama 2002a; Chapter 12 herein) and Gunma Prefectures (Shiraishi 1992; Tsude 1992; and Chapters 9, 10 and 11 herein) have found themselves excavating sites that have been heavily covered with tephra layers. These are the two areas in Japan in which the sub-discipline developed, and its nature is due to the condition of the archaeological record – not from a perspective of Quaternary volcanological processes or terminology. More recently, excavations involving tephra layers have increasingly been acknowledged in Aomori, Akita and Iwate Prefectures of the northern Tōhoku region (Chapters 6 and 8), extending the reach of TephroArchaeology throughout Honshu.[4]

Japanese contributions to disaster studies began around the turn of this century (Shimoyama 1997, 1999, 2002b; Machida & Sugiyama 2002). Recently, a movement in Japan has emerged to recombine the several sub-disciplines named above, that developed somewhat separately, into an archaeology of all sorts of natural disasters (Okamura et al. 2013; Okamura 2015). A Disaster Archaeology database is currently being established at the Nara National Research Institute for Cultural Properties (Nabunken) by reviewing published site reports and collating information (Okamura 2015: 251). This resumes the early efforts of Shimoyama (1997, 2002b) and the presentation of the archaeology of natural disasters at previous World Archaeology Congresses (WAC4, WAC5) (Shimoyama 1999; Torrence & Grattan 2002; Grattan & Torrence 2007). However, the emphasis of this research in examining past disaster damage and resiliency differs from that proposed by Gould (2007), which deals with current disasters and the recovery of information, aligned with forensic anthropology.

Grattan and Torrence (2007: 11) spoke of a 'new discipline' prefacing their collected volume on the cultural impacts of volcanic eruptions; however, they did not give it a name, referring instead to the "science of environmental catastrophes" noted by Leroy (2006). In contrast, this volume takes the formulation of the Japanese sub-discipline of TephroArchaeology as its starting point and investigates the various aspects of volcanic disasters primarily in the North Pacific, most of which range far beyond consideration of volcanic ash *per se*. For a view from the Southwest Pacific, see Cronin et al. (2008); for other areas of the world, see Harris (1999); and for a geological introduction similar to this, see Elson & Ort (2018).

A Briefing on Volcanic Matters

Although it is always tedious to have to explain specialist jargon or terminology, the chapters herein may be using frameworks and concepts derived from volcanology that are unfamiliar to archaeologists. This section aims to provide as much of a background as necessary to put the chapters in context and note where within them the terms and concepts are being used. This introduction is augmented by: Appendix

[2] See review articles by Barnes (2010, 2015, 2017). The effects of both volcanic eruptions and tsunami, however, are acknowledged to be further widespread than the subduction zone itself. For a quick review of the geological development of Japan and introduction to terminology, see Barnes (2003, 2008).

[3] See Appendix A-1 for prefecture, district, and island locations and boundaries.

[4] The literature in Japanese on excavations in these prefectures is too vast to list! See individual chapters for site-specific references.

B, providing a basic geological background in elements, minerals, and magma as relevant to volcanology; Appendix C, contextualizing Pacific Rim volcanoes within the North Pacific subduction zones; and an Index which lists terms related to volcanoes and tephras (as well as archaeological sites). Volcanoes worldwide mentioned in this volume appear in Figure 2. More can be discovered in the Global Volcanism Program (2013) of the Smithsonian Institution, the Volcano Hazards Program (USGS n.d.), and in Volcano World (OSU 2017) etc., while Japanese volcanoes are described online at the JMA (2013 in English, 2017 in Japanese).

Volcanic Ash or Tephra?

FIGURE 2 WORLDWIDE LOCATIONS OF VOLCANIC ACTIVITY MENTIONED IN THIS VOLUME
For Japan and Cascadia, see Appendix C; for the North Pacific, see Chapter 5: Figure 1

'Volcanic ash' was historically and mistakenly equated with wood ash, and even its formal term as a 'pyroclast' ('fire fragment') perhaps encourages this line of thinking. However, in a geological context, 'ash' is simply a measure of particle size: pyroclasts less than 2mm. These are extruded from a volcano during an explosive eruption which pulverizes the magma and rock surrounding the volcanic vent. Volcanic ash has variable composition: it may contain rock particles, fragments of glass bubbles, and individual mineral crystals that had already formed within the magma. It can be divided into coarse ash (2 mm–0.06 mm) and fine ash (<0.06 mm) – the latter may also be called 'dust' (Lowe & Hunt 2001).

Ironically, the term 'tephra' originally meant 'ash' in Greek, but it has been adopted in geology to encompass particles of all sizes, including ash, referring specifically to those materials aerially extruded during a volcanic eruption. This definition differentiates tephra from lava, which generally seeps out of a volcano as a viscous substance on the ground except as ejected in fire fountains and as lava bombs. Tephra is divided into size classes: ash (<2 mm), lapilli (2–64 mm), then bombs and blocks (>64 mm). Lava bombs are ejected as fluid and solidify during flight (forming pointed ovoid shapes like an American or rugby football), while rock blocks are ejected as solids (Tucker 1991: table 10.1).

These latter projectiles can be very large in size and are potentially quite dangerous. In order to be inclusive of all sizes of volcanic ejecta, the term 'tephra' is now preferred to that of 'volcanic ash' – a term which should be confined to describing ash-sized particles.

Tephra Deposition

Tephra is usually deposited on the ground in one of three ways, in addition to the actual ejection of large projectiles: through fallout from an eruption column and ash cloud; by heavy, dense clouds of ash and rock fragments rolling down the flanks of a volcano as 'pyroclastic flows'; or as lighter 'pyroclastic surges' composed mainly of ash. Pyroclastic flows and surges cross the landscape in different ways, affecting how they will be discovered in the archaeological record. Pyroclastic flows tend to follow established stream valleys leading down the mountain's flanks, and they can cut deeper valleys as described for Mt Paektu [Baekdu][5] in Chapter 7. Their remains thus concentrate in hollows. Surges, on the other hand, can flow over hills but still settle thicker in depressions than on rises (Figure 3). These contrast with the more even blanketing by aerial fallout of tephra. Thus, the discovery of thinner or thicker tephra layers in a confined area of archaeological excavation may not represent the wider depositional situation – even before erosion, weathering, etc.

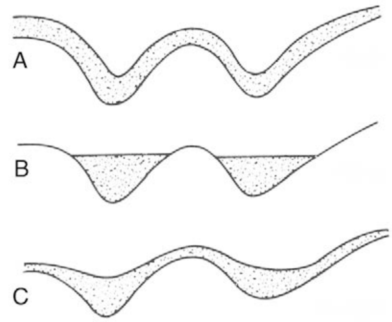

FIGURE 3 TEPHRA LAYERING BY DEPOSIT TYPE
A Ash fallout blanketing
B Pyroclastic flow in hollows
C Pyroclastic surge draping the topography

Along with pyroclastic flows, lahars can be highly dangerous; these are water-saturated tephra flows that may start as landslides and then flow down hollows in the landscape – including river valleys where the tephra may be put into suspension in the water and be carried great distances. Lahar movement may coincide with deposition if the tephra is extremely wet; or rain-saturated tephra deposits may move at any time – even years – after their deposition. Barring the first possibility of wet tephra flowing upon deposition to form a primary deposit, by definition lahars are secondary deposits of tephra. They can consist of fine-grained mudflows of volcanic ash (the original meaning of *lahar* in Indonesian), or a lahar can be full of rocks and large-size tephra (then referred to as blocky debris flows). Lahars and debris flows travel much slower than pyroclastic flows but can extend many kilometres. Lahar damage associated with the 6th-century eruptions of Mt Haruna are discussed for Gunma Prefecture in Chapters 9, 10, and 11, while Chapter 6 deals with lahar deposits having intruded into and buried standing houses in 10th-century Tōhoku.

The eruption sequence of a volcano can change during a single eruption or between eruption events (Soda 1993, 2006). For example as presented in Chapter 10, a 6th-century volcanic event begins with a volcanic ash fallout, then a pyroclastic surge, and finally a pyroclastic flow during the same eruption. Although several 'styles' of eruption are used to classify volcanic activity, as presented below, the idiosyncratic nature of individual eruptions is also becoming more recognized and studied (Cashman & Biggs 2014). In reconciling the general or common aspects of volcanic eruptions with the unique histories of individual volcanoes, the archaeologist is in a position to increase this geological knowledge through detailed excavation.

Tephra deposition is ideally depicted as lobate areas of decreasing tephra thicknesses, with the direction of ash deposition determined by the prevailing winds (Figure 4); these distributional trajectories can vary with wind patterns from season to season, so the tephra from different eruptions of the same volcano will not always fall in the same direction. Moreover, animations of tephra-fall distribution from the 2010 eruption of Eyjafjallajökull in Iceland rather put paid to the idealistic view of the interactions between

[5] This volume uses the McCune-Reischauer transcription system for Korean; the South Korean government spelling is given in square brackets on first mention.

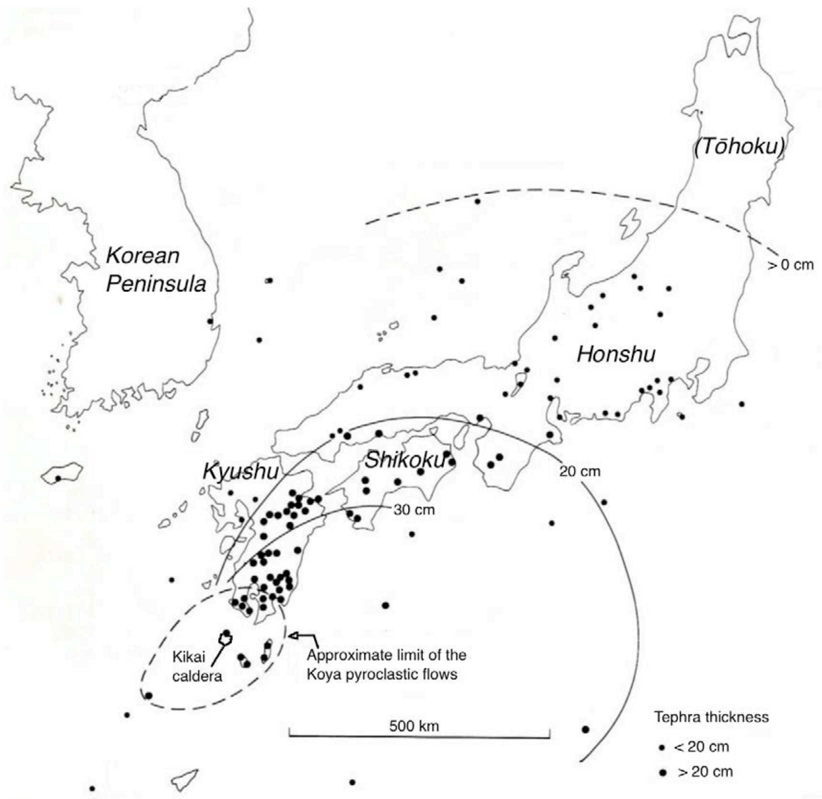

FIGURE 4 ISOPACH DISTRIBUTION OF AKAHOYA (K-AH) TEPHRA erupted from Kikai off southern Kyushu ca. 7300 bp

tephra and wind (Crowe 2010; djxatlanta 2010; NASA 2010); this dissonance has yet to be incorporated into ongoing archaeological fieldwork.

From modern assessments, a tephra fall between 10 and 15 cm deep and lasting for 5 to 7 days will kill pasture plants, crops and soil microbes – leaving the area sterile for up to a year; if more than 15 cm of tephra falls, all vegetation is killed, and "soil formation must begin again from this 'time zero'" (USGS n.d, unpg.). These statistics suggest that the 500 km^3 Dense Rock Equivalent (DRE) of tephra deposition from the Kikai eruption (Tatsumi et al. 2018) exterminated living things in most of the south-western Japanese Islands, including all of Shikoku and most of Kyushu. This is confirmed by investigations that found a hiatus of ca. 900 years before reoccupation of the land from the north and west (Machida & Sugiyama 2002). According to breaking news, there is a 1% chance of a large eruption from a massive lava dome in Kikai caldera within the next 100 years, following activity there in 1934–1935 (Tatsumi et al. 2018). Such lava domes form at the end of an eruption and often collapse later, becoming deadly pyroclastic flows.

Pumice & Scoria

Cross-cutting the size classes presented above, tephra can take different forms depending on the chemical composition of the parent magma. Two important types are pumice and scoria; both are vesicular glasses, formed of magma froth and riddled with holes which were once gas bubbles. Pumice is a product of high-silica magma, whereas scoria forms from low-silica magma (see Appendix B-3). A common name for scoria is 'cinders' – another mistaken analogy with burned material – and scoria extrusions are often said to form 'cinder cones'. Cinders are most commonly of lapilli size, though large bombs do exist.

Pumice is more common than scoria in the Northern Pacific because subduction zone magmas have intermediate to high levels of silica. We are mostly aware of small pumice rocks which we use as bathing utensils. However, like scoria, it can occur in all size-ranges and can be deposited as a pyroclastic flow or fallout (Yagi et al. 2006: table 1),[6] accumulating to be several hundred metres thick. Pumice tends to exist for long periods as unconsolidated material and is subject to erosion during that time. Southern Kyushu

[6] The term 'airfall' is deemed passé by Lowe & Hunt (2001); 'fallout' or tephra-fall' are preferred.

Island still sports deep deposits of pumice called *shirasu* (Figure 5). It was emplaced by the Ito pyroclastic flow during the eruption of the Aira Caldera 29–30 thousand years ago.

With sand of an average grain size (0.062–1 mm), the *shirasu* is unconsolidated and therefore easily dug but too deep to excavate from the top; it has presumably buried numerous Palaeolithic sites, some of which have been excavated during road cuts.

Tephrochronology & Tephra Characterization

Lowe distinguishes between broad and strict definitions of tephrochronology. The former encompasses "all aspects of tephra studies and their application" (2017: 4, fig. 2). The latter is more of concern here: a tephra layer comprising an event-based distribution of sediment across the Earth's surface whose primary deposition provides a natural "stratigraphically fixed tie-point" that allows correlation between locations on a shared time-plane (Lowe 2017: 1). Correlation of distributions relies on accurate tephra characterizations or fingerprints, obtainable through both field observation and laboratory procedures. Once identified, these key tephra layers form a contemporaneous marker bed over broad swaths of landscape, continuous or even discontinuous.

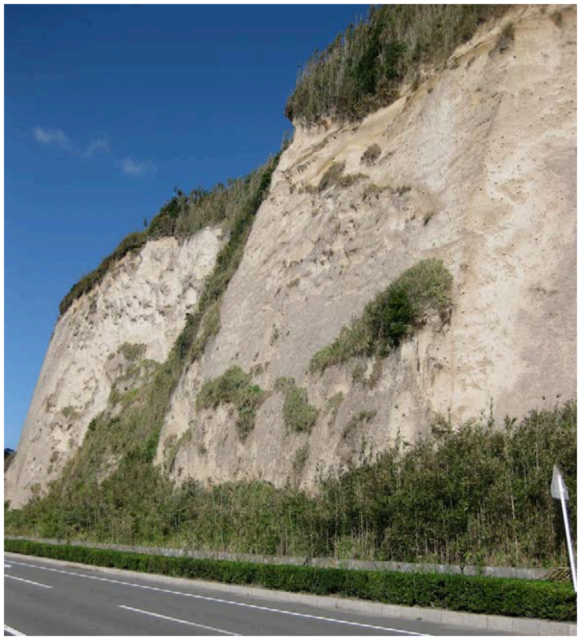

Figure 5 Shirasu Pumice in Road Cut, Southern Kyushu

In Appendix E, Machida and Arai outline the steps leading to tephra identification (separating it from non-tephra sediments) and characterization (distinguishing features of each tephra) – first in the field and then in the lab. Proper field observations are extremely important, as they often provide defining characteristics for a tephra which cannot be known through lab analyses. This means that tephra samples should be taken not by archaeologists but by tephrochronologists, who can make a proper examination of in situ deposition. This is particularly important in distinguishing different strata of tephra from a 'single' eruption that may undergo several stages, as characterized for the Haruna Hr-FA tephra (Sōda 2006).

Laboratory procedures include optical and scanning electron microscopy, electron probe and geochemical analyses (Lowe 2017: table 3); Machida and Arai also describe the uses of refractive index for tephra characterization (Appendix E-6), a method developed in the early 1970s (Arai 1972). Geochemical analyses with electron microprobe can reveal the chemical composition of individual mineral crystals and glass shards. The identification of a previously unknown tephra from Mt Samalas in Indonesia, by correlating the composition of single flakes of volcanic glass from an Iceland core with the composition of pumice deposits near the Samalas volcano that erupted in 1257, have been been taken as fact despite the tentative conclusions of the researchers (Lavigne et al. 2013; Lavigne & Guillet 2015). But as Lane et al. (2011: 87) caution, the chemical compositions of tephra which erupted at different times from the same volcanic system may have similar compositions; therefore "it seems that composition alone is insufficient for the correlation of some widespread tephra layers: good stratigraphic information and/or robust dating control are also essential."

Despite the 'chronology' in tephrochronology, the absolute age of the tephra may be unknown and be dated only through association with cultural materials or relationship with other dated tephra in stratigraphic sequences. Even in these cases, one tephra type still may provide an "age-equivalent dating method" (Lowe 2017: 1) because it represents a slice of time that is correlated over a widespread area via the distribution of the tephra.

Lithified & Weathered Tephra

Tephra when solidified becomes a sedimentary rock – even though it is of igneous origin. Volcanic ash forms tuff, a soft carvable rock (Figure 6) much quarried for use in architecture. If the volcanic ash is extremely hot when laid down, as in a pyroclastic surge, it may lithify as welded tuff, with the clasts welded together. Pyroclastic flow sediments, particularly those containing much pumice and/or blocky material, lithify as 'ignimbrites' or as welded tuff. Ash that accompanies the pyroclastic flow is co-ignimbrite ash.

FIGURE 6 PEACE BODHISATTVA SCULPTURE OF OYA TUFF
disused tuff quarry, Utsunomiya City, Tochigi Prefecture

The weathering of tephra, whether lithified or unconsolidated, produces various types of clays dependent on climate, precipitation, flora, and its chemical composition (see Chapter 13). Exposure to water will leach out the alkali and alkaline elements (calcium–Ca, sodium–Na, magnesium–Mg, and potassium–K), leaving concentrations of aluminium–Al, silicon–Si, and iron–Fe (Velde & Meunier 2008: 132, 249). These, together with oxygen-O and hydrogen–H, are the building blocks of 2:1 structure clays (Figure 7) which support agriculture around the world.

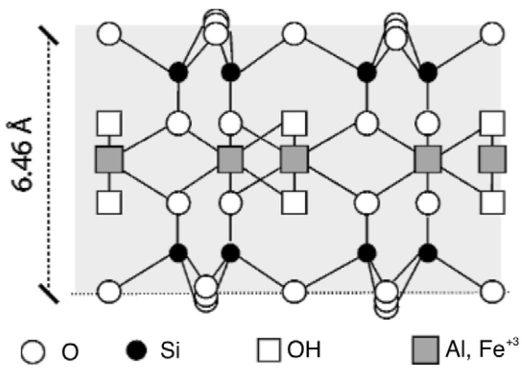

FIGURE 7 ATOMIC POSITIONS IN A 2:1 CRYSTAL STRUCTURE OF CLAY

Weathering of tephra by water alone can take close to a million years, as documented for New Zealand (Lowe 1986). Once plants 'install themselves' on a rock surface, however, plant/rock interaction can form clays within years or decades. The type of plant grown influences the type of clay formed. Soils that are derived from volcanic ash are called 'andosols', with *ando* being a Japanese word meaning 'dark earth'; nevertheless, andosols (or andisols) in Japan are actually called *kurobokudo* 'black fluffy earth' (see Chapter 13). The clay species typical of andosols include gibbsite, kaolinite/halloysite, and smectite as well as the alteration products allophane and imogolite (Shoji et al. 1993). The island of Honshu (at least) in Japan has been called an island of smectite (Taylor & Eggleton 2001: fig. 2.48). 'Imogolite' is also a Japanese word derived from *imo*+*ko* meaning 'potato child' (*imogo*) – obviously an agricultural reference. Chapter 14 deals further with these agricultural implications, hoping to shed light on the argument whether volcanic ash soils are good for agriculture or not.

Other forms of tephra are also important in Japan. Weathered pumice is often called *miso-tsuchi* – earth with the grainy consistency (and colour!) of miso, the fermented soybean cooking ingredient. Perhaps the most notorious unconsolidated tephras are those incorporated into the Kantō Loam – deep deposits of weathered Middle–Late Pleistocene loess and redeposited volcanic ash from Mt Fuji and Mt Hakone that contain many Palaeolithic sites within them. In Chapter 2, Soda cautions that the volcanic ash in the Kantō Loam layers is of secondary deposition, not primarily laid in an eruption.

Describing Volcanoes and Their Eruptions

Several distinctions have been made above that follow from magma chemistry, volcanic structures, and the many modes of eruption. These multi-dimensional aspects interact in different ways to produce volcanic products of unique specificity. Space allows only brief characterizations of these below. For details, see the Smithsonian's webpage 'Types and Processes Galleries' in the Global Volcanism Program (2013) and Sigurdsson et al. (2015).

Magma Types

Magmas are primarily categorized by their silica contents along a continuum from rich to poor (Appendix B: Figures B-1, B-3, Table B-2). In the past, silica-rich magmas have been described as 'acid' because it was originally thought that silicic acid was a major component. This has been disproved, and now the term 'felsic' is preferred, derived from the magma's feldspar and silica contents. Silica-poor magmas are classified as 'mafic', derived from their manganese and iron contents; magmas virtually lacking in silica are 'ultra-mafic'. And in between rich and poor are the intermediate magmas. Chemically, these three compositions are described from rich to intermediate to poor as having the composition of rhyolite (rhyolitic), andesite (andesitic), and basalt (basaltic). Thus, rhyolitic products are rich in silica, basalt is poor in silica, and andesite is intermediate between the two. The greater the silica content of a magma, the more viscous it is, preventing it from flowing freely.

These magma types influence both the energy of the eruption and the shape of the volcanic pile. Most silica-poor (basaltic) lava is emitted slowly in 'effusive eruptions'; their low viscosity allows gas to escape gradually. Silica-rich (rhyolitic) magmas tend to be more explosive in nature because their viscous nature does not allow continuous de-gassing: the gas builds up pressure in the magma and causes 'explosive eruptions'. These different magma types lead to different shapes of volcanic edifices produced.

Volcano Shapes

Most basaltic volcanoes emit lava slowly, in effusive eruptions, spreading over large areas. Flood basalts that flow from *fissure vents* can cover hundreds of square kilometres and accumulate to several kilometres deep, forming Large Igneous Provinces (LIP). The Siberian Traps (Figure 2) are one such example of an LIP. Hot spots and magma plumes, which arise from deep in the Earth's mantle usually within a tectonic plate, characteristically form basaltic *shield volcanoes* which are broad and low, such as the Hawaiian Island volcanoes. Mt Paektu (Chapter 7) apparently began as a shield volcano before building into a cone with a change in magma composition. Fissure vents on these volcanoes can also be responsible for outpourings of lava. Basaltic volcanoes, however, are not immune to the pressures of gas or the addition of water, both of which increase explosivity. *Cinder cones* and *spatter cones* can form from explosively emitted basalt, resulting in piles of small particles in the first instance or droplets of solidifying magma in the second.

As magma becomes silica-rich, more tephra than lava is extruded through more explosive eruptions, forming *stratovolcanoes*. Cone-shaped volcanoes are young stratovolcanoes, so named for the multiple eruptions that build up layers of tephra, leading them also to be called *composite volcanoes*. These are the idealized Fujiyamas of the world. Some composite volcanoes have multiple vents and build a small mountain range with different peaks formed from different eruptions, making them *compound volcanoes*. Mt. Haruna in Japan is such a compound volcano, with the Futatsudake vent having exuded tephra that caused great damage in 6th-century Japan, as discussed in Chapters 9, 10, and 11. Stratovolcano products are usually andesitic to dacitic (intermediate to medium-rich in silica) in composition and often host a crater lake less than 1 km in diameter after eruption.

Two other types of craters can occur on flat land: *maars* and *tuff rings*. Both result from the interaction of water with a magma source and cause explosive distribution of pyroclastic material. Maars were initially identified in southern Germany, but Lake Nyos in Cameroon is one of those existing worldwide. Laacher See (Riede 2017)[7] is often called a maar, but its crater resulted from a Plinian eruption rather than the more maar-like eruption caused by a mixture of water and magma. There are three maars in northwestern Japan that are named as 'lagoons'; two are mentioned in Chapter 8 as Ninomegata and Sannomegata (Figure 1 above).

Silica-rich magma may form a *lava dome* during the last stage of eruption within the volcanic crater itself, as with the current dacite cone at Mt Haruna; or a dome may build up through time and at vents other than the main crater. They can be very unstable, and dome collapse can cause great pyroclastic flows (Figure 8).

Mega-eruptions can occur on stratovolcanoes or shield volcanoes; the summit and flanks of the volcano are subject to collapse inwards to form *calderas*, after emptying tremendous amounts of material from the magma chamber. Some calderas form in clusters, doming the landscape before erupting and collapsing; these are the largest and often most difficult to recognize as belonging to a volcano. The classic case is Yellowstone Park in the north-central United States, the park itself consisting of three overlapping calderas.

FIGURE 8 THE CO-IGNIMBRITE ASH CLOUD OF A PYROCLASTIC FLOW
Caused by lava dome collapse at Mt Unzen, Kyushu
as caught on film on 8 June 1991 by co-editor SODA Tsutomu, who hails from Nagasaki Prefecture

The most recent Yellowstone caldera formed 640,000 years ago, measuring 48 x 72 km – smaller than the previous erupted caldera (NPS 2017). New caldera fields have been elucidated across the

[7] Also known as Lachaer See.

Nevada–Utah state borders; the largest known eruption 30 million years ago, ejecting about 5500 km^3 of pyroclastic material which solidified to form the Wah Wah tuff, came from an unnamed oval caldera about 40 x 87 km in area (Best et al. 2013; King n.d.).

There are 14 caldera volcanoes in Japan (JMA 2013), one of which is Mt Aso in central Kyushu, which erupted 70–90,000 years ago; the caldera is 25 km in diameter, and the pyroclastic flows from its eruptions cover most of Kyushu Island. Towada Lake in northern Japan sits in a 10 km diameter caldera that formed through many eruption events, one forming a smaller caldera 2 km across within the caldera lake. Towada is a grand tourist attraction – as so many caldera lakes are. Towada last erupted in 915 AD through a small volcano, Ogurayama, sited on the smaller crater rim. Chapter 8 assesses the effects on the populations of northern Tōhoku of the Towada eruption together with the 10th-century Mt Paektu eruption. Crater Lake in Oregon is a caldera about 9.5 km across; the eruption that formed it around 6800 years ago spread Mazama Ash over much of northwestern North America. Its effects on the landscape are investigated in Chapter 4.

Eruption Styles

As mentioned above, volcanic eruptions are classified along a continuum of effusive to explosive styles. Effusive eruptions consist mainly of lava flows and tend to be basaltic, while the explosive eruptions involve the fragmentation of magma and country rock (the rock through which the magma intrudes) to form pyroclasts, produced by andesitic to rhyolitic magmas. However, any volcanic vent or fissure, regardless of edifice type or magma chemistry, can produce either and/or both styles at different stages of eruption or in different eruptions. This makes tracing the eruption history of a volcano (and its several vents) very complicated and involves multiple lava/tephra identifications and dating. Tephrostratigraphy and tephrochronology are the two sub-disciplines charged with these analyses.

There are six or seven 'styles' of eruptions, often named after the volcanoes where the conditions were first described – Hawaiian, Strombolian, Plinian, Vulcanian, Pelean, etc.; but the number of styles and their descriptions often overlap, partly due to historical progress in characterizing them. Generally, the styles move from effusive Hawaiian-style basaltic eruptions to super-explosive rhyolitic eruptions of Ultra-Plinian style (King n.d.). Included in the last are supervolcano eruptions such as Yellowstone and the Wah Wah Springs volcano (Best et al. 2013). The styles are based on the volume of erupted tephra and the eruption column height (USGS 2016). The severity is measured on the Volcanic Explosivity Index; from VEI 2 upwards, the scale is logarithmic. Thus, the Wah Wah Springs pyroclastic emissions (VEI 8) in the southwestern USA, at 5500 km^3 DRE, were 5000 times greater than the Crater Lake eruption (VEI 7) at 150 km^3 DRE in the northwest (King n.d.). From VEI 6 upwards, volcanic eruption columns can send gases and particles into the stratosphere (>15–50 km), making them a global hazard. The explosive styles and their products are (Figure 9): *Strombolian*: cinder cones; *Phreatomagmatic*: base surges and maars; *Sub-Plinian* & *Vulcanian*: composite volcanoes, lava, tephra, small pyroclastic surges; *Plinian*: tephra, pyroclastic surges, small to medium caldera formation; *Ultra-Plinian*: enormous pyroclastic surges, tephra (mainly small glass shards), with large caldera and pyroclastic terrace formation.

Explosivity is increased by both gas pressure and the presence of water, be it groundwater, lakes, or ice and snow cover, etc. Magma reacts to water as hot oil does, so any water that meets magma can cause a reaction, instantly turning the water to steam and driving the explosion of the magma (often called 'phreatomagmatic' or hydromagmatic explosions). Volcanoes with crater lakes or that are covered with snow and ice, therefore, comprise a greater hazard than those that are not. Eruptions may also be termed 'phreatic' when water is turned to steam and expelled with country rock but not involving molten magma.

We tend to think of volcanic eruptions as single events in time, but in fact they are often comprised of a series of events, as illustrated by Mt Unzen in Nagasaki Prefecture, Japan (JMA n.d.). Historical eruptions are documented for 1663, 1792, and 1798; but beginning in 1922 through 1989, earthquakes occurred repeatedly every few years and almost annually from 1966. These presaged a large phreatic eruption in 1990 which was surrounded by earthquake tremors before and after. Then in 1991, small eruptions of lava and earthquakes continued until pyroclastic flows, caused by the collapse of the growing lava dome, began on May 24th. The pyroclastic flow on June 3rd comprised one of the most devastating volcanic events of recent times, killing 43 people including several volcanologists and damaging 179 buildings. Another pyroclastic flow on June 8th (Figure 8) damaged 207 buildings, and on September 15th a third pyroclastic flow damaged 218 buildings. Lava dome growth and collapse, causing more pyroclastic flows, continued through 1996, but from 1997 onwards there was a switch back to earthquake tremors that decreased in frequency over time.

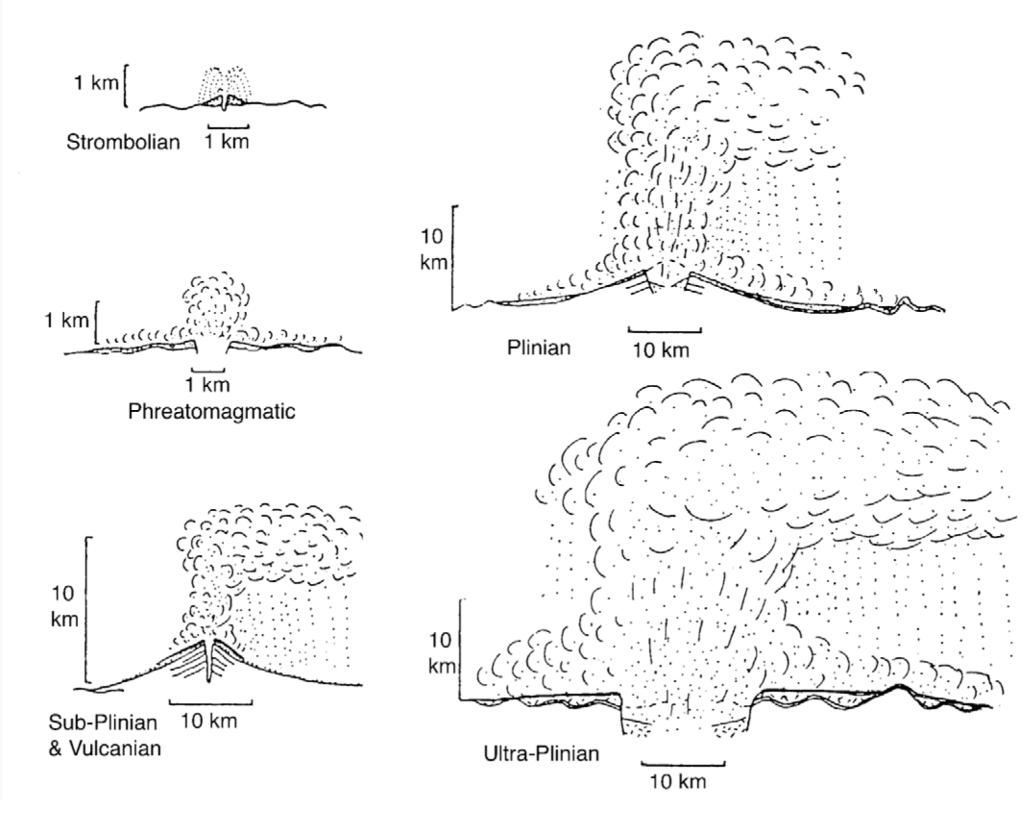

FIGURE 9 THE VARIOUS STYLES OF ERUPTION AND THEIR VOLCANIC STRUCTURES

Each of these volcanic events potentially leaves stratigraphic evidence that records stresses on local populations of plants, animals, and humans. It is the job of archaeology to retrieve information on how each of these populations were affected by or reacted to such volcanic hazards, be they single events or multiple events through time. The main variables in terms of human behaviour and choices made when confronted with volcanic eruptions are discussed in Chapter 15.

Gas Emissions

In the Forum discussions noted in the Preface, one concern was whether 'tephroarchaeology' was a justifiable name for this new field of endeavour because volcanic gases are not tephra but nevertheless should be considered for their role in causing disasters due to volcanic eruptions. Included here, therefore, is basic information about volcanic gases so that more consideration might be given to this issue in future tephroarchaeological research. The same is true of the next section on volcanic epi-phenomena.

The major forms of gas extruded, both from explosive pyroclastic and slower lava eruptions, are carbon dioxide (CO_2), sulphur dioxide (SO_2), and the halogens fluorine (F) and chlorine (Cl), in addition to water vapour (H_2O). As we all now know, carbon dioxide is a major greenhouse gas that contributes to climate warming. In contrast, sulphur dioxide can be converted in the atmosphere into acid rain and sulphate aerosols through several complicated chemical routes (Khoder 2002). The aerosols serve to reflect sunlight and cool the atmosphere, somewhat counteracting the action of greenhouse gases. In great quantities, following a large volcanic eruption such as Tambora in 1815 (Wirakusumay & Rachmat 2017), the aerosols can change seasonal and yearly climate until they are dispersed (Robock 2000). Eruption columns which reach the stratosphere (>15 km) can put aerosols into circulation through the jet streams and affect the entire globe. Surface temperatures cool 1 or 2 °C, which together with bad weather and tephra fallout can damage crops and affect harvests for up to two years (e.g. Lavigne & Guillet 2015). Eventually these aerosols and acid rain lead to ocean acidification.

Gases from Flood Basalts

Flood basalts are a specific type of magma extrusion through crustal fissures rather than volcanic edifices. The eruptions can be fire fountains many metres high and/or continuous lava flows; pyroclasts can also be extruded from the fire fountains, and gases may be released both directly through magma degassing before and during the eruption and from the flowing lava. Flood basalt flows are generally thought to be a product of hot spot activity.

The Laki fissure eruption in Iceland in 1783–1784 is classified as a flood basalt and provides the classic case of disastrous effects from volcanic gas release (Thordarson & Self 1993, 2003; Thordarson et al. 1996). Approximately 235 megatons (Mt)[8] of water, 122 Mt of sulfur dioxide, 15 Mt of chlorine, and 7 Mt of fluorine were released, affecting local plant and animal life (Thordarson & Self 2003: 7-4, 7-6, 7-13). Large numbers of cattle died of fluor poisoning within 2 to 14 days of the Laki eruption, while overall more than 60% of grazing livestock died within a year from chronic fluorosis in the affected area (Ibid.: 7-3).

Such devastation by gas emissions is generally archaeologically undetectable; the Laki cattle bones did not remain in the archaeological record. In an attempt to assess fluorine poisoning on the human population, researchers recently exhumed human skeletal material from two church graveyards in use at that time and analyzed the fluorine content of teeth and bones, but they were unable to find any evidence of skeletal fluorosis (Gestsdóttir, Baxter & Gísladóttir 2006). Despite this finding, it is estimated that 20% of the Icelandic population died from the aftereffects of gas emissions: illness (scurvy, respiratory and heart problems, acid rain burns); crop and forage failure, malnutrition, and a 3-year famine; and environmental stress (Thordarson & Self 2003). Efforts to attribute increased mortality in England during the Laki eruption, however, have not been successful (BGS 2013). More than 80% of the Laki sulphur dioxide emissions were lofted 10 to 15 km into the lower stratosphere; the bulk of these were converted to sulphuric aerosols through combination with water, forming the sulphuric cloud ('haze') that spread over the northern hemisphere and caused unusual weather patterns and crop failures all the way to Japan (Thordarson & Self 2003).

Within the geographic remit of this volume lie the Columbia River flood basalts of the northwestern United States (Reidel & Tolan 1992: fig. 1B). The most accepted hypothesis for the creation of these basalts is a hot spot for mantle plume action – possibly the same mantle plume that is responsible for Yellowstone Park volcanics (Reeg n.d.). But because the Columbia River basalts erupted between 17 and

[8] Mt = megaton = 1 x 10^9 kg

15 million years ago (mya), they had no impact on human communities. Other flood basalt provinces in the western North Pacific – Emeishan in southwestern China (260 mya) and the Siberian Traps (250 mya) in Russia – are even older (cf. Jerram & Widdowson 2005). The Emeishan sequence is 4–5 km thick (Jerram et al. 2016) and was formed within one to two million years (Zheng et al. 2010; Shellnutt 2014).

Flood basalt eruptions have been characterized as much more dangerous than volcanic eruptions: flows can persist over years and decades intermittently through centuries and millennia, all the while emitting copious amounts of gas and lava. Saunders & Reichow (2009: unpg.) estimate that a single 'flow field' of 1500 km^3 would bury the whole of the UK beneath about 6 metres of lava, or Greater London beneath about 1 km. Assuming a total volume of 3 million km^3 for the Siberian Traps, this could bury the whole of western Europe beneath more than 1 km of basalt, or the whole of the UK beneath about 12 km.

The climatic effects of very large flood basalt emissions are potentially disastrous, as they have been linked to three or four of the mass extinctions when concurrent with meteoric impacts (White & Saunders 2005; Rampino 2016). Human society has not yet been exposed to this extreme situation, though we are carrying out our own form of environmental extinctions. But the climate effects from Laki were severe enough to generate concern about the possible effects on previous communities in the archaeological record.

Gas Emissions From Volcanoes

There has been a tendency to dismiss gas emissions from volcanoes (rather than fissures) as unimportant. For example, Mt Asama in Japan erupted the same year as Laki, in 1783, but the amount of sulfur dioxide was described as "inconsequential", at 0.2% of the SO_2 mass-produced by the Laki eruption (Thordarson & Self 2003: 7-2). However, Etna, Stromboli and Vesuvius (discussed in Chapter 15) also erupted in 1783, contributing to the dry acid fogs that damaged crops in the Mediterranean Basin. Calculations of gas emitted from large volcanic eruptions show that several, including Mt Paektu discussed in Chapter 7, come within an order of magnitude of Laki's emissions (Figure 10), and halogen emissions from two of the volcanoes exceeded Laki.

A rather different kind of gas hazard is the eruption of gases – carbon dioxide (CO_2) or methane (CH_4) – through lakes; these are called lake overturns or 'limnic eruptions'. Some of these gas accumulations result from biogenic decay mechanisms, while others are volcanically fed as at Lake Kivu between the Congo and Rwanda (Nayar 2009) and Lakes Nyos and Monoun in Cameroon (Kusakabe 2017). In either case, the gases are kept dissolved in the lower stratified water column until they exsolve and erupt catastrophically. The mechanisms are hotly debated, but in the cases of Nyos and Monoun Lakes, it is clear from its geochemistry that the carbon dioxide derives from the mantle through a basalt dike (Kusakabe 2017: fig. 29).

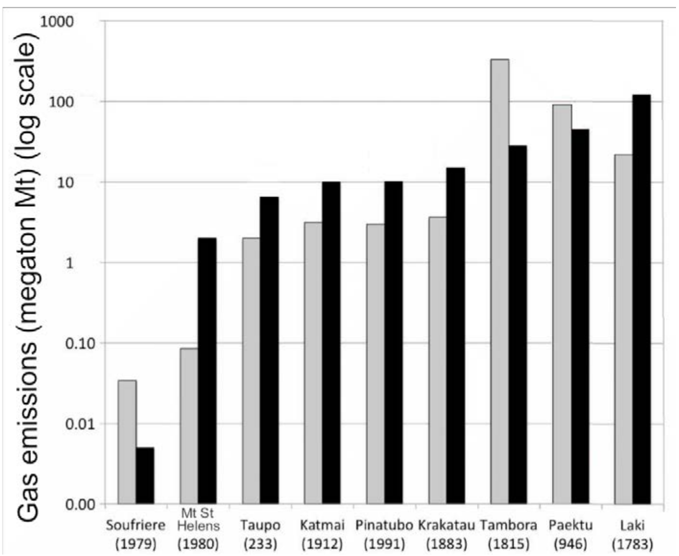

FIGURE 10 COMPARATIVE GAS EMISSIONS FROM LARGE VOLCANIC ERUPTIONS

Grey = Halogens: F (Fluorine) + Cl (Chlorine)
Black = S (Sulphur)

The eruptions of such gas concentrations are lethal; because CO_2 is heavier than air, the gas cloud follows the valleys – as pyroclastic flows do – suffocating all life before the cloud disperses. The 1986 Lake Nyos eruption instantaneously killed more than 8000 cattle and 1746 humans (Kusakabe 2017: 2, 6). At Lake Kivu, "gaps in layers of plankton fossils at the bottom of the lake suggest that such paroxysms have struck several times in the past 5,000 years" (Nayar 2009: 322). Kusakabe compiled oral traditions of previous possible lake eruptions that specifically documented people moving across the landscape, giving motivation for migrations that might be seen in the archaeological record. Without such documentary records – oral or written – that detail these effects of volcanic gas release on local and distant populations, how are archaeologists to identify and assess their impact on prehistoric populations? Lacustrine coring is one approach; Barker and Bintliff (1999) further suggest the use of EDMA[9] to recover evidence from sediments of toxic gases which might have adhered to or been incorporated into tephra and deposited with it. Only since the limnic eruptions in the mid-1980s have scientists become aware of the hazard associated with volcanic lakes, either maars or crater lakes. After the Nyos maar eruption, an International Working Group on Crater Lakes (IWGCL) was convened, which was formalized in 1993 as the Commission on Volcanic Lakes (CVL, under the auspices of IAVCEI, the International Association of Volcanology and Chemistry of the Earth's Interior).[10]

Thunder & Lightning

The epi-phenomena of storm-like emissions of volcanoes have rarely been considered by archaeologists – even though such effects have been known since Pliny the Elder recorded their occurrence during the eruption of Mt Vesuvius in 79 AD. The sounds of the eruptions have been compared to thunder, as described in Chapter 4 on behalf of prehistoric Native American populations on the Great Plains. Within the last 200 years, volcanic lightning has been recorded over 200 times (Weirup 2010; McNutt & Williams 2010; Cimarelli et al. 2016). In 2016 scientists in two different studies documented two different ways lightning is generated within ash plumes: by ash particle friction in the lower ash plume as recorded for Sakurajima (Cimarelli et al. 2016), and by ice particle collision with charged ash particles in the upper troposphere (Van Eaton et al. 2016). The impact of the sight and sound of lightning generation during volcanic eruptions – what Elson and Ort (2018) describe as a 'full sensory experience' – must have added further terror and awe for those affected.

Archaeological Implications

The sub-discipline of TephroArchaeology

The point of the above review is to emphasize the fact that TephroArchaeology cannot be isolated from volcanic processes; these are very complicated and not understood in detail by most archaeologists. There is more to TephroArchaeology than just digging in tephra or discovering it in excavated strata. The term needs to be understood in its widest context of everything related to volcanic eruptions, and as Soda admits below, we may well be on our way to adopting 'Volcanic Archaeology' or 'Archaeological Volcanology' as umbrella terms (cf. Elson & Ort 2018; Riede 2015a,b). Whatever the name of the sub-discipline, there are two aspects that must be addressed: how archaeologists, through special methodologies, can retrieve information on 1) the sequences of volcanic events during (and after) an eruption, and on 2) a micro-timescale that reveals human reactions to each of those events.

[9] EDMA = Energy Dispersive (X-ray) Micro-analysis

[10] See the CVL website at https://iavcei-cvl.org/

The 'archaeology' part of the proffered umbrella terms is quintessentially cultural: this sub-discipline is primarily concerned with the effects of volcanic eruptions on *past* societies – in Riede's term, it is the study of 'palaeosocial volcanology' (Riede 2015b). It meets the field of 'historic social volcanology' (Scarlett, forthcoming) which leads into 'social volcanology' as dealing with volcanic hazards, mitigation, and studies of resilience in *today's* population (e.g. Donovan 2010; Donovan, Oppenheimer & Bravo 2012). The special issue "Volcanoes and Human History" (Cashman & Giordano 2008) brought together archaeology and oral history, while studies in the sociology of volcanoes are often published in the *Journal of Applied Volcanology*, begun in 2009, and *Quaternary International* (Riede ed. 2016). We look forward to seeing similar studies in the new open access journal, *Volcanica*. TephroArchaeology is one method by which palaeosocial volcanology can be conducted. It comprises the archaeological techniques of capturing the data needed for social analysis beyond standard cultural change. Moreover, archaeologically excavated data can feed back into volcanology to inform on the minutiae of eruptions that would not necessarily be discovered by geologists.

Nevertheless, volcanology is the bedrock for TephroArchaeological studies, and the crucial tool is for archaeologists to be able to recognize tephra in the field in all its forms – the various macro-deposits discussed above as well as the presence of cryptotephra, discoverable only microscopically. The second step is to have the tephra characterized and dated. The characterization of tephra involves many procedures, which are outlined in Appendix E. These form the basis for coordinating tephras across the landscape and through time.

SODA Tsutomu (Chapter 2 herein) provides a history of the development of this sub-discipline in Japan, going back to the 19th-century scholars who first took an interest in tephra deposits – including the traveller who sketched the picture of houses buried in an eroded lahar (see Chapter 6: Figure 2). He contextualizes the geological and archaeological work that led up to the definition of the field called *kazanbai kōkogaku* (volcanic ash archaeology). Once entering the current era, he gives a detailed overview of the tephra deposits that have affected one of the homelands of TephroArchaeology, Gunma Prefecture. The story would be incomplete without an explanation of the role tephra dating played in the Palaeolithic scandal of 2000 at Kami-Takamori site. Both Soda and Machida had expressed reservations about site stratigraphy, and Soda called for a re-evaluation of the site in 1991. His views, as well as reservations about the site by ODA Shizuo and Charles Keally, were rejected, indeed involving personal persecutions due to the traditional academic and Japanese social characteristics of bowing to authority and non-confrontational interaction. Perhaps this incident was needed to shake up the field to allow criticism and critique to have a place in academic exchange. Soda finishes with a discussion of new avenues of research being taken in TephroArchaeology in Gunma Prefecture.

KUWAHATA Mitsuhiro has written a response to the initial concept of TephroArchaeology by expanding its original remit in prehistory to investigate historic volcanic disasters and analysis of artefacts incorporating tephra. His presentation of Tokui's graph (Chapter 3: Figure 1) on the disturbance gradient of damage in volcanic disasters forms the background for several further discussions in this volume. The procedures he specifies for dealing with tephra in the field and in the laboratory are illustrated with tephra sections from some of the sites excavated in southern Kyushu, the second homeland of TephroArchaeology.

Tracking Human Behaviour

There is a huge range of *volcanic* behaviour that must be met by appropriate *human* behaviour in order to survive. The reality of sudden and/or multiple eruptions or shifting eruption styles that cannot be predicted increases risk; perhaps the wide range of possibilities is one aspect that causes complacency when decisions should be made about what to do in the face of an impending or ongoing eruption. Torill Christine LINDSTRØM, in Chapter 15, presents some of the psychological mechanisms inherent in facing volcanic eruption risk – a new perspective that can be added to other limiting factors she names that can also determine responses, such as geography, culture, and social and physical restraints.

The Kurile and Aleutian volcanic arcs (Appendix C-1), which form the northern border of the Pacific Rim, are younger and compositionally different from the Japan arc which forms the stage of most of the chapters herein. The northern arcs present geographic and climatic challenges that are absent further south, and so they provide good comparative material to monitor small-group colonization of difficult terrain under environmental constraints as well as volcanic hazards. Chapter 5, by Ben FITZHUGH, Caroline FUNK, and Jody BOURGEOIS, takes issue with the standard interpretation of abandonment in the face of volcanic disasters in the Kuril and Aleutian archipelagos. Despite geological and climatological similarities between the arcs, the authors find that geographical constraints are foremost, conditioning different behavioural patterns between the island chains. Most notably, the abandonments that are apparent in the archaeological record cannot be explained by volcanic activity.

The potential long duration of intermittent volcanic activity means that each eruption, from onset to cessation, will inspire different sets of behaviour through time and between individuals or groups according to their beliefs, perceptions, preparedness, and social contexts. MARUYAMA Koji deals with two successive 10th-century eruptions in Chapter 8: the 10th-century eruption of Mt Towada, now known as Lake Towada in the northern Tōhoku area of Honshu Island, Japan (Appendix C-4), and Mt Paektu (Baekdu or Changbaishan) on the border between China and North Korea (Appendix C-8). Maruyama has painstakingly extracted data on the presence of these two tephras in pit-dwellings in northern Tōhoku that have previously been recorded in published archaeological reports. Going beyond mere abandonment as a generalized response, he has archaeologically assessed contemporaneous settlements which show either depopulation or population increases; by matching these trends with ceramic data, he proposes differential migration patterns between the areas. By considering together areas that *were* and *were not* affected by tephra fallout, he has modelled differential responses among peoples of differing cultural affiliations. The strength of his analysis lies in not limiting his study to areas affected by the eruptions *per se* but broadening it to include contemporaneous sites that reveal the radiating social effects of survivor behaviour. Moreover, such behaviour appears to have been conditioned by the nature of the social structure, varying from egalitarian societies beyond the reach of the archaic state to those close by and benefitting from state interaction.

Following the 10th-century Mt Towada eruption, a lahar buried many houses further north in Akita Prefecture. In Chapter 6, MURAKAMI Yoshinao describes in detail how the lahar entered standing houses at the Katakai-Ienoshita site, in Akita Prefecture, preserving them upright; careful observation of ceramics caught in the lahar allow them to be interpreted as swept off a shelf inside a house. Similar to the woven fence at Kanai in Gunma Prefecture (Chapter 10), several pieces of architectural organic matter were preserved by the lahar, allowing more detailed reconstructions of the buildings. The presence of these structures in the ground has been known for a long time, having eroded out of a flood bank and been documented in the early 19th century; to have sketches and text to compare with current excavation findings doubles the interpretive strength of the materials. The interesting aspect of one of the sketches (Chapter 6: Figure 2) is that the house is basically a pit-house, with ladders leading down inside, and yet the roof does not extend to the ground as in prehistoric pit-houses but is supported on board walls lining the inside of the pit. The excavated pit-houses at Katakai-Ienoshita were unusual in having surrounding ramparts rather than deep pits, and two were found with indoor hearth and flue systems. One of these pit-houses was connected to a pillared building beside it, giving rise to speculations on the varying use of these architectural structures in the 10th century. Paddy fields were discovered adjoining the residential area, allowing insights into Medieval farming practices in the far north of Honshu Island.

Moving into central Honshu, SODA Tsutomu in Chapter 2 discusses the volcanics of the Central Honshu and Fuji volcanic zones (see Appendix C-5, C-6) and the formation of the Kantō loam. Within Central Honshu, HORAGUCHI Masashi provides a general contextual overview in Chapter 9 of the two active volcanoes in Gunma Prefecture, Asama and Haruna, and an exposition of repeated eruptions affecting society from the Kofun Period (250–710 AD), through the Heian Period (794–1183), to the Edo Period (1603–1868). Horaguchi is particularly interested in human reactions to eruptions at the various sites, and he proposes a series of distinctions in activities based on terminology in Japanese. He extols the detail of preserved settlements, never before obtained in Gunma archaeological excavations, and promotes three key uses of tephra cover. His work sets the stage for the ensuing chapters on Gunma sites, Chapters 10 and 11 by Sugiyama and Sakaguchi, respectively.

The data from the Kanai sites in Gunma Prefecture, discussed by SUGIYAMA Hidehiro in Chapter 10, provide unparalleled insights into human reactions to a 6th-century eruption of the Futatsudake vent on Mt Haruna: these reactions were one of leisurely acceptance and one of reverential finality. The two Kanai sites, Higashi-ura and Shimo-shinden, were differentially hit by tephra fallout, a pyroclastic surge, then a pyroclastic flow. The detailed effects of these are documented in rock impact traces, tomb scouring, and hut flattening. Footprints of humans and horses reveal some had time to escape, while others were not so lucky – as several skeletal remains of both have been preserved in the tephra. The 'man in armour' is an exceptional find. Many sets of armour have been excavated from tombs as funerary goods, but this is the first time one has been found being worn. The man, facing the oncoming pyroclastic flow, knelt in a ditch, took off his helmet, turned it around so that it faced him, spread out the cheek flaps, and bowed his head onto the helmet crown before being consumed in the ashes. A woman nearby splayed out in the ditch shows more panic in trying to escape. Underneath the tephra, an elite settlement has been revealed, with a 3-metre high woven fence partitioning off the main residence. Unparalleled insights into their residential structures, gardening efforts, and ritual concerns make Kanai one of the most important sites for understanding Kofun-Period society in this frontier region.

The main aim of Chapter 11 by SAKAGUCHI Hajime is to assess the seasonality and timing of two volcanic eruptions in the 6th century in Gunma Prefecture by comparing the conditions of paddy fields and irrigation canals buried by tephra fallout and lahars with the modern agricultural cycle. He is able to narrow down the time of year of both these eruptions to one month during the late spring/early summer planting seasons. This involved detailed analysis of field and canal construction with added footprint data. Concomitant with his analysis, he reveals that the local farmers in the 6th century would work through 10 cm tephra depositions and 5 cm thick lahars to continue their seasonal agricultural tasks. It is not likely that they had experienced previous episodes of light volcanic activity, so what made them carry on with complacency? Did they rely on folk wisdom shared within the greater community? Why, in that case, did they not anticipate the devastating lahars that followed? Were they themselves able to escape? We are left with a human story that is illuminated by the results at the Kanai Higashi-ura site.

At the southern end of Japan, KUWAHATA Mitsuhiro writes in Chapter 12 about field systems in the mid-2nd millennium in Miyazaki Prefecture, Kyushu. Two active volcanoes, Shinmoe-dake in the Kirishima Volcanic Zone (see Appendix C-7) and Sakurajima (a parasitic volcano on the rim of the Aira Caldera in Kagoshima Bay), have regularly covered the region in volcanic ash. Both paddy fields and extensive ridge-and-furrow traces have been excavated from underneath tephra erupted in the late 15th and early 18th centuries. Kuwahata reveals efforts to restore fields to productivity after the tephra fallout; in only one out of four cases were the fields abandoned.

In Chapter 13, Gina BARNES continues the study of tephra affecting agricultural systems by examining soils that develop from tephra deposits and assessing their productivity. After a brief introduction to the place of tephra-derived soils in soil taxonomy schemes, she focuses on the formation of andosols, emphasizing the black andosols (*kurobokudo*) found under grasslands in the Japanese Islands. These have incited much hypothesizing about their generation – the most convincing argument proposing that these appeared simultaneously with the peopling of Japan after 40,000 BP and resulted from the firing of the landscape. For what purposes, it remains for archaeologists to specify. As tephra-derived soils have often been thought to be infertile for agriculture, the geochemistry and nutritional values of andosols are examined in general in Chapter 13 with details in Appendix D.

The succeeding Chapter 14 by NOTO Takeshi and Gina BARNES provides an overview of the historical materials on agricultural innovations to compare with excavated evidence in Gunma Prefecture. This topic ranges more widely than just farming tephrogenic soils, but land-use patterns can partly be explained by soil infertilities caused by tephra weathering. The problem of swidden agriculture is discussed, but only as one of several strategies using fire to control plant growth and provide arable and pasture lands. The discovery of field systems under tephra, especially under successive burial events by tephra deposition, allows the exploration of mechanisms for restoring or redeveloping fields, as in Chapter 11. However, examined in light of the historical documents, a broader, more detailed view emerges that links directly to political systems of different periods – as also shown in Chapter 8. The impact of socio-political systems on people's behaviour in the face of disaster is a new direction in tephroarchaeological studies that can be studied comparatively through time as well as cross-culturally.

Gerry OETELAAR's Chapter 4 is unique in using the Mazama tephra deposits at excavated archaeological sites to understand landscape evolution on the northwestern Great Plains upon retreat of the ice sheet. Mt Mazama, now known as Crater Lake, belongs to the Cascade Range of volcanics in northwestern North America (Appendix C-2). Oetelaar details changes in northwestern Great Plains terrain after tephra-fall from the volcanic eruption hundreds of miles to the southwest. He investigates terrace, dune and alluvial fan formation, and explores the drying out of ice-block potholes. Such landscape reconstruction for specific periods of time and specific locales is essential for understanding the potential for human occupation as dependent on the flora and fauna – and particularly water and fuel supplies – within those micro-environments. Oetelaar then in turn examines the behaviour of prehistoric inhabitants in occupying these new landforms – which in the main are not volcanically generated. He makes the important point that groups reoccupying ancestral areas buried by tephra must have made use of landmarks to guide them back. One might envision that any drastic landform changes (such as rerouting of rivers) would have interfered with their objectives. Moreover, trails across such changing landscapes would have to be forged anew. The feedback loops of tephra cover > geomorphological change > archaeological discovery > geomorphological reconstruction > and behavioural interpretation are fully interdisciplinary.

Finally, we are honoured to have Chapter 7 written by a historian. Keith PRATT delves into the science of Mt Paektu, an unusual example of alkaline volcanics far from the active subduction zones (Appendices B-3, C-8). He evaluates the histories of both China and Korea for evidence of eruptions of Mt Paektu – both before and after the Millennium Eruption of 946 AD. In addition to laying bare Korean political reactions to the 10th-century eruption, Pratt exposes modern-day North Korean elite claims and ritual concerns involving Mt Paektu. These works provide interestingly different perspectives on human behaviour than those gleaned from artefacts and settlement remains. It should be remembered that eruptions even in pre- or proto-historical periods probably exerted great pressure on political as well as social systems, though evidence may be more difficult to obtain. In any case, the detail offered by historical sources are rich and varied but still may not give us the full picture. Assumptions must still be made about people's motives – as Pratt surmises that the northward building of garrisons on the Korean Peninsula in the 10th century was prompted by the desire to reincorporate Mt Paektu into the political realm. This chapter exemplifies the necessary inter-disciplinary nature of volcanic disaster research and the onus on each individual researcher to completely grasp the science behind volcanic eruptions. But it also has cautionary lessons for non-historians who use historical documents in trying to understand both the geologic event and the archaeological remains.

Prospectus

With contributions from psychologists, historians, archaeologists, soil scientists, geologists, volcanologists, tephrochronologists, geographers, and botanists, TephroArchaeology is becoming an accepted sub-field in the North Pacific. Further collaborations among these with politics, social science, religious studies, oral history, and research in volcanic epi-phenomena are all signposted within the chapters offered here. We look forward to such future interdisciplinary studies.

One of the points of doing TephroArchaeology is to help prepare for future volcanic disasters, as discussed in the WAC8 and SAA Forums as mentioned in the Preface. However, as Kling (2016: unpg.) notes,

> Jumping from 'doing science' to 'applying science' is not easy. It requires a much broader understanding of the natural 'system', which includes not only the underlying science but various social and political aspects as well.

We have argued here for a closer discipline familiarity and collaboration between archaeologists and volcanologists, but even this volume just scratches the surface of what needs to be done to bring volcanic hazard research to public policy planning.

Figure Sources

Figure 1 after Barnes 2003: fig. 4, based on Yonekura et al. 2001: fig. 1.3.2; base map by Durham Archaeological Services
Figure 2 after Outline World Map Images 2009-2018 [http://www.outline-world-map.com/blank-thick-white-world-map-b3c], modified by GLB; licensing conditions are "royalty free for any legal purposes" with the copyright displayed
Figure 3 after Tucker 1991: fig. 10.7, modified by GLB
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Figure 6 photo by author
Figure 7 after Velde & Meunier 2008: fig. 1.4, modified by GLB
Figure 8 photo by SODA Tsutomu
Figure 9 after Machida & Arai 1992: fig. 18, modified by GLB
Figure 10 after Iacovino et al. 20 16: fig. 1A, modified by GLB

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CHAPTER 2

Tephroarchaeology and its History in Japan

SODA Tsutomu *

Introduction

It is well known that there are many volcanoes distributed throughout the Japanese Archipelago. Changes to the dating of the Quaternary reveals that the number of Quaternary volcanoes has increased to 456. Among those, 111 are classified as Active Volcanoes (see Appendix C-3), having erupted within the past 10,000 years; they are targeted by disaster prevention policies. Resulting from the explosive eruptions of many volcanoes, enormous amounts of tephra are distributed over the Japanese Islands and their peripheries. This has stimulated various kinds of research relating to tephra and its uses within the Quaternary research sciences in Japan. Recently, research of human history that involves tephra has come to be called 'tephroarchaeology'. Here I would like to introduce the research contents of tephroarchaeology and the trends that led to its advocation as well as directions of its future development. The names and dates of tephra discussed accord with the latest edition of the *Atlas of Tephra* (Machida & Arai 2011), and volcanoes discussed herein appear in Figure 1.

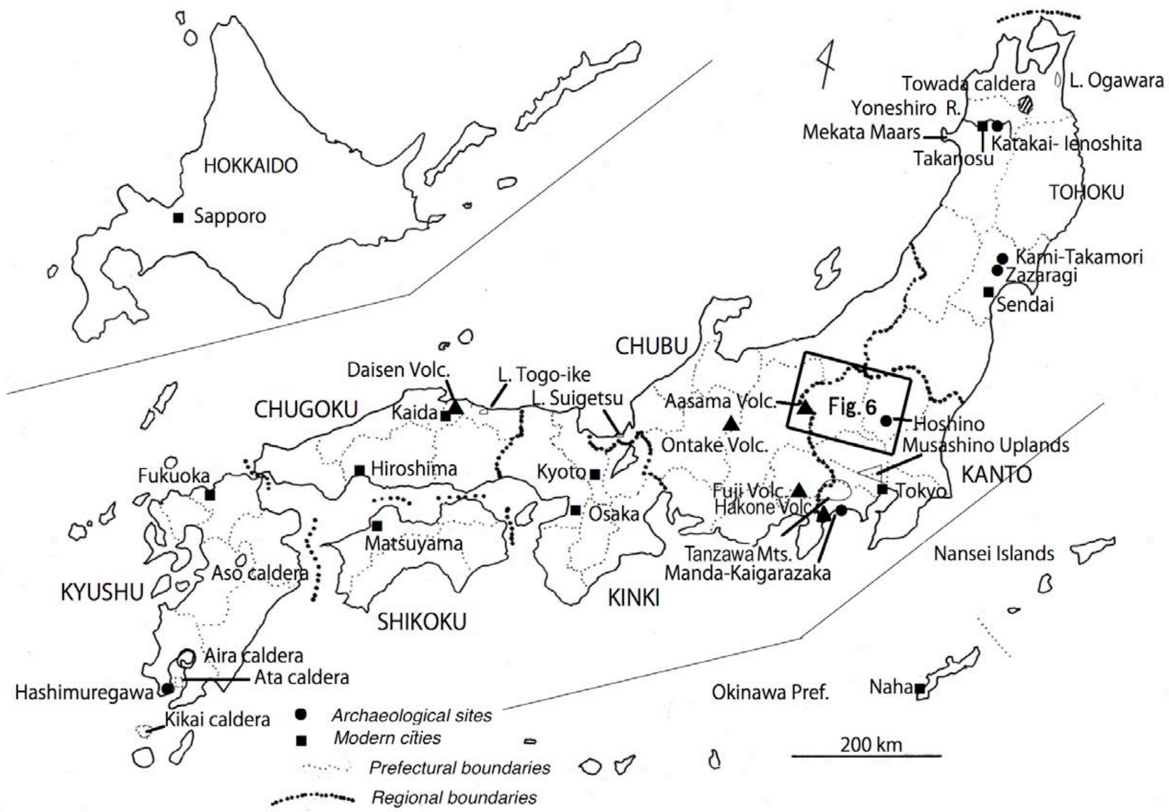

FIGURE 1 LOCATIONS OF PLACENAMES IN THIS CHAPTER
See Appendix A for all prefectural names

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Research History of Tephra Relating to Japanese Archaeology

The First Period: Before the Pacific War (WWII)

The recording of archaeological sites and objects began very early in Japan, but the first of those records dealing with artefacts and features affected by tephra seems to be the travel journal of SUGAE Masumi in the Edo Period (1603–1868). During his trip to view the results of a great flood, he became interested in houses and objects exposed in the eroded bank of the Yoneshiro River in the northern part of the Tōhoku region. In June of 1817, he drew a picture of the discovered house located in Takanosu in modern Akita Prefecture (Uchida & Miyamoto 1973; see also Chapter 6: Fig. 2). Judging by the details recorded by KUROSAWA Michikata, this house is thought to have been buried by the lahar following the 915 AD eruption of Towada caldera. It is similar to the houses buried by lahar sediments which were discovered in 2016 at the Katakai-Ienoshita site in Akita Prefecture (see Chapter 6).

From the Edo into the Meiji Period (1868–1912) as Japan began to walk the road of modernization, researchers from Europe and North America were invited to Japan and greatly contributed to research in various fields and their proliferation. Geology was one that benefitted: W.P. Blake and R. Pumpelly were invited to Japan by the Edo Bakufu government, and they demonstrated that tephra sedimentary layers were built up from active volcanoes in Hokkaido (Pumpelly 1866). David Brauns from Germany, who was invited by the Meiji government, thought that the red earth called ‘loam’ that covers the broad terraces of southern Kantō consisted of airborne deposits similar to loess (Brauns 1881). His student instead proposed that the red earth was volcanic ash originating from volcanoes to the west (Suzuki 1888). It is now known that the ash may be either primary deposits from eruptions or secondary deposits deriving from ash beds nearby (cf. Figure 2).

FIGURE 2 AERIAL VIEW OF MT FUJI FROM THE SOUTHEAST
The bare ground on the volcano’s flank (arrow) is comprised of tephra-fall remaining from the 1707 eruption; it is a supply point for aeolian dust to be redeposited on the Kantō Plains.

In 1918–19, HAMADA Kōsaku had the opportunity to see Pompeii during his period as a student at University College London. Excavating the Hashimure-gawa site in Kagoshima Prefecture, southern Kyushu, upon his return from London, he instigated using tephra layers as the stratigraphic standard for the first time in Japan (Hamada 1921). Also, in 1925, at the excavations of the Manda-Kaigarazaka site in Kanagawa Prefecture, southern Kantō, pottery was discovered among plural tephra layers (Yamazaki et al. 1925). Inspired by Hamada's work, researchers in Gunma Prefecture in northwest Kantō used tephra in dating mounded tombs (Iwasawa et al. 1932). Around this time in Hokkaido, pit-houses werediscovered from lower tephra layers (Kono 1932; Teshigawara 1988). In the 1930s–1940s, progress was made in recording the stratigraphy and distribution of tephra layers in Hokkaido and Kantō as part of the policies to increase food production.

From the Pacific War through Economic Expansion: Increase in Information on Tephra

In 1946, AIZAWA Tadahiro, an amateur archaeologist, discovered stone artefacts in the loam layers of Iwajuku, Gunma Prefecture (Figure 3). Excavations in 1949 by Meiji University confirmed the existence of the first known Palaeolithic stone tools (Sugihara 1956). This discovery re-energized the Japanese populace, who had suffered defeat in the Pacific War, and its introduction into school textbooks greatly influenced the young generation of that time (Tozawa 1996). Moreover, the excavation of artefacts from tephra strata demanded research on tephra stratigraphy and chronology from the disciplines of archaeology as well as geography and geology. Therefore, the field of tephrochronology put forward by S. Thorarinsson in 1944 was introduced into Japan in 1948 (Imamura 1948).

FIGURE 3 IWAJUKU SITE, GUNMA PREFECTURE
The first Palaeolithic site discovered in Japan, in 1946

By the late 1950s, Japan was facing a period of intense economic growth. Due to large construction projects, numerous outcrops of tephra were exposed in every region of Japan, allowing the progressive recording of tephra stratigraphy. Especially in the southern Kantō region where development was rife, detailed stratigraphic records were made of the 'loam' layers. Based on the relationships of tephra to the terrace surfaces in Kantō (Figure 4), tephra categories were extended throughout Japan and regional stratigraphies became clarified. Within the Musashino Loam is a tephra layer discussed below: the Hakone-Tokyo pumice (Hk-TP) erupted from Hakone volcano ca. 66,000 years ago.

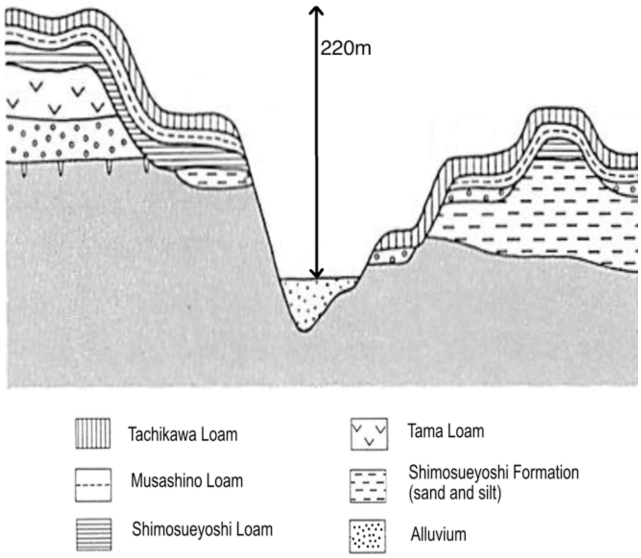


FIGURE 4 KANTŌ LOAM
Section drawing of the Pleistocene terraces and their tephra covers in Southern Kantō

Meanwhile, Kobayashi et al. (1967) noticed that one tephra stratum in the stratigraphic column of the Musashino Uplands of southern Kantō consisted of Ontake Pumice I (On-Pm I) originating from the Ontake volcano in Nagano Prefecture, which erupted 95,000 to 100,000 years ago. This discovery highlighted the importance of identifying each tephra layer and its distribution, and Kobayashi (1970) urged the development of new tephra identification methods. As if in response, Arai (1972) successfully improved the method of refractive index measurement, demonstrating that the refractive index of volcanic glass and minerals is valid in identifying different tephras (Appendix E-6).

1970 to 1990s: Tephra Framework for Widespread Tephra, and Differentiating Research Paths

MACHIDA Hiroshi, who researched the process of slope development of Mt Fuji and other mountains, noticed the existence of transparent bubble-type volcanic glass in the deposits of the Tanzawa Mountains of southern Kantō; together with ARAI Fusao, he searched for the source. They discovered that it derived from the volcanic ash accompanying the Ito pyroclastic flow of the Late Pleistocene caldera eruption of Aira in southern Kyushu, dating to ca. 30,000 years ago (Figure 5; see also Appendix C-7). They named this the Aira-Tanzawa volcanic ash (AT) (Machida & Arai 1976).

Following the identification of AT volcanic ash, discoveries of widespread tephra were made one after another, and these became the spatio-temporal axes of the tephra framework standard for key marker tephra distributed throughout the Japanese Islands and peripheries (e.g. Machida & Arai 1978, 1983). In 1972, Kobayashi again requested the construction of a tephra catalog to which Machida et al. (1984) responded by compiling an archaeological tephra atlas. Thereafter in 1992, they published the proper *Atlas of Tephra* for the Japanese Islands and surrounding areas (Machida & Arai 1992). This atlas contained several thousand entries on tephra dates and rock/mineralogy identifications (see Appendix E-6); it has been revised twice (2003, 2011), and is currently being updated again.

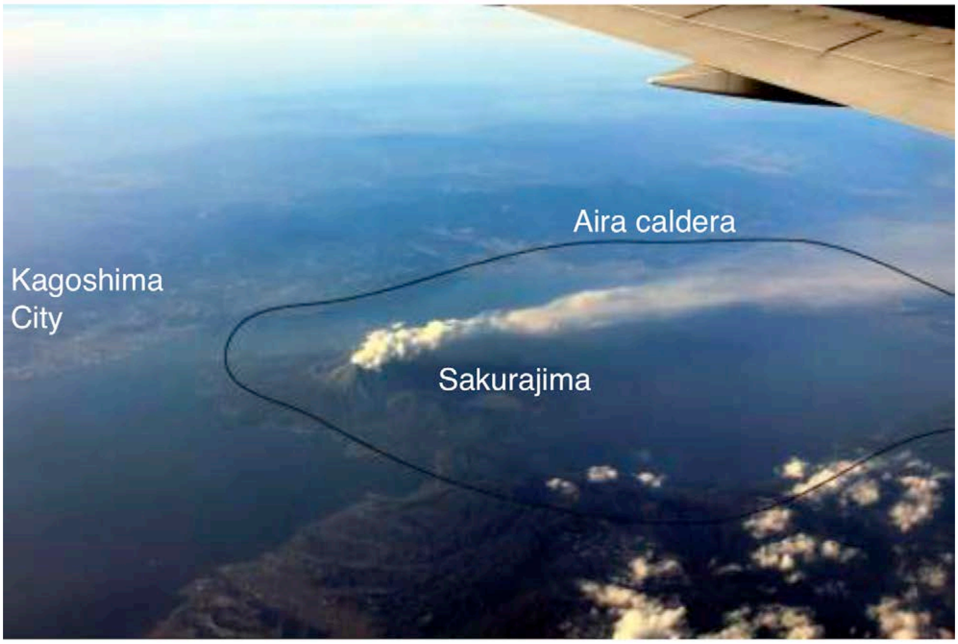


FIGURE 5 AIRA CALDERA VIEWED AERIALLY FROM THE SOUTHEAST
Sakurajima, erupting, is a daughter volcano positioned on the Aira caldera rim (black outline)

In 1983, a special issue of *The Quaternary Research* journal (*Daiyonki-Kenkyū*) of the Japan Quaternary Research Society (Nihon Daiyonki Gakkai) was published on "Japanese Archaeology and Quaternary Research". Under that title, widespread tephra relating to archaeological research was discussed, and several papers on the use of AT in constructing a Palaeolithic cultural chronology were included. On the archaeological side as well, a compendium was published of sites throughout Japan where tephra had been discovered in excavation (Maibun 1987). As a result, tephrochronology began to be seriously integrated into the discipline of archaeology.[1] Even when tephra layers could not be identified by eye in archaeological excavations, the search for cryptotephra was carried out in the lab, so the recognition of successive tephra-fall layers of marker tephra flourished.

Also at that time, evidence began to accumulate in the research history of volcanic disasters. In 1978, a special issue of the journal *Dolmen* focussed on archaeological research relating to volcanic eruptions, introducing volcanic disaster research in central Hokkaido, northern Tōhoku, northwestern Kantō, and southern Kyushu. In 1981, a trench excavation at Kanbara in Gunma Prefecture (Asama 1982) uncovered the remains of two females who were discovered lying on the lower steps of a temple as they tried to escape a debris avalanche caused by the 1783 (Tenmei 3) eruption of Mt Asama (Figure 6, right). The foreground surface in Figure 6 (left) is the top surface of that debris avalanche, and the bridge covers the former excavation of the lower stairs underneath the avalanche sediments.

For determining the age of tephra, the use of AMS radiocarbon dating began from 1980 and rapidly became standard for carbonized and decayed organic matter associated with tephra layers. Chronological research on other dating methods such as thermoluminescence was also implemented. Meanwhile, in the field of tephra identification, a modified "temperature-change-type of refractive index measurement" was developed in the late 1980s (Yokoyama et al. 1986). As a result of new instrumentation such as RIMS

[1] More recently, *Quaternary International* carried a commemorative volume honouring Machida's seminal role in developing the field of tephrochronology (Lowe et al. 2011, ed.).

(Refractive Index Measurement System), high quality refractive index measurements could easily be obtained. Moreover, analyses of major and minor chemical elements in volcanic glass etc. identified with EPMA and ICP [2] became standard analyses at all research institutions. The research history of tephrochronology has been documented by Machida (1977, 1991, 1999).

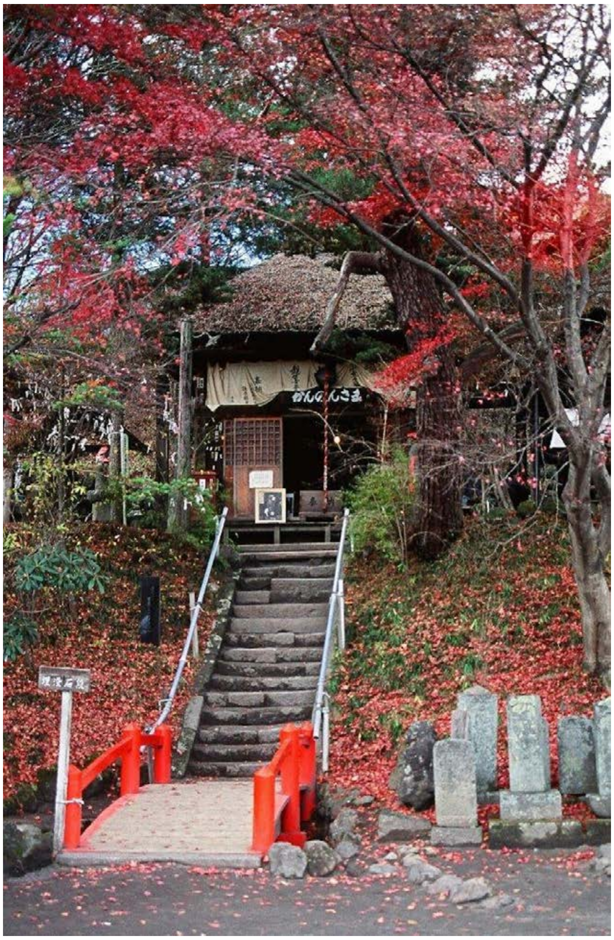


Figure 6 Temple of Kanbara Kannondo, Gunma
Two debris avalanche victims of 1783 were excavated on the temple steps in 1981.

A Proposal for "Tephroarchaeology"

In Japanese Quaternary studies, with the intensification of tephrochronology research, a movement began seeking expansion of the field. The term *kazanbai kōkogaku* was initially used by SHINTŌ Kōichi in the title to his 1988 book, but he did not clearly define what it meant.

ARAI Fusao, who had much experience with archaeological site excavations while affiliated with Gunma University, worked together with MACHIDA Hiroshi in furthering tephra research in Japan (Arai & Machida 1992). In his 1993 publication, Arai named a new field of research on the human history associated with tephra, using Shintō's 1988 term *kazanbai kōkogaku*. In Japanese, *kazanbai* means 'tephra' [3] and *kōkogaku* is 'archaeology'. For use in English, I have translated this term as 'tephroarch(a)eology' in parallel with the term 'tephrochronology' (Soda 2016a).

[2] EPMA = Electron Probe Micro-Analysis; ICP = Inductively Coupled Plasma emission spectrometry.

[3] *Kazanbai* literally means 'volcano ash', but it is variably used by Japanese geologists to mean both ash-size fractions, and ash fallout and pyroclastic flow/surge tephra without strict restriction of particle size.

In Arai's edited book, entitled *Kazanbai Kōkogaku* (1993), 4 chapters concern geology, 3 relate to physical geography, 2 to archaeology, 1 to history and 1 to civil engineering (Table 1).

TABLE 1 TABLE OF CONTENTS OF *KAZANBAI KŌKOGAKU*, ED. BY ARAI FUSAO, 1993

ARAI Fusao (Geologist): Preface

MACHIDA Hiroshi (Geographer): Volcanic eruptions and the environment

ARAI Fusao (Geologist): Eruptive history of volcanoes in the Gunma area

NOTO Takeshi (Archaeologist): Volcanic disasters investigated by archeological excavations

ARAMAKI Shigeo (Geologist): Transition of Asama 1783 eruption and its problems

MINEGISHI Sumio (Historian): Social change in Kantō caused by the Asama 1108 eruption

SŌDA Tsutomu (Geographer): Two eruptions of Haruna volcano in the Kofun Period

SAKAGUCHI Hajime (Archaeologist): Methods of eruptional age and season estimation

MORIYA Ichio (Geographer): Eruptive history of Akagi volcano and its future

TOKUI Yumiko (Geologist): Volcanic eruptions of 17th–19th centuries AD in Hokkaido

ODA Shizuo (Archaeologist): Volcanic disasters in the Palaeolithic and Jomon Periods

TSUJI Seiichiro (Geologist): Impacts of volcanic eruptions on the ecosystem

OMURA Kazuo (Engineer): Civil engineering technology relating to tephra

MACHIDA Hiroshi (Geographer): Postscript

The deepening of collaboration between research on volcanoes and tephra with human historical research firmly set the direction of studies noted by Arai as suggested in the tephrochronological studies revealing intimate and knowledgeable links between humans and their environment.

Thus, in Japanese archaeological research there are examples of employing tephrochronology in chronological studies, of research on volcanic disaster histories, and of material studies of artefacts and features affected by tephra. Tephrochronology utilizes the standard spatio-temporal distributions of widespread marker tephra throughout the archipelago; these are especially useful in constructing detailed chronologies of artefacts and features in southern Hokkaido and Kantō (for Palaeolithic through Edo Periods), in Tōhoku (for Palaeolithic through Heian Periods), in Chūgoku (for Palaeolithic through Jōmon Periods), and Kyushu (for Palaeolithic through Medieval Periods). Volcanic disaster research particularly focusses on the middle to southwestern part of Hokkaido (for the Edo Period), northern Tōhoku (for the Heian Period), northwestern Kantō (for Kofun through Edo Periods), Chūbu (for Edo Period), and southern Kyushu (for Kofun through Muromachi Periods).

Especially for Gunma Prefecture (northwestern Kantō; cf. Appendix C-5), a detailed diagram of tephra timing and distribution has been made (Table 2), establishing a basis for precise tephroarchaeological research. The names in the boxed area at the top (Investigation Scope) are represented in Figure 7. Excavations of archaeological sites in this prefecture have revealed villages, fields, and victims buried by tephra fall layers, pyroclastic flows, pyroclastic surges, debris avalanches, and lahars (Table 3, Figure 7).

TABLE 2 TIME-SPACE DIAGRAM OF MARKER TEPHRA IN NORTHWESTERN KANTŌ

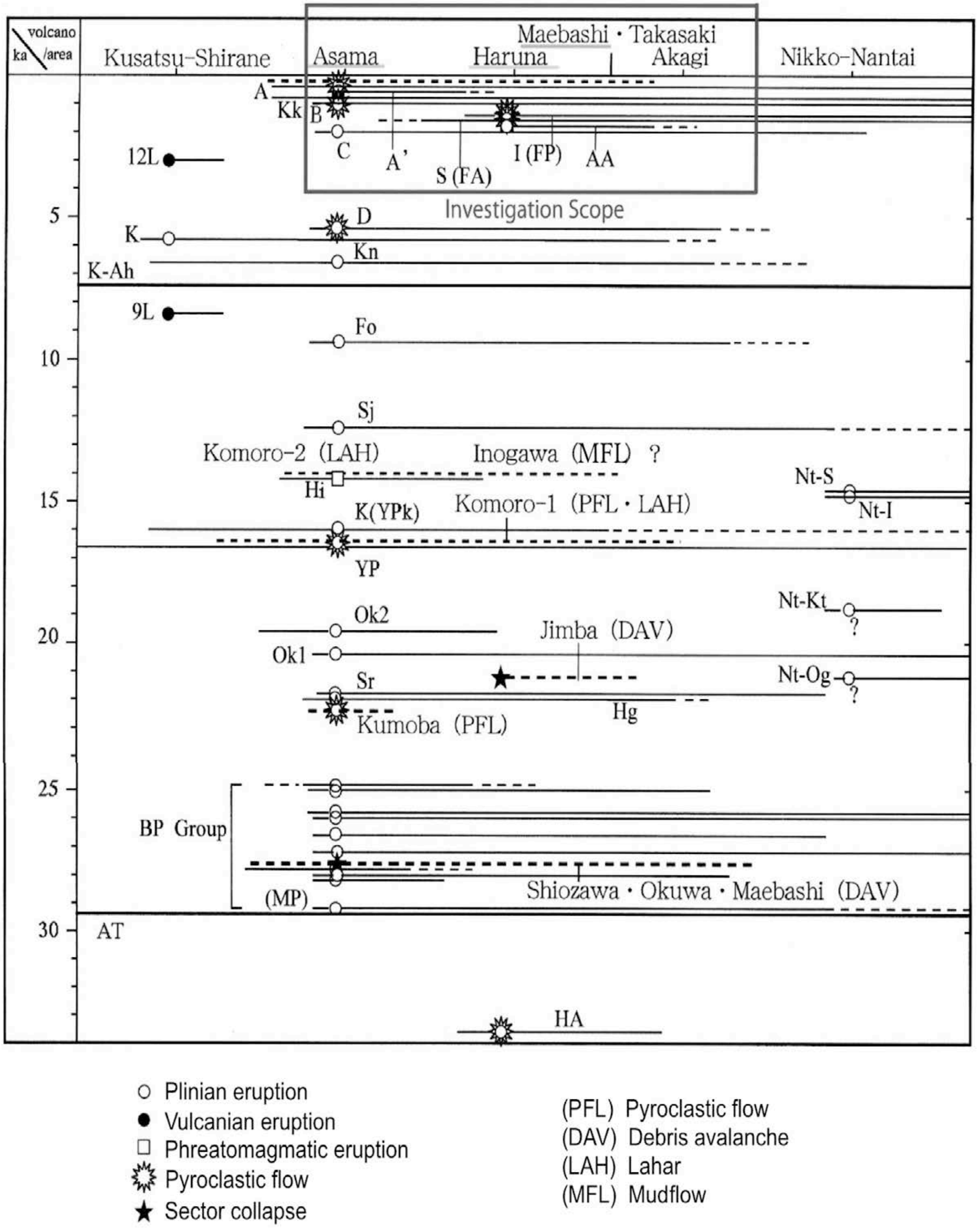
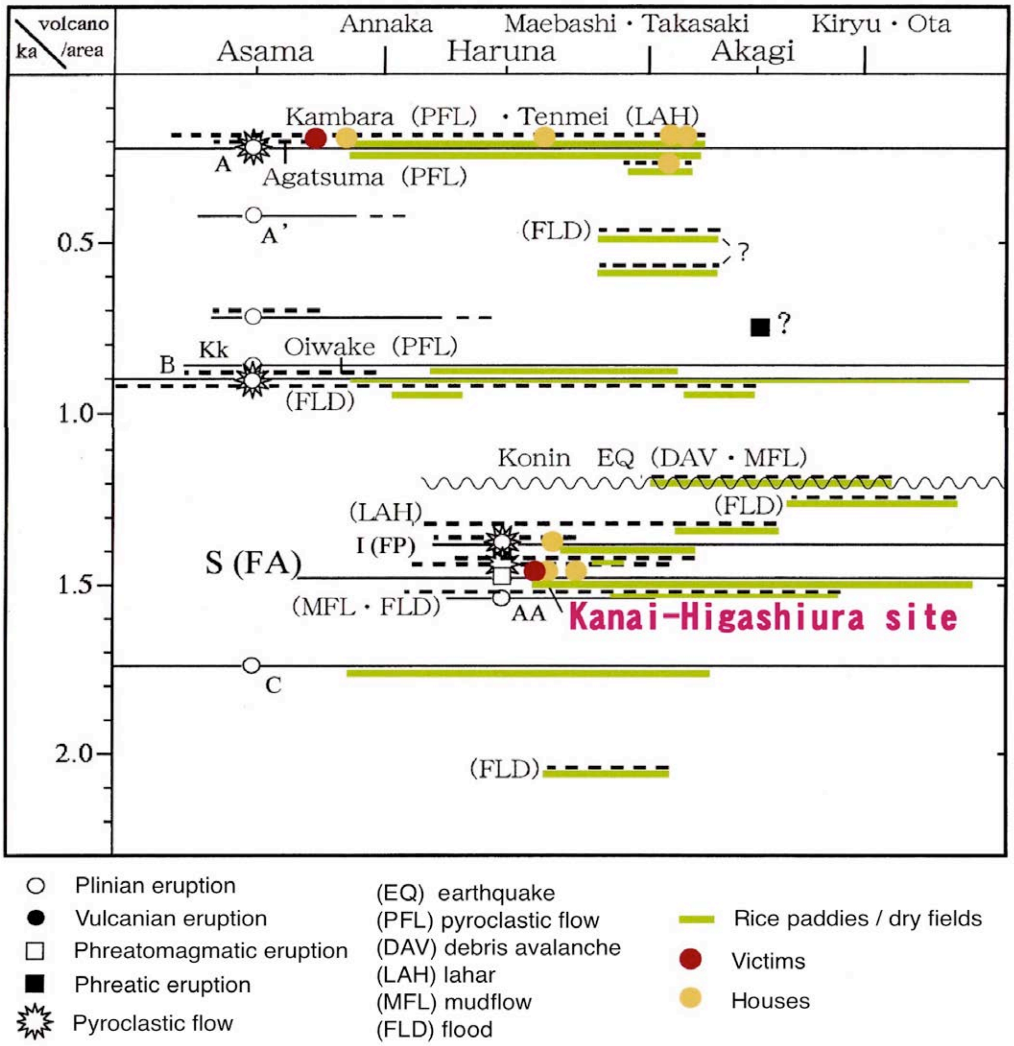


TABLE 3 STRATIGRAPHY OF VOLCANIC DISASTER REMAINS AS EXCAVATED IN NORTHWESTERN KANTŌ



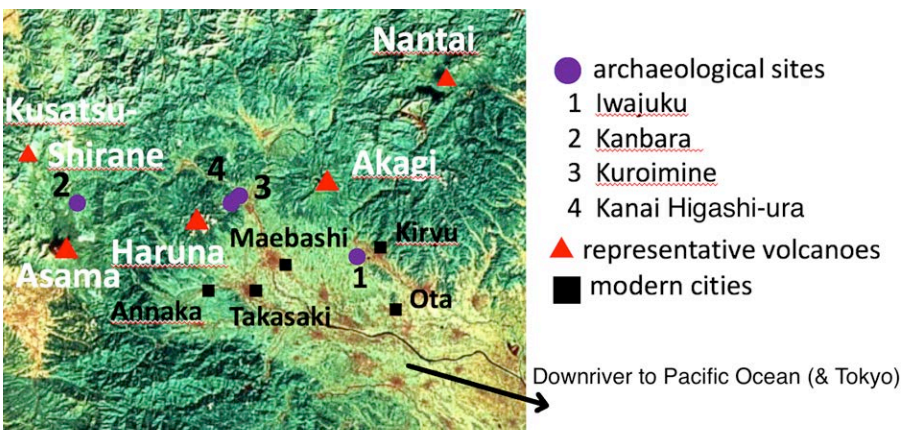


FIGURE 7 LANDSAT MAP OF VOLCANOES AND REPRESENTATIVE ARCHAEOLOGICAL SITES IN GUNMA AREA, NORTHWEST KANTŌ

Topics and Trajectories of Tephroarchaeology after its Introduction

Reassessment of previous tephra studies

In 1995, a problem arose in understanding the formative processes of 'volcanic-ash soil' (火山灰土 *kazanbaido*), composed from lower 'loam' layer and an upper *kurobokudo* (andosol) layer that together had long been thought to be ash fallout layers. For volcanic-ash soils that were previously considered to be built up through successive eruptions, Hayakawa (1995) demonstrated that they did not increase in thickness towards the volcanic source, as one would expect. Instead, loam layers and the surface *kurobokudo* formed via deposition of fine grains scoured from the bare ground and redeposited on the surrounding grassland. Even today during seasons of high winds, scoriaceous tephra, which was erupted from Mt Fuji in 1707 and deposited in the gravels along the eastern foot of the mountain, is lifted by strong winds and redeposited in the southwestern Kantō region (see Figure 2). Thus, there are still archaeologists who confuse *kazanbaido* and andosols with tephra layers.

Also in relation to tephra ages as perceived, advances were made in dating methods and progress in compiling the radiocarbon calibration curves. The discovery of and research on the annual varves in Lake Suigetsu in Fukui Prefecture impacted on several fields of chronological reckoning (Fukusawa 1997). The excellent continuity of the Suigetsu varves was internationally recognized (Ramsey et al. 2012), and the high quality of the radiocarbon dates for organic material in the varves and varve annual succession were incorporated into the $IntCal_{13}$ radiocarbon calibration program (Reimer et al. 2013). However, for relatively recent periods, $IntCal_{13}$ does not conform to the calibration curve derived from tree-ring data sourced in Japan (e.g. Sakamoto et al. 2003), and it will be a matter of some time before this local wiggle matching method of high accuracy becomes more widely used. Elsewhere in Japan, annual varve sediments yielding tephra have been found at Lake Ogawara in Aomori Prefecture, Mekata Lagoon in Akita Prefecture, and Lake Tōgō in Tottori Prefecture.

The Palaeolithic Scandal and Tephroarchaeology

It is unfortunate that I must report on the international-scale Palaeolithic scandal that occurred in Japan at the beginning of the millennium (Keally 2000; Yamada 2002). Research on the initial occupation of the Japanese Islands has been a prominent topic in Japanese archaeology. Following the discoveries at Iwajuku site, people were influenced by the rather 'legendary hero' who first identified Palaeolithic artefacts, and interest in old finds increased, as in any age. Naturally, tephroarchaeology came to be closely associated with Palaeolithic studies.

Debate over the existence of Late Palaeolithic artefacts in Japan had arisen early on. In the 1960s centring on SERIZAWA Chōsuke at Tōhoku University, many reports of Palaeolithic site discoveries from Tōhoku to Kyushu were energetically published (e.g. Serizawa & Nakagawa 1965). For those reports that were not vigorously debated in archaeological circles, Arai (1971) criticized their views from the standpoint of Quaternary geology. On one hand, while acknowledging the tephrochronological ages of the artefactual layers at the Hoshino site in Tochigi Prefecture, northern Kantō, he then pointed out the problem on stone tool identification with reference to the sedimentary processes of the layers in which the stone tools were found; Arai did not accept the artefacts as being of human manufacture.

Without having confirmed evaluations of the ancient sites reported by Serizawa, his students formed the Stone Age Culture Club (Sekki Bunka Danwakai, SBD) and proceeded in their aim to discover new Palaeolithic sites in central Tōhoku (cf. Appendix C-4). In 1983, they published a report on the 1981 excavation of Zazaragi site in Miyagi Prefecture, where the lower Yasuzawa tephra was dated by thermo-luminescence and fission track to 41–44,000 years ago (SBD 1983). Several successive living floors were reported in the layers containing artefacts in the site's lower Yasuzawa volcanic ash layer. In response,

FIGURE 8 EXCAVATION OF KAMI-TAKAMORI SITE, MIYAGI PREFECTURE
The location where the Palaeolithic scandal was revealed

tephra specialists pointed out problems with the tephra being pyroclastic flow sediments (Machida et al. 1984; Sōda 1989). Soda, having called for the necessity of re-investigating the site by associated archaeologists (1991), received no response from the archaeology side except from a small number of practitioners. The SBD went on to discover stones that were regarded by the majority of archaeologists as humanly modified from even lower layers of tephrogenic soils (*kazanbaido*); these 'tools' were confirmed as being from sufficiently old stratigraphic horizons with reference to the chronologies of stone tool successions and by various dating methods. Thus, the unearthing of stone tools from ever earlier sediments accelerated.

In the autumn of 2000, apparent stone tools were discovered from sediments estimated to date more than 600,000 years ago at Kami-Takamori site, Miyagi Prefecture (Figure 8; tephra layers visible in hillside). The outcrop in the foreground of this picture yielded the samples for the various dating methods applied to the site. The tephra dates were solid, but investigations by the *Mainichi Newspaper* revealed that the stone tools had been intentionally buried by the person who had discovered them, FUJIMURA Shin'ichi, and that he had done so in every region of Tōhoku starting with Miyagi Prefecture. The Japanese archaeological community was devastated. When the topic of his site discoveries was introduced into the national school curriculum, the fraud of presenting fake Early and Middle Palaeolithic sites became a nationwide social problem. As a result, archaeologists in collaboration with natural scientists re-excavated both sites contaminated by the fraudster and uncontaminated sites for comparison, and they reinvestigated the stone tools that had been intentionally buried. Their results, including checks on 3000 stone tools from about 200 loci, were published by the Japanese Archaeological Association in (JAA 2003); the dates of all 29 sites where the fraudster had been involved were rejected.

Thereafter, to establish a base for renewing studies on the date of human occupation of the Japanese Islands, examinations were made of tephras immediately preceding the Late Palaeolithic and within the first half of the Late Palaeolithic in both eastern Hokkaido in the north and the Nansei Islands off Kyushu in the south (e.g. Sōda 2011, 2016c). Recently, there have been reports of lithic discoveries earlier than the Late Palaeolithic, so we are able to celebrate a new phase in research on this ancient period.

New Research Topics

Tephra can be utilized in research on site formation processes and in material studies of artefacts and features, under the umbrella of tephroarchaeology or otherwise. For example, when each layer of tephra is preserved in good condition, obviously the stratigraphic position of features and structures is easy to determine. And when the sedimentary structures of tephra layers are investigated in detail, even the structural aspects of organic features which have disappeared through weathering can be estimated. In addition to being able to assess the topography prior to tephra fall, the land surface just below the ash layer will provide insights for reconstructing the local environment.

An example is the Kuroimine site in Gunma Prefecture, where a village was discovered overlain by a 2-metre thick layer of pumice (Hr-FP) from the Futatsudake vent of Mt Haruna, erupted in the mid-6th century (Tsude 1992). From changes in the layering of the pumice fallout, the structures of buildings could be ascertained even though the architectural members had decayed away. Combining these findings with investigation of plant remains, including seeds and phytoliths in the cultivated soil of agricultural fields covered by tephra, minute details of the village and its surroundings can be reconstructed, to the extent of revealing activities of people within their houses and being able to estimate the season in which the site was buried (Ishii & Umezawa 1994).

Also, activities carried out on top of tephra layers are being investigated. A series of cave tombs of the Kofun Period in southern Kantō had been dug into the Hakone–Tokyo pumice (Hk-TP) which had erupted ca. 66,000 years ago (Takamura & Ikegami 1999). One interpretation postulates that the pumice was targeted for tomb-building in order to avoid groundwater seepage (KOBAYASHI Kazuki pers. comm. June 2017).

Recent excavations at the Kanai Higashi-ura site in Gunma Prefecture revealed the remains of several victims buried by an ash cloud surge from Mt Haruna at the beginning of the 6th century (cf. Chapter 10). Their good preservation was due to the repeated layering of coarse pyroclastic flow sediments, fine-grained ash cloud sediments, coarse tephra, and fine-grained soil that contributed to the formation of a capillary barrier structure, as elucidated by a civil engineer (Nishimura 2017). His interpretation is very interesting in light of the tendency among Japanese archaeologists and anthropologists to blame acidic sediments for the poor preservation of organic material. This now needs rethinking.

Lithified tephra is commonly used for building materials: in Kofun-Period stone chamber tombs and stone sarcophagi, and in the walls, bridges, canal linings, and buildings of the Medieval Period. For example, welded tuffs deriving from the Ata caldera and Aso caldera eruptions in central and southern Kyushu have been used for these purposes in western Japan (e.g. Makabe 2007). In northern Kyushu, pyroclastic flow tuffs host cave tombs and Buddha carvings. Even during the Yayoi Period in this region, pumice stones have been found used as fishing floats. Volcanic minerals and glass from tephra sources are found in Jōmon ceramic bodies; it is possible that tephra was intentionally added to the clay. Among obsidians used as stone tools might be materials extracted from pyroclastic flow sediments, but more detailed research is needed for other rock types.

The Great Tōhoku-oki Earthquake and Tephroarchaeology

Because the Japanese Islands are positioned in a tectonically active area, massive natural disasters are frequent. Especially the Great Tōhoku-oki Earthquake of 2011, though named after its epicentres off the coast of Tōhoku, caused severe damage in eastern Japan as well. Grasping this opportunity to emphasize the effectiveness of research in disaster archaeology for modern disaster prevention, the Science & Technology • Academic Council of MEXT[4] instructed the Nara Cultural Properties Research Institute to

[4] MEXT: Ministry of Education, Culture, Sports, Science and Technology of the Japanese Government.

compile a database on evidence of natural disasters discovered in archaeological sites (Nabunken 2016). There are differing opinions as to whether or not archaeological research reports relating to past natural disasters can be used as is by natural scientists, but the progress in public dissemination is certainly significant.

The 2011 earthquake was a once-in-a-millennium event for eastern Tōhoku, but catastrophic eruptions happen in Japan on a longer time scale, with a frequency of every 10,000 years. As the last disastrous eruption was 7300 years ago, there is momentum building within volcanology to progress research on major eruptions; in 2014, a special issue of the journal *Kagaku* (Science) was published by Iwanami Shoten, devoted to "Large eruptions affecting Japan". In archaeological circles, much research is being conducted on the effects of the latest large eruption from the Kikai caldera ca. 7300 years ago on Jōmon-Period lives (Kuwahata 2016). Such interest is also being extended to collecting evidence on volcanic disasters in the Palaeolithic Period.

Even when not on the scale of these large caldera eruptions, Japan's volcanoes are intimately involved in people's lifestyles, both positively and negatively (Figure 9). Volcanic disaster archaeology is not simply a discipline which elucidates the history of disasters: it analyses the contemporaneous social structures (see Chapters 5, 6, 8, and 14). Thus, it is important to emphasize the claim by Noto (1993) that the target of that science should be assessing the directions regional society should take in coping with disasters occurring in the future.

Towards a conclusion

Arai (1993) proposed that tephroarchaeology was not merely a sub-discipline of archaeology but one that encapsulated natural history research; its systematization is a project for the future. For tephroarchaeology to evolve towards the temporarily named 'archaeovolcanology' (*kōko-kazangaku*), problems of excavation methodologies to deal with disaster remains caused by volcanic gases or lava flows need to be solved, as well as problems in the collaboration between archaeology – deemed a humanities subject – and the natural sciences.

For tephrochronology, techniques of tephra identification are being refined, but many downsides exist: the alienation of youth from the sciences, the decrease in stratigraphic tephra exposures due to economic stalemate, the decline of fieldwork skills that are needed to increase efficient investigation, and the problems of recognizing strata containing cryptotephra only through lab work (Nagahashi & Kataoka 2015). This last problem cannot be overlooked, too, in volcanic disaster history studies where it is necessary to comprehend the accurate stratigraphic relationships between tephra and artefacts and features.

As written in the postscript of Arai's 1993 book entitled *Kazanbai Kōkogaku*, while we now probe human existence within natural history, tephroarchaeology is a research field that can provide the raw materials for contemplating what we should do to ensure human survival. There can be no doubt concerning the importance of this.

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Figure & Table Sources

All illustrations and tables are by the author except for:
Figure 4 modified from Yoshikawa et al. 1981: fig. 6.1 by GLB
Figure 6 (right) courtesy of the Tsumagoi Folk Museum 嬬恋郷土資料館
Figure 7 basal Landsat map is presented by Tokai University Research and Information Center
Table 2 after Sōda 2016b: fig. 5; Kusatsu-Shirane data from Hayakawa 2016

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CHAPTER 3

Volcanic Disaster Archaeology: Notes on Methodological Prospects and Issues

KUWAHATA Mitsuhiro *

Introduction

Tephroarchaeology is a research discipline that deals with volcanic ash in archaeological excavations and research. However, in recent years, in accordance with the progress of archaeological investigations, the scope of the discipline has expanded, with volcanic ash recognized and methods applied in a greater number of site excavations, with more intensive research into individual regions and concrete case studies, and with the introduction of more precise analyses. Nevertheless, there has not been a clear systematization of what this academic discipline actually consists of. This presentation will refine the definition of tephroarchaeology and subsequently identify the methods and procedures of volcanic disaster archaeology as one sub-discipline within tephroarchaeology.

Tephroarchaeology Definition

Tephra, as debris from volcanic eruptions, is useful when it is applied to archaeological investigations in the following ways, as specified by Shimoyama (1999):

1) to establish chronology (tephrochronology) based on stratigraphic studies;
2) to compare archaeological materials above and below tephra layers to note similarities and differences and to assess cultural commonalities or dissimilarities;
3) to understand village structure at the time of eruption via their burial under sediments accompanying the disaster; and
4) to reconstruct the influence of the disaster and create abstract hypothetical constructions.

Tephroarchaeology Redefinition

In this paper, I propose that tephroarchaeology include the following four items:

① that it is grounded in stratigraphic methodology, establishing a standard chronology of archaeological materials;
② that it includes contemporaneity studies which focus on analyses of information on well-preserved cultural materials that were buried simultaneously according to tephra stratigraphy;
③ that research is conducted into historical volcanic disasters where the analysis of archaeological materials reveals the influence of volcanic eruptions on human groups;
④ that by using the limited geographical distribution of tephra, research is conducted into the production locations of archaeological materials which incorporate or are even made of tephra.

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Research on contemporaneity studies is based on stratigraphic chronology; with tephra identified among cultural layers, the history of volcanic disasters becomes an unexpectedly positive development.

Measures of Volcanic Disasters

Differences in the extent of volcanic disasters depend on the scale and style of eruption as well as on the proximity to the volcano. Previous research based on these premises used standard analyses of the geographic limits of tephra-fall and its thickness to analyze information gained from site investigations (Tokui 1989; Shimoyama 2002). Building on these studies, we can construct a graphic depiction of tephra hazards in the areas of volcanic disasters. Figure 1 shows a schematic view of volcanic disaster area divisions.

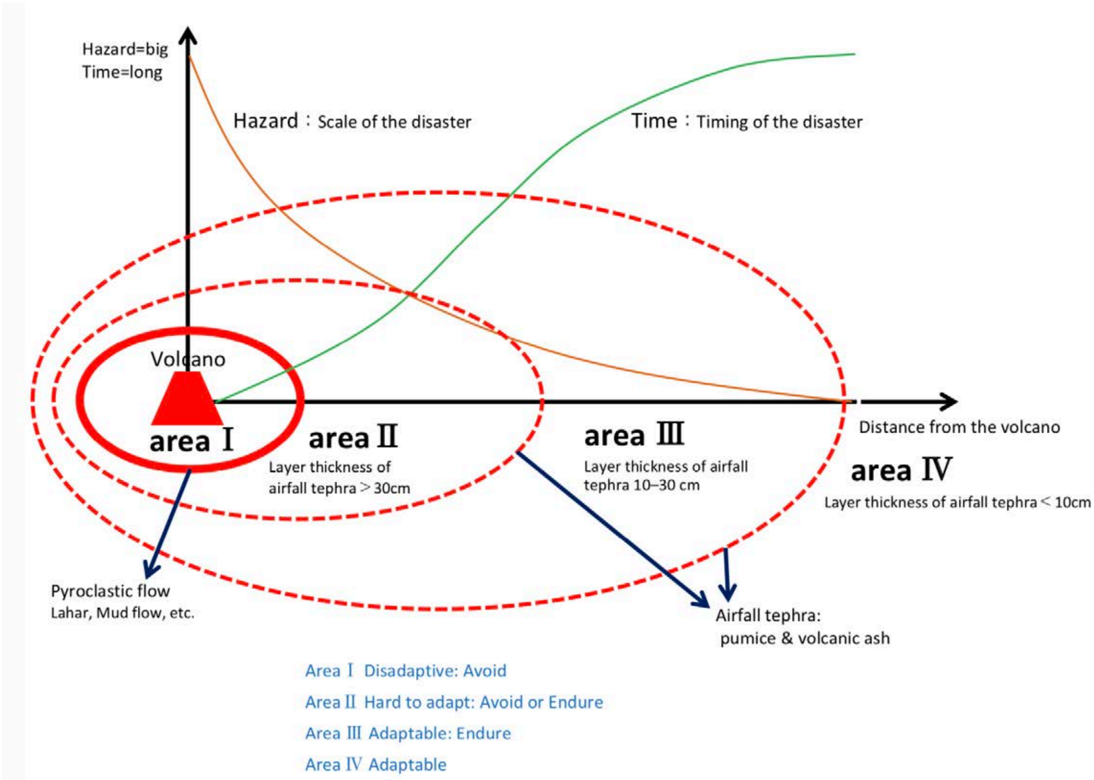

FIGURE 1 DISTINCTIVE AREAS OF TEPHRA HAZARDS

In this figure, the X-axis represents distance from the volcano. As can be seen by the concave curve from upper left to bottom right, the hazard decreases with distance; this is also reflected in the progression of areas of adaptation from uninhabitable in Area I to subsistence continuity in Area IV. The Y-axis represents the time elapsed after eruption; distal areas are more at risk later, as represented by the curve rising to the upper right. The four areas can be described in terms of adaptability and response. Area I is subject to pyroclastic flows, lahars and flooding that its conditions cannot be adapted to, and the best response is to avoid the area altogether. Area II is extremely difficult to adapt to and should be avoided, though the conditions there can be endured. Area III allows adaptation and the endurance of society. Area IV allows further adaptation with some impact on society. However, people may migrate beyond the area of tephra fallout, so coordination of archaeological materials in tephra and non-tephra regions is very important (cf. Chapters 5, 6).

South Kyushu (Figure 2) has been the locus of two very large (VEI 7) eruptions (Kuwahata 2014): the Aira eruption of 30,000 cal. BP (Smith et al. 2013) in the Late Palaeolithic, and the Kikai eruption of 5300 BC (Tatsumi 2018) during the Jōmon Period of hunter-gatherers (cf. Appendix C-7). Volcanic ash from both eruptions form key strata throughout the Japanese Islands. Tephra from Aira, located in Kagoshima Bay (cf. Chapter 2: Figure 5), was discovered in the Tanzawa Mountains near Tokyo, giving the tephra a dual name as Aira-Tanzawa (AT). The Kikai tephra is assigned the name Kikai-Akahoya (K-Ah). Both Aira and Kikai calderas are located in the Kirishima volcanic zone of southern Kyushu (cf. Appendix C-3: Figure C-7). Residents of the Japanese Islands have not experienced such intense broad-scale eruptions since the Kikai event.

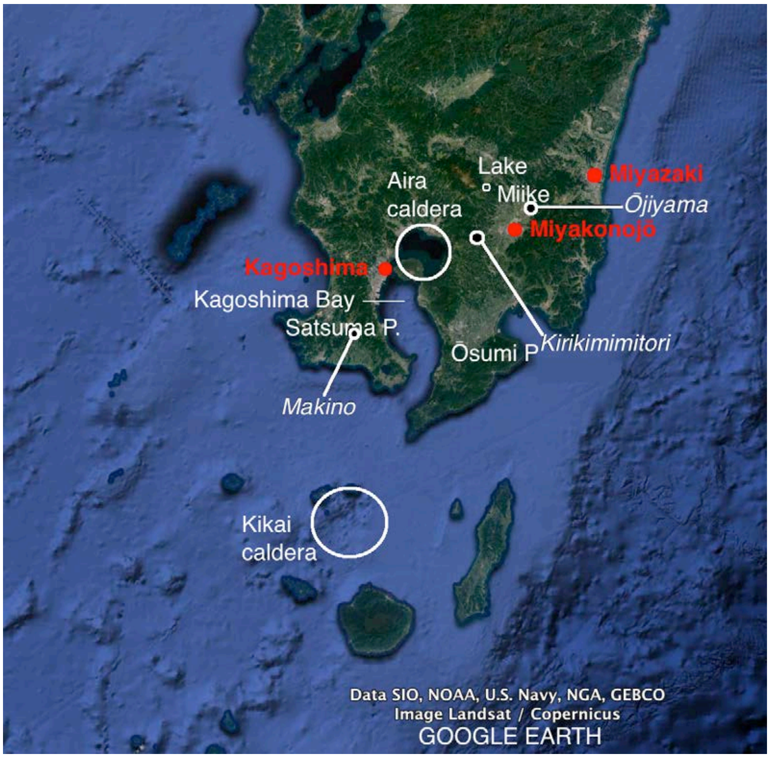

FIGURE 2 MAP OF SOUTHERN KYUSHU

The Aira eruption (411 km^3) (Nagaoka, Okuno & Arai 2001) exuded pumice pyroclastic flows within radii of 90 km from the vent. This area would fit within Area I as defined above in Figure 1, where survival was impossible and post-eruptive adaptation was difficult. The pumice resulting from the Ito pyroclastic flow (A-Ito) reached a maximum depth of 150 m, forming new barren uplands around the volcano. After deposition, the pumice was remobilized to flood the Miyakonojō Basin. Between this basin and the caldera (now the upper part of Kagoshima Bay), ^{14}C evidence at the Kirikimimitori site indicates that it took between 970 and 1550 years for people to re-establish themselves, attested by the introduction of a the new knife-tool culture into the area.

The Kikai volcano erupted 7300 years ago at peak sea level during the Climatic Optimum (Kuwahata 2014; Machida & Sugiyama 2002). The submerged caldera, 19 km dm, extruded more than 500 km^3 of magma (Tatsumi et al. 2018). The Kōya pyroclastic surge designated as K-Ky fanned out 100 km from the vent, and the co-ignimbrite K-Ah ash reached eastern Japan more than 1000 km distant (Figure 3). Within the areas of the Kōya and K-Ah ash deposits currently measuring 30 cm deep (Areas I–III in Figure 1), except for a few sites at the northern edge of the K-Ky deposit, all other sites with Nishinoen-type pottery (dating 5300–5000 BC) are distributed much further north, while none exist in the Satsuma and Ōsumi Peninsulae surrounding Kagoshima Bay nor on islands further south. These areas were totally devastated. However, after 4900 BC, sites with Todoroki B-type pottery are found throughout southern Kyushu except for the lower tips of the Peninsulae and southern islands. This changes after 4300 BC when Sobata-type pottery becomes ubiquitous except for on mountainous islands. It is notable that, during the Nishinoen and Todoroki B-1 phases, nut-processing tools are extremely rare, reflecting the damage done to the forests. Recovery is seen during Todoroki B-2 when querns and grinding stones again re-enter the toolkit. Ash cover is damaging, as seen during volcanic eruptions in 1959 and 1977; not only does the ash contribute to soil acidification, it cements with heavy rainfall, hindering forest recovery.

A third large volcanic eruption occurred at 4600 cal. BP from the Kirishima Miike vent, measuring VEI 5, forming the Miike caldera 1 km dm and the Miike crater lake. The Kirishima Miike tephra (1–10 km^3) was distributed to the southeast; pyroclastic surge deposits occur within 5–10 km of the vent. Thick pumice was also deposited to the southeast, affecting life in the Miyakonojō Basin. After total destruction of the flora, the basin was colonized by bamboo species (*medaka* and *nezasa*) and Miscanthus (*susuki*) (cf. Chapter 13). At the site of Kirikimimitori in Kagoshima Prefecture, where the Kirishima Miike tephra is currently 10 cm thick, a type of winter hazel (*Distylium racemosum*, *isunoki*), belonging to the Laurilignosa forest, was found directly under the tephra. This type of forest survived where the tephra was <10 cm.

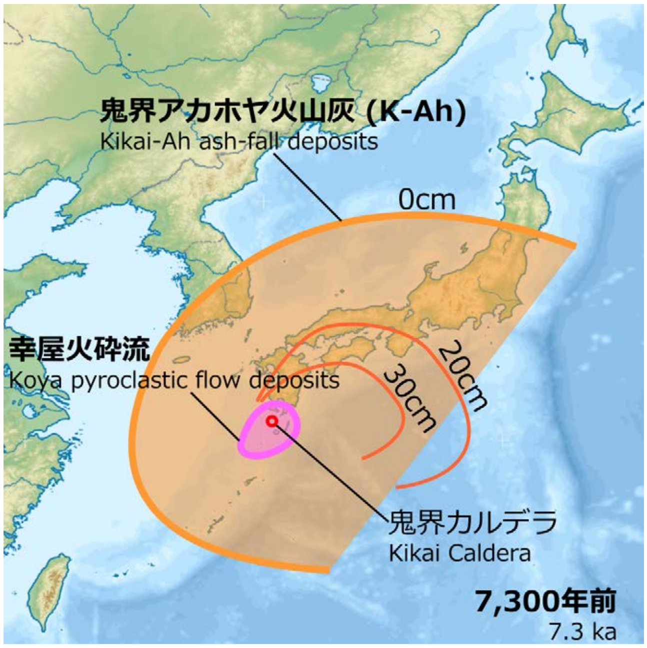

FIGURE 3 TEPHRA DISTRIBUTION FROM THE KIKAI ERUPTION 7300 CAL. BP

Work procedures in Archaeological Research on Volcanic Disasters

On-site Procedures

If samples of tephra are merely collected on site and taken to the lab for observation and analysis, the mode of deposition cannot be ascertained. A rigid distinction between sediments must be made. For example, in the case of the Akahoya tephra (K-Ah) from the Kikai caldera eruption, the chemical compositions of the volcanic glass and minerals are the same at the two sites shown in Figure 4.

However, at the Makino site in Kagoshima Prefecture (Figure 4, left), the K-Ah stratum is the result of a pyroclastic flow. At the Ōjiyama site in Miyazaki Prefecture (Figure 4, right), the K-Ah stratum consists

FIGURE 4 SECTIONS OF KIKAI-AKAHOYA TEPHRA (K-AH)
Left: Makino Site Right: Ōjiyama Site

of an ash fallout deposit. It is impossible to judge these sedimentation factors in a laboratory, thus on-site observation during sampling is crucial.

It is important to inspect and discuss the tephra stratigraphy in section plan among both archaeologists and tephra specialists and come to mutually agreeable interpretations. Ascertaining the exact stratigraphic relationships between each tephra layer and archaeological artefacts and features at each site can help build a picture of regional responses.

Procedures in the Laboratory

Determinations for identifying tephra should be made at both rock and mineral levels, and calculations should include the proportions of volcanic glass to minerals (see Appendix E). Chemical composition can be assessed using EPMA (electron probe micro-analysis). Artefact analysis involves investigation of changes through time in the forms of objects or their transformation, and changes in relative proportions of objects. In particular, comparisons can be made of material cultures before and after the tephra-fall. Similar comparisons can be made for land uses before and after the tephra-fall. The way the land was occupied and used often varies after the land surface has been covered with tephra. And finally, processes of recovery and restoration after the tephra-fall can be assessed.

Construction of Models of Human Adaptation in Volcanic Disasters

The procedures listed above must be repeated at each site. With the accumulation of case studies, disaster areas (tephra hazards) for each eruption can be clarified. By identifying the extent and pattern of each eruption and the nature of archaeological remains in these disaster areas, it will be possible to construct models of human adaptation in volcanic disasters.

Summary

By investigating the nature and extent of volcanic damage at each archaeological site, and by accumulating case studies, it becomes possible to distinguish various adaptations of humans who suffered volcanic disasters. The social structure of each society, each political system and economic foundation, and the values that the humans held conditioned their responses to volcanic disasters (cf. Chapter 15). We can track through time how they did or not adapt.

In future, we need to intensify our research into every corner of the Japanese archipelago. Then, having carried out comparative studies on comparable regions or within slices of time, it will become possible to develop a holistic approach to the subject.

Figure Sources

Figure 1 based on Tokui 1989: fig. 6
Figure 2 from Google Earth, modified by GLB
Figure 3 by © Hugo Lopez –Yug / Wikimedia Commons / CC-BY-SA-3.0
[https://commons.wikimedia.org/wiki/File:Kikai_K-Ah_tephra_7,3ka.svg]
Figure 4 supplied by the author

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CHAPTER 4

Volcanic Ash and Landscape Evolution: Reconstruction of a 7000-Year-Old Landscape on the Northwestern Great Plains of North America

Gerald A. Oetelaar *

Abstract

A decade ago, colleagues and I used the results of studies conducted after the 1980 Mt St Helens eruption in Washington State, U.S.A. to evaluate the impact of the Mazama ash fall on the ecology of the Northwestern Great Plains. More recently, I assessed the impact of this eruption on the nomadic bison hunters of the Northwestern Plains and argued for the abandonment of the region for a period of approximately 500 years. The displaced human populations sought refuge among their neighbours where they adopted and adapted a technological innovation allowing them to cope with the prolonged effects of future natural disasters. In this semi-arid environment, the ash fallout also offers opportunities to explore the evolution of the physical landscape and to examine how these changes may have influenced the activities of human groups occupying the Northwestern Plains at critical times during the Holocene. The discovery of this distinctive ash layer in river terraces, alluvial fans, prairie potholes, bluff edge dunes and lake cores allows us to correlate stratigraphic sections across multiple landforms and to explore landscape evolution on local and regional scales. Furthermore, a detailed examination of the deposits within these stratigraphic sections provides interesting insights into the pattern of sediment mobilization after the ash fallout but also raises concerns about some of the inferences generated by such studies.

Introduction

In the introduction to their book *Volcanic Activity and Human Ecology*, Sheets and Grayson (1979: 6) note that archaeologists all too often record the presence of a volcanic ash layer within an archaeological site without ever considering the ecological and social implications of the associated natural event. This observation also applies to researchers working in western North America who have used tephras as stratigraphic markers (e.g. Hallett et al. 1997; Mehringer et al. 1977; Mehringer et al. 1984; Porter 1978; Westgate & Briggs 1980; Westgate et al. 1970) but have rarely explored the potential impacts of the volcanic eruption on the local ecology or the landscape. Similarly, archaeologists and Earth scientists have relied on tephras to correlate stratigraphic sections across significant distances, but few have examined the associated landscape changes across landforms (e.g. Vreeken 1989, 1999).

This situation is unfortunate because tephra layers are preserved in a variety of geomorphological contexts, some of which are separated by thousands of kilometers. In fact, glass shards from Oregon's Mount Mazama have been recovered from Greenland ice cores (Zdanowicz et al. 1999), and cryptotephra from several Cascade Range volcanoes (cf. Appendix C-2) have been identified in Nordan's Pond Bog in eastern Newfoundland (Pyne-0'Donnell et al. 2012). The discovery of such chronostratigraphic markers allows researchers to correlate events across great distances and to relate local landscape changes to the established frameworks for regional developments.

Most of the thin tephra chronostratigraphic marker beds used in palaeoenvironmental reconstructions derive from lakes and swamp deposits, primarily because the preservation of thin tephra in terrestrial environments is poorly documented (Blong et al. 2017). However, Dugmore and his colleagues have

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recently explored the effects of slope and vegetation on the preservation of thin tephra in distal contexts (Cutler et al. 2016a; Cutler et al. 2016b; Dugmore et al. 2018). The results of their research suggest that vegetation more than slope influences the preservation and survival of thin tephra (<30 cm). Similarly, Blong et al. (2017) identify rapid initial compaction, vegetation and bioturbation as the important variables in the preservation of thin tephra deposits in terrestrial environments. One of the main objectives of this study is to illustrate the potential of such thin tephra chronographic markers in the interpretation and correlation of local and regional geomorphic processes and their relationship to the arrangement and distribution of archaeological sites on the landscape.

The Mazama Eruption

Mount Mazama, in southwestern Oregon state, is one of approximately 20 large volcanoes in the Cascade Range of Western North America (Figure 1), and these peaks account for at least 88 major eruptions during the Holocene (Kiver 1982). Of these, only Mount St Helens, Glacier Peak, and Mount Mazama have contributed tephra layers to deposits on the Northwestern Plains (Beget 1984; Blinman et al. 1979; Carrara 1995; Harris 1986; Mehringer et al. 1984; Vreeken 1986, 1989, 1999; Westgate & Evans 1978), but only the ash from the climactic eruption of Mount Mazama is sufficiently widespread for expansive long-distance correlations. The series of events culminating in the Plinian eruption of Mount Mazama and the formation of Crater Lake are described in detail in Bacon (1983).

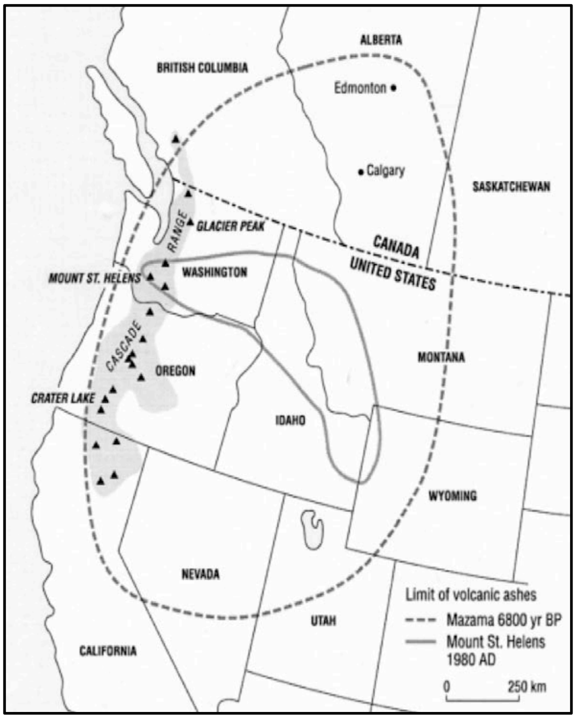

FIGURE 1 CASCADE RANGE AND ASH DISTRIBUTIONS FROM MOUNT ST HELENS AND MOUNT MAZAMA (CRATER LAKE)

The most recent calendrical age estimate for this event derives from Bayesian modelling of all previous radiocarbon age estimations (Egan et al. 2015). This estimate (7682–7584 cal. BP 2σ, 95.4% HPD; 7652–7605 cal. BP, 68.2% HPD; 7743–7567 cal. BP, 99.7% HPD)[1] is in very close agreement with radiocarbon dates obtained on organic sediments from a lake in Washington and one in Oregon (Blinman et al. 1979), on charcoal from a road cut in Oregon (Bacon 1983), and on charcoal and twigs from a lake in British Columbia (Hallett et al. 1997). The date also agrees well with the estimate of 7627±150 calendar year BP obtained through a detailed analysis of a short segment from the GISP2 ice core in Greenland (Zdanowicz et al. 1999) and the weighted ^{14}C date of 6730±45 (7640–7620 cal. BP) calculated by Hallett et al. (1997). Therefore, the age estimate for the Mazama ash is now relatively precise and can be used with confidence as a correlation point in palaeoenvironmental reconstructions (Egan et al. 2015).

[1] HPD = highest posterior density. In Bayesian statistics, the highest posterior density interval is the narrowest interval for a given posterior probability such as 95.4%. The posterior probability is derived from the sample of dates used in the calculations. In this case, one can be 95.4% certain that the actual date occurs within the interval defined by 7682 cal. BP and 7584 cal. BP. Note that this date supersedes the date in Figure 1.

On the autumn day of the eruption some 7630 years ago, the initial blasts from Mount Mazama were probably heard on the Northwestern Plains (Figure 2), some 1300 km northeast of the source, approximately one hour later. For the people living in central Montana, southern Alberta and southwestern Saskatchewan at this time, the sounds were probably interpreted as thunder, albeit a somewhat unusual thunder given the season of the year (Burrows et al. 2002). Some thirteen to sixteen hours later, the people braced for the impending storm as they witnessed the approach of an ominous dark cloud regularly illuminated by spectacular lightning displays followed by thunderous blasts. Instead of the anticipated rain, a dry snow settled on the ground and apparently continued to accumulate for approximately three years (Zdanowicz et al. 1999).

FIGURE 2 MAP OF THE NORTHWESTERN GREAT PLAINS & STUDY AREA

At the time of the eruption, large quantities of tephra were transported up to 2000 km north and east of the source vent, eventually covering well over one million square kilometers of western North America (Oetelaar & Beaudoin 2005), although individual shards and crytotephra travelled much greater distances (Pyne-O'Donnell et al. 2012; Zdanowich et al. 1999). Carried by the westerly airflow, the plume extended primarily to the north-northeast and blanketed the western portion of the Northwestern Plains in a relatively thick layer of ash. Where present, the ash layer today is typically from 5 to 10 cm thick (Beaudoin & King 1994; David 1970; Oetelaar 2002, 2004; Reeves & Dormaar 1972; Roed & Wasylyk 1973; Sauchyn & Sauchyn 1991; Vreeken 1994; Waters & Rutter 1984; Westgate & Dreimanis 1967). However, the fresh layer of ash deposited across central Montana, southern Alberta and southwestern Saskatchewan was probably 15 to 20 cm thick, because fresh layers of silt-sized ash from Mount St Helens were compressed by 47% after the first few rainfalls. Using this same ratio and an average thickness of 7 cm for the preserved ash layer in the Northwestern Plains, the fresh ash must have been, at least, 15 cm deep at the time of deposition. This estimate, of course, does not include the compaction resulting from the 1 to 1.5 m of clastic sediment overlying the ash at many localities, nor does it incorporate the potential loss of ash through various geomorphic processes such as heavy rains.

The impact of volcanic ash accumulations depends, to some extent, on the local climate, topography, and vegetation of the study area. For example, thick ash accumulations do not remain in place very long in environments with heavy rainfall (de Silva et al. 2000) or very strong winds. By contrast, ash fallouts in semi-arid environments tend to have a greater impact on the grassland vegetation and more prolonged residence times given the limited amount of precipitation (Oetelaar & Beaudoin 2005, 2016; Beaudoin & Oetelaar 2006). Destruction of or damage to the grassland vegetation, in turn, affects the survival of the animals, namely bison. When combined with the additional resource failures such as berry crops destroyed by late frosts and tubers stunted by lack of nutrients, the eruption of Mount Mazama forced the local population to abandon the area and seek refuge among their relations in non-impacted regions to the east (Oetelaar 2015; Oetelaar & Beaudoin 2016).

Upon their return, the descendants of the groups who abandoned the Northwestern Plains often returned to the campsites of their ancestors even though traces of the former occupants were no longer visible. The material remains, if present, were now buried beneath layers of tephra and clastic sediments mobilized by the absence of or decrease in vegetation cover. Groups returning to the Northwestern Plains after a prolonged absence of several centuries must have relied on landmarks and place names to guide them on their return journey. If so, researchers must determine the extent of any local and regional changes to the landscape resulting from this natural disaster. As noted below, the presence of Mazama tephra in a variety of landforms across the Northwestern Plains allows us to explore changes in landscape features ranging from the topography of the site or locality to the disappearance of water bodies ranging from glacial lakes to prairie potholes.

The Northwestern Plains

The Northwestern Plains, as part of the Great Plains region of North America, is defined in this study as extending from the eastern margins of the Rocky Mountains to the Missouri Coteau, a prominent ridge of hills extending from central North Dakota to central Saskatchewan, and from the Parkland in the north to the Yellowstone River in the south. Bordered on the west by the Rocky Mountains and the Foothills, the land generally slopes down to the east. Although often described as a flat, featureless landscape, the Northwestern Plains are dissected by deeply entrenched river valleys with misfit streams (Figure 3).

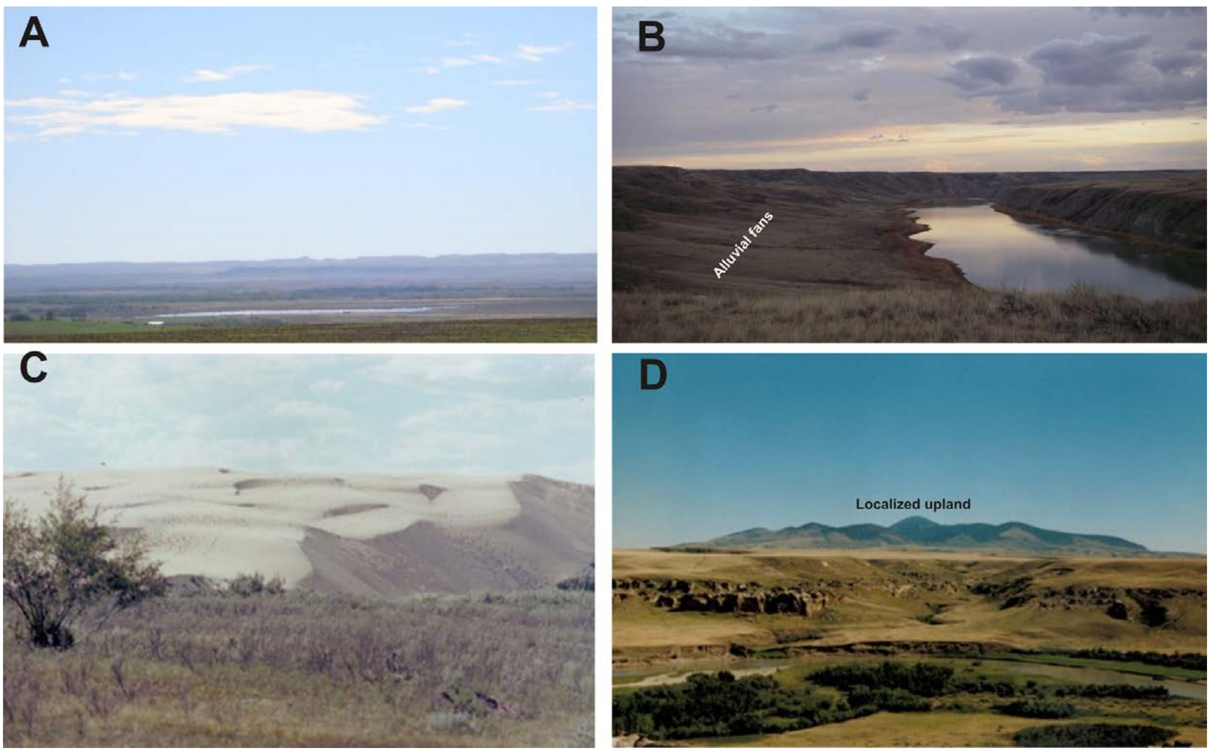

FIGURE 3 LANDFORMS OF THE NORTHERN GREAT PLAINS

A prairie pothole, **B** alluvial fans, **C** sand dunes, **D** entrenched valley and localized upland

Small tributary valleys and deep, steep coulees provide access to and egress from the floodplains of the major rivers. In addition, localized uplands, hummocky terrain, and sand dune complexes dot the prairie landscape. The hummocky terrain is widely scattered across the study area, as are the sand dune complexes. However, there is one dune concentration occurring in the eastern half of the study area where the Great Sandhills and adjacent dune complexes occupy large tracts of land in southwestern Saskatchewan. The localized uplands, from north to south, include the Neutral Hills, Hand Hills, Porcupine Hills, Milk River Ridge, Cypress Hills, Sweetgrass Hills, Bearspaw Mountains, Little Rocky Mountains, Highwood Mountains, Judith Mountains, Moccasin Mountains, Big Belt Mountains, Little Belt Mountains, Big Snowy Mountains, Little Snowy Mountains, Crazy Mountains, and Bull Mountains (Figure 4).

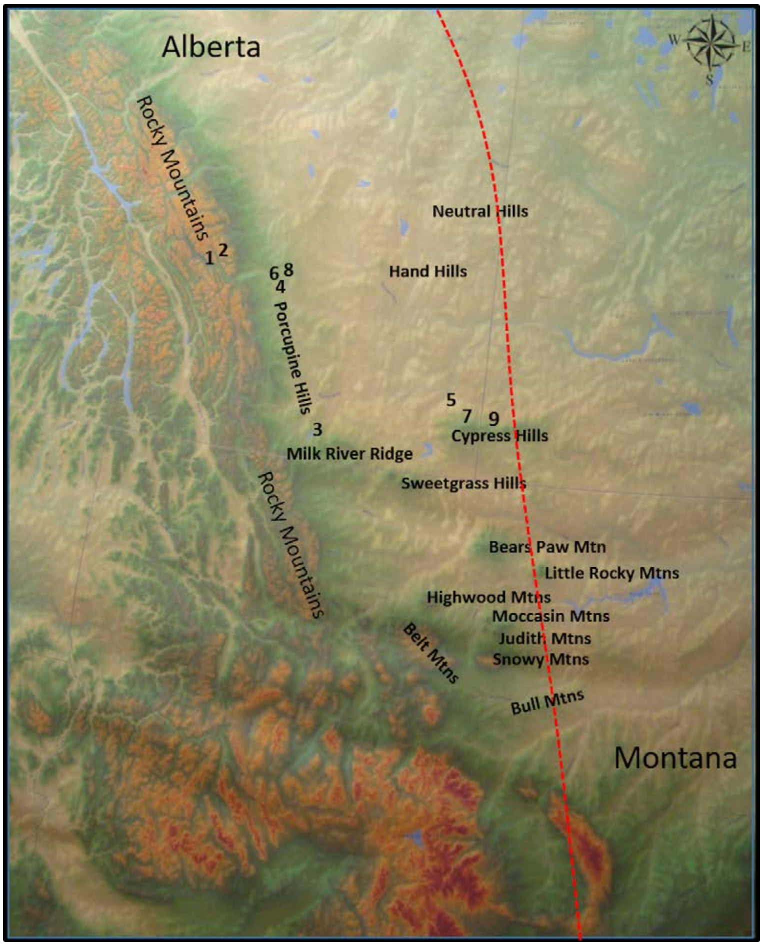

FIGURE 4 DIGITAL ELEVATION MODEL OF THE STUDY AREA
Localized uplands and sites (numbers # keyed to text)
Red dashed line=extent of Mazama Ash from west

Most of the landforms north of the Missouri River were initially created or modified by the advancing and retreating ice sheets. Water from melting ice formed large glacial lakes which later drained precipitously, creating major spill-ways, including many of the entrenched valleys currently occupied by misfit streams (Campbell & Campbell 1997; Christiansen 1979; Fisher 1999; Klassen 1994; Kulig 1996; Schreiner 1983; Wild 2003). Large blocks of ice periodically breaking off the nose of the glaciers sometimes melted in place, creating the hummocky terrain (Yansa 2006, 2007). In addition, sediments exposed by the retreating ice and the drainage of glacial lakes were mobilized by strong winds, and some of these deposits accumulated as sand dune complexes (David 1993).

Subsequently, geomorphological processes continued to alter actively the landscape. For example, changes in the rates of river discharges and sediment delivery to the drainage basin produced a succession of terraces within the main and tributary valleys (Evans et al. 2004; Jackson 1997; Oetelaar 2002; Rains & Welch 1988), whereas aeolian processes created the complexes of sand dunes and bluff edge dunes formed along the margins of exposed valley walls (David 1970; Wilson 1983: 418; Wolfe & Lemmen 1999). Colluvial and fluvial processes did and continue to generate slump blocks and alluvial fans, most of which accumulate at the base of steep slopes along the entrenched valley margins and localized uplands (Goulden & Sauchyn 1986; Thomson & Morgenstern 1977). In addition, the prairie potholes scattered across the landscape, especially in areas with hummocky terrain, are gradually filling in with sediment through natural and cultural processes such as sheet wash and cultivation respectively.

As implied by the name, the Northwestern Plains is a semi-arid grassland environment with a continental climate characterized by cold winters and short, dry summers, with most of the precipitation coming in May and June (Beaudoin 2003; Case & MacDonald 1995; Sauchyn et al. 2002; Sauchyn & Beaudoin 1998). Atmospheric moisture inputs vary from west to east with the greater amounts of precipitation (over 800 mm) falling in the mountains, primarily as snow during the winter months (Phillips 1990). By contrast, the most arid areas near the eastern margins of the study area receive less than 300 mm of annual precipitation, mostly summer rainfall. Strong westerly winds, some of which are associated with winter chinooks[2] which sublimate the accumulated snow, promote evapotranspiration and contribute to soil moisture deficits and drought – both of the latter common on the Northwestern Plains (Rannie 2006; Sauchyn & Skinner 2001; Sauchyn et al. 2003; Woodhouse & Overpeck 1998).

The major rivers flow from west to east and form part of two major drainages, the Saskatchewan and Missouri systems. The Saskatchewan drainage consists of the North Saskatchewan River and its main tributary, the Battle River, and the South Saskatchewan River which accepts waters from the Oldman, Bow and Red Deer Rivers. The Missouri River drainage includes waters from the Milk, Marias, Sun, Smith, Musselshell and Yellowstone Rivers. Throughout most of the study area, peak discharges occur in May and June, primarily from snow melt in the mountains (Axelson et al. 2009; Case & MacDonald 2003). By late summer, most of the smaller tributaries are mere trickles of water, and even the larger rivers have markedly reduced flows. Many closed drainage basins within the study area contain saline lakes (Last 1999), while the hummocky terrain is dotted with potholes or sloughs, most of which dry up completely in the summer.

Trees occur on the eastern slopes of the Rocky Mountains, in the foothills, on the localized uplands and within restricted sections of the river valleys. Although the absence of trees across most of the Northwestern Plains has been attributed to the dry climate and strong westerly winds, fire and bison also contributed to the restricted distribution of arboreal vegetation across this landscape. The implementation of fire suppression practices and the extermination of bison have allowed trees to encroach on grassland (Campbell et al. 1994). Shrubs and forbs tend to occur within the valleys and along the slopes of the dissected terrain and localized uplands. These plant communities also include a variety of berry bushes and species with edible shoots and roots. The grasslands consist of several plant communities which provide seasonal forage for the herbivores, including the bison. The grasslands have been subdivided into a number of ecoregions which, from north to south, consist of aspen parkland, moist mixed grassland, and mixed grasslands (Strong & Leggat 1992). A somewhat more restricted ecoregion, the fescue grassland, is located along the foothills and constitutes an important winter pasture for bison.

At the time of contact, the Northwestern Plains encompassed the homeland of the Blackfoot people and their neighbors. Accomplished bison hunters, these groups served, in large part, as the basis for the identification and definition of a ‘Typical Plains Culture’ (e.g. Wissler 1914). However, human occupation of the Northwestern Plains spans the Holocene with the earliest dates deriving from sites located in the mountain valleys and neighboring foothills (Kooyman et al. 2001, 2006; Landals 2008). Although horse and mountain sheep may have been the prey of choice for some of the earliest occupants of this environment, bison was the resource of prime importance throughout most of the human occupation on the Northwestern Plains (Bamforth 1988; Reeves 1990; Vickers 1986). The diet of meat was supplemented by a diversity of botanical resources (Armstrong 1993; Kaye & Moodie 1978; Peacock 1992), but water and fuel were the important constraints on the selection of locations for the establishment of campsites (Vickers & Peck 2004). Presumably motivated by the migratory habits of the bison, the

[2] The chinook is a warm winter wind from the west which can raise surface temperatures by as much as 30–40°F and sublimates the accumulated snow pack. The chinook wind is called the snow eater by the Blackfoot and other groups living in this area.

seasonal rounds of these hunter-gatherers are normally described as a movement from their winter camps in sheltered valleys along the Foothills and Parkland to their summer camps on the open prairie (Bamforth 1988; Brink 2008; Epp 1988; Hanson 1984; Morgan 1980; Peck 2004). The locations of campsites and kill sites reflect this patterned use of the landscape. Although winter campsites tend to be located in the wooded valley bottoms, the summer camps are arranged along a network of trails which, given the transportation technology, are located along the valley margins in the vicinity of important landmarks (Oetelaar & Olson 2000). Therefore, a good understanding of geomorphological changes across different types of landforms is important to the archaeologists working on the Northwestern Plains.

Evolution of the Northwestern Plains Landscape

From the Late Pleistocene to the Present

Using data from the study of landforms, stratigraphic sections and pollen cores, researchers working in this area have outlined the basic framework of ecophysical changes on the Northwestern Plains throughout the Holocene (Beaudoin & Oetelaar 2003; Kulig 1996; Sauchyn 1993a, 1993b; Vreeken 1986, 1993, 1994, 1996, 1999). The earliest evidence of human occupation in the area coincides with the melting of the ice sheets, the creation of glacial lakes, and the formation of meltwater channels as the lakes drained precipitously at the end of the Pleistocene (Landals 2008; Wilson 1983). The saturated sediments and steep valley margins initiated an episode of landscape instability characterized by mass movements of clastic debris in the mountains and along the margins of entrenched valleys and localized uplands (Christiansen & Sauer 1988; Jackson et al. 1982; Wilson 1983). The saturated sediments also created a park oasis where arboreal vegetation grew along the margins of potholes created by melting blocks of stagnant ice (Yansa 1998, 2006, 2007).

During the succeeding Hypsithermal interval (ca. 9000–5000 uncal. bp), decreased precipitation and increased temperatures lowered water tables, increased salinity in ponds and lakes, expanded grasslands, decreased vegetation cover, mobilized sediment, and increased fire frequency (Oetelaar 2011; Robertson 2011). The final interval (ca. 5000 uncal. bp ~ present), which includes the Sub-Boreal and Sub-Atlantic of the Blytt-Sernander sequence, is one of landscape stability with some evidence of dramatic landscape changes at the local level. Although such general frameworks are important, archaeologists need to understand changes at the local level and to correlate local changes across different types of landforms. The presence of volcanic ash in stratigraphic sections exposed during archaeological excavations allows us to correlate such local changes and to relate them to the broader framework.

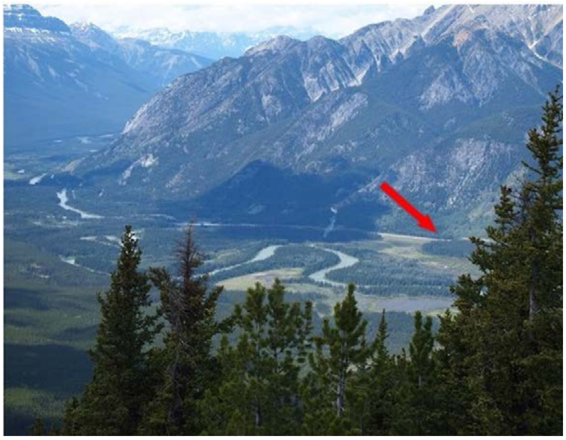

FIGURE 5 THE VERMILION LAKES SITE
Situated on an alluvial fan at the base of a mountain

Landforms and Archaeological Sites

Mountain Valleys: The Vermilion Lakes (Figure 4 #1)

The earliest evidence of human occupation in this area occurs within the mountain valleys and along the eastern foothills of the Rocky Mountains where the inland corridor or the first strip of deglaciated land on the Northwestern Plains occurred. The inland corridor was colonized from the north and/or the south (Bobrowsky et al. 1990; Gillespie 2002; Ives 2006; Kooyman et al. 2006). However, mass wasting of the unstable slopes created by the rapid drainage of mountain lakes was prevalent during the Late Pleistocene and Early Holocene as indicated by the presence of Mazama ash near the top of the alluvial fans produced by these processes (e.g. Roed & Wasylyk 1973). Despite being unstable, the alluvial fans were selected as loci for occupation when humans moved into these recently deglaciated environments – as illustrated by excavations at the Vermilion Lakes site near the town of Banff (Figure 5). At this site, the layer of Mazama ash is present near the top of the profile and the archaeological deposits, dating from 10,770 to 9640 uncal. bp, occur beneath the tephra (Fedje et al. 1995).

These data suggest that well before the tephra fallout, the alluvial fans had stabilized but were no longer selected as prime locations for campsites, perhaps because water was now more readily accessible at lower elevations within the valleys.

Mountain Lakes: The Lake Minnewanka Site (Figure 4 #2)

The Lake Minnewanka site is another archaeological locale near the town of Banff with evidence of human occupation extending back to ca. 10,800 uncal. bp (Figure 6). Occupation levels with the remains of hearths and associated artifacts were uncovered in sandy sediments of lacustrine or aeolian origin with occasional lenses with higher clay contents (Landals 1998, 1999, 2008).

FIGURE 6 EXCAVATIONS AT THE LAKE MINNEWANKA SITE
Inset: Plano point found at this location

Although the Mazama ash was present near the surface of the excavations, the units were located on the north shore of the lake where overlying sediments were removed by water and wind. Cultural materials of more recent age were recovered from occupation levels in similar sandy environments adjacent to the active shoreline. At this location then, the sediments above and below the tephra indicate very little change in the depositional environment. This evidence thus indicates that the earliest occupants moving through this area settled on the shore of a lake, presumably formed by meltwater from the valley glaciers, and continued to select this same place for the establishment of successive campsites throughout the Holocene, in part because the landscape was relatively stable at this location. Of equal importance is the fact that the Lake Minnewanka site is situated near Swan's Bill, a prominent landmark along the western margin of the Northwestern Plains indicating the location of an important pass across the Front Range of the Rocky Mountains.

River Crossings: The Wally's Beach Site (Figure 4 #3)

A third site with evidence of even earlier occupation is located along the eastern shore of the Saint Mary Reservoir in southern Alberta (Waters et al. 2015). Known today as Wally's Beach, the site is situated at an important historic crossing of the Saint Mary River (Kooyman et al. 2001, 2006). There is no continuous stratigraphic profile nor identifiable tephra at this locality, primarily because the sediments have been mobilized and redeposited by wind and water (Figure 7). Nevertheless, the river crossing and the coulees or ravines providing access to the ford appear to have been stable for some 11,000 years as indicated by the nature and linear arrangement of several horse skeletons (interpreted as horses that were intercepted and killed as they crossed the river at this location). That the landscape has been stable throughout most of the Holocene is further corroborated by the presence of diagnostic points from virtually every time period in the sample of surface collected materials from this locality.

In summary, the landscape of the Northwestern Plains may have been unstable during the Late Pleistocene and Early Holocene as suggested by the sedimentary profile at the Vermilion Lakes site, but other places selected for occupation by human groups such as Lake Minnewanka and Wally's Beach appear to have been relatively stable during this interval.

FIGURE 7 WALLY'S BEACH SITE
Exposed shoreline of the St Mary Reservoir during recent lowering of the water level

Bow River Terraces: The Mona Lisa Site (Figure 4 #4)

The major rivers intersecting the Northwestern Plains flow from west to east within deeply entrenched valleys, most of which were formed by very large quantities of glacial meltwater. The precipitous discharge of water from glacial lakes created very deep channels with steep, unstable walls of saturated sediments which collapsed and covered the basal sands and gravel with landslide debris. Thereafter, changes in base level, stream discharge, and sediment load caused episodes of aggradation and degradation (Figure 8) which created a series of terraces within the major river channels (Oetelaar 2002). In the glaciated portion of the study area, the river valleys typically contain a series of paired terraces at higher elevations and several unpaired terraces at lower elevations. In an earlier study, I used the presence of Mazama ash to correlate the lower series of paired terraces (T3) and to reconstruct the evolution of these alluvial landforms within the entrenched river valleys. Briefly, the highest and oldest paired terraces formed sometime between 10,000 and 9000 uncal. bp when a lowering of the base level and a marked increase in discharge allowed the rivers to cut a new channel through the thick layer of coarse gravel and sands which previously had filled in the meltwater channel sometime between 11,500 and 10,000 uncal. bp. A second episode of aggradation between 9000 and 5000 uncal. bp filled in this channel with a thick layer of landslide debris from the unstable slopes, followed by overbank deposits which include a layer of Mazama ash and a well-developed buried soil. From 5000 uncal. bp to the present, the rivers again down-cut through these sediments, creating a series of unpaired terraces within the present channel.

The nature and formation of these alluvial landforms once again serves to highlight their relationship to the general models of landscape evolution while, at the same time, revealing some local variations. For example, the rapid infilling of the meltwater channels and the subsequent dramatic down-cutting to form the upper series of paired terraces is consistent with the inferred instability of the landscape during the Late Pleistocene and Early Holocene. Furthermore, the relatively thick overbank deposits present in the stratigraphic profiles of the second set of paired terraces formed when river discharges were low and sediment load was high, as would be expected given the arid conditions of the Hypsithermal interval. However, the presence of a well-developed buried paleosol dating to 8000 uncal. bp located less than 10 cm below the tephra suggests the presence of a brief interval of landscape stability. During this episode of unknown duration, the floodplain was not subjected to periodic flooding because either the river discharge increased or the sediment load decreased.

FIGURE 8 BOW RIVER TERRACE AND PALEOSOL
Left: model of terrace formation along the Bow River
Right: photo of a T3 Terrace with a buried paleosol and a layer of Mazama Ash (white)

In addition, understanding how the terraces were formed allows researchers to identify landforms which are more likely to contain deeply buried archaeological sites of specific ages. Some researchers have suggested that the Northwestern Plains were largely abandoned during the Hypsithermal interval because of increased aridity (Albanese & Frison 1995; Forbis 1992; Husted 2002), whereas others argue for a change in subsistence and settlement strategies with a focus on refugia such as river valleys (Buchner 1980; Sheehan 1994, 2002). Still others suggest that the lack of sites is due to our failure to discover the deeply buried sites of this time period (Albanese 2000; Artz 2000; Bettis 1995; Mandel 1992; Reeves 1973; Waters & Kuehn 1996). Significantly, the paired terraces containing the Mazama ash are precisely those which formed by overbank deposition during the 3000-year Hypsithermal interval; archaeological sites such Mona Lisa, Gowen, and Saint Louis confirm the presence of deeply stratified cultural deposits dating to this interval within these terrace sediments (Amundsen & Meyer 2003; Cyr et al. 2011; Walker 1992; Wilson 1983).

Tributary Drainages: The Saamis Site (Figure 4 #5)

Rains and Welch (1988) used Mazama ash to establish the timing of terrace formation in the tributary drainages of the major rivers. They noted that the oldest terraces in the tributaries started to form at the same time as the paired terraces containing Mazama ash in the major rivers. Shortly thereafter, several researchers noted the presence of tephra layers in terraces along several tributaries of the main drainages in the study area (see Jackson 1997). These tributary drainages and the associated coulees provide access to the deeply entrenched river valleys and tend to funnel people and animals as they move across the landscape. Given the challenges of crossing these major river valleys, the tributary valleys and the associated fords become focal points of human activity, as indicated by the presence of surface features such as tipi rings (anchors for conical lodges) (e.g. Amundsen-Meyer 2014) and cultural material buried in the overbank deposits of the terraces such as the Saamis site (Brumley 1978).

The Nose Creek valley contains terraces with layers of Mazama ash (Figure 9) and provided access to the ford across the Bow River for people moving along the Old North Trail. However, not all tributary drainages contain terraces with identifiable layers of Mazama ash, and those lacking this chronostratigraphic unit are assumed to have formed sometime before or after the deposition of the tephra. Therefore, the presence of Mazama ash enables researchers to construct a temporal sequence for the development of terraces in tributary drainages across the Northwestern Plains. This information, in turn, allows archaeologists to determine when particular river crossings became accessible to the people moving across this landscape.

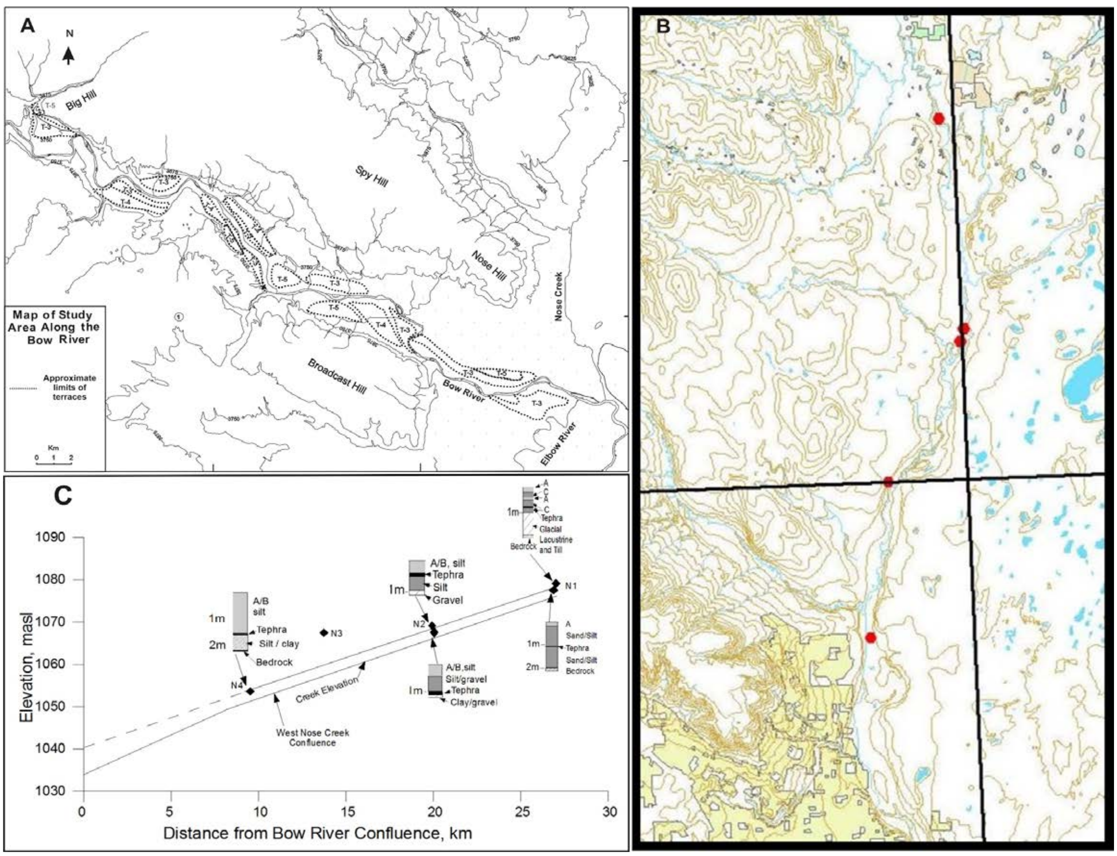

Figure 9 Maps of the Nose Creek
A: as a tributary of the Bow River, B: showing the locations of terraces with Mazama Ash, and C: the respective stratigraphic sections

Bluff Edge Dunes: The Tuscany Site (Figure 4 #6)

As noted earlier, the human groups who colonized the study area at the end of the Pleistocene probably moved northward along the inland corridor into the recently deglaciated landscape. As the continental ice sheet retreated eastward, the people soon started to colonize these areas as well. However, given the presence of expansive glacial lakes and deep meltwater channels filled with water, their movement was restricted to the lakeshores and margins of the meltwater channels. Even after the drainage of the glacial lakes and meltwater channels, people continued to follow the established trails along the valley margins because of the saturated sediments in the lake basins and valley floors. The subsequent invention or development of the dog travois made travel along the valley margins a necessity given the limitations of this transportation technology (Henderson 1994). For people moving along the valley margins, the slight relief and sandy deposits of bluff edge dunes become attractive dry locations for human settlements.

Bluff edge dunes form along the valley margins where erosion has exposed sediments to the force of strong prevailing winds. When the wind contacts the exposed bluff face, the moving air dislodges and transports particles of silt and fine sand to the top of the exposed face of the cutbank. As the wind breeches the crest of a valley margin, its energy dissipates and the sediment is deposited along the top of the exposed bluff face, with the coarser material being deposited near the valley margin and the finer sediments being released further from the edge of the valley. Dune formation continues as long as the bluff face remains exposed, and some bluff edge dunes contain a record of sedimentation spanning the Holocene (Oetelaar 2004). Sometimes, the bluff edge dune also impedes the local drainage and creates a small wetland on the lee side of the sand ridge, making such locations even more attractive as stopping places along one's journey.

The presence of Mazama ash in these accretional landforms allows us to correlate dune formation with other landscape changes and to describe, in more detail, the changing landscape experienced by the people whose undisturbed campsites are preserved in the deeply buried archaeological deposits present in these sand ridges. This is especially true of the bluff edge dunes that have been forming since the end of the Pleistocene and thus preserve a history of landscape changes and human travel through the area for 10,000 years or more. At the Tuscany site (Figure 10), for example, the stratigraphic profile across a bluff edge dune located on margins of the Bow River Valley reveals the presence of two buried paleosols beneath a layer of Mazama ash and one cumulic soil at the surface, each buried soil having associated cultural

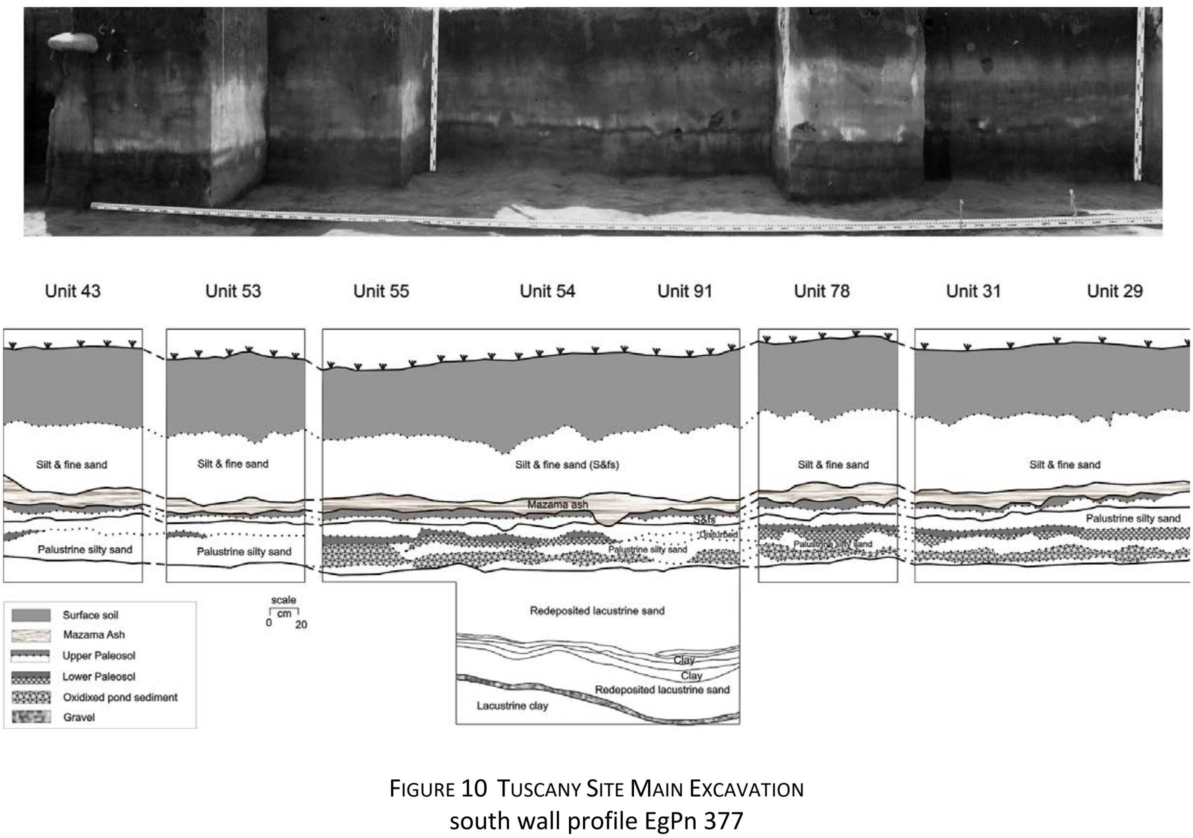

FIGURE 10 TUSCANY SITE MAIN EXCAVATION
south wall profile EgPn 377

materials (Oetelaar 2004). The lower paleosol in this bluff edge dune dates to the same time period as the 8000-year-old buried soil encountered in terraces along the Bow River and in alluvial fans along the valley margins (Wilson 1983). The presence of volcanic ash and buried soils within bluff edge dunes allows us to reconstruct the changing topography of the site area during successive periods of occupation and to compare the associated stratigraphic section with those of nearby river terraces (Wilson 1974).

Alluvial Fans: The Stampede Site (Figure 4 #7)

Many of the localized uplands scattered across the Northwestern Plains are veritable oases with a diversity of plants and animals, many of which have been introduced by people who have used these prominent features as landmarks for thousands of years (Oetelaar & Oetelaar 2007, 2008). In addition to food resources, the forested islands provide not only fuel but also water emanating from springs, most of which are located at the heads of local drainages (e.g. Goulden & Sauchyn 1986). The drainages create a series of alluvial fans at the base of the upland slopes; these landforms have been favored locations for the establishment of campsites. Deeply stratified sites with occupations spanning most of the Holocene preserve a history of landscape and cultural change, while the presence of Mazama ash in the resulting stratigraphic sections provides a mechanism for correlating the local geomorphological and cultural developments to changes happening elsewhere on the Northwestern Plains (Robertson 2002, 2006).

The Stampede site is one such deeply stratified, multicomponent open-air site located on an alluvial fan at the foot of the north slope of the Cypress Hills in southeastern Alberta, Canada. The cultural deposits extend over a large area on both sides of a small spring-fed stream flowing into an artificially enhanced marshland located at the eastern end of Elkwater Lake (Gryba 1972, 1975; Quigg 1979; Brumley 1980). Nineteen cultural components dating between 8000 uncal. bp and the present have been identified in sediments extending some 6 m below surface (Figure 11). A minimum of five cultural occupations predate the deposition of Mazama ash, whereas thirteen postdate the eruption. Additional culture-bearing strata have been identified below the lowest level in the excavation, but access to these materials has been precluded by an elevated water table.

The predominantly alluvial sediments with occasional lenses of colluvium exposed in the stratigraphic profiles at the Stampede site are relatively uniform in texture. However, the thicknesses of the deposits between dated paleosols are variable and this variability is attributed to differences in sedimentation rates ranging from 0.29 to 120.00 cm/100yrs (Oetelaar & Beaudoin 2016). Some of the observed differences in the sedimentation rates were relatable to the regional landscape changes described earlier, but others reflect a far more complex set of geomorphic processes operative in the area. For example, we personally witnessed the rapid accumulation of thick deposits of alluvium at this site during the exceptionally wet spring and summer of 2002 when storms deposited approximately one meter of snow on the plateau of this localized upland, while warm weather a few days later caused the snow to melt very rapidly. The sudden influx of water into the narrow channel caused the stream to overflow its banks and to deposit a layer of alluvium approximately 4 cm thick just west of the excavation (see Figure 11: top right). A succession of three such events over a period of ten years would account for the apparent anomalous sedimentation rate of 120.00 cm/100yrs noted at the Stampede site.

In addition to abnormal weather conditions, the activities of animals such as the beaver can account for rapid sediment accumulation in a particular drainage (Butler & Malanson 2005). In the case of the Stampede site, the small stream flowing across the alluvial fan contains a series of beaver dams (comparable to the one depicted in the second photo in Figure 11) spaced at somewhat regular intervals upstream of the site. Although the ages of the beaver dams at the Stampede site have not been determined, dated samples of beaver gnawed wood have been recovered from Holocene deposits throughout southern Alberta and southern Saskatchewan (Beaudoin 1992; Dew 1959; Rains 1987; Yansa 2006). Even slight fluctuations in water level or stream discharge can breach beaver dams causing successive failures and a sudden influx of sediment across the alluvial fan.

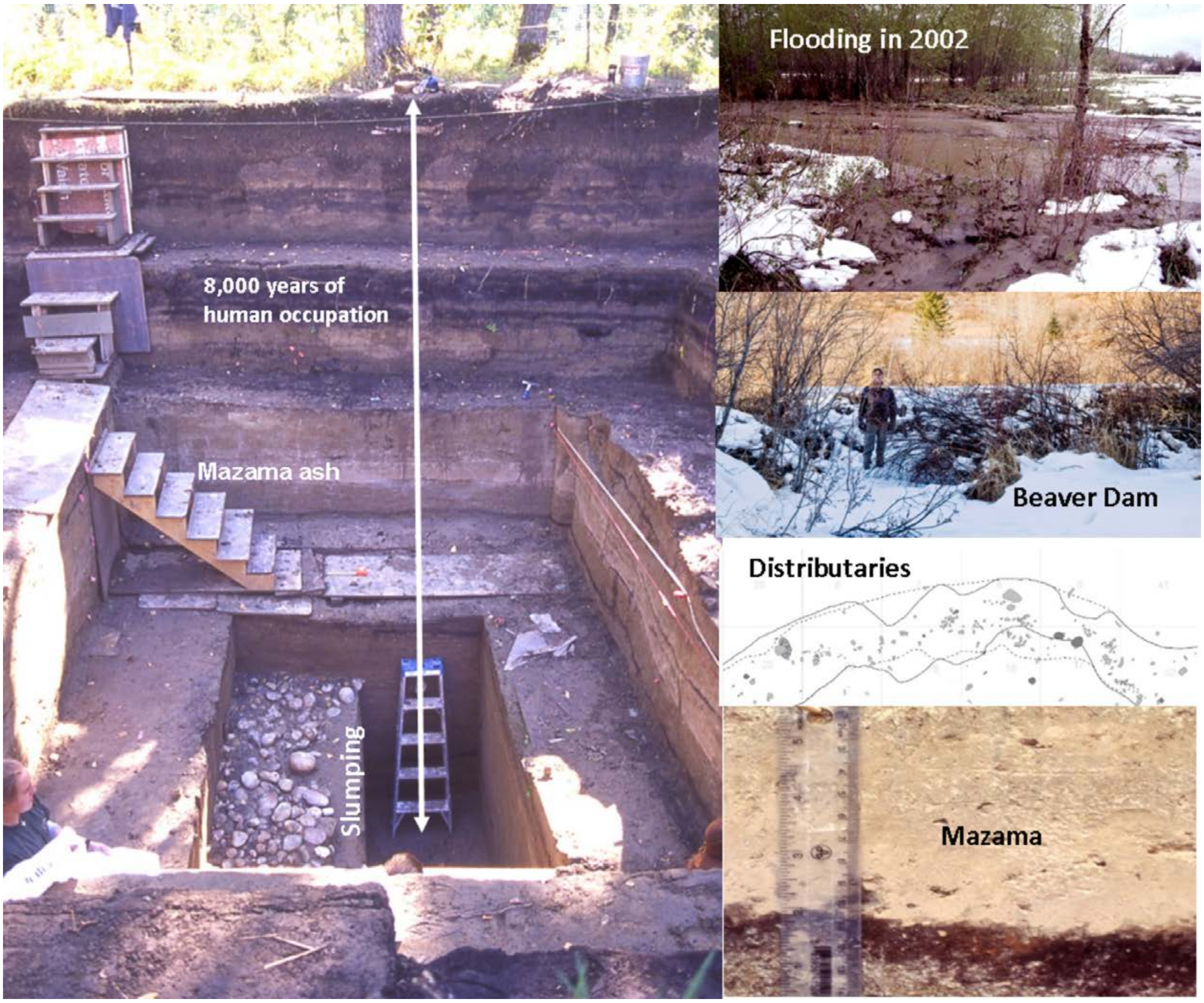

FIGURE 11 EXCAVATION AT THE STAMPEDE SITE

Left: South wall showing the locations of buried soils and the intervening sediments
Right: Processes potentially responsible for the introduction of sediments to this alluvial fan

The arrangement, movement and distribution of the channels flowing across the surface of alluvial fans also influence local rates of sediment accumulation. The distributaries flowing across the surface of an alluvial fan remove sediments from some locations and deposit materials elsewhere on the landform. That such processes were active at the Stampede site was confirmed by the exposure of a former channel in the southern portion of the excavation (see line drawing of the channel in Figure 11). Significantly, artifacts, including faunal remains, were recovered from within the channel suggesting that these processes were probably responsible for the overlapping dates in this section of the profile. As a result, the distributaries do influence local rates of sediment accumulation and removal, but they also contribute to potential errors in the calculation of these values through the vertical displacement of datable materials.

Another process contributing to the high rates of sediment influx locally was mass wasting by valley head erosion, especially during episodes of increased moisture availability (Lemmen et al. 1998; Sauchyn & Golden 1988; Sauchyn & Nelson 1999; Spence & Sauchyn 1999). Rain and melt water readily permeate the loess and conglomerate, while the underlying beds of sand, silt, and clay induce lateral flow – creating seeps and springs along the valley margins (Sauchyn 1999). During particularly wet intervals or seasons with high runoff, the fine-grained sediments underlying the Cypress Hills Formation are susceptible to mass wasting and eventual transport downstream (e.g. McPherson & Rannie 1969). Subsequent headward erosion undercuts the Tertiary-age conglomerate which eventually collapses causing the clasts to be transported down the valley where they come to rest on the alluvial fan (see Figure 11). Similar clasts were encountered at roughly the same elevation in two bore holes located 150 m east of the archaeological excavation (Catto 1981; Quigg 1979). Surprisingly, the mass wasting which appears to have contributed to the deposition of the coarse gravel layer at the Stampede site occurred shortly before the deposition of Mazama ash during the interval of maximum aridity between 7700 to 6800 uncal. bp (Sauchyn & Sauchyn 1991).

In addition to these local processes, there is evidence that the deposition of Mazama ash also affected the rate of sediment accumulation. For example, the very high C/N (carbon/nitrogen) ratio (45.5:1) for the paleosol located immediately below the tephra suggests a rather sudden cessation of microbial activity due to rapid burial of the vegetation by volcanic ash (Klassen 2004: 745). That disruption of vegetative growth may have initiated an episode of rapid sediment accumulation is suggested by the propensity of deposits overlying the tephra to slump during excavation. At both the Stampede and the Tuscany sites, only the sediments located right above the Mazama ash tended to slump. At the Tuscany site, the slumping of sediments located above the tephra was attributed to the absence of pedogenic units in this section of the profile. Ironically, contractors working on the nearby residential development encountered similar problems while excavating trenches for water mains and sewer lines; they blamed the slumping on the presence of the tephra lens which they assumed created a slip face for the overlying sediment.

At the Stampede site, wall failure could not be attributed to the absence of buried soils because the lower 2 m of the excavation never slumped, even though the vertical exposures in this section contained no evidence of soil formation. Furthermore, the walls in the bottom of the excavation did not collapse even though the units were regularly submerged in 2 to 3 meters of water. Moreover, wall collapses did not occur after increases in precipitation, nor could they be attributed to the careless actions of the excavators. The most logical explanation for the slumping, in my opinion, is that the tephra fallout initiated the mobilization of some surface deposits and contributed to the rapid accumulation of sediments. As a result, the deposits located above the ash tended to slump during excavation because the sediments did not have adequate time to compact during the interval of accumulation.

Since its discovery in the late 1960s, the Stampede site has been the subject of numerous investigations including three designed specifically to establish the horizontal and vertical extent of the cultural deposits. To accomplish these objectives, researchers have employed a hollow core auger, a backhoe, a bucket auger, and a geoprobe (Catto 1981; Brumley 1980; Quigg 1979; Robertson 2006). Several of the extracted cores and the stratigraphic profiles in the backhoe trenches contained identifiable layers of Mazama ash as well as a layer of coarse gravel. Preliminary investigations of the stratigraphy in these samples indicated obvious changes in the local topography and the location of the main creek channel. To reconstruct the local topography at the time of ash deposition, Blakey (2002, 2003) extracted a series of cores along transects which extended from the alluvial fan to the meltwater channel along the north face of the West Block of the Cypress Hills. The preliminary results of her analysis clearly illustrate changes in the local topography and highlight the potential use of tephra layers to reconstruct the land surface of some sites at the time of the volcanic eruption.

Hummocky Moraine: The Hawkwood site (Figure 4 #8)

At the end of the Pleistocene, stagnant blocks of ice scattered across the Northwestern Plains melted in place, creating potholes filled with water surrounded by ridges of till, a landform variously known as hummocky moraine or 'knob and kettle' terrain. The fortuitous discovery of preserved beaver-gnawed tree trunks and assorted macro-botanical remains by local farmers and ranchers trying to deepen dried-out potholes to reach groundwater for their animals prompted the systematic investigation of these prairie potholes (see Dew 1959). Detailed analyses of the stratigraphy, botanical remains, faunal remains, and associated radiometric dates enabled researchers to revise our understanding of the landscape and vegetation changes during the Late Pleistocene and Early Holocene (see left panel in Figure 12). In particular, earlier reconstructions of the regional vegetation as a succession of spruce and pine forests were replaced by models where the distribution of arboreal vegetation was restricted to the margins of the prairie potholes in a setting described as parkland oases.

Shortly after deglaciation, for example, the uplands of the Northwestern Plains were covered with prairie grasses and herbs, whereas the lakes and ponds on the hummocky moraines were surrounded by spruce trees, shrubs, and occasional deciduous trees (Yansa 2007). As the saturated sediments of the surrounding area lost their moisture and water levels in the lakes and ponds decreased between 11,500 and 9000 uncal. bp, the spruce parkland gradually gave way to a deciduous parkland and eventually a grassland. In this reconstruction, the persistence of arboreal vegetation on the prairie landscape is attributed to the gradual drying of the saturated sediments created by the melting of the ice and the drainage of the glacial lakes. The lakes and ponds, especially those concentrated within the areas of hummocky terrain scattered across the Northwestern Plains, served as oases with potable water, fuel, and diverse subsistence resources. The widespread distribution of these oases gave people considerable flexibility in the direction and distance of travel, and in the selection of suitable campsites.

The stratigraphic sections of these potholes indicate that, by the time of the Mazama tephra fallout, many of the prairie potholes no longer contained standing water, and even fewer had trees growing in the area. In some cases, the snowmelt in the spring replenished the water supply temporarily, but most of these sources of potable water dried out completely by late summer. For human groups moving across the Northwestern Plains at this time, the number of oases was now very restricted; and for travelers in summer, the once potable sources of water became alkaline sloughs unfit for human consumption. Therefore, as the parkland oases of the early Holocene gave way to dry prairie potholes, human groups changed the locations of their travel corridors and campsites to take advantage of springs located along valley margins and the steep slopes of localized uplands. In fact, some of the depressions once filled with water were now selected as suitable places for the establishment of campsites.

The Hawkwood site in the city of Calgary, Alberta, is one such campsite with cultural materials recovered from six occupation levels extending some two meters below surface. The stratigraphic profile includes alternating pond sediments and buried soils beneath a layer of Mazama ash, with aeolian and colluvial sediments – some of which also contain buried soils – occurring above the tephra (Figure 12). This deeply stratified site has four cultural levels beneath the tephra level and two occupations above the layer of Mazama ash. The earliest occupation, which dates from 8000 uncal. bp, is associated with one of the lower paleosols; it includes hearths and large stones, the latter possibly serving as anchors for a structure. The remaining cultural components located beneath the ash have diagnostic artifacts and radiometric dates consistent with occupations predating the deposition of Mazama ash. The cultural deposits located above the tephra are generally contemporaneous with those exposed above the tephra in the bluff edge dune at the Tuscany site discussed earlier.

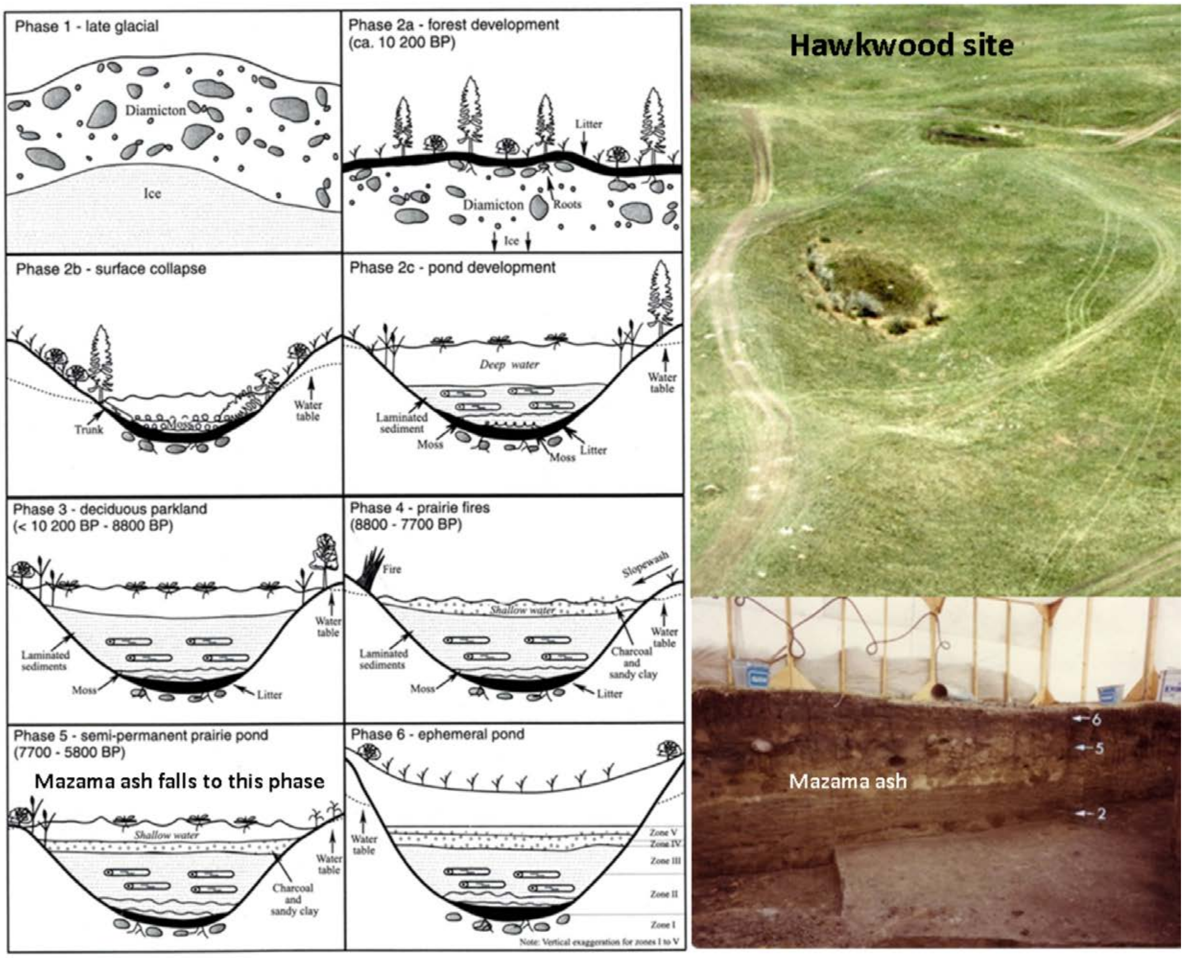

FIGURE 12 POTHOLE DEVELOPMENT

Left: Reconstruction of Late Glacial to mid-Holocene Paleoenvironmental change at a prairie pothole
Right: Photographs of the Hawkwood Site provide details on sediment accumulation during the mid- to late-Holocene

In a preliminary study of tephra deposits in the Calgary area, Svoboda (n.d.) recorded the depths of Mazama ash lenses in terraces along primary and secondary drainages, and in depressions such as the one occupied by the Hawkwood site. As defined in that study, depressions consist of closed topographic lows varying in size from tens of meters in diameter to seasonally dry sloughs covering a hundred hectares or more. Primary drainages in the area include year-round streams such as the Bow River, Elbow River, Nose Creek, West Nose Creek, Fish Creek, Pine Creek, and Lott Creek. Secondary drainages are here defined as seasonal or intermittent watercourses together with their alluvial fans which, in the study area, consist primarily of coulees and gullies. Given the variability in the processes responsible for the addition of sediments to these different landforms, there is a remarkable degree of similarity in the thickness of deposits overlying the tephra layers (Table 1). However, the accumulation of sediments on the terraces of the primary drainages probably was very sporadic after the river started to down cut at approximately 5000 uncal. bp. Thus, the thicker layer of sediment located above the tephra on the terraces accumulated in approximately 2000 to 3000 years, whereas the thinner deposits overlying the ash layers in the depressions accumulated in the past 6000 to 7000 years.

TABLE 1 THICKNESS OF SEDIMENTS OVERLYING MAZAMA ASH IN STRATIGRAPHIC PROFILES FROM TERRACES AND PRAIRIE POTHOLES

Landforms	**Number**	**Depths recorded in cm below surface**			
		mean	median	maximum	minimum
Primary drainages	44	116	100	300	30
Secondary drainages	83	98	90	250	34
Depressions	163	78	74	200	25
All Deposits	290	97	88	300	25

Lacustrine Sedimentation: Harris Lake (Figure 4 #9)

When encountered in pollen cores, Mazama ash is normally used as a chronostratigraphic marker which, along with a series of radiocarbon dates, is used to derive sedimentation rates for particular lake basins. Changes in the sedimentation rates within these cores are then related to geomorphological processes which presumably influenced sediment delivery to the catchment basin of the lake. Sauchyn (1990), for example, computed sedimentation rates ranging from 2.8 to 17.0 cm /100 yrs for the core extracted from Harris Lake (Figure 13).

FIGURE 13 LOCATION OF HARRIS LAKE ON THE NORTHERN SLOPES OF THE CYPRESS HILLS

The highest sedimentation rate (17.0 cm/100yrs) occurred between 5000 and 3500 uncal. bp, an interval of higher humidity which increased ground water discharge and caused a higher number of landslides in the drainage basin. The second highest sedimentation rate (14.5 cm/100 yrs) was computed for the 1800-year interval between 6880 and 5000 uncal. bp. In this case, the dramatic increase in the rate of sediment accumulation in Harris Lake was attributed to the mobilization of sediments following the denudation of the local vegetation after the Mazama tephra fallout.

More often, the presence of Mazama ash in pollen cores is used to correlate vegetation changes over large areas. In these studies, the nature of the local and regional vegetation cover is inferred from the proportional representation of plant species identified from the preserved pollen grains and, to a lesser extent, from the preserved macrobotanical remains. Assessments of the density of vegetation cover, by contrast, are derived from pollen accumulation rates or estimates of pollen influx. Such estimates are based on pollen grain counts relative to a standard – such as the number of *Lycopodium* spores introduced during sample preparation – and the sedimentation rate, which is normally assumed to be relatively constant over time.

In the majority of pollen studies, the density of vegetation cover is normally sparse during the Late Pleistocene and Early Holocene and fluctuates somewhat thereafter. For the remainder of the Holocene, the proportional representation of particular species is of primary interest. Recently, however, several researchers have attempted to evaluate the recovery rate of local vegetation after a tephra fallout (Long et al. 2014; Lotter et al. 1995; Rainville 2015). For example, Rainville (2015) estimated the interval for the recovery of vegetation after the deposition of Mazama ash to be approximately 200 years. Such information is particularly valuable for researchers interested in the length of the interval for human reoccupation of an area impacted by tephra fallouts. However, we need also to remember the geological processes which can alter the rate of sediment delivery to the lake basin (e.g. Sauchyn 1990). Assuming that the Mazama tephra fallout did kill off the grasses and, by extension, promoted the mobilization of sediments, then the low pollen counts derived from samples located above the tephra layer could, in fact, reflect an increase in the sedimentation rate rather than a reduction in pollen influx per se. If correct, this observation has important implications for those who attempt to model the recovery rate of local vegetation after a tephra fallout.

Discussion

Although volcanic ash has been used as a chronostratigraphic marker for many decades now, researchers should begin to explore new opportunities beyond the simple correlation of deposits in widely separated stratigraphic sections. For example, the presence of glass shards in the Greenland ice cores identified as originating from Mount Mazama allowed Oetelaar and Beaudoin (2005) to relate the inferred impact of the tephra fallout on northern hemisphere climate to the failure of berry crops for hunter-gatherers living in the Northwestern Plains area. In this chapter, the focus is more on the exploration of stratigraphic correlation as a tool to examine the evolution of the landscape on a local and regional level.

As noted throughout this chapter, the presence of a tephra layer in a stratigraphic profile allows researchers to relate local changes to established regional sequences. In some cases, the local changes accurately reflect the shifts observed at the regional level; in other instances, processes operative at the local level contribute to very different outcomes. For example, the landscape of the Late Pleistocene and Early Holocene is normally described as very dynamic, an observation consistent with the nature of alluvial fans in the foothills and Rocky Mountains as well as in the meltwater channels and some of the glacial lakes. At the same time, specific locations along the shores of some lakes and at particular river crossings appear to have been relatively stable throughout this interval. Significantly, both stable and unstable geomorphological landforms exhibit evidence of human occupation, although stable locations tend to have more evidence of prolonged use, sometimes covering the entire cultural sequence in the area. Significantly, these places represent important locations along travel corridors through the area.

Although the botanical and faunal resources are important determinants of subsistence and settlement strategies, the availability of potable water is also an important consideration on the Northwestern Plains. During the early Holocene, depressions, especially those in hummocky terrain, were veritable oases with abundant potable water and a supply of fuel provided by the trees and shrubs growing along the margins of the ponds. No doubt, animals were attracted to these same places to satisfy their thirst and to bathe in the cool water. These oases were, in all probability, more stable and attractive to the resident population, especially when compared to the river valleys with their unstable margins and floodplains subjected to massive influxes of sand and gravel. Furthermore, the moisture from the decaying ice, glacial lake draining, and the saturated sediments – all of which were responsible for the mass wasting along the valley walls – helped to maintain the water level within the depressions. Movement across this landscape was thus constrained by the presence of dry land corridors connecting a series of suitable potholes.

The persistence of warm, dry weather during the Hypsithermal interval led to the gradual evaporation of soil moisture and the eventual lowering of the water table until the prairie potholes were little more than damp depressions. Although the spring snow melt sometimes contributed sufficient moisture to create a standing body of water, these depressions soon dried out in the summer heat. This process of desiccation was well under way by the time of the eruption and the deposition of the Mazama ash. Nonetheless, the addition of the ash to the few remaining potholes with standing water posed serious challenges to the occupants of the Northwestern Plains at this time. Their quest for potable water presumably led them to the springs, most of which occur along the margins of river valleys and localized uplands of various sizes. At this time, the sediment load in the rivers and the energy of the currents set the stage for aggradation by overbank deposition of alluvium, making the valleys more attractive for human settlement. At the time of, and shortly after, the eruption of Mount Mazama, people moved along a network of trails bordering the river valleys, with campsites established in the vicinity of springs and cottonwood groves. When travelling from one river valley to the next, the hunter-gatherers established their camps near springs located along the margins of localized uplands. As noted above, the various places selected by these groups exhibited varying degrees of landscape modification, most of which were somewhat localized.

Conclusion

Although volcanic ash deposits have a long history of use as chronostratigraphic marker beds, only recently have archaeologists begun to explore in detail the impacts of the tephra fallout on the local ecology and on the resident human groups, whether they be hunter-gatherers or sedentary horticulturalists. The use of tephra layers has opened new opportunities for exploring the rate of vegetation recovery, the survival or return of animal populations, and the resilience of human groups in the face of such disasters. Moreover, the identification of glass shards in ice cores in Greenland and the recovery of cryptotephra from bogs in eastern North America allows researchers to relate atmospheric changes of relatively short duration documented in glaciers to potential events in the lives of individuals living in the impact zone at the time of the eruption. The challenge presented to the archaeologist is to identify the material consequences of such events during the excavation of sites having evidence of occupation before and after the eruption.

The primary objective of this research was to explore the potential use of tephra deposits in correlating local and regional landscape changes. The presence of Mazama ash in the stratigraphic profiles of units excavated in alluvial fans, lake margins, river terraces, bluff edge dunes and prairie potholes scattered across the Northwestern Plains provides unique opportunities to explore such changes. Of particular interest to this study is the impact of such changes on the patterned movement of humans across the landscape. Although subsistence resources are important influences on the nature and direction of travel, so too are other critical resources such as fuel and water. Thus, the conversion of early Holocene parkland oases into a grassland with depressions containing water only for a brief interval after the snow melt limited the number of suitable locations for the establishment of campsites by nomadic groups occupying the Northwestern Plains at this time. Thereafter, the people had to rely more on the springs for potable water and this resource was now available primarily along the valley margins and the peripheries of localized uplands. The preferred avenues of communication now shifted to the valley margins where bluff edge dunes were often selected as suitable locations for the establishment of camps. At the same time, terrace development in the main river valleys and the establishment of tributary drainages provided access to a greater number of river crossings and to the diverse resources within the valleys. The presence of deeply stratified archaeological sites in the majority of these landforms allows archaeologists to explore the possible relationship between changes in the local landscape and changes in the adaptive strategies of the groups living on the Northwestern Plains.

Figure & Table Sources

Figure 1 courtesy of Alwynne Beaudoin
Figure 2 modified by GLB from Farrell & David 2014: fig. 1 of WWF illustration
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Figure 9-A by author, B and C courtesy of Carl Svoboda
Figure 10 photo and profile drawing by author
Figure 11 courtesy of Dale Walde depicted in the photo.
Figure 12 graphic courtesy of Catherine Yansa; photos courtesy of Royal Alberta Museum
Figure 13 image from Google Earth

Table 1 data compiled from information presented in Svoboda n.d.

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CHAPTER 5

Volcanoes and Settlement in the North Pacific: Late Holocene Settlement Patterns in the Western Aleutian and Kuril Islands

Ben FITZHUGH *, Caroline FUNK ** & Jody BOURGEOIS ***

ALAID VOLCANO, NORTHERN KURILS VEWED FROM SHUMSHU ISLAND

Abstract

Archaeologists working around the North Pacific 'Ring of Fire' frequently invoke volcanic events in archaeological interpretations of regional abandonment. The Aleutian and Kuril archipelagos stretch for thousands of kilometres around the subarctic North Pacific Rim. Both chains are volcanic and tectonic in origin and are exposed regularly to volcanic eruptions, earthquakes, and tsunamis. Despite these hazards, humans have settled and survived in both chains for thousands of years. Unangan (Aleut) ancestors have a more or less unbroken 6500-year history of occupation in the central and western Aleutian Islands but even longer on the eastern islands in the archipelago. By contrast, the central Kuril Islands appear to have been depopulated twice in the late Holocene. We explore the hypothesis that these different occupational histories are related to marked regional differences in the proximity of active volcanoes.

Introduction

We examine evidence from two regions – the Rat Islands in the western Aleutians, and the central Kuril Islands – to ask how often people might have witnessed hazardous volcanic events while living in these archipelagos in the archaeological past and whether settlement patterns were influenced by volcanic hazard avoidance. To place these regions in a larger context, we review some of the largest Holocene eruptions around the North Pacific Rim and their reported impacts on human settlement. Then we focus in on our study areas and discuss stratigraphic records and settlement distributions to address these questions. Based on these comparisons, we argue that volcanic activity affected archaeological locations

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much less often in the Rat Islands than in the central Kurils. This may have been because ancient Unangan people were able to place settlements far from volcanoes there. In the central Kurils, volcanoes left many more deposits in archaeological stratigraphy; but even in those cases, past settlement history was not significantly altered, and most eruptions would have done little more than trigger temporary evacuations. In neither region do we have evidence of long-term abandonment of regions in relation to large volcanic eruptions as has been reported elsewhere. Despite this assessment, we think advances in methods are needed to be able to study the question of volcanic impacts at local scales.

The impacts of volcanoes on the persistence and settlement practices of North Pacific Rim hunter-gatherers in the Holocene are poorly studied, and little is known about the degree to which volcanic hazards were common and catastrophic for communities and groups living throughout the area. This is especially true for the remote island regions of the Aleutians and Kurils (Figure 1), where eruptions could have had exaggerated impacts on ecosystems and the limited land areas that people depended on for their settlements and livelihoods. In this paper we seek to evaluate the degree of hazard people faced in living with volcanoes in these regions. We review published evidence of the effects of prehistoric volcanic eruptions on human occupants around the greater region and then compare the volcanic geology and archaeological settlement patterns in two case studies focused on the western Aleutian Rat Islands and the central Kuril Islands, respectively. Our main lines of evidence for comparing these cases will be tephra-archaeological stratigraphy and settlement distributions relative to active volcanoes.

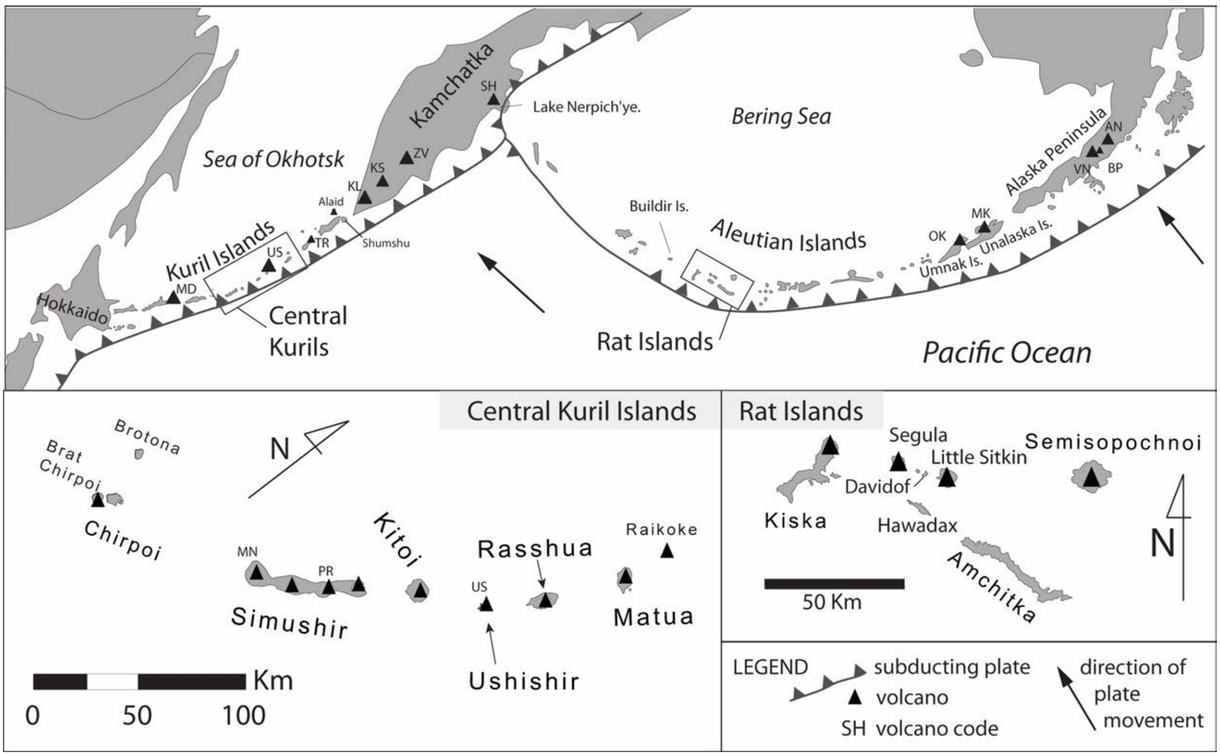

Figure 1: Map of the North Pacific Rim

The case study regions compared in this paper: central Kuril Islands (left box) and the western Aleutian Rat Islands (right box). Arrows indicate direction of movement of the Pacific Plate; dark lines are plate boundaries with 'sawteeth' indicating subducting contacts. Black triangles at top represent the volcanoes discussed:

West: MD: Medvezhiya; US: Ushishir; TR: Tao-Rusyr; KL: Kuril Lake; KS: Ksudach; ZV: Zavaritsky; SH: Shiveluch
East: OK: Okmok; MK: Makushin; VN: Veniaminof; BP: Black Peak; AN: Aniakchak

We frame our analysis around the following questions:

1) How significant were volcanic events in the human settlement histories of the North Pacific Rim, based on existing evidence?

2) How did volcanoes challenge settlers in two rather similar and remote island regions?

3) Could volcanic hazardousness help explain the similarities and differences in human settlement histories between these regions?

Geographic Context

The North Pacific Rim is a dynamic natural and cultural region connecting the continents of Asia and North America, and the waters of the North Pacific, through its marginal seas, to the Arctic Ocean. Geologically defined, the Rim is a tectonic landscape created by the subduction of the Pacific Plate beneath the North American Plate. On its east and west sides, the margins of northeastern Asia and western North America are fringed with volcanoes and uplifted mountains, while the small volcanic islands of the Kurils and Aleutians complete the circle on the northern arc of the great Pacific "Ring of Fire" (cf. Appendix C-1). These two major arcs, the Aleutian and Kuril island chains, collectively span more than 3500 km of otherwise open ocean. In addition to their tectonic genesis and regular rejuvenation, these islands share a climate driven by the winter-dominant Aleutian Low weather pattern and ecological similarities driven by integrating ocean circulation (the North Pacific Subpolar Gyre and its offshoots). Together these factors shape temperate to subarctic marine ecosystems. These islands also share deep, though apparently unconnected, histories of maritime-focused hunting and gathering peoples.

Of these island regions, the Aleutian Island Chain is longer, consisting of approximately 200 islands and extending for almost 2500 km from the tip of the Alaska Peninsula in the east to the Kamchatka Peninsula in the west. The economies of ancestral and contemporary Unangan people rely on the marine and littoral ecosystems (Black 1981; McCartney 1977, 1984), which are supported by the churning of nutrient-rich waters in and around island straits. Sea mammals, fish, and shellfish have been central to subsistence lifestyles for thousands of years. Birds, eggs, and terrestrial and marine plant foods are and were vitally important. This was also true for occupants of the Kurils for several millennia.

For the purposes of this paper, the central Kurils are designated here as those from the Chirpoi group in the southwest to Raikoke to the northeast. They include the smallest and most remote volcanic islands in the Greater Kuril Archipelago (so-called to differentiate this long island chain from the shorter "Lesser Kuril Islands" extending northeastward into the Pacific from Hokkaido's Nemura Peninsula). The central Kurils are most distant from the nearest large landmasses of Hokkaido and the Kamchatka Peninsula. They tend to be smaller than adjacent northern and southern Kuril Islands and are separated from them by deep and wide straits influenced by strong tidal currents that serve to limit biotic exchanges and thus ecological diversity in the more remote islands, making long-distance boat travel hazardous.

The Rat Islands in the western Aleutians are also far from adjacent large landmasses of southwest Alaska and the Kamchatka Peninsula. Like the central Kurils, they are positioned between deep and turbulent ocean straits far from mainland. The geographic remoteness and small size of the Rats and the central Kurils make them useful places to examine settlement in volcanically active regions. Despite deep histories of human occupation, the central Kurils and the Rat Islands are now effectively abandoned, in part due to recent histories of incorporation into global nation states, disease, and forced relocations.

Archaeology and Volcanism around the North Pacific Rim

A rich body of literature provides archaeological and ethnographic perspectives on human approaches and responses to places subject to hazards such as earthquakes, tsunamis, and volcanic eruptions (e.g., Bawden & Reycraft 2000; Black 1981; Grattan & Torrence 2007b; Hoffman & Oliver-Smith 2002; Johnson 2002; Maschner & Jordan 2008; McCartney 1984: 61; McCoy & Heiken 2000; McGuire et al. 2000; Oliver-Smith & Hoffman 2002; Oliver-Smith et al. 1999; Riede 2016; Saltonstall & Carver 2002: 172; Torrence 2012; Vanderhoek & Nelson 2007; Workman 1979). Impacts can range from catastrophic loss of life to damaged infrastructure and changes in the environmental conditions underpinning economic adaptations. Human responses, in turn, can range from emigration to rebuilding, adjustments in subsistence pursuits, and increased trade with communities outside of the zone of impact. Cultural changes might include new pre- and proscribed behaviours encoded in oral histories that, for example, may discourage settlement in hazardous locations or aid in the advance detection and mitigation of impending hazardous events (e.g., Lowe et al. 2002; McAdoo et al. 2006). The impact of volcanic eruptions and related hazards should not be assumed to be catastrophic always (Coombes & Barber 2005; Grattan & Torrence 2007a: 1; Lowe et al. 2002; Torrence & Grattan 2002a: 2-3). Most eruptions are small, have limited effects on surrounding land and marine environments, and in some cases create net positive benefits in the form of nutrient enrichment to soils and aquatic systems. For many such events, temporary movement may be enough to avoid serious impacts, and reuse of affected regions may be possible in days, weeks, or months.

Modest volcanic activity is common around the North Pacific, with multiple events recorded every few months (GVP 2013). The westernmost Aleutians are least affected, with a gap in volcanoes between Buldir Island and Kamchatka. West of Buldir, plate geometry shifts from an oblique convergent (subducting) contact zone to a principally transform boundary with the Pacific Plate sliding past rather than diving under the Bering Sea portion of the North American Plate. The horizontal distance from the trench to active volcanoes is shorter in the Kurils when compared to the converging regions of the Aleutian Trench because the subducting crust in the former case is older and denser and thus the subduction angle steeper. These differences influence island geographies and the nature of volcanic hazards to ecosystems and human inhabitants.

While many modest events occur regularly, catastrophic events are also documented, though more rarely. In addition to direct impacts of explosive eruption and extruded debris, this volcanic activity can trigger catastrophic landslides, pyroclastic flows, debris and lava flows, which can directly bury or destroy villages and generate large, local tsunamis with little or no warning (e.g. Waythomas et al. 2009). In the Kurils in 1872, a volcanic earthquake-triggered landslide on Shiashkotan Island reportedly buried an Ainu village (Gorshkov 1970: 116). In 1933 a flank of Kharimkotan volcano collapsed following a local eruption, generating a tsunami with a maximum 20 m run-up that killed two people (Belousov & Belousova 2009: 524). Geomorphological research reveals at least two previous avalanches on Kharimkotan Island 2000 and 1100 years ago, respectively, that would have had catastrophic consequences for human communities in their paths (Belousov & Belousova 1996). The two largest archaeological sites recorded on that island were located on the landforms created by those two earlier landslides (Fitzhugh et al. 2009). Either slide could have buried older archaeological sites as well as active communities (MacInnes et al. 2014).

Archaeological records around the North Pacific also sometimes suggest volcanic impacts on communities in the deeper past. For example, thick tephra deposits cover early Holocene sites of the Anangula tradition in the Eastern Aleutians, including both the Anangula Blade Site situated on the small Ananuliak Island adjacent to Umnak Island, and two sites on small Hog Island in Unalaska Bay, Unalaska Island. These sites were buried around 9000 cal. BP by thick tephra layers from two separate eruptions (Okmok on Umnak Island and Makushin on Unalaska Island) (Dumond & Knecht 2001: 27). Archaeologists reasonably speculate that these eruptions may have ended the occupations at these sites while acknowledging the possibility of site abandonment prior to the eruption (Black & Laughlin 1964; Davis and Knecht 2010: 513; Dumond & Knecht 2001: 27; McCartney & Turner 1966: 37; McCartney & Veltre 1999) – as seen also at Kanai Shimo-shinden site (Chapter 10). Initial speculation linked catastrophic eruptions to an apparent long hiatus in occupation of the region, but more recent discoveries have demonstrated continuous occupation through the centuries and millennia following those eruptions (Davis & Knecht 2010; Dumond 2001; Knecht & Davis 2001; Rogers et al. 2009). We must now conclude that whatever impacts these eruptions had locally, their effects on the broader occupation history of the eastern Aleutians were limited.

A more substantial impact of volcanism appears to have occurred just east of the Aleutians, on the Alaska Peninsula between Port Moller and the Ugashik Lakes. There, based on extensive archaeological and geological research, VanderHoek and Myron (2004) have assembled compelling evidence of unusually severe volcanic impacts on human settlement and ecology. They find that a series of three colossal (VEI 6) eruptions of the Veniaminof, Black Peak, and Aniakchak volcanoes within an interval of approximately 300 years, around 3500 years ago (GVP 2013), wiped out or forced the abandonment of the entire central Alaska Peninsula from the Bering Sea coast to the Gulf of Alaska. The cumulative impacts of these eruptions on the landscape appear to have discouraged resettlement by human populations for more than 1000 years. Explosive, caldera-forming eruptions, pyroclastic flows, and thick ash deposits from these eruptions directly altered the terrain of more than 20,000 km^2 of land surface. The higher elevation areas closest to the resulting calderas remain unvegetated even today. VanderHoek and Myron estimate that the effects on terrestrial and riverine ecosystems through burial, high sediment mobility, and siltation in streams rendered the region largely uninhabitable from the time of the eruptions until almost 2100 cal. BP.

The immediate impact and aftermath of such an eruptive series on the ecology and human settlement of areas around it would have been catastrophic, though the slow recovery and long delay in human (re)settlement, even on the Pacific and Bering Sea coasts, defies expectation given the usual resilience of marine and littoral ecosystems and human communities. Even so, the post-eruption absence of archaeological evidence in the region for more than a millennium is convincing evidence that people used that region sparsely, if at all, for a long time following those eruptions. We can speculate that some combination of slow ecological recovery and cultural proscriptions deterred settlement and established a cultural barrier separating the Unangan people of the Aleutian world from the rest of Alaska. Oral histories and cultural proscriptions could have prolonged the abandonment, so that a return of significant settlements could have been delayed for hundreds of years after re-colonization would have been feasible.

While the late Holocene eruptions of Aniakchak and neighbouring volcanoes stand out near the extreme end of the scale of geomorphological, ecological, and human impacts – not only in the North Pacific but globally – the 1750 cal. BP eruption of Ksudach Volcano (KS_1) (VEI 6) on the Kamchatka Peninsula may be the next most significant Late Holocene event currently reported on the North Pacific Rim. Originating in the south Kamchatka Peninsula, KS_1 sent a plume of ash up the Pacific side of the peninsula, blanketing the ground as far northeast as Karaginsky Bay, 800 km away, and from the mountainous spine of the peninsula to the Pacific coast. Over much of this area, KS_1 is represented today as a 5–8 cm thick marker tephra in sedimentary sections (Braitseva et al. 1996; see also Ponamareva et al. 2007).

Interdisciplinary research into the archaeological, palaeoecological, and geological history of the Lake Nerpich'ye region, 600 km to the northeast of Ksudach, reveals changes in the ecosystem and human settlement correlated in time with the KS_1 eruption. Pendea and colleagues (2016; also Hulse et al. 2011) conclude that the KS_1 eruption changed the character of terrestrial vegetation and may have been a factor in a shift in hunter-gatherer subsistence from terrestrial towards a more maritime emphasis around that time. Palynological results show that even at this distance from the eruption, forest cover yielded to a more open grassland environment – a change lasting for up to a century. Interestingly, tephra from numerous eruptions of much closer Shiveluch volcano, less than 100 km to the west, is also found throughout the Holocene stratigraphy of the Lake Nerpich'ye region with little apparent effect on human settlement or economy (Pendea et al. 2016).

To summarize, published 'tephroarchaeological' studies lead us to the provisional conclusion that hunter-gatherers around the North Pacific Rim, in both island and mainland settings, experienced the effects of eruptions frequently. But in most cases, those events were either insignificant, with populations rebounding quickly, or well mitigated. Even so, the archaeological and geological record of human engagement with volcanic events in this region lacks the coverage or resolution needed to evaluate this impression rigorously. Searching for direct evidence of the impact on humans and of human responses to eruptions in archaeological contexts is especially challenging where population densities were low and lifestyles relatively mobile. On the other hand, adaptive resilience to unpredictable but common hazards like volcanic eruptions and ash fallouts should translate into predictable and observable patterns of archaeological settlement and land use. We turn next to explore archaeological histories, evidence of volcanic event frequency and intensity, and settlement practices in the Aleutian Rat Islands and central Kuril Islands for evidence that people sought to mitigate volcanic hazards through avoidance of high-risk locations.

Occupation History of the Aleutian and Kuril Islands

The earliest Aleutian settlements have been found in the eastern Aleutian (Fox) Islands and dated to roughly 9500 cal. BP. A nearly continuous sequence of archaeological sites in the region argues for cultural continuity from that time to the present (Hatfield 2010). To the west, the Islands of the Four Mountains, Andreanof Islands, and Rat Islands were settled by at least 6500 cal. BP, while the Near Islands in the far west may not have been occupied until 3000 years ago (Corbett et al. 2010; Funk 2011). To date, the Commander Islands – westernmost in the Aleutian chain, closest to Kamchatka – appear to have been unoccupied prior to the shipwreck of the Bering expedition in 1741 AD, diminishing the likelihood of any significant and direct interaction between the Aleutians and Kamchatka. As archaeologists have filled in the archaeological history of the Aleutians with new research findings, there is a growing understanding that the contemporary Unangan (Aleut) people are the descendants of a more than 9500-year sequence of cultural continuity in the Aleutians. Despite regional differences, residents of the Aleutian Islands are considered part of a pan-Aleutian culture group, distinct in many ways from all other indigenous groups in Alaska and Northeast Asia. Their history was not static, however. People moved, intermarried, traded, fought, experienced natural hazards and climate changes, suffered food shortages, and celebrated good times. At least once they appear to have been joined with people from outside the region who added their own influences to Unangan culture (Misarti & Maschner 2015; Smith et al. 2009).

The earliest evidence of occupation in the Kuril Islands comes from the Yankito site complex on Iturup Island in the south, dating to approximately 7800 cal. BP (Yanshina & Kuzmin 2010). While other radiocarbon-dated sites are scarce before 4000 cal. BP, mid-Holocene occupation of the southern islands near Hokkaido is inferred from diagnostic pottery of the Early and Middle Jomon Periods[1] (Shubina & Samarin 2009). The remote, smaller, and more isolated central islands may not have been settled until after 4000 cal. BP. Soon after, archaeological sites are present throughout the chain, and a growing number of sites suggest steady population expansion or at least persistence for 2000 years during the Late/Final Jomon and Epi-Jomon phases, in terms of the prominent regional culture-historical scheme. Numbers of occupied sites appear to decrease dramatically through the later Epi-Jomon phase, from 2000 to 1300 cal. BP. Around 1300 cal. BP, a new and unrelated cultural group from the western Sea of Okhotsk, the

[1] See chronological charts in Appendix A-2, A-3.

Okhotsk, moved in and expanded rapidly for roughly 300 years. The Okhotsk settlements in the Kurils ultimately also suffered a collapse between 700 and 600 cal. BP. The islands were recolonized by Ainu immigrants roughly around 500 cal. BP (1450 AD) and by Russian and Japanese settlers in the past 250 years.

Volcanism and Human Settlement – Case Studies

To what extent were these islands' settlement histories influenced by the volcanic hazards of each region? Was volcanism significantly more hazardous to human settlement and persistence in the Kurils compared to the Aleutians? We compare the geography and archaeology of the Rat Islands in the Aleutians and the central Kuril Islands to address these questions (Figure 2).

We expect that settlement locations in both regions were selected to mitigate the impact of volcanic hazards where possible – if volcanic hazards factored at all in the settlement decisions of hunting and gathering communities in these island groups. The goal would have been to minimize the exposure to catastrophic, if unpredictable, events within the constraints imposed by the local landscape. If the Rat Islands or central Kurils offered less or more risk, respectively, from volcanic threats, we expect that settlement location patterns in the two regions should differ with regard to the geographic location of active volcanoes.

We assume that volcanic threats have always been present in both island groups and predict that, in general, archaeological sites should be situated away from active volcanic activity where possible to reduce the chance of exposure to gas, heat and tephra in the case of venting or an outright eruption. Furthermore, we expect that settlement should be placed on landscapes where the number of ash layers in geological (and archaeological) strata are minimal compared to those in other parts of the archipelago with more imminent threats. Realistically, we also expect these principles to be violated to some extent in pursuit of other priorities such as access to good hunting and gathering locations, exploitation of volcanic raw materials, or even to take advantage of the thermal benefits of hot springs in cold winters. Those trade-offs, however, would have put people in greater risk, and some balance can be expected with the most durable and long-term settlements in less exposed positions.

Here we focus on volcanic hazards, but the potential damage from storms and tsunamis would also be factored into settlement decisions, often by placing sites on higher-elevation landforms and perhaps on less exposed sides of islands (Bourgeois & MacInnes 2010; Hatfield et al. 2016; Fitzhugh 2012; MacInnes et al. 2016). Landslides and debris flows from earthquakes and volcanic activity could also generate catastrophic tsunamis that would most affect shoreline communities across bays and on adjacent islands, depending on the geometry of wave propagation.

Case 1: Rat Islands Volcanoes and Human Settlement

The Rat Island group of nine islands spans approximately 175 km of a submerged (-91 m) Pleistocene marine platform. The northern Rat Islands are formed of extruded volcanic materials, while the southern Rat Islands are formed of uplifted sedimentary bedrock (Black 1974, 1980; Jacob et al. 1977; Lewis et al. 1960; Synder 1957). The ocean floor is complexly faulted in the region, which is located 125 km north of the Aleutian trench and directly above the subduction zone. The region is seismically active. More than 6900 seismic events have been recorded in the Rat Islands since the first recorded event in 1906 (USGS n.d.). The long duration of earthquake measurement in the region means that four different measurement scales have been applied. The smaller-scale events, often measured in ML (the original Richter Scale), range from .05–2.5 ML and number over 2500. These would have been imperceptible to humans. Larger-scale events, measured in ML, Mb, Ms, and Mw (a more recently developed scale with high efficacy in measuring larger scale events), number more than 4000, with a maximum event of 8.7 Mw. All of these (74% of the total) are perceptible to humans.

Volcanoes in the Rat Islands are situated along an east-west line at the northern (Bering Sea side) of the archipelago, and they are active (Figure 2-A). They expel steam and gases more or less daily; three of the five volcanic cones in the Rat Islands – Semisopochnoi, Little Sitkin, and Kiska – have 15 confirmed or uncertain eruption records since 1772 (GVP 2013; Miller et al. 1998). Segula and Davidof, also along the northern line of the island group, are remnants of a pre-Holocene submarine caldera with possible Holocene activity. Amchitka Island, Hawadax Island, and the southern half of Kiska Island are removed from direct volcanic proximity, providing potential habitat for people and ecosystems at lower risk from active volcanoes (Figure 2-A). Prevailing winds shift seasonally but the strongest winds are from the east, southwest, and west (Armstrong 1977; Rodinov et al. 2005). Storms track from the south and southwest throughout the seasons. Lighter winds from the north may occur in any season, but prevailing winds and storm tracks would usually move gases and ash plumes away from the more southerly islands. This means that Hawadax and Amchitka islands and southern Kiska Island would rarely be impacted physically by volcanic activity, even if such activity were visible to people living there.

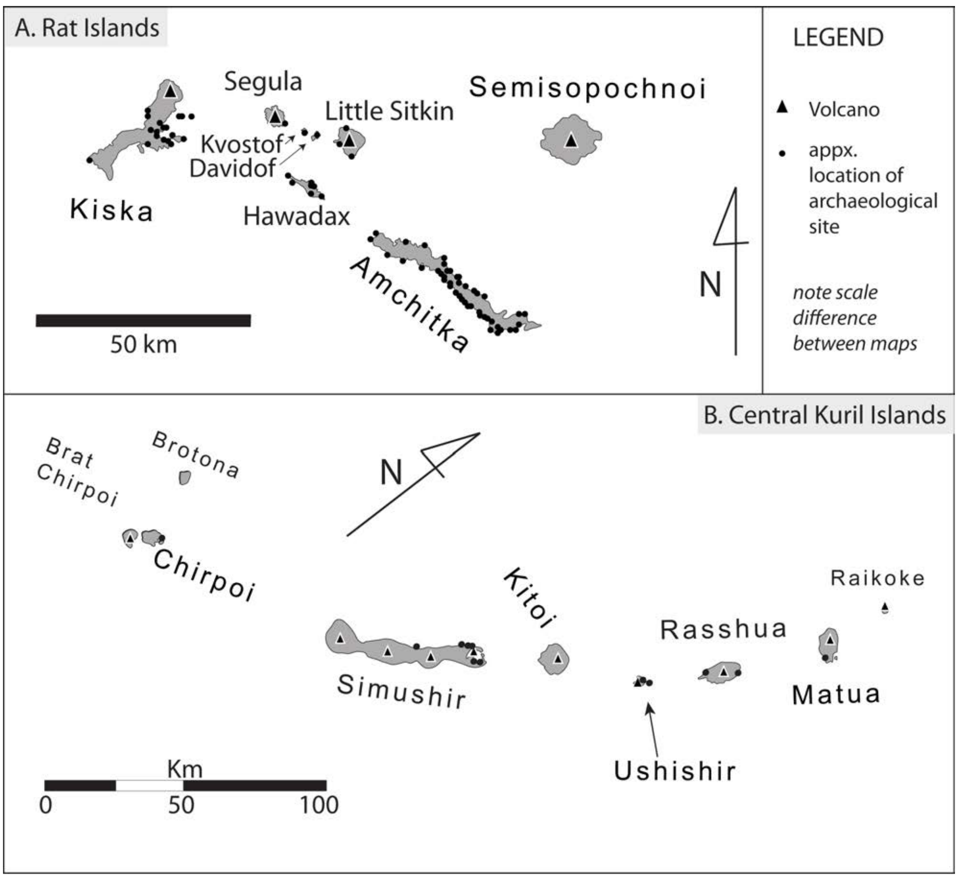

FIGURE 2 ARCHAEOLOGICAL SITE DISTRIBUTIONS

A: compared to volcanoes in the Aleutian Rat Islands
B: compared to volcanoes in the Central Kuril Islands

Evidence of the relative security of this region from direct volcanic impacts is reinforced by the low incidence of tephras in archaeological and palynological excavations in these areas. Only one tephra has been identified on Kiska Island, near KIS-050. Archaeological site KIS-050, on southern Kiska Island along the Pacific coast, was a large village, occupied episodically for approximately 2500 years (2570 to 190 cal. BP). No tephra layers were identified in the 2-metre-deep, 2 m x 2 m excavation unit (Funk 2014). A 4-metre-long peat core recovered from near the KIS-050 archaeological site includes a record spanning the past 10,000 years. The sole tephra layer identified in that core is dated to ca. 5800 cal. BP (Funk et al. 2015). Other archaeological test units on Kiska Island also did not reveal any tephra layers (Table 1).

The situation is similar on Hawadax (formerly Rat) Island, where one to three tephra layers were observed in a small test unit, but tephra layers were absent in all other archaeological tests. The tephra layer visible in the RAT-080 test unit (60 cm deep, 450 cal. BP) is comprised of a 1 cm fine white ash layer, which intermixes with a dense dark brown soil directly below it (Figure 3) (Funk 2009, 2014). RAT-080 is on the south, or Bering Sea, side of Hawadax Island, facing Kiska Island and possibly Kiska Volcano. One larger scale test excavation in archaeological site RAT-081 did not reveal tephra layers. RAT-081 is on the north shore of Hawadax Island; it was an ancestral Unangan village occupied for at least eight hundred years (1300–400 cal. BP) (Funk 2011). No tephras are visible in the 1.3-m-deep, 2 m x 2 m excavation (Funk 2011). Other smaller scale test units on the island also did not include tephras (Table 1).

TABLE 1 DEPTH OF TEST EXCAVATIONS WITHOUT TEPHRA at dated sites on Kiska (KIS) & Hawadax (RAT) Islands

Archaeological site	Excavation depth (cm)	Date (cal. BP)
KIS-005	30	undated
KIS-010	450	undated~ 430 BP at surface
KIS-042	60	600
KIS-043	60	2300
KIS-046	60	600
KIS-051	150	3505
KIS-055	60	3820
KIS-057	60	270
KIS-060	60	255
KIS-065	20	2445
KIS-069	30	2160
RAT-139	60	450
RAT-140	60	3200
RAT-149	60	350
RAT-155	60	4000
RAT-156	60	2500

FIGURE 3: RAT-080 TEST UNIT 2
Probable tephra layers visible ~25 cm below the surface

Amchitka Island was tested for archaeological deposits in association with the atomic testing projects of the 1960s (Desautels et al. 1970; Merritt & Fuller eds. 1977; Sense & Turner 1970; Turner 1970). The island is remarkably dense with ancestral Unangan occupations (see also USBIA 1992). One site, RAT-032 on the south shore facing the Pacific Ocean, may include (at least) two 2-cm-thick tephra layers. Level 4 in the site is a 2 cm white-grey coarse sand extending across all 'undisturbed' units in the excavation (Cook et al. 1972: 16), and level 6 has a similar geometry but is fine-grained and grey. Occupations subsequent to deposition of Level 4, dated as prior to 500 cal. BP, cut into and removed it (Cook et al. 1972: 16).

Thin tephra layers deposited during active ancestral Unangan occupation of landscape and archaeological sites may not have survived daily activities and foot traffic around settlements. RAT-132 shows that the use of occupation places after tephra deposition does disturb and even eradicate thin layers. The few tephras identified may have been deposited during inactive phases of site use and buried quickly, or they may in fact have been substantial enough to impact occupants, leading to periods of abandonment. Because tephras are present, even if rarely, in some locations on the southern Rat Islands, we know that ancestral Unangan occasionally experienced ash fallouts, despite apparent efforts to mitigate risk by settling outside of dangerous areas.

Rat Islands' archaeological settlements are generally placed as we would expect if people were wary of settling in close proximity to volcanoes (Figure 2-A). The densest areas of ancestral Unangan settlement are found on the southern islands and southeastern Kiska Island (southwest Kiska has not yet been systematically surveyed). Only eight (~5%) of the 155 known Aleut occupation sites in the Rat Islands are located on the smaller conical volcanic islands. One of them, RAT-162, is positioned directly on a smoking sulphur vein on Little Sitkin Island, one of the active volcanoes in the Rats (Funk 2014). This site seems to be an occupation associated with mineral resource extraction rather than domestic pursuits (Funk 2014). No discernible ash lenses were visible in a small-scale test excavation at the site (60 cm deep, 615 cal. BP) (Funk 2014). Another site, RAT-00161, is placed on the coast at the base of Segula Volcano. Like RAT-162, this undated and untested site is characterized by atypical feature size, shape, and distribution and does not seem to represent normal domestic space. Large ancestral Unangan village settlements on Kiska Island are located as close as 5 km south of the active Kiska volcano (KIS-005 for example), but these sites are separated from the volcano by an extensive lagoon and lake system. The archaeological sites on Amchitka, Little Kiska, and Hawadax islands are separated from volcanic cones by open sea at distances ranging from 15 to 50 km.

In sum, Rat Island settlers appear to have been interested in and able to mitigate their exposure to local volcanic events by settling away from volcanoes in landscapes that rarely received volcanic fallout. As elaborated in the following case history, it appears that residents of the central Kurils were less fortunate with their geography.

Case 2: Central Kurils Volcanoes and Human Settlement

The central Kurils (Figure 2-B) present a very different case from the Rats, largely because of differences in island configurations, tectonic setting, and prevailing winds. Tectonically, the Rat and central Kuril Island chains have basic similarities but also distinct differences. Subduction in the Kurils is more orthogonal and the subduction zone steeper; thus, the Benioff zone is narrow and well expressed, and the volcanoes are close to the trench, with no forearc-uplifted islands such as the southern Rat Islands. The basement of the Kuril Islands is mid-Cenozoic in age, with the island emerging by the late Pliocene to early Pleistocene (Avdeiko et al. 1991; Ishizuka et al. 2011; DeGrave et al. 2016). The central Kurils experienced a pair of Mw >8 (8.3, 8.1) seismogenic tsunamis in December 2006 and January 2007 (Ammon et al. 2008), and there is evidence of paleotsunamis throughout their Holocene history (MacInnes et al. 2016). The central Kurils have a less complete historical record of seismicity than the Rat Islands, but we can assume it is comparable. The wind patterns in the Kurils shift seasonally and are highly variable (Shevchenko & Saveliev 1999; Razjigaeva et al. 2013).

Approximately 8 to 10 central Kuril volcanoes have been active historically (GVP 2013; Nakagawa et al. 2009). Most of these eruptions were modest in scale and limited in intensity, though at least one, the VEI 4 eruption of Mt Sarychev on Matua Island between June 11 and 20, 2009, was unusually explosive (GVP 2013). In a series of events, roughly 0.4 km^3 of ash and large amounts of sulphur dioxide gas were ejected from the peak and dispersed thousands of kilometres east and west by shifting winds, as tracked by satellite remote sensing (Rybin et al. 2011). Astronauts aboard the International Space Station captured a June 12 explosion in dramatic profile (Figure 4). A larger eruption, on June 14, sent a plume of ash as much as 21 km into the atmosphere (Rybin et al. 2011). The airborne ash disrupted air traffic over the busy circum-Pacific Asia and North American flight path for several days, and airborne ash associated with the Sarychev eruption was detected two weeks later at 12 km in the atmosphere over Germany (Mattis et al. 2009). Locally, pyroclastic and lava flows remodelled the northern two-thirds of the island, while leaving the southeast third virtually untouched by volcanic flows or ash fallout. Prehistoric archaeological sites and an abandoned military base, themselves constructed on an ancient volcanogenic landform, were in the untouched portion of the island and generally were unimpacted.

While nobody was living on Matua at the time, a scientific team visited the island less than a week later, noting the presence of dead voles and foxes in that southeastern area of the island, presumably from the toxic gases emitted during the eruption (N. Razjigaeva pers. comm. 2009). A local sea lion was observed with singed hair on its head, presumably from hot pyroclastic debris, but the herd appeared unfazed and foraged normally around the island. Notably, a team of marine mammal biologists were camped out next to a sea lion colony not far north of Matua, and they witnessed no effects from the eruption – which did not even disrupt the persistent rain they had that week (A. Burkhanov pers. comm. 2009). That this powerful eruption was so minimal in its impact to the surrounding region, even sparing the most habitable areas on the same island, is another clue that volcanic eruptions are often of limited local impact, even when they may affect atmospheric conditions and even influence hemispheric climate.

FIGURE 4 THE ERUPTION OF SARYCHEV VOLCANO ON MATUA ISLAND JUNE 12, 2009

More than 70 volcanic eruptions left ash layers in the central Kuril Islands during the Holocene (Nakagawa et al. 2009: fig. 7). Based on tephrostratigraphic surveys from the Kuril Biocomplexity Project (KBP) expeditions (Fitzhugh et al. 2016), eruptions deposited at least, on average, one tephra layer per century in the central Kurils for the last 9000 years. Very large explosive (Plinian) eruptions generating tephra layers over multiple islands occurred at least six times in that same 9000-year interval. Three of those were from eruptions located within the central Kurils – two from Sarychev on Matua (4200 and 2800 cal. BP) and the VEI 4, caldera-forming Ushishir eruption, ca. 2000 cal. BP (Nakagawa et al. 2009: table 1). Two Plinian eruptions of Zavaritsky Volcano in southern Kamchatka dropped ash in the central Kurils, forming marker tephra layers ca. 8800 and 1000 cal. BP (Nakagawa et al. 2009). Other eruptions which may also have affected the central Kurils were: the VEI 7 eruption of Changbaishan/ Baitoushan tephra (B-Tm) ca. 1000 cal. BP on the modern border between North Korea and China (see

Chapter 7); the ca. 2000 cal. BP caldera-forming eruption of Medvezhiya (Moyorodake) in the southern Kurils (northern Iturup); the ca. 7500 cal. BP, VEI 6, caldera-forming eruption of Tao-Rusyr in the northern Kurils (southern Onekotan); and the ca. 8500 cal. BP, southern Kamchatka VEI 7 Kuril Lake eruption; as well as very large eruptions from northern Hokkaido (GVP 2013).

The 2000 cal. BP, caldera-forming eruption of Ushishir volcano (today's Yankitcha and Riponkicha Islands) dropped more than 30 cm of tephra on the Epi-Jomon settlement of Rasshua 1, 25 km away, in what would have led to a hasty and challenging evacuation if anyone was living there at the time (Fitzhugh 2012). Even so, archaeological deposits lie directly above as well as below the tephra (Figure 5-B). It is unknown how long people may have been absent from the site, but dates above and below the ash layer (2010±30 ^{14}C bp and 1920±25 ^{14}C bp; Fitzhugh et al. 2016) allow for interpretations of anything from a very short abandonment to as much as a 200-year gap.

Sarychev volcano on Matua, discussed above, was one of the most active of the central Kuril Islands. It erupted violently three times in the Holocene and spread tephra widely while dumping thicker deposits of coarse-grained pyroclastics on Matua itself (Nakagawa et al. 2009; Razjigaeva et al. 2018). An excavation at the Ainu Bay site on Matua revealed ten tephra and pyroclastic layers above a Final Jomon or Epi-Jomon archaeological deposit (Fitzhugh et al. 2002). This shows that Sarychev Volcano did not always spare Matua's southeast region as it did in the 2009 eruption. The layer directly above an archaeological deposit dating roughly to 2000 cal. BP was also a massive 30-cm-thick pumiceous tephra that, if discharged locally by Sarychev, may have arrived super-heated and accompanied by poisonous gases. Here, too, is a potential case for a catastrophic outcome.

Figure 5 shows representative sedimentary section schematics and photos of tephra-archaeological stratigraphy from Simushir, Rasshua, and Matua islands. This illustration conveys the clear implication that people lived with repeated volcanic activity, and they would have been affected directly or indirectly by these events occasionally, whether or not they were lucky enough to have been elsewhere during the onset of the eruption.

On southern Rasshua Island, stratigraphic analyses reveal at least 17 tephra layers in sedimentary sections spanning the past 7000 years, an average of once every 400 years (KBP, unpublished data). At least four of these layers are interspersed with archaeological deposits of the Epi-Jomon Period from 2500 to 1700 cal. BP (Fitzhugh et al. 2016). This evidence suggests an average of one tephra-depositing eruption every 200 years, which is probably still a conservative frequency since human activities would have disturbed thin tephras that fell on their living surfaces without forcing evacuation. If people or subsequent volcanic deposits do not bury them, thin tephra layers become incorporated into growing soil horizons (Razjigaeva et al. 2018: 385), where they lose distinctiveness. From this we may infer that the tephra layers preserved in archaeological sequences should represent intervals of interrupted occupation that persisted long enough for the tephra to be locked into the site's sedimentary structure but not long enough for a visible soil layer to form in that exposed layer. Tephras will be better preserved in that interval because of a subsequent rapid burial by anthropogenic deposits.

The Rasshua 1 site was occupied frequently, if not continuously, from approximately 4000 years ago to the 18th century. The same is true on Shiashkotan Island's Drobnyye 1 site (just north in the north central islands). Other sites in the central Kurils have evidence of consistent occupation from between 2500 and 2000 years ago to recent centuries, though we expect undiscovered occupations back to 4000 cal. BP as well (Fitzhugh et al. 2016). From our survey results, archaeological sites appear less densely distributed in the central Kurils than they are in the southern Rat Islands (Figure 2-A). Of the 12 sites we documented in the region (compared with 155 reported above for the Rats), all but two are within 10 km of at least one

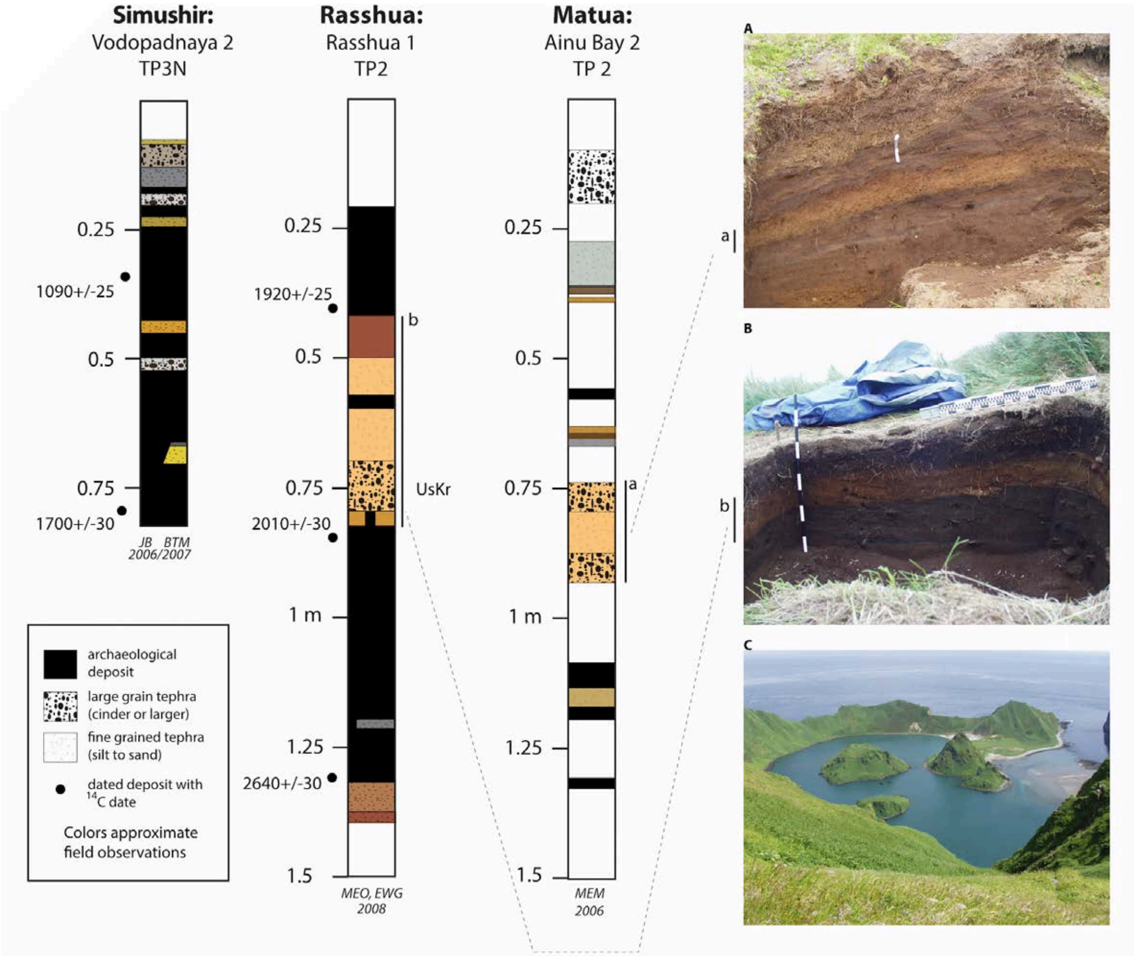

FIGURE 5 SCHEMATIC TEPHRO-ARCHAEOLOGICAL STRATIGRAPHIC SECTIONS FROM NORTHERN SIMUSHIR, SOUTHERN RASSHUA, AND SOUTHERN MATUA ISLAND

Matua and Rasshua sections are respectively paired with photos A and B of the reference excavations: A) Ainu Bay 2, Test Pit 2, 2006; B) Rasshua 2, Test Pit 2 north section showing thick Ushishir (UsKr) tephra from the 2000 cal. BP eruption (indicated by "a" on photo and section drawing linked by dashed line in the figure); C) Ushishir caldera in Yankitcha Island created by the 2000 cal. BP UsKr eruption

active Holocene volcano. The two that are slightly more distant from active volcanoes are in an extinct Pleistocene caldera on northeast Simushir Island, only 14 km from the active Prevo volcano. The relatively high density of sites (5) at the northeast end of Simushir may reflect the benefits realized by living just a bit further from active volcanoes. In some cases, this might also reflect the loss of visibility of archaeological sites buried or obliterated by volcanic activity. Milna Volcano on the southwest end of Simushir has erupted several times in the last 200 years and produced a number of lava flows. Survey of the lowlands northeast of the volcano revealed highly altered landscape and no archaeological features in a region that would otherwise have been a promising area for settlement. While such impacts to archaeological sites probably exist elsewhere in the region, we have conducted an analysis of archaeological site ages relative to land-surface ages and are confident that the aggregate record of late Holocene occupation history is not substantially biased by volcanic alteration of archaeological landscapes (MacInnes et al. 2014).

In sum, caldera-forming and other large eruptions of Ushishir and Sarychev would have had direct and indirect effects on central Kuril residents on and near to these volcanoes. For the most part, however, direct effects of more typical Kuril eruptions would have been minimal. Temporary displacement of people as a result of eruptions seems a more likely consequence of the rare large, local eruptions, and we can speculate that people in the region must have received volcanic refugees from time to time, as they would have been forced to flee occasionally themselves.

Discussion and Conclusion

Based on these limited comparisons, we make the following observations. First, the Rat Islands were settled about 2000 years earlier than the central Kurils, and subsequent archaeological site densities are significantly greater in the Rats, especially in regions away from volcanoes. Stratigraphic observations there suggest that the locations of archaeological sites rarely received volcanic tephra or pyroclastic deposits. Other factors, including perhaps a more consistently productive near-shore foraging environment, must also contribute to explaining the apparently much higher populations there, but not the preference for living far away from the neighbouring volcanoes. By contrast, the central Kuril Islands offer few alternatives for settling away from active volcanoes, and eruptions frequently covered archaeological sites with ash and pyroclastic debris. This leads us to expect that Kuril populations may have had to move around somewhat more often, either visiting friends and relatives or moving to previously unoccupied locations (perhaps re-occupying more ancient settlements and thus not significantly adding to the density of sites). Even so, people lived in the Kurils, too, for thousands of years, usually within 10 km of active volcanoes, and often closer.

Do these differences in exposure to active volcanoes have any relevance for the differences in human settlement history or site densities? Other than the apparent later colonization of the central Kurils compared to the Rats (4000 vs 6500 cal. BP, respectively), occupants of both remote regions appear to have been able to persist in place for millennia. Based on available archaeological radiocarbon dates (for which we have substantially more for the central Kurils compared to the Rats), both regions may have experienced periodic abandonment in addition to persistent intervals of settlement. On current evidence, the longest documented intervals of consistent occupation were from about 4000 to 1300 cal. BP in the central Kurils and from at least 2500 cal. BP (but probably 4000 cal. BP) to the past century in the Rats (Funk 2011, 2018). In the case of the Kurils, this stretch of over 2500 years included numerous small and moderate eruptions that would have affected some settlements on each island probably every 100 years or even more frequently.

The large caldera-forming eruption of Ushishir ca. 2000 cal. BP and a similarly aged eruption burying the Matua site of Ainu Bay occurred at the peak of Epi-Jomon settlement intensity. While population did start to decline slowly throughout the Kurils after that (Fitzhugh et al. 2016), it did not decline precipitously. Indeed, as we have seen, human settlement picked up where it left off soon after the Ushishir eruption significantly buried (20–25 cm of compressed ash) the Rasshua 1 site just 25 km northeast of the new caldera. The decline of Epi-Jomon settlements in the Kurils remains unexplained, but volcanic impacts do not seem a likely cause. The subsequent arrival of the Okhotsk population, which expanded in the Kurils (including the central Kurils) from 1300–1000 cal. BP, and its subsequent precipitous decline from 900–700 cal. BP, are similarly disconnected from any plausible volcanic explanation. Settlement practices of the Rat Islands appear to have been even less affected by volcanic events by virtue of the availability of good settlement options at distance from the active volcanoes in the northern part of the island group.

Based on available evidence, we conclude that while the volcanic history of the central Kurils and Aleutian Rat Islands differ, volcanism had relatively little adverse impact on human settlement history even though it would have affected individual communities, especially in the central Kurils, sometimes severely. We expect that people in the Kurils had to move more often to avoid volcanic impacts than did the Rat Islanders, though they would rarely have had to move farther than the next island or two, and often just a few km up or down the coast or to the other side of the island. Similar strategies would have helped to mitigate effects of local damage from occasional large tsunamis (Fitzhugh 2012). Because most of their subsistence came from the ocean, eruption effects on terrestrial ecosystems would have had limited impact on human livelihood. Intertidal and pelagic ecosystems might be patchily affected by tephra siltation – but usually in very limited areas and short duration given the flushing of ocean tides. The most damaging after-effects of significant eruptions to island residents may have been isostatic shifts of coastal regions due to the mass balance of additive (e.g. lava flows) or subtractive (e.g. caldera explosion) processes. Rapid shoreline emergence or subsidence would move rooted intertidal and subtidal taxa out of their ideal elevations and could result in catastrophic die-offs with implications for fish, birds, sea mammals, and human foraging ecology within the affected region.

In the end, we are able to draw conclusions *in aggregate* about the relatively limited impact of volcanism on the broader cultural history of the two case study regions considered (the Rat and central Kuril Islands). The fact that people settled small, active volcanic islands and continued to live on them through millennia of volcanic activity (especially in the central Kurils) suggests that people were more or less able to mitigate the associated hazards. The fact that people opted to live in more protected locations, when options were present (such as the southern Rat Islands) also tells us that settlers were sensitive to volcanic hazards.

What we cannot yet say is how often volcanic events directly impacted or displaced people from particular locations. Nor can we say how long people stayed away from an affected location before returning, if, in fact, they did. The following four questions should guide future 'middle range' research in tephro-archaeology:

1. How can we quantify the time elapsed between archaeological deposits and superposed volcanic layers?
2. How can we quantify the time elapsed between tephra layers and superposed archaeological deposits?
3. What minimum criteria should be invoked to support interpretations of direct volcanic impacts and abandonment of archaeological sites... and regions?
4. How can we develop realistic assessments of spatial and temporal scales of impacts due to eruptions of different magnitude and kind? This question moves beyond deposit formation issues to how we interpret events ranging from small eruptions to catastrophic super-eruptions.

If we knew how long archaeological deposits may have persisted at the ground surface between their last use and the arrival of an ash layer that caps it, we could make stronger claims about the possible impacts of an eruption on site residents. Likewise, if we could quantify the time elapsed before a new archaeological deposit covered a tephra (as at Rasshua 1, Figure 5), we could estimate how long people might have avoided returning to a site occupied before the ash fallout. Future work should seek to address these questions through geoarchaeological and other methods.

Around the volcanic islands of the North Pacific Rim (Figure 1), the primary, non-anthropogenic source of sedimentation is volcanogenic. As a result, archaeological deposits are frequently capped by layers of sediment derived from eruptions (e.g., ash, cinders, pyroclastic flow deposits). These sediments may be easily identified to their volcanic source if preserved by rapid burial, or they may be made less diagnostic through weathering or other disturbance. This implies that methods to measure the degree of weathering at deposit surfaces could lead to inferences about the duration of exposure before subsequent burial. Commonly, the presence of recognized volcanic layers atop archaeological deposits has led archaeologists to view eruptions as the cause of settlement abandonments. The ability to diagnose weathering on an archaeological surface before tephra fell on it would disprove direct impacts. Likewise, weathering or soil formation on the top of tephra layers might be used to evaluate the interval over which that location was not occupied.

We suppose that micromorphological investigations of degrees of weathering and soil formation atop cultural and tephra layers could lead to improvements in the diagnosis of elapsed time between occupations and eruptions and between eruptions and new occupations. Experimental research in this area is needed and could advance research in tephroarchaeology significantly. This could be especially helpful in areas like the North Pacific Rim, where for most of human history people hunted, fished, and gathered at the shore and on the water, living in small and semi-mobile residential populations.

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We wish to thank Gina Barnes for urging us to prepare this paper and for her patience as we slowly warmed to the idea. The result allowed us to resurrect a languishing collaboration to compare the human ecodynamics of the Rat and Kuril Islands. Whether the results are successful, we leave to others to judge, but the effort rejuvenated our interest in additional analyses of 'tephroarchaeology' in the North Pacific. The primary financial support for the Kuril Island research reported here came from U.S. National Science Foundation (NSF) Grants 0508109, 9910410 (Ben Fitzhugh, PI) and 9505031 (Ted Pietsch, PI). Partial support for the Kuril research also came from a Eunice Kennedy Shriver National Institute of Child Health and Human Development research infrastructure grant, R24 HD042828, to the Center for Studies in Demography & Ecology at the University of Washington. The Aleutian case study was based on research on Unangan lands, graciously approved by the Aleut Corporation. Financial support came from the U.S. Fish and Wildlife Service and the Alaska Maritime Refuge, and NSF PLR-1303566 (C. Funk PI). We thank our many collaborators, sponsors, and logistics operators for helping to generate the data summarized here, for encouraging and facilitating our research, and for getting us safely to and from 'remote' volcanic islands of the North Pacific to discover that even those now lonely places had once been the centre of the world for generations of people in the past.

Figure & Table Sources

Frontispiece: photo by B. Fitzhugh 2016
Figure 1 maps by authors
Figure 2 maps by authors
Figure 3 photo by C. Funk
Figure 4 image courtesy of the Earth Science and Remote Sensing Unit, NASA Johnson Space Center, ISS020-E-9048 [http://eol.jsc.nasa.gov]
Figure 5 photo A by M.E. Martin, 2006; photo B by B. Fitzhugh, 2008; photo C by V. Golubtsov, 2007

Table 1 data from Funk 2009, 2011, 2014; Lech & Hutchings 2010; Lech et al. 2012

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CHAPTER 6

Katakai-Ienoshita Site, Akita Prefecture, Buried by the Lahar Accompanying the 10th-century Eruption of Mt Towada

MURAKAMI Yoshinao *

Abstract

Katakai-Ienoshita in Akita Prefecture is a volcanic disaster site that was buried by an unprecedented mudflow (lahar) of remobilized tephra – not tephra fallout but pyroclastic flow sediments – accompanying the large eruption of the Towada volcano in 915 AD. The village and surrounding landscape was sealed by the thick lahar sediments, which preserved everything to the present day. The site contains an enormous amount of information that will help solve problems and progress research on several fronts: not only archaeology and history but architecture and disaster studies. It is truly an important site for academia.

Introduction

The 915 AD eruption of Mt Towada was the largest eruption in Japan since historic records began (see also Chapter 8; Appendix C-4). Its associated lahar was given the name '*shirasu* flood' (meaning a flood of pumice) by geologist HIRAYAMA Jirō and has garnered much attention (Hirayama & Ichikawa 1966). It is thought that the lahar occurred slightly after the Towada eruption ended, and its sediments cover the entire Yoneshiro Basin except for the headwater region. Thereafter, the sediments were eroded over a long period of time, and today the only remaining portion forms the Kemanai surface on the lowest terrace of the basin.

Within the Yoneshiro Basin, many small villages are suspected to have been destroyed in the 915 lahar (cf. Chapter 8). Several cases of buried buildings have been known since the Edo Period (1603–1868), as detailed below; but since such sites were generally deeply buried by the lahar, only ten locations have been confirmed. In 2015, an exploratory investigation was undertaken at Katakai-Ienoshita, in conjunction with the construction of the Ōdate Industrial Park. At first, it followed the rescue excavation proposal, but once the importance of the site was recognized, we were able to exclude 39,000 m^2 from the proposed Industrial Park area to be preserved. The data presented here are based on the results of these extended investigations (AAC 2016, 2017).

The greatest value of the Katakai-Ienoshita site was the fact that an entire village and its associated paddy fields were preserved under the lahar. This is one of the rare sites that entails enormous amounts of information – similar to but perhaps even more so than the site clusters around Mt Haruna in Gunma Prefecture (cf. Chapters 9, 10, 11), though the burial conditions differ. At first, 3-dimensional traces were recovered of the slanting roof of a buried small hut-like pit-building. This stirred great interest, but the discovery that the houses in the village remained in their 3-dimensional standing position is critical to the possible designation of the area for cultural heritage. Despite their differing degrees of preservation, all of the houses were buried at the same time. They date to the Heian Period (794–1135 AD); some of their features remain as they were back then, while others have decayed away.

This chapter presents some of the extraordinary details recovered during the excavation of the houses at Katakai-Ienoshita and disabuses us of the idea of perfect preservation. Recovery of traces of organic materials that had already decayed was a challenge, but new information has been obtained on walling,

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flooring, fences, roof materials, and interior structures. The village also provides a new view on volcanic disasters, as the houses are deemed to have been abandoned a considerable time before the 915 AD eruption. The occupants are presumed to have been *emishi* – referring to peasants living beyond the jurisdiction of the Ritsuryō state of the Nara (710–794 AD) and Heian Periods.[1] The abandoned village thus raises questions concerning the relationship between the Heian capital (in Kyoto) and these far northern peoples as the Court extended their rule into this region in the 9th century.

Buried Buildings in the Yoneshiro Basin

The buried houses at Katakai-Ienoshita are not alone: distribution of buried buildings extends over a broad area in the central Yoneshiro Basin from Ōdate City to Noshiro City (Figure 1). Within this distribution and 17 km to the WNW of Katakai-Ienoshita in the Kurumidate site in Kita-Akita City are more buried buildings. Again, excavated in their constructed state, they embodied incomparable value as ancient architectural materials, and it is primarily those excavated pieces which led to designation of the Kurumidate site as a National Important Cultural Property.

Actually, the discovery of buried buildings is quite old, going back to the Edo Period. About 200 years ago, the traveller SUGAE Masumi (1754–1829) left a journal record with illustrations (Figure 2) (Uchida & Miyamoto 1973, 1974). Sugae showed keen interest in buried houses discovered in Ogata, now in Kita-Akita City, and also in houses along the Hikkake River, a tributary of the Yoneshiro River, in what is now Ōdate City. The latter are located about 5–7 km downriver from the Katakai-Ienoshita site. In addition to Sugae's work, the buildings are also known through the *Kōkoku Doseikō* (Hirata 1800) and the *Akita Sennen-gawara* (Kurosawa 1817). Another record worthy of note was written by NAGASAKI Shichizaemon (1817): there, the appearance and construction of the buildings, and detailed descriptions of unearthed artefacts, are described for the 34 buildings that had so far been discovered in the earth.

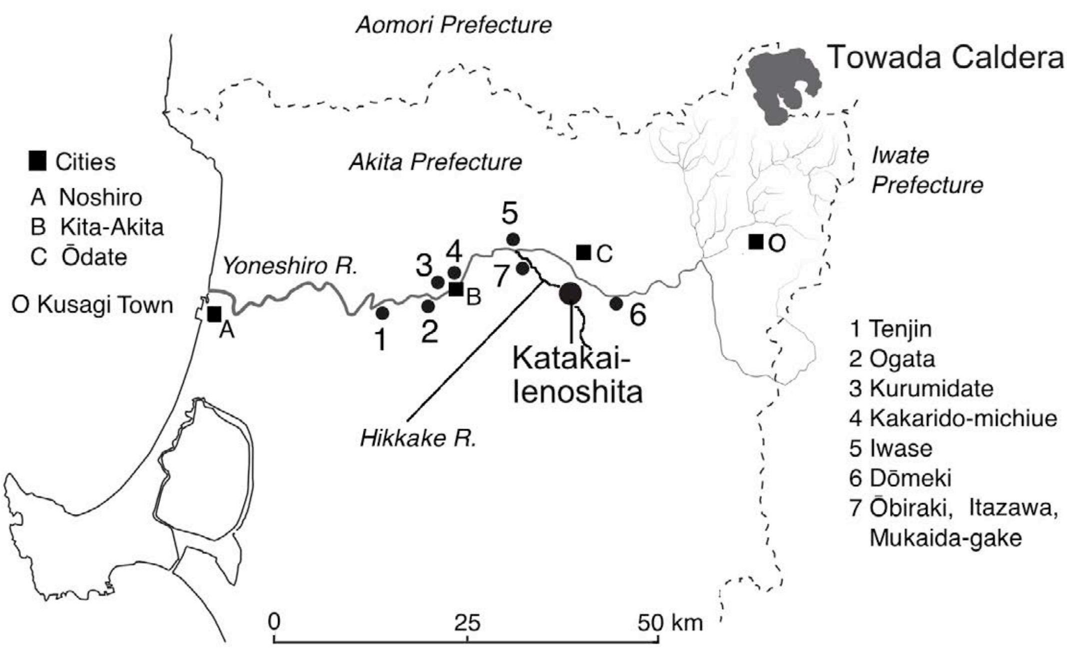

FIGURE 1 DISTRIBUTION OF SITES IN YONESHIRO BASIN YIELDING BURIED BUILDINGS

[1] See full chronological charts in Appendix A-2, A-3.

In addition to the buried houses that interested Sugae, 7 km distant to the east of Katakai-Ienoshita is the Dōmeki site, situated along the main Yoneshiro River. In 1999, pillared buildings were found buried during construction work. Immediately the Ōdate City Board of Education mounted an emergency rescue excavation (Itabashi 2000). More recently, buried buildings have been uncovered in the uppermost Yoneshiro Basin some 500 m from the Yoneshiro River.

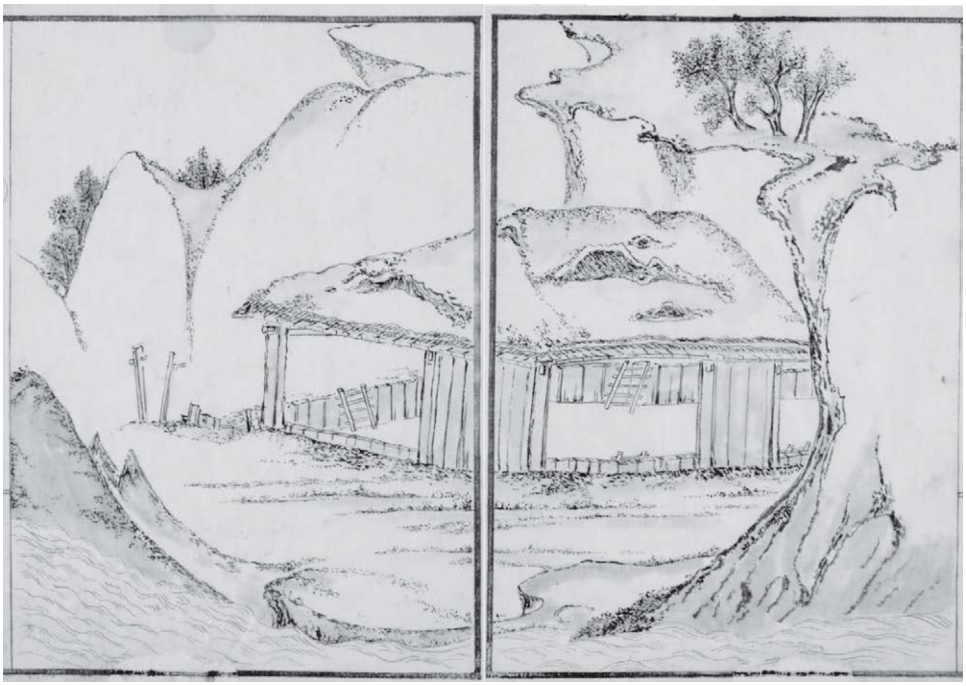

FIGURE 2 EDO-PERIOD DRAWING BY SUGAE MASUMI OF BURIED HOUSE EXPOSED DURING FLOOD EROSION

Katakai-Ienoshita Site

Outline

The Katakai-Ienoshita site lies about 40 km to the southeast of the Ogurayama vent of Mt Towada, which erupted in 915 AD. The materials presented here are drawn from the Akita Archaeological Center (AAC 2016, 2017) and Akita Prefectural Board of Education (Akita-ken Kyōi 2016, 2017). Located 6 km south of the Ōdate City centre in northern Akita Prefecture, Katakai-Ienoshita occupies a natural levee currently at 58 msl between the old course Hikkake River and the canalized course (Figure 3) (left bank of the river's old course). Dating to the Heian Period, the site is estimated to be about six hectares in extent. Until recently the area had been farmed as rice paddy, seen as rectangular plots in Figure 3. Less than a kilometre east of this site on a 10-m high terrace can be seen the location of the contemporaneous Katakai site. Four sherds of Haji pottery have been unearthed there that bear the written character *tera* for 'temple', giving a clue to the site's nature.

In March 2015, three buried buildings with slanted roofs were discovered, including a hut-like pit-building, garnering great interest. Much of the architectural structures had decayed except for those embedded in the high water table. Further excavation in 2016 uncovered the full remains of the standing buildings, consisting of one pit-building and two pillared buildings, and a sector of paddy fields. From the deposition of Towada tephra layers II~III, it was confirmed that the buildings and paddies dated to the same age. These conditions allowed an extremely detailed reconstruction of the village and its surrounding farmland. It was the first time that Heian-Period paddy fields had been discovered in the Yoneshiro River basin, providing a clear view into one aspect of Heian peoples' livelihood.

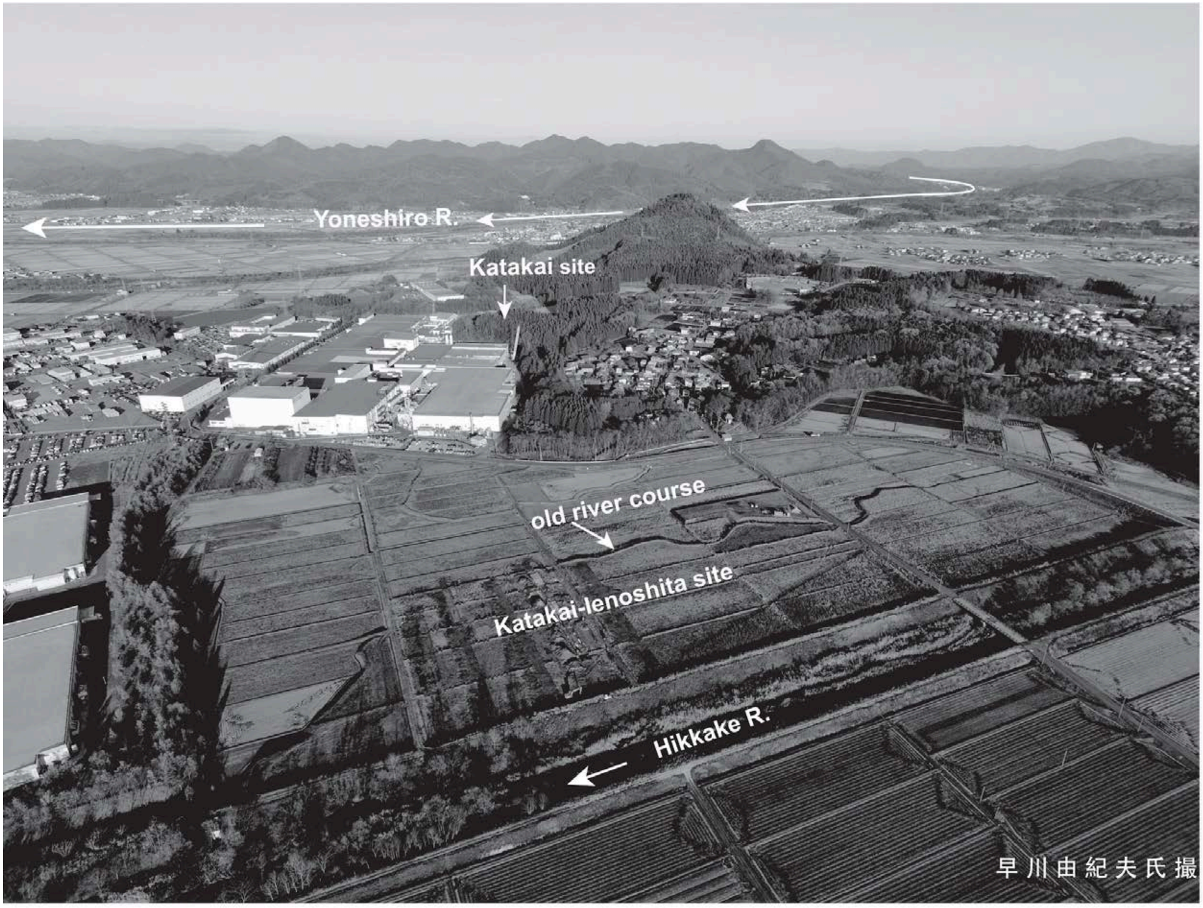

FIGURE 3 LANDSCAPE SETTING OF KATAKAI AND KATAKAI-IENOSHITA SITES FROM THE WEST

The Excavation

Stratigraphy

The site stratigraphy is divided generally into six strata numbered vertically downwards:

I: The modern cultivated soil, 20–40 cm thick, blackish brown silt.

II: The lahar sediments, including the *shirasu* pumice, comprising 10–250 cm thick, olive-brown sandy silt; the upper layer includes pumice, while the lowest layer has a base of 1–3 cm clay or fine sandy silt. The upper layer shows signs of erosion and razing by small stream activity and cultivation processes, etc.

III: The Ōyu pumice fallout layer, 5–10 cm thick, yellow-brown grains ca. 3 mm in diameter, deposited during the Towada eruption. This is draped over the micro-topography of Stratum IV, the Heian-Period land surface.

IV: The cultural stratum, 5–20 cm thick, blackish brown clay; Heian-Period artefacts have been recovered from its upper surface layer. Some areas have been gleyed and preserve plant macro-remains.

V: A sterile layer, 20–35 cm thick, sticky yellow-brown clay.

VI: A deep or basal layer of the natural levee consisting of gravel.

Excavation Methodology

In 2015 the objective was to unearth the features of the upper surface of Stratum IV, which lay approximately 2 m below the current surface. The confirmatory investigation consisted mainly of trench (T) excavation; eight trenches (T1–8) were put in and carefully excavated (Figure 4). Because of the depth, the trenches were 4–6 m wide, stepped down to Stratum IV for safety purposes. The results allowed estimations of the site's extent, and the number and dimensions of the standing structures.

In 2016 excluding one area, features were uncovered on the surface of Stratum II. A further nine trenches (T9–17) were inserted while Trenches T4 and T5 were extended to clarify some of the previous year's findings.

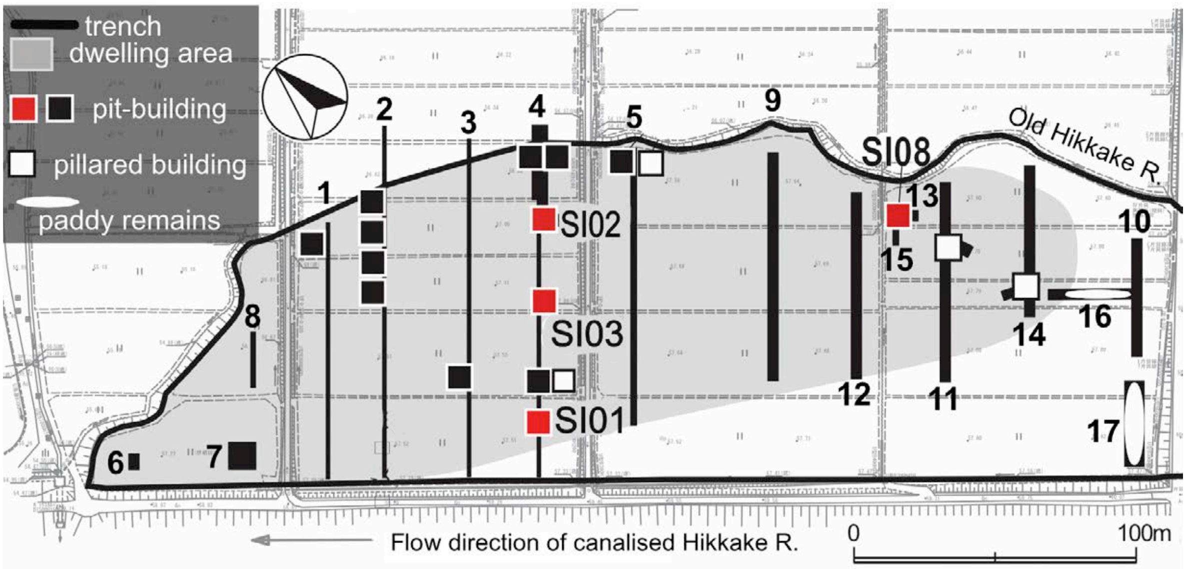

Figure 4 Katakai-Ienoshita Site
Trench excavations revealing buried buildings in dwelling area and adjoining paddy field remains

Features Excavated

Among the features discovered in these two excavations were 13 pit-buildings, 1 pillared building with a depressed floor, 3 standard pit-buildings, 9 lengths of board fences, 6 pits, 8 burned-earth areas, paddy fields, 15 lengths of ditches, 1 stream-bed, 11 features of unknown function, and 30 post-hole-like pits. The excavated area comprises less than 10% of the site extent. Moreover, since the 2016 excavation concentrated on the surface of the lahar Stratum II, the features on and dug into the cultural Stratum IV are unknown. If those areas were all to be excavated down to Stratum IV, as in certain trenches, the numbers of features would increase considerably. Taking these circumstances into consideration, the village is estimated to have been very large indeed.

It must be heeded that prior to their burial by the lahar sediments, a cluster of pit-buildings had already been abandoned and filled up. These would only be exposed on the surface of Stratum IV by the removal of Strata II and III. The 2015 excavation revealed that far more features than appeared in Stratum II had been preserved in Stratum IV; from this it was concluded that those features seen in Stratum II were only part of the latest buildings that made up the settlement. In order to clarify the history of the village that survived over a long time, it would be necessary to ascertain the number and characteristics of features in the cultural Stratum IV and analyse their accompanying artefacts.

Pit-building Features

Pit-buildings were uncovered in Trenches T1 to T4, and T13, and clustered in the northeastern side of the site (within the area investigated). An old streambed of the Hikkake River ran past this area, and the features were situated on the highest surface of the natural levee, which was judged to have been a residential area. The pit-buildings were square, 3 to 6 m on a side; the floors of the deepest ones were 70 cm below the contemporaneous ground surface and 1 m below the top of the levee (Table 1).

TABLE 1 ATTRIBUTES OF PIT-BUILDINGS YIELDING TEPHRA

Pit-building	Trench	Orientation	Size (m) L x W	Depth of pit (cm)	Tephra
SI01	4	NE–SW	5.9 x 5.2	70	lahar
SI02	4	NE–SW	6.2 x 5.9	60	pumice fallout, lahar
SI03	4	NE–SW	4.2 x 4.2	70~80	pumice fallout, lahar
SI08	13		>6x??	40	lahar

Nine buildings in Trenches T1 to T4 contained anthropogenic fill, on top of which lay the lahar sediments (Stratum II). These buildings were already missing their roofs and had been completely back-filled by humans, with no natural sediment accumulation evident in their interiors. Thus, these structures had been abandoned and intentionally buried prior to the Towada eruption, and the ground stood empty before the lahar struck.

Four buildings in Trenches T4 and T13 contained naturally accumulated sediments; these can be divided into two sub-groups:

1) One (pit-building SI02 in Trench T4) had pumice fallout (Stratum III) on the floor, covered by lahar sediments (Stratum II). This building had been abandoned and the roof dismantled; but before the house pit had been back-filled, the Towada eruption began. Being open to the elements, it had accumulated pumice fallout on its floor and then was buried by the lahar.

2) Three (pit-buildings SI01 and SI03 in Trench T4, and SI08 in Trench T13) had lahar sediments (Stratum II) directly covering the floors and the ground outside the pit-buildings. Their roofs were intact, so they were occupied at the time of the lahar and had been consumed by it. Thus, they are understood to have been abandoned because of the volcanic-related activity. These pit-buildings are discussed in detail below.

<u>SI01 pit-building in Trench T4</u>

This was the first buried building to have been discovered in the initial 2015 investigation (Figures 5, 6). It was excavated down to the floor through the centre, but only to Stratum II level to the sides. No trace of the roof could be ascertained, but in the 2016 excavation one part of the roof was identified in the southwest corner. Around the hut was a rampart (not shown) mounded on original land surface to a height of 40 cm; it was covered directly by Stratum III pumice fallout. The interior of the hut was filled with Stratum II lahar sediments; adhering to the walls was a layer identified as part of the wall covering.

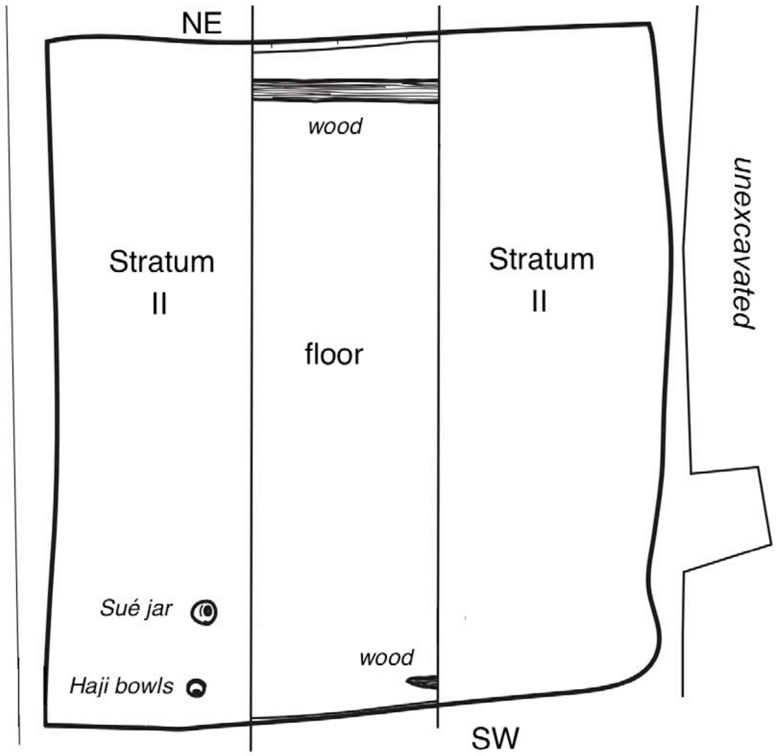

FIGURE 5 PLAN OF SI01 PIT-BUILDING, 5.2 x 5.9 m
Trench down middle excavated to floor level

Near the floor was water seepage; the floor surface was gleyed and weakly consolidated; it could not be confirmed as a prepared floor. Directly above the floor surface was a 5-mm thick deposit of iron oxide. On the floor 20 cm from and parallel to the northeast wall lay a piece of board 4.5 cm thick and 16 cm wide; other fragile pieces of wood architectural members were unearthed from the central floor and close to the southwest wall.

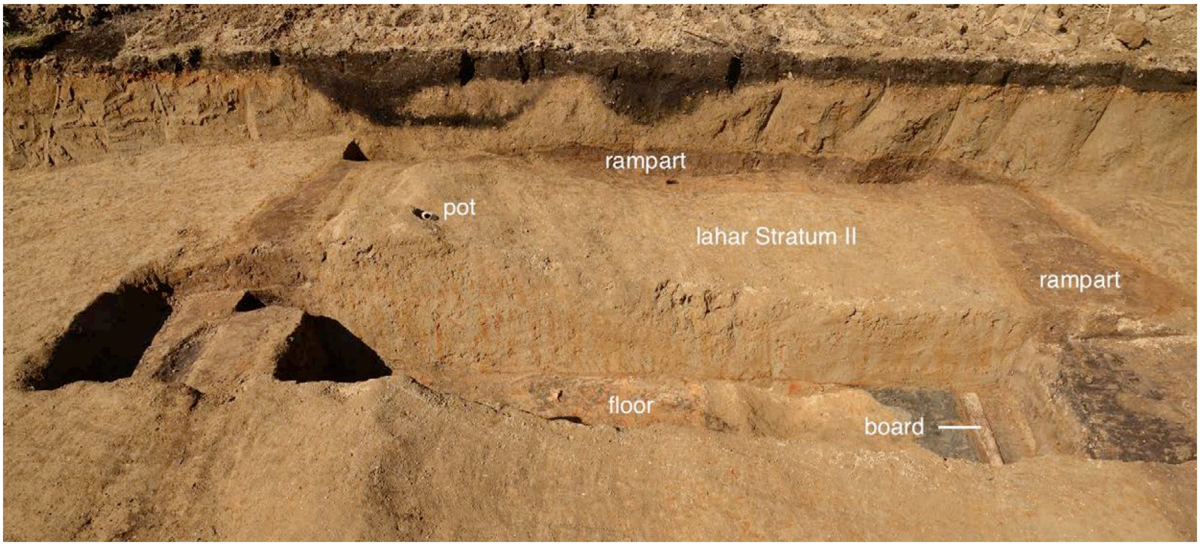

FIGURE 6 SIDE VIEW OF SI01 WITH CENTRAL TRENCH RUNNING RIGHT TO LEFT

Artefacts from the pit-building (Figure 7) include a Hajiware bowl, wooden chopsticks, and other wood pieces of unknown function recovered from the floor surface. From within Stratum II positioned between 1.1–1.2 m above the floor, two more Hajiware bowls stacked together and one Suéware jar were recovered. Because the lahar sediments contained no other artefacts, it is highly likely that these latter ceramics had been stored within the hut on a shelf. The Haji bowls have string-cut bases, indicating that they were thrown on a fast wheel; the lower part of the Sué jar has scrape marks angling down to the base (arrows), indicating surface trimming.

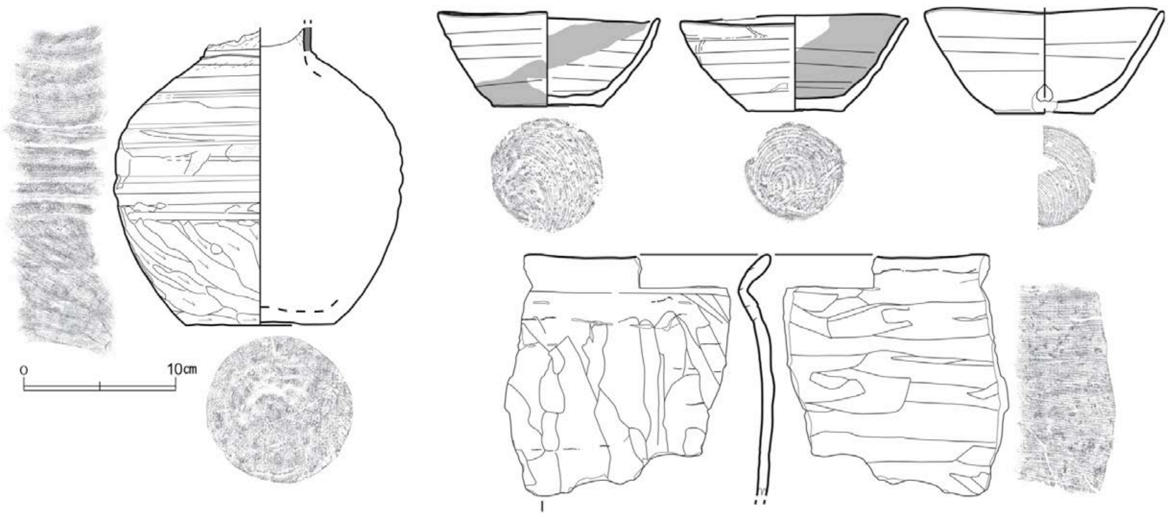

FIGURE 7 SUÉ STONEWARE JAR (LEFT) AND HAJI EARTHENWARE BOWLS AND COOKING POT (RIGHT)

SI02 pit-building in Trench T4

Two of the walls of this pit-building are crooked, but the building was probably intended to be square (Figure 8). The fill consists of Stratum III pumice fallout and Stratum II lahar sediments, and these were bordered by a rampart. Stratum III is indicated on the southwestern side of the building in Figure 8 and was confirmed through excavation near the crook in the northeastern wall; there it was clearly overlaid by lahar sediments. About 1 m from the southeastern wall was a feature of burned earth.

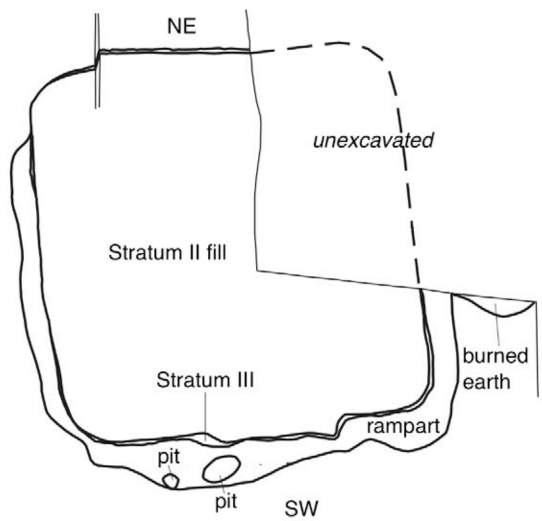

FIGURE 8 PIT-BUILDING SI02, 5.9 x 6.2 m

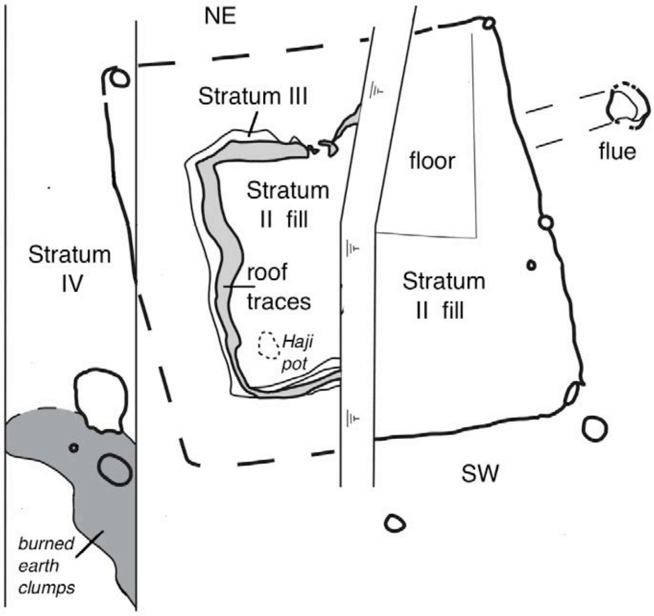

FIGURE 9 S103 PIT-BUILDING FLOORPLAN, 4.2 x 4.2 m

S103 pit-building in Trench T4

This feature was excavated to various levels: to Stratum IV on the left side of Figure 9, to the top of Stratum II fill in the centre section, and through the fill on the right-hand side with one pit extending to the hut floor. Four post-holes were ascertained at the corners and mid-section of the walls; these were mainly empty holes, ca. 10 cm in diameter. The empty ones are interpreted as post-holes whose posts had decayed away.

Traces of the roof appeared high up in Stratum II (Figure 9); in section, it can be seen to spread sideways (Figure 10) out to a ≤30-cm high rampart which surrounded the floorplan. The roofline was indicated by a 6 to 7-cm thick layer of yellow-brown earth which angled in a straight line from the rampart directly to the top of the lahar Stratum II at an angle of roughly 35° (45° from the southwestern wall, 36° from the northwestern wall, and 25° from the northeastern wall). At intervals within this layer, offsets were recognized that may reflect the buildup of roofing materials and support structures. This layer also includes clay clumps that came from Strata V and VI. Directly above the yellow-brown earth lay the 5-cm thick pumice fallout Stratum III.

The lahar sediments Stratum II filled the interior below the roofline and over Stratum III. Pumice is concentrated on the top of Stratum II. Within this fill, approximately 1.6–1.7 m off the floor, were embedded fragments of a Hajiware cooking pot; because of its position high up in the lahar fill, this pot

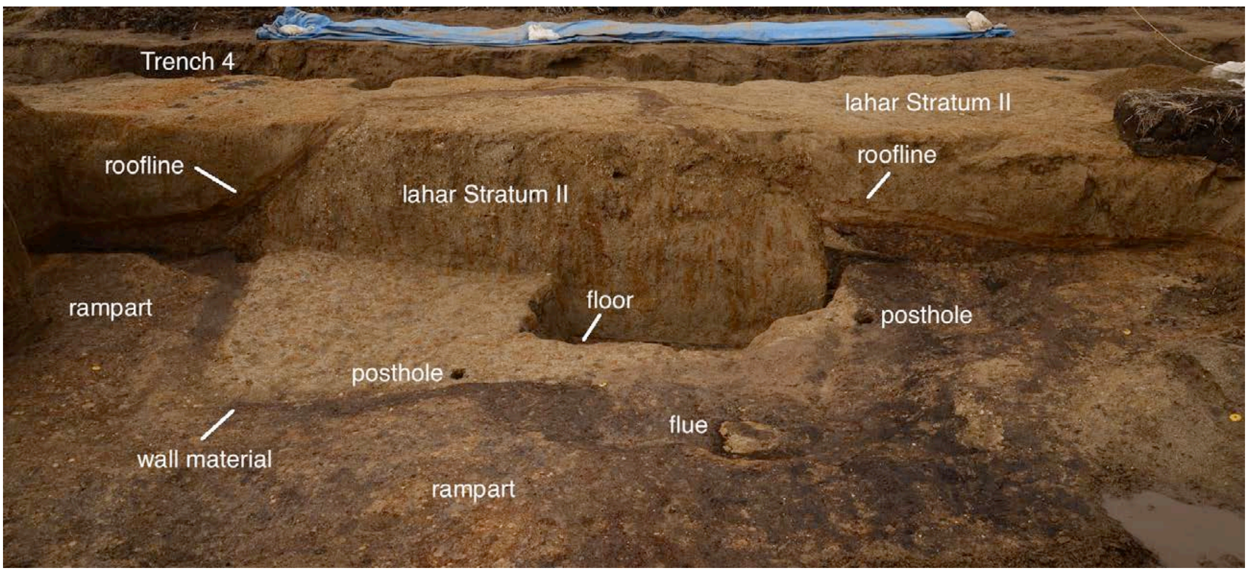

FIGURE 10 VIEW OF SI03 FROM SOUTHEAST ILLUSTRATING ROOFLINE IN SECTION, FLUE, AND SURROUNDING RAMPART

is thought to have been stored on a shelf as in SI01. No other artefacts were recovered from the lahar fill. About 1 cm of undecayed organic matter covered the pit-building floor. On the interior walls could also be detected traces of wall covering. Near the southeastern wall interior, a portion of a clay-built hearth (not pictured) was discovered with fragments of a Hajiware pot on top. One metre beyond the southeastern wall, a flue emerged from the interior hearth; it was 40 cm in diameter and marked by burned earth.

SI08 pit-building in Trench 13

Only the southeast corner of this pit-building could be confirmed; the longest wall is more than 6m. A rampart surrounds the pit and might extend into Trench T12. A hearth was built into the southeastern wall. Because no pumice fallout could be identified on the floor, which was covered directly by lahar sediments Stratum II, it is understood that the lahar entered the pit-building while it was still roofed. Several Hajiware sherds were collected from the floor. In the trench section, another pit-building-like feature had been dug into the lahar fill of SI08, but its size and date were unclear.

Pit-building and Pillared Building Combinations

Features which might represent combinations of a pit-building with a pillared building appeared in Trenches T4 and T13, while one clear example was excavated in Trench T5, discussed below. Pit-buildings have a depressed floor, while pillared buildings are surface structures with load-bearing pillars and board or wattle-and-daub walls. The latter generally remain in the archaeological record as post-hole alignments, but because of the tephra at this site, more of their attributes such as wall structures could be recovered. The pillared buildings discussed in this section seem to be adjunct features of the pit-buildings. Isolated pillared buildings are discussed in the next section.

In the slight extension of Trench T4 to the east of pit-building SI01, a square pit measuring 5 m on one side was uncovered at the top of Stratum II lahar sediments; there was a concentration of pumice inside the pit. In the sub-trench that was put through SI01, a flat surface comprised of mixed brown and black clay existed 1 m below the top of Stratum II. This surface was suspected to be the floor of a pillared building, and it is possible that it formed a set together with SI01 pit-building as in Trench T5. There was no indication of any pumice fallout Stratum III on the floor surface; it was directly covered by lahar Stratum II. Thus at the time of the lahar, this pillared building is hypothesized to have been in use.

In Trench T13, in the southwestern wall of pit-building SI08 where the hearth was located, traces of activity scraping towards the outside and formation of burned earth above suggest that there was a shed attached. Since there was no pumice fallout Stratum III in this area, it must have been roofed and formed a shed attached to the pit-building.

Combination of pit-building and pillared building in Trench T5

In the 2015 trench excavation, an area of burned earth was identified on the contemporaneous ground surface; this led to further investigation the next year by extending the excavated area to both the east and the west of the trench. The structure subsequently identified was apparently a combined pit-building and pillared building. Walls and posts of the pillared building (Figure 11, right) and the slanted traces of the pit-building roof (Figure 11, left) were clarified both in plan and in section.

In the western sector, the horizontal cross-section of the pit-building roof in plan and its shape in vertical section were all that could be ascertained. From the angle of the roof traces (Figure 12), the pit-building is estimated to have been 5.8 m on one side. The top of the roof had been sliced off by lahar erosion and further agricultural levelling activities. The plan of the top of the lahar sediments Stratum II revealed a rectangular structure with an entrance extension to the west. The gap between the northeast and southwest roof segments over this entrance measured 4.2 m. The sediments of the roof structure yielded two

Hajiware fragments. As at SI03, the interior had been filled with lahar sediments that had flowed in; the pit-building floor was not revealed.

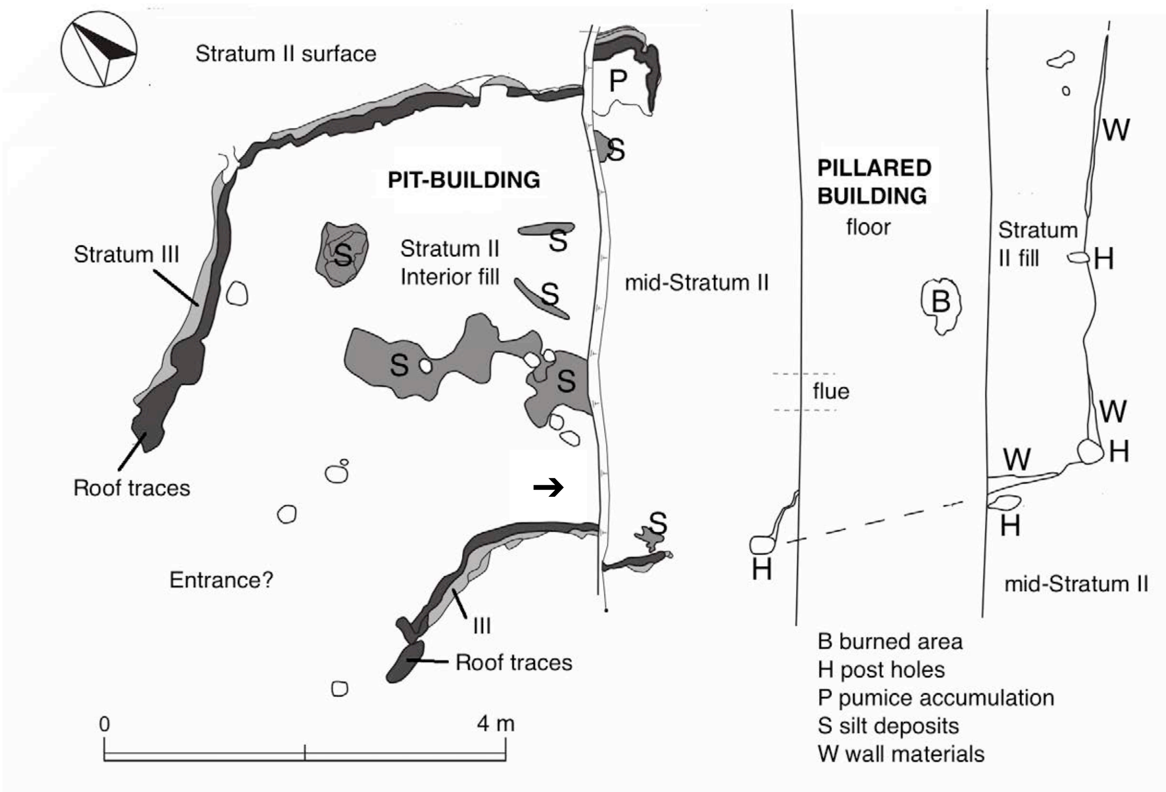

Figure 11 Plan of Composite Pit-building (left) and Pillared Building (right) in Trench T5
➔ indicates direction of photo in Figure 12

In the original trench and in the eastern sector were the remains of a pillared building. A flue emerged from the trench's western wall ostensibly from the clay-built hearth of the pit-building to the west. The flue was constructed as a clay pipe that lay across the floor of the pillared building, not dug into the floor; the inside walls of the flue were discoloured and hardened (Figure 12). In the pillared building's lahar layer were blackish-brown stains that ran like stripes from the southeastern wall to the southwestern wall. A 4.2-m length of the southeastern wall could be measured, but it is estimated to extend farther to the north. The floor of the building formed the bottom of Trench T5; it was a prepared floor of mixed brown and black clays. Burned areas are thought to be indicative of indoor activity areas.

Pillared Buildings

Pillared buildings were present in Trenches T4, T11, and T14, recognized on top of the lahar sediments Stratum II as sets of squarish pumice concentrations with stains representing wall materials along their borders. A few others could be recognized by their location near wall materials or stains thought to be pillar timbers in square-shaped interiors. The dimensions of two buildings are known: in Trench T11, the building measured 7 x 9+ m; and in Trench T14, 5 x 9 m. Both were rectangular in plan.

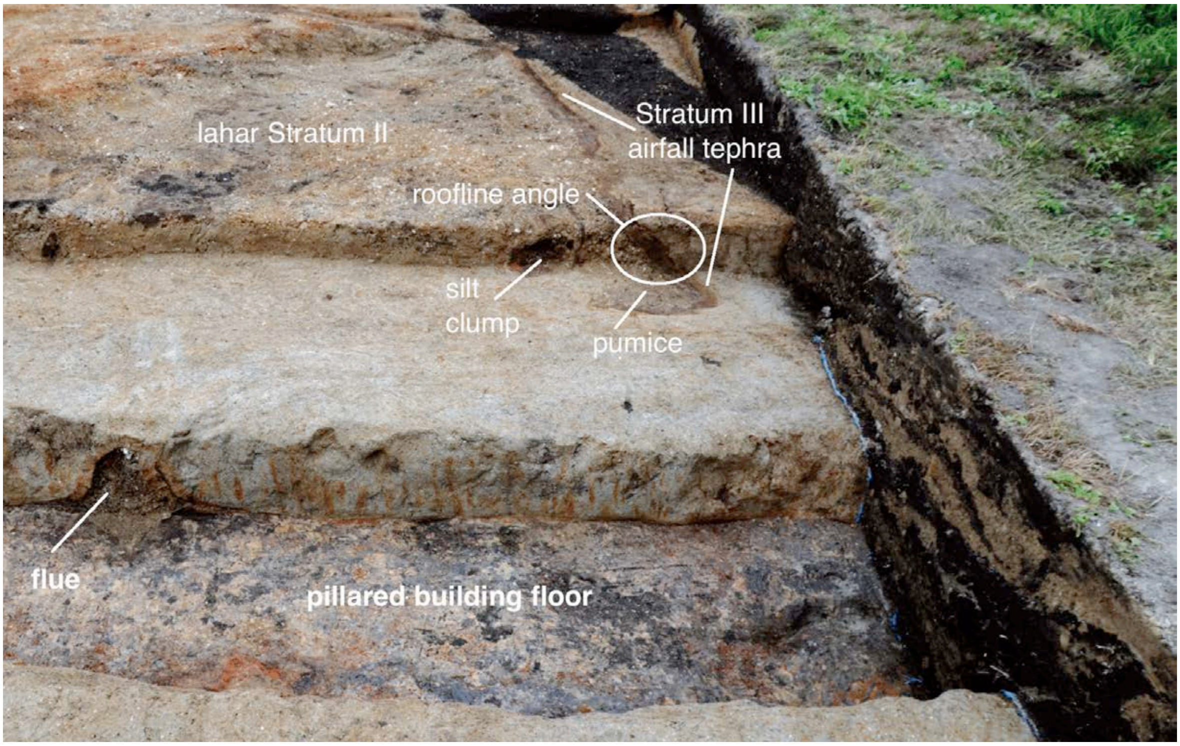

FIGURE 12 VIEW FROM PILLARED BUILDING TO PIT-BUILDING, WITH FLUE HOLE AND ROOFING ANGLE

The pillared building in Trench T11 had a depth of 80 cm from the top of Stratum II, where the walling first appeared, to its floor surface. Because the end of the northeastern wall could not be fully ascertained, it might have served as the door area. This building was constructed on peaty land so that wall materials beneath the water table have survived. In addition to architectural members, there was a single roughly fashioned pointed stake driven into the house floor. Because of its location, it must have had a different function than a normal house. Due to the discontinuous distribution of pumice fallout Stratum III on top of peaty soil within the building, it is thought that there was a roof at the time of the lahar.

Paddy Field Remains

In Trenches T16 and T17, paddy fields were widespread at 2–2.5 m depth from the top surface of the lahar. Two of those in Figure 13 measured ca. 7 m on one side. In the trench sections, paddy field bunds of trapezoidal shape were clearly visible, standing 20–30 cm above the paddy field surfaces. Both fields and bunds were completely blanketed by pumice fallout Stratum III. The paddy soil, consisting of clays of Strata IV and V, had undergone reduction and turned grey. It contained some thin carbonized matter; wooden objects like chopsticks and carbonized materials. Below the paddy soils was the gravel layer of Stratum VI, and a bit of gravel was incorporated into them. The paddy surfaces consisted of a very friable clay layer and were quite disturbed. Tephra fallout Stratum III filled the hollows, and in places where it had been removed were footprints 22–23 cm long, suggesting recovery work was done before the lahar. Many of the discovered bunds had trapezoidal shapes of considerable height in vertical section; they do not seem damaged to any significant degree after construction. Phytolith analysis revealed low levels of plant matter, indicating that the fields were probably in use only a short time (Kokankyō Kenkyūsho 2017).

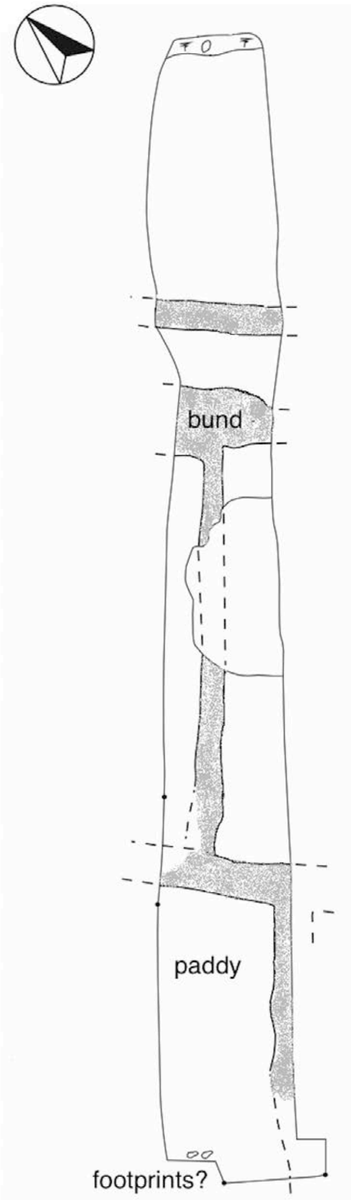

Figure 13 Paddy Fields Divided by Bunds

The residential area and paddy fields were separated by a ditch 2.3 m wide, narrowing to 1.4 m wide at its base, 70 cm below the surface. On the residential side of the ditch were the remains of wood materials used for shoring up the ditch wall; these also appeared as stains in the vertical section. This ditch is interpreted as an irrigation canal for rice cultivation. More wood materials were found in Trench T17 within the lahar sediments Stratum II; they outlined an area 80 x 90 cm in which pumice had accumulated. The type of wood, number, and shape of the pieces are unclear. They appear to have been a facility constructed in the paddy fields to partition off an area, for whatever reason.

Reflections on the Excavation

It is of great significance that ancient villages located in the alluvial flats before the eruption of 915 AD – which were previously attested by legends and previous discoveries of buried buildings – have now been confirmed by archaeological excavation. There must be other such undiscovered villages buried by pumice, and we now have a situation that we cannot ignore the potential existence of such lowland settlement when pondering areas occupied by people prior to the eruptions.

The remains of pit-buildings which have been buried upright consist of traces of wall materials and pillars within the lahar Stratum II. The original appearance of those buildings, the slant of their roofs, and the angles of their wallboards have all been elucidated. Except for a few pieces of construction materials, these have all decayed away, but their traces remain as stains or hollows in the tephra. In addition, the roofs that covered pit-buildings – whether independent or attached to pillared buildings – could be known by sediment layers that followed their straight slopes. These layers, about 10 cm thick, were formed primarily of blackish-brown clayey silt with yellow-brown clumps of clayey silt within; some contained small sherds of Hajiware. The lower wallboards of some pillared surface structures, as in Trench T11, have also survived.

In addition to these building remains, a feature interpreted as a board fence has also been recovered; it was buried upright and attached to pillared remains that appeared as blackish-brown stripes aligned in a row on the upper surface of lahar sediments Stratum II. The longest was ca. 6 m, likely enclosing a pillared building.

Topics for Future Research

• At the moment, we cannot assess how long the Katakai-Ienoshita site was occupied as one of the few Heian-Period villages in the Yoneshiro Basin. First, we must find out when the site was established; as a concrete measure, we need at least to clarify the date of the pit-buildings which had been abandoned and already back-filled before the Towada eruption. Then, we can anticipate the actual conditions of lowland settlements, a number of which may have been distributed in the Yoneshiro Basin at the beginning of the 10th century. By clarifying the nature and economic situation of the villages in northern Dewa (now northern Tōhoku) in the late 9th century, we might understand why the local *emishi* inhabitants rose up against the tyranny of the Akita Castle regime, inciting the Rebellion of 878 (Gan'gyō no Ran). Seen against the specifics of wet-rice agriculture initiation in this northern region, the relationship between village position and subsistence is a very important topic that will be key to our understanding. There is much potential for discovering other such villages, and their accumulated data will greatly influence theses about population dynamics in the Yoneshiro River drainage.

Except for their outlines, there are many uncertainties about the abandoned pit-buildings that subsequently were buried by the lahar. We do not yet know the specific dates of these buildings, but since the artefacts recovered from the cultural layers are no earlier than the first half of the 9th century, we expect that the life of the village was, at most, about 50 years.

• The buried building recorded by SUGAE Masumi had been discovered after the collapse of a river bank during a flood. This building was exposed by the erosion of the edge of the terrace bearing the Kemanai pumice surface. Because the Kemanai surface had been subjected to considerable erosion and razing for agricultural purposes, it is unknown when land use practices had been initiated in this area. Judging from the known trends in the distribution of 10th-century sites within the Yoneshiro Basin, it is proposed that refugees from disaster areas moved from the alluvial flatlands to the terraces. Such may have been the case at Katakai site, located on the terrace above Katakai-Ienoshita. Katakai village site received ash fallout but was not buried by the lahar; the village shows signs of rebuilding shortly after the Towada eruption (AAC 2016, 2017). There is also the view that iron smelting features, which increased in the Yoneshiro Basin after the eruption, were linked to iron sand incorporated in the pumice (Yaguchi 2016). The Kemanai surface, newly formed 1100 years ago, now supports many houses and people's lives. It was fairly stable in the Edo Period (1603–1868); however, exceptionally heavy thunderstorms and unprecedented rainfall possibly linked to global warming are possibly accelerating erosion, so care must be taken.

• It is commonly understood that the buried buildings discovered so far in the Yoneshiro Basin survived as intact wooden structures. But our investigation revealed that most of the structures at Katakai-Ienoshita site had decayed. The stains that could be seen in the lahar sediments Stratum II, the weakened and porous areas, and the hollow post-holes are all traces of former wood components. The locations where wood and other organic materials survived are deeply buried, as on the floors of the pit-buildings; from visible water seepage, the preservation conditions of the buried buildings have been dependent on the intersection of vertical architectural members and groundwater level.

• In this investigation, the roof line of a hut-like pit-building could be recovered; however, nothing could be ascertained about the structure holding up the roof or the roofing materials. Nevertheless, this discovery will greatly stimulate progress in researching buried buildings as to the modes and manifestations of wood deterioration when water levels are low in tephra cover. Judging from buried building excavations and the Ogata records relating to such structures, the buried buildings of Akita Prefecture are viewed by Nagai (1975) as intermediate between Japanese-style buildings further south and those of the northernmost climes. This viewpoint is very important for researching the construction of buried buildings in the Yoneshiro Basin as well as the pit-buildings at Katakai-Ienoshita site.

• Pit-buildings SI01 and SI03 in Trench T4 yielded ceramics within the lahar layer Stratum II at greater than 1 m above the floor. Other than these ceramics, no artifacts were found within the lahar sediments. Thus, the pots are considered to be in their original locations, stored at that level within the pit-buildings on hanging shelves. These indicate the use of space within the pit-building. In future when investigating buried buildings, careful attention must be paid to construction materials that facilitate the use of interior space and the artefacts that accompany them.

• The large lahar that inundated the Yoneshiro Basin was an unusual event, given the remains of many buildings buried in an upright position. The volcanologist HAYASHI Shintarō (2015) points out that the lahar was a low-energy flow, indicated by minimal disruption of the earlier pumice fallout covering the roofs of pit-buildings. The Katakai-Ienoshita site is located about 2 km from the main Yoneshiro River course which formed the main path of the lahar flow.

Through the agency of these two types of tephra, pumice fallout and lahar sediments, the contemporaneous land surface is well preserved. Protruding features such as the ramparts around buildings were easily identified, as were small depressions and rises. The low-temperature lahar differs from a pyroclastic flow in that it does not burn wooden structures; instead, if conditions are good, it actually preserves them as they were because of its water-saturated sediments. Information in three dimensions can then be obtained for the buildings' superstructures. Perhaps more information is garnered from these building remains than through the similar cluster of sites at the foot of Mt Haruna in Gunma Prefecture.

In closing, it is worth noting sites in relation to the geography and excavation record of the Yoneshiro River course (Figure 14). Following that is the legend that accompanies the Towada eruption.

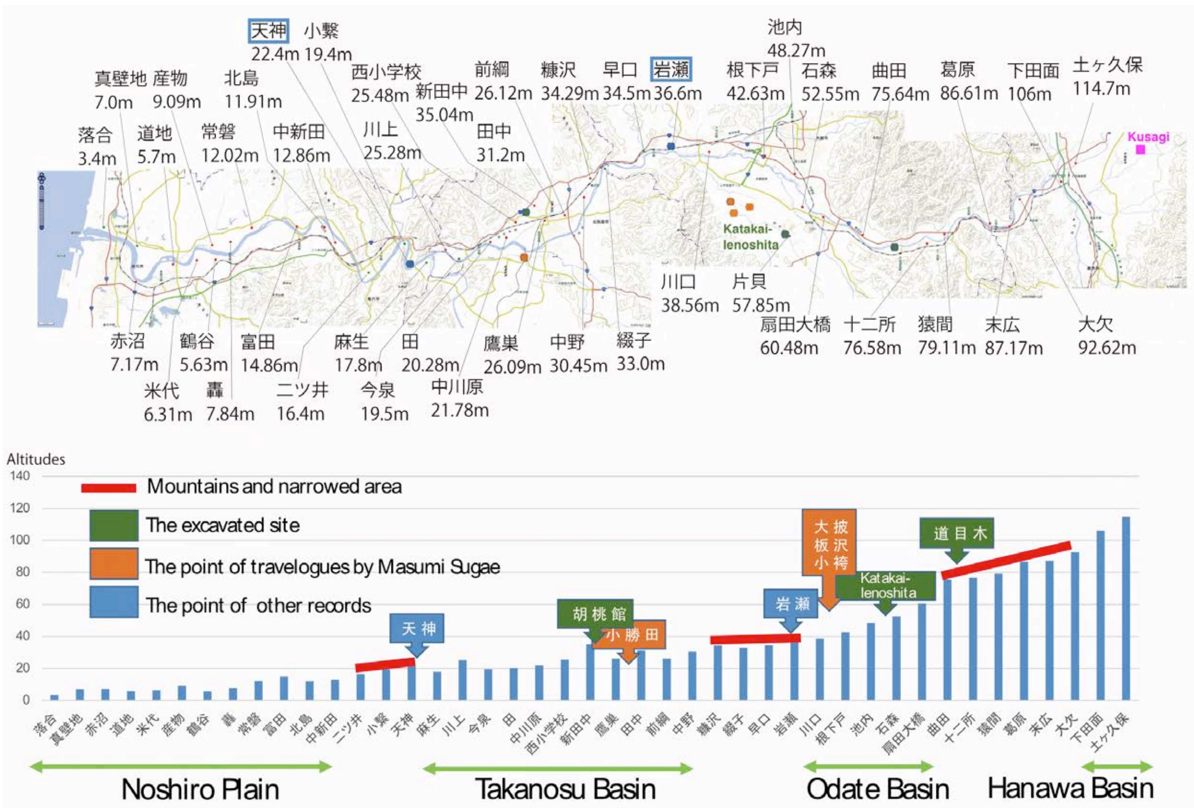

FIGURE 14 ALTITUDES ALONG YONESHIRO RIVER AND SITE LOCATIONS

Column

"Akita's Three Lakes"

the legend of Hachirō Tarō and the dragon

Once upon a time, there lived a youth named Hachirō Tarō in the village of Kusagi in Kazuno County, Akita Prefecture. He was a hunter; however, one day he took a friend to Lake Towada for fishing. Hachirō Tarō caught a mountain trout (*iwana*) but did not share it with his friend, instead eating it all himself. Doing so, he became very thirsty and drank Lake Towada dry. As a result, he changed into a dragon and took up residence in Lake Towada.

Hearing the rumor that a dragon lived in Lake Towada, the monk Nansobō from the Jōbōji Temple in Iwate Prefecture left for Lake Towada saying, "I will vanquish the dragon." He fought the dragon that was Hachirō Tarō for seven days and seven nights, resulting in the escape of Hachirō Tarō the dragon down the Yoneshiro River valley. In several places along the Yoneshiro River, Hachirō Tarō the dragon dammed up the river and rested there before going further. When he reached Oga Peninsula at the shore of the Japan Sea, he settled in the Hachirō Lagoon.

There he met a dragon princess like himself named Tatsuko-hime who lived in nearby Lake Tazawa. Knowing of her beauty, every night Hachirō Tarō the dragon extracted himself from the lagoon and poured himself into Lake Tazawa. Thus, Hachirō Lagoon became ever more shallow with the absence of its dragon, and conversely, Lake Tazawa into which Hachirō Tarō the dragon flowed became the deepest lake in Japan.

The three lakes of Towada, Hachirō (lagoon), and Tazawa form the stomping grounds of the legend's protagonist, Hachirō Tarō the dragon. The link with Tazawa Lake was probably a later addition to the original legend in which the dragon is thought to represent the highly destructive lahar that followed the pyroclastic flow from the Towada eruption. Hirayama and Ichikawa (1966) view the legend of the fight between the monk and the dragon as referencing the actual eruption of Towada volcano in 915 AD.

There are considerable pumice deposits around the mouth of the Yoneshiro River where it meets the Japan Sea, and in several narrow places along the river course are located natural dams formed of pyroclastic material carried by the lahar (Figure 14). Between these dams, lahar sediments backed up, submerging many villages. Places where houses were buried by these pooled lahars are clustered in the Ōdate and Takanosu Basins. These are places where Hachirō Tarō the dragon rested on his way downstream. That the eruption of Mt Towada, the pyroclastic flow, and subsequent lahar were all immortalized in legend tells us how utterly destructive their effects were.

In Japan, past damage due to a volcanic eruption was characterized in terms of dragons; the *Nihon Sandai Jitsuroku*, completed in 901 AD (Kuroita 1937), also records a legend that two dragons flowed out of Mt Chōkai (Yamagata/Akita border) during its eruption in 871. These Japanese legends contrast with the Greek legend of Typhoes, the storm-god buried under Mt Etna in Sicily: he was "so huge that his head brushed the stars" [an apt description of an eruption column] and he had "two coiled serpents in place of legs…and a hundred serpent-heads for fingers" [the pyroclastic flows and tephra fallout?] (Atsma 2000-2017, unpg. [editorial insertions]). The eruption of Mt Vesuvius in Pompeii is also depicted surrounded by snakes (see Chapter 15: Figure 3). The cross-cultural visual analogies are interesting, but whereas serpents are mainly seen as vile, dragons are a beneficial water animal associated with rain in East Asia. In addition to their sinuous morphology, the dragon's water connection might have been crucial to their association with lahars.

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Figure Sources

Figure 2 with permission of Ōdate City Library
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Figure 14 courtesy of M. Kobayashi, modified by GLB
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CHAPTER 7

Portrait of a Volcano: the Paradox of Paektu (Changbaishan)

Keith PRATT *

Profile and Geographical Conspectus

The subject of this paper is the composite stratovolcano known to Manchurians as Golmin Sanggiyan Alin ('Long Smoky Mountain'), to Chinese as Changbaishan ('Persistently White Mountain'), and to Koreans as Paektusan [Baekdusan][1] ('White-headed Mountain'), and pronounced in Japanese as Hakutōsan or Hakutō. The majority of scientific papers refer to it as Changbai or Changbaishan, reflecting the fact that most research into its geological and volcanological history has been done by Chinese scientists on the PRC side of the mountain. In keeping with the multiple identities of the volcano, we shall here refer to it either as Changbaishan (CBS) when discussing the scientific literature and Chinese historical records, or as Paektu (Baekdu) when discussing the Korean historical records. It is the tallest peak (2749 m) in the Changbai range that separates the Korean Peninsula from continental East Asia. The Changbai mountain range in northeast China covers an area of 8000 km^2, 190,000 ha of which were nominated by UNESCO in 1979 as an 'International Biosphere Reserve'. The volcano straddles the present border between the People's Republic of China (PRC) and the Democratic People's Republic of Korea (DPRK, North Korea). Changbaishan also stands at the head of the great ridge (*taegan*) that runs down the east coast of the Korean Peninsula containing Mt Kumgang ('Diamond Mountain') and Mt Taebaek ('Great White Mountain') (Figure 1). It is "one of the most dangerous, active volcanoes in the world" (Wei, Taniguchi & Liu 2002: 191), but unlike Vesuvius, Etna, Tambora, Krakatoa or Mt St Helens, its name is hardly known beyond its own region and readers of volcanological research papers. In Korea, however, both North and South, images of it adorn public places, and inhabitants of both rival states revere it as a national symbol.

Paektu Volcanism

Volcanism developed through the Miocene (25–23 Ma) in northeast China (cf. Appendices B-3, C-8) with the orogenesis of green tuff during the opening of the Sea of Japan around which similar characteristics of eruptive frequency, magmatic composition, and geo-chemical structures are found. Thus "investigating and discussing the synchronous volcanism of northeast China and the Japan arc is important for understanding the geo-dynamic evolution and forecasting the

FIGURE 1 MT PAEKTU / CHANGBAISHAN IN REGIONAL CONTEXT

[1] This article uses McCune-Reischauer transcriptions for Korean and pinyin for Chinese words; 'Baekdu' is the spelling approved by the South Korean government.

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re-eruptive possibility of NE Asia volcanism" (Liu, Chen & Guo et al. 2015: 57). The construction of the CBS volcano began with a shield-building stage (5–2 Ma) and was followed by an intermediary period of cone formation (from 1 Ma). The start of the explosive stage that forms the main focus of this paper is placed at ca. 20,000 years ago. Its ash can be identified by its distinctive rock spectrum continuous from rhyolitic to trachytic (Sun, You & Liu et al. 2014). Many of its rocks (trachytes, comendites, and pantellerites) are products of alkaline volcanism (see Appendix B-3).

Changbaishan's many eruptions formed three cones in sequence from southwest to northeast: Wang Tian'e (in the PRC, 2051 m) has a basalt-trachybasalt platform, a middle-stage body of trachyandesite-trachyte and later outcrops of pantellerite; Tianchi (on the PRC/DPRK border, 2749 m) has a basalt platform and trachytes cone, with pantellerites at the summit; and Namphothe (in the DPRK, 2343 m) is a trachyte peak with pantellerites and welded tuff (Liu, Chen & Guo et al. 2015: 47). The principal peak, Tianchi, holds an eponymous caldera lake with a surface area of 9.4 km^2. The lake's name, Tianchi (Kor. Ch'ŏnji, Heavenly Lake), is often used for the mountain as a whole (Figure 2).[2] The only escape for water from the caldera itself is by a dramatic, 20.7 metre-high waterfall on the north side; but amid scenes of great natural beauty, the first signs of the great Tumen, Yalu and Songhua Rivers also trickle out from the mountain's flanks. Today the first two of these rivers partition North Korea from China and Russia, but over the past four millennia, Paektu has 'belonged' to tribes, states, kingdoms, and empires of central Asians, Manchurians, Mongols, Chinese, Koreans, and Japanese.

The NE China-North Japan Axis and B-Tm

Figure 2 The Crater Lake Tianchi of Mt Paektu, Shared Between China and North Korea

The geological link spanning Northeast China, the Japan Sea, and northern Japan – sometimes called the Japan arc – is "characterised by an alkaline explosive volcanism" (Machida 2002: 19). Distal tephras beneath the seas around Japan were first studied in the early 1970s; in northern Japan two tephra layers were frequently found that were later known to have been deposited 10 to 30 years apart. The lower layer, known as Towada-a (To-a) (Machida & Arai 1983: 154), is associated with an eruption of Mt Towada on the Japanese island of Honshu in 915 AD (see Chapter 8). The upper one, of volcanic ash found in many parts of northern Tōhoku and southern Hokkaido in Japan, and beyond, shows the constituent characteristics of proximal tephra from the 10th-century eruption of Changbaishan (Sun, You & Liu et al. 2014: 217). It was first identified at Tomakomai, Hokkaido, and later identified with Mt Paektu (Baekdu); the tephra is now designated as B-Tm (for Baekdu–Tomakomai) (Machida & Arai 1983).

B-Tm tephra has a dual composition resulting from two major eruptive stages: first, a tephra fallout of white alkaline rhyolitic pumice, then a pyroclastic flow of grey trachytic pumice (Sun, You & Liu et al. 2014). B-Tm tephra in general is distinguished by its "high content of total alkali (8%–12%) and FeOT

[2] A detailed map of 1861 names the lake 'Daeji' (Great Lake) (Kim 1861).

(3.7%–5%)" (Ibid.: 5). In contrast, the To-a tephra has a glass alkali content of below 7% in common with most Japanese volcanic ash deposits; B-Tm composition also contains "fine-grained pumiceous and bubble-walled glass shards and small quantities of alkali feldspar, generally lacking in Japanese ashes" (Machida, Moriwaki & Arai 1987: 2). B-Tm tephra found in Japan has a very wide range of refractive index, 1.506–1.516, indicating a heterogeneous composition which is recognized as a combination of the two major Paektu eruption products (Ibid.: 2; Machida, Moriwaki & Zhao 1990: 6). B-Tm has now been found in the DPRK, eastern Russia, widely across the Sea of Japan, and in southern Hokkaido and the Tōkohu region of Honshu (Sun, You & Liu et al. 2014). Its thickness diminishes from West to East but is still 4 cm deep in Hokkaido, 1200 km from its vent (Machida & Arai 1983: 151-164), and may have affected the central Kuril Islands (cf. Chapter 5).

The Mountain and its Eruptive History

The creation of the stratovolcano took place between the late Pleistocene and the Holocene eras. J. Liu et al. (2015: 47) consider that its constituent peaks "were derived from a common source and had similar eruption processes", but that "diversity of the eruption scale, characteristics, and eruption products indicate distinct styles and/or heterogeneity of the mantle source and magma ascent process."

In the late Pleistocene (ca. 17,000 BP) a lava flow up to 40 m thick was deposited on the north side of the mountain from the direction of Qixiangzhan (where a meteorological station now sits on the northern edge of the crater) (Singer et al. 2014: 2795-96). In the Holocene, Changbaishan's supposed principal eruptions are listed in the Smithsonian Global Volcanism Program as 2160±100 uncal. bc, ?1000 BC, 180±75 uncal. bc, 942±4 cal. AD, ?1413, ?1597, 1668, 1702, 1898, and 1903 (GVP 2013). Some of these are unconfirmed, marked here with '?'. The events in 1413 and 1668 have been assessed as "phenomena of Asian dust" and that in 1903 as a hailstorm accompanied by lightning and thunder (Kang, Baag & Chu 2011). A greater frequency of smaller incidents is indicated by Paone and Yun, who report that "since the Millennium eruption, more than 31 eruptive events have been documented" (2016: 170). In this chapter, primary mention will be given to the 10th century AD, when the great eruption frequently known as the Millennium Eruption (ME) took place and formed the present shape of the caldera.

Scientific Interest in the 20th Century

When KANO Tadao researched the glacial topography of the Kaema plateau in northern Korea in 1936, Paektu was – by virtue of its height – the only mountain on the Korean peninsula to be identified as hosting a Pleistocene-era glacier (Kano 1937). As discussed in Machida, Moriwaki and Arai (1987), a scientific expedition to Paektu was conducted by Koyama and Asano in 1942–1943, and Asano carried Japanese research forward into the post-war era. Pre-eminent among Japanese researchers in the post-War era has been the great tephro-chronologist MACHIDA Hiroshi (b.1933; Suzuki, Moriwaki & Lowe 2011). His investigation of Mt Paektu and its contribution to B-Tm ash began around 1980 with analysis of what he and his collaborators recognized in northern Japan and the Sea of Japan as ash from Towada, underlying and combining with ash from the middle to late eruptive phases of Paektu (Machida & Arai 1983). They dated Paektu's Millennium Eruption to 946/7 and identified six likely phases in the chronology of that event (Machida, Moriwaki & Zhao 1990: 12):

(a) Possible earthquakes result in debris 50 km from the summit near Erdaobai, depositing giant boulders and starting rockslide avalanches.
(b) A Plinian column erupted, dropping pale silicic pumice 90 cm thick near Yuanchi, east of the summit, and thinning further across most of the mountain.

(c) On the northeast slope a pyroclastic surge of grey sandy ash, under 2 cm thick, preceded thick, white/grey pyroclastic flow deposits covering ±2000 km^2 with an estimated volume of ca. 10 km^3 down as far as the lower flood plains.

(d) Volcanic mudflow (lahar) deposits filled major river courses; near Liangjiang, ca. 70 km north of the summit on the Erdao river, terrace scarps cutting the lahar expose "rounded pumice and scoria, volcanic sand, vitric ash and rounded non-volcanic gravels bearing numbers of small flakes of carbonized wood", now visible to a maximum thickness of 10 m (Ibid.: 10).

(e) Explosive activity produced tephra fallouts; widespread tephra on the east side of the mountain shows that (c) "was not the post-plinian pyroclastic flow but the intra-plinian deposit" (Ibid.: 10).

(f) Smaller pyroclastic flows occurred; at Baishan, 21 km northeast of the caldera, an 8-m deep pyroclastic flow can be seen in a valley wall; (c), (e), and (f) jointly form part of Paektu's distal B-Tm tephra. "Extensive occurrence of B-Tm shows that it represents the largest part of the total [Millennium Eruption] deposit", estimated to be more than 50 km^3 (Ibid.: 12).

The ecological damage done by ME was a primary concern for Machida, whose sympathy for rural life had begun during a period of convalescence following illness as a boy (Suzuki, Moriwaki & Lowe 2011: 3). At Mt Paektu, his team discovered that the pre-eruptive forests of conifer (above 1300 m msl) – and mixed forest of Korean pine and deciduous broad-leaved trees below – were completely destroyed by the pyroclastic flow and ash fallout over an estimated 4000 km^2 (Machida et al. 1990). Recovery had been more or less achieved on surfaces composed of pyroclastic flows because of their stability but was still far from complete on the eastern flank covered by unstable tephra fallout deposits.

Late in the 20th century Machida did fieldwork with ZHAO Dachang under difficult conditions in China (Machida, Moriwaki & Zhao 1990; Suzuki, Moriwaki & Lowe 2011: 8), and in 1999 the Chinese government set up the permanent onsite Tianchi Volcanic Observatory at a point 40 km away from the main magma vent, together with five seasonal outstations (Liu, G. et al. 2011: 44).

The 21st Century: Advances in Understanding

In 2001, a team of scientists from Beijing and the DPRK was the first to carry out fieldwork on the North Korean side of the Paektu volcano, and they immediately began recording activity within the mountain (Liu, J. et al. 2015: 46-7). Recurring signs of volcanic activity between 2002 and 2009 persuaded the DPRK government to invite western volcanologists James Hammond, Clive Oppenheimer, and Richard Stone to investigate its dormancy. Their on-site research of current volcanic activity, begun in 2011, simultaneously succeeded in settling a historical debate that had foxed expert opinion for decades – namely the precise year and even the season of the enormous explosion commonly known as the 'Millennium Eruption'.

The 'Millennium Eruption' of 946 AD: Data

Estimates for the date of this eruption had ranged widely between the 8th and the 14th centuries (Paone & Yun 2016: 174) until it was placed definitively in the early 10th century using data from various sources: tephra found in China, Russia, and Japan; ice-core samples from Greenland (Sun, Plunkett & Liu et al. 2014); varve chronology; wiggle-matching ^{14}C dating; dendrochronology; dust storms; and historical records.

Tephra

In 1948, T. Asano had described 'mud-lava' on the northwest side of Paektu which led Machida, Moriwaki and Zhao to speculate that probably "almost all of the gentle slopes of the volcano were covered" (1990: 9). Wei, Liu and Gill estimated that the comendite magma was 10–20 kya old at the time of eruption (2013). Changbaishan (CBS) proximal tephra is dominated by gray and white pumice, the former of trachyte and the latter of alkaline rhyolite. These two compositions are found in Japanese deposits of B-Tm ash, which however lacks the enriched alkaline feldspar of CBS tephra (Sun, You & Liu et al. 2014: 220). Comparison of the CBS and B-Tm tephras shows that distal B-Tm tephra was produced by Paektu's Millennium Eruption (ME) (Ibid.: 221). By analysis of the chemistry of CBS proximal tephra and distal content within B-Tm tephra and by paying particular attention to the importance of glass chemistry in source identification, Sun, You and Liu in 2014 favoured a date of between 1012 and 1004 years BP (AD 1002–1010) for the ME but cautioned that there was "no consensus" on its accurate dating (Ibid.: 224); this has been shown to be too late (see below). Chen et al. (2016) have since confirmed the second lowest stage of Paektu's pyroclastic flow units, light grey in colour, as being that of the Milllennium Eruption, overlaying the yellow stratum of the suspected Qixiangzhan Period (see section below on The Tianwenfeng Eruption).

Ice-core Records, Varve Chronology, WM ^{14}C, Dendrochronology

In 1943, Kohyama had found carbonized wood buried in a layer of volcanic sand 30 cm deep in the pyroclastic flow (Machida, Moriwaki & Zhao 1990: 9). Samples of wood found on the slopes of Paektu produced wiggle-matched carbon dates of 1190–735 cal. BP (Sun, You & Liu et al. 2014: 225). Hayakawa and Kohyama (1998) thus concluded a date of 1004 BP. Nakamura (2007) used dendrochronology to date the remains of a wooden house buried in tephra at Odate and planks cut from a wooden channel in Nohaji to AD 912–972. Yin et al. (2012) obtained "a reliable age of 1029–1009 cal. years BP, with the most probable occurrence in 1012 or 1011 BP" (Sun, You & Liu et al. 2014: 226). Xu et al., while attributing the spread of CBS ash as far east as the Kuril Trench, could find no indication in Greenland of a sulphate spike that might be associated with the ME (2013: 54). They did, however, report a larch tree trunk with bark, buried ~14 m deep by pyroclastic flow at Xiaoshahe on the west of Changbaishan, which produced a 14C wiggle-matched date of AD 946±3 (as reported in Ibid.: 55). Sigl et al. (2015: 545, fig. 2), using a revised ice-core timescale, cite non-seasalt sulphur records from depths of 183–514 m in the Greenland ice core NEEM-2011-51 which, when associated with the aforesaid tree and supported by dendrochronology, agree a date of 946/7 for the Tianchi tephra. The date matches that given by B-Tm deposits in varve lakes as far apart as northeast China (Sihailongwan) (Guo et al. 2005) and Japan (Lake Kushu on Rebun Island) (Chen et al. 2016). Its furthest spread southeastwards in Japan may have been to the coastal lake of Suijin-numa in Honshu (Sun, You & Liu et al. 2014: 217).

Dust Storms

Strong westerly winds carry meteorological dust across northeast China, Korea, Japan and into the Pacific Basin from the Gobi Desert, the Hexi corridor (formerly associated with the Silk Road through China's Gansu province), and the Tibetan Plateau. Evidence for the characteristics and environmental and climatic effects of dust storms in northeast China has been preserved in sediment lining the base of shallow maar lakes, including one, Lake Sihailonguan, in the proximity of Changbaishan (Chu et al. 2009). Today the storms cause concern for their environmental, health, and economic effects: in the past, they were liable to be interpreted as signs of heaven's displeasure, and thus were dutifully recorded in official records.[3] Confusion between meteorological dust and volcanic ash may account for the inclusion of 1597 and 1668 in lists of Paektu's eruptions (see above).

[3] "Upon a dust outbreak, rulers refrained from all kinds of entertainment and consecrated themselves with awe" (Chun 2000; Chun et al. 2000a; quotation from Y. Chun et al. 2008: 823).

Historical Records

Historical records from China and Korea that make specific mention of volcanic events and their effects are few in number and often insufficiently precise to do more than corroborate indications from scientific data of seismic and climatic events. But Fei and Zhou found that the dates of unusual meteorological occurrences were sometimes recorded with apparent accuracy (2006: 448). For example, during the eight-year long Icelandic eruption of Eldgjá that began in 934, the Chinese capital Kaifeng had some exceptionally cold winters through the 940s. When snow – which helped to settle dust and kill off pests such as locusts – did not arrive in winter, the emperor might order officials to restore the proper seasonal conditions by praying for it. Heavy snow was experienced on 4 April 945, and a ten-day period of snow near Kaifeng began on 31 January 947. Drought and locust plagues contributed to a long sequence of climatic problems in China through the period 923–954; however, Paektu erupted without mention in the official records.

To summarise the above data, a towering plume rose about 25 km above the volcano,[4] “spewing an estimated 100 cubic kilometres of grey ash and pumice into the atmosphere and pouring some 24 cubic kilometres of magma across 33,000 square kilometres of northeast China and Korea” (Stone 2011: 584). Iacovino et al. estimate that 45 megatons of sulphur belched out (2016: 7). Pyroclastic flows raced 25 km down from the summit[5] at an initial speed estimated by Paone and Yun (2016: 176) as 300 m^{-s}, gauging out a channel 120 m deep down the western (Chinese) side of the mountain and an even deeper one to the north (Stone 2011: 585). These volcanic activities formed today’s popular tourist sites known as the Grand Yalu River Canyon, the Grand Jinjiang Canyon, and the Pumice Forest (Xiagu Fushilin) (Sun, You & Liu et al. 2014: 220). The ‘mud-lava’ on the northwest side of Paektu that Asano had described in 1948 piled up to a depth of 100 metres and led Machida, Moriwaki & Zhao to affirm that “almost all of the gentle slopes of the volcano were covered” (1990: 9) and that “the [pyroclastic] flow must have reached to the lower flood plains in most directions.” Great devastation of mature forestry occurred over a vast area (Machida, Moriwaki & Arai 1987).

An average of 5 cm of ash covered about 1.5 million km^2 of the East Sea (Sea of Japan) and northern Japanese Islands (Figure 3), and a further deposit was laid down in the Greenland ice core (Oppenheimer et al. 2017: 167; Sun, Plunkett & Liu 2014). Such a volume of ash would have buried the entire UK knee deep (*The Guardian*, 23 January 2017). Only about 1 cm thickness of ash is sufficient to destroy most crops; even light dustings at critical periods such as pollination can cause crop failure (Wei et al. 2003: 520). Yet there is no evidence today from tree rings or ice-cores near or far for a dip in global temperatures at the time (Voosen 2016: abstract).[6] The likelihood is that wind carried much of the ash away from the Korean Peninsula (Oppenheimer et al. 2017: 165), thus averting serious loss of life in both China and Korea. The collapse of the volcanic cone into the emptied magma chamber formed the caldera for the eponymous lake at the Tianchi summit, which today has an area of 8.8 km^2 and a maximum depth of 373 m (Yang et al. 2014: 107).

[4] Wei et al. (2007: 322) say 35 km, lasting “for a few days”.

[5] Yang et al. (2003) say 60 m from the crater. Wei, Liu & Gill (2013: unpg.): “The lahars from the Millennium Eruption left deposits up to 300 km from the source”.

[6] Cited by Voosen (2016: unpg.) and queried by Oppenheimer (2017: 168). Xü et al. (2013: 57) had proposed that it was the lower quantity of sulphur in the Millennium Eruption, which they estimated as 53–58 Tg (teragrams = one trillion grams), as compared with that in the 1815 Tambora eruption (93–118 Tg), that accounted for the insignificant climatic impact of the former. They further assign it a VEI of 6.8 as opposed to 7.0.

By taking into account data from all such sources above, and by calibrating the radiocarbon dates obtained from several trees buried on the mountain and subjecting one of them to dendrochronological examination, the Oppenheimer, Hammond and Stone expedition concluded that the Millennium Eruption began in AD 946, probably in late October–early November (Oppenheimer et al. 2017: 167-68).

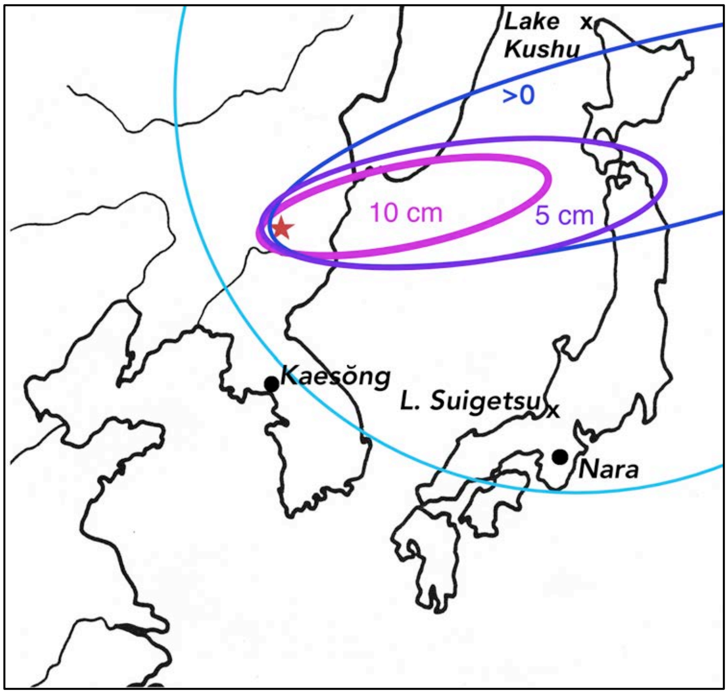

FIGURE 3 ISOPACH DISTRIBUTION OF TEPHRA FROM MT PAEKTU ERUPTION IN 946 AD

Previously acknowledged extent of B-Tm tephra indicated by dark blue >0 cm isopach.
Light blue line to left shows broader distribution limit based on corings at Lake Suigetsu and historic reports of 'white ash' falling in Nara

The 'Millennium Eruption' of 946 AD: Narrative and Interpretation

Narrative

During the night of 3 November 946,[7] a heavy rumbling awoke the Korean court in Kaegyŏng (modern Kaesŏng). So alarmed was the superstitious King Chŏngjong at the inexplicable noise that he quickly ordered the release of prisoners (*Koryŏsa* 1972.1: ch. 2). The effects were also noted 1100 km away in the capital area of Japan. Perhaps it was the sound of this eruption that was heard in Kyoto on 7 February 947 – described as the "thundering of drums" (Xü et al. 2013: 56). Monks at the temple of Kōfukuji (Kor. Hŭngboksa) in Nara reported "white ash falling like snow" (Oppenheimer et al. 2017: 168). That is all that extant records tell us; what more may be deduced and inferred?

[7] Precise date suggested by Oppenheimer et al. (2017: 169) with some reservation; see Chapter 8.

Interpretation

China, Korea, and Japan all have rich documentary historical sources. Today's scientists, astronomers and archaeologists may all help to verify their data, but sometimes authorship or political context opens their interpretation to question, and sometimes incorrect 'facts' do undoubtedly enter the chain of historiographical citation, their veracity becoming accepted simply due to their antiquity or inherent possibility. The user of East Asian records must be particularly wary, no more so than when trying to evaluate stories about climatic or volcanic occurrences. Without relevant scientific evidence it can be tempting, but possibly misleading, to use circumstantial links from documentary sources to imagine a connection between volcanic activity and known historical events. Such, for example, was the causative link once made between the Millennium Eruption and the fall of the Bohai (Parhae) state in southern Manchuria.

The earliest extant reference to Changbaishan comes in the Chinese *Classic of Mountains and Seas* (*Shanhaijing*, 3rd–1st century BC), where it was called 'Mount Not-whole' (*Buxian Shan*). The translation is that of Anne Birrell (Birrell 1999: 183). There are other possibilities, such as 'Not-bite', and if that makes little sense to a modern reader, so I would suggest do the literal translations of some other ancient Chinese mountain names found in Birrell's admirable rendering of this fascinating classic. In the case of Buxian, we might do well not to risk imputing a remarkable degree of prognostication about how the mountain peak would look to the editors of the classic a thousand or so years before it blew its top in 946 and assumed today's 'unfinished cone' shape. Strangely, though myth and legend swirled around the mountain in medieval times, we find that writers in the 10th and 11th centuries – just when we might have expected the region's greatest ever eruption to be uppermost in their minds – make little reference to it, giving modern historians a problem about its date.

The *Jiu Wudai Shi* ('Old History of the Five Dynasties', first printed AD 973–974) temptingly records snow, ice, frost, fog and eventually famine in Manchuria between January 940 and January 947,[8] which would fit in nicely with speculation that after the ME, local monthly temperatures may have fallen by an average of 2.25 ºC and across the northern hemisphere by 0.85 ºC (Wei et al. 2003: 520). With the publication of Oppenheimer's evidence that Changbaishan must have erupted in late 946, it became clear that the *Jiu Wudai Shi* was recording events which took place mostly *before* Changbaishan's eruption. Fei and Zhou (2006) link the bad weather, locust plagues, drought, and famine that China suffered in 939–942 with the global cooling that occurred after the Icelandic volcano Eldgjá's eruption in 934 and not with Changbaishan. They attribute the fall of the Later Jin dynasty (936–947) in northern China in part to the climate changes and consequent starvation around its capital, Kaifeng, of "several tens of thousands of people" (Ibid.: 452).

All this happened against a backdrop of political upheavals that dominated northeast Asia in the early 10th century. The great Tang dynasty had fallen in China in 906; the neighbouring kingdom of Parhae (Ch. Bohai) was destroyed by the Manchurian Khitan armies in 926; on the Korean Peninsula, the Unified Silla dynasty (668–915) collapsed in the face of rebellion led first by a discontented prince, Kungye, who set out to establish what he called Later Koguryŏ, and then by his rival WANG Kŏn, who sought to incorporate the former northern territories of Koguryŏ into his own new kingdom of Koryŏ, which endured as the Koryŏ Dynasty (918–1392).

8 *Jiu Wudai Shi* chapters 78, 83, 86, 100, cited in Fei & Zhou 2006. Imperial prayers were offered when snowfall was too heavy, but when there was less than usual in winter 942–943, officials were told to pray for more. Perhaps the intention was to try to eradicate the locust plagues that were causing havoc throughout the land.

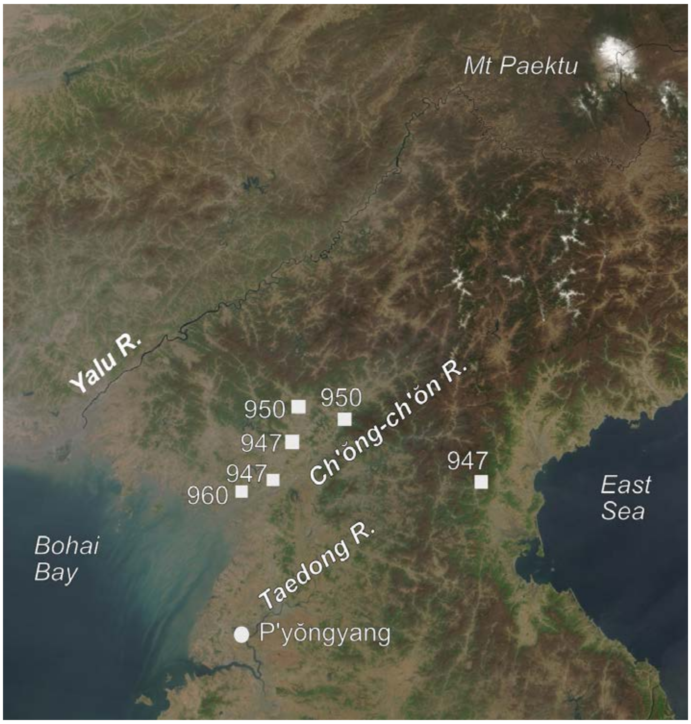

FIGURE 4 WANG KŎN'S 10TH-CENTURY GARRISONS IN THE NORTHERN KOREAN PENINSULA, WITH ESTABLISHMENT DATES

WANG Kŏn strategically headed towards the Changbaishan mountain chain from his capital at Kaegyŏng, establishing garrison settlements up the Taedong and Ch'ŏngch'ŏn river valleys into northeastern Korea (Figure 4) as defence against the Khitan and Jurchen people who threatened from beyond the mountains. He was still a long way short of the northern borders beyond the Yalu River ostensibly claimed by the early Koguryŏ state in the 6th century (see Barnes 2001), but KIM Kwanŭi's 12th-century *P'yŏnnŏn T'ongnok*,[9] quoting the *Koryŏsa sege*, tells us that WANG Kŏn's ancestral spirit Hogyŏng came from the slopes of Mt Paektu (Changbaishan), and we may guess that Wang had in mind eventually to reincorporate Paektu into Korea. But he died with this unfulfilled, and Rogers' conclusion is that "we can only regard the rise of Paektu-consciousness in the Korean peninsula as a *twelfth-century* phenomenon" (1982–3: 36, my italics).

Writing when he did, KIM Kwanŭi may actually have known one other vital fact about the mountain that WANG Kŏn could not possibly have suspected, namely that it was about to explode. Since the volcano had been dormant throughout Wang's lifetime and long before it, he was surely unaware of its devastating potential. When Wang – as King T'aejo, founder of the Koryŏ dynasty – died in 943, he had united much of the Peninsula within its realm. But Paektu still stood some distance beyond its northern reaches, and the new kingdom suffered frequent attacks from its powerful Manchurian rivals. Not only that, but T'aejo's successor King Hyejong also died unexpectedly in 945. The third king within a matter of four years, the 22-year-old Chŏngjong, struggled to establish a power base for himself (Breuker 2010: 154-5). Koryŏ could have done with a sign of encouragement from the heavens, instead of which, in November 946, just two to three years after the death of two kings, Paektu erupted with a fury that must have affected its neighbouring inhabitants whether Chinese, Manchurian or Korean, alike. Many of them must surely have seen it as an omen.

The Koryŏ capital of Kaegyŏng was about 450 km southwest of Paektu as the bird flies. The capital's guardian mountain was Mt Song'ak, supposedly invested with powerful *p'ungsu*[10] and mythology of its own by virtue of being connected to a branch of the Baekdu Taegan mountain spine that originated in Paektu and linked the far north with the far south of the Peninsula (Breuker 2010: 71-2). It is impossible to tell how many people lived in the remote mountains of Paektu and its vicinity at that time, although as the source of three vital rivers, Tianchi may have favoured agriculture in some of its valleys. It is also

[9] *P'yŏnnŏn T'ongnok* was a collection of myths and legends, not an attempt at serious history. See Yoon (2013), Rogers (1982–3), and the Chinese and Korean Historical Records reference section.

[10] Chinese *fengshui* ('wind and water'), the geomantic concept of spiritual force emanating from natural topography and influential in human affairs.

possible that small monastic communities were tucked away in the mountain folds. Even so, the region was probably thinly inhabited by poorly educated and superstitious people. Current online estimates for the whole of Korea in the 10th–12th centuries range from 2.1 to 7 million. But even if the death toll on the mountain slopes in 946 was low and even insignificant to officials in the capital, the climatic downturn must have been experienced there.

So why do we see no detailed meteorological reports from within Korea itself – evidence perhaps from military or government officials returning to the capital from rural districts, or conveyed by diplomatic missions from China? The height of the Plinian column alone must surely have brought it to the notice of the authorities in Kaegyŏng, however short-term the effects felt there might have been. Medieval Korean astronomers enjoy an exceptional reputation today among their peers in East Asia (Stephenson 2013a, b), and surely those in Kaegyŏng could not have failed to observe or receive reports of such unusual phenomena in 946 or 947. It seems inconceivable that such an enormous eruption should have passed almost unnoticed, though it is worth noting that the even bigger explosion and collapse of Mt Samalas on Lombok Island in 1257 was only identified and researched by volcanologists from 2012 onwards (Klemetti 2013, Vidal et al. 2016). Its Plinian column may have reached 43 km in height (Guillet et al. 2017), and the eruption is held responsible for climatic changes that caused widespread death and economic turmoil across the northern hemisphere.

Were Korean officials in 946 frightened to report bad news to the court? King Chŏngjong, a novice politician, may have been preoccupied with arguing (unsuccessfully) that the capital should be shifted near to his own factional supporters in P'yŏngyang, but he did manage to establish twelve national granaries (*Koryŏsa* ch. 79, Choe 2005: 14). This was in keeping with the guidance for good government laid down in King T'aejo's dying will, but was it also an answer to famine created by the eruption?[11] Did the court itself decide on an official cover-up for fear of frightening the populace? Might the *Koryŏsa*'s virtual silence be explained by the fact that Paektu did not stand in Koryŏ itself and so was not yet 'Korean'? Or is the truth that when the Khitan attacked and sacked Kaegyŏng in 1011, relevant bureaucratic records covering the events over half a century previously were destroyed (Reckel 2001: 61)?

Other Eruptions of Mount Paektu

Overview

Changbaishan's Millennium Eruption has been authenticated and analysed in a sizeable body of scientific literature, but the volcano's other outbursts have attracted far less critical research. Table 1 shows the range of recorded and suggested dates for supposed eruptions since the 4th millennium BC. Study of rock, volcanic crystal and glass particles, dust from pumice tephra around the mountain, tree-ring and vegetation samples has begun to clarify the sequence of explosive events through the Holocene era, but affirmative dating of the earliest eruptions cannot yet be attempted (Yang et al. 2014: 106). A comprehensive picture of all activity from the late Neolithic onwards should also take into account relevant information from documentary sources and local myth and legend – and therein lie multiple distractions.

Eruptions that seem more or less to coincide with significant events or developments in Chinese and Korean history, or are woven into local folk tales and observances, should be treated with particular caution pending the availability and assessment of corroborative scientific data. Table 1 suggests a general pattern of roughly millenarian eruptive activity. A sceptic might say that in the 2nd millennium AD, when literary output and book buying were growing exponentially across East Asia, claims of approximately

[11] I am grateful to Prof. Clive Oppenheimer for drawing my attention to this good deed. 'Charitable Granaries' (*ŭich'ang*) were first created in the late 10th century in emulation of the long-established system of Chinese *yichang*. King T'aejo "is supposed to have established the so-called 'black granaries' (*hŭkch'ang*) for relief" (Palais 1976: 331).

centennial activity in the mountains also indicate the credulity of storytellers and readers. On the other hand, one might suspect that many another outburst from the distant mountainside could have gone unremarked during the long gaps suggested in earlier millennia.

TABLE 1 CHRONOLOGY OF ESTIMATED CHANGBAISHAN / PAEKTU ERUPTIONS

Millennium	**Periodization**	**Paektu eruptive dates**	**Historical periods/events**
4th millennium BC: 3999 – 3000	'Tianwenfeng' Period	ca. 3050 BC[a]	Chinese & Korean Neolithic cultures
3rd millennium BC: 2999 – 2000	'Qixiangzhan' Period	ca. 2050 BC[b]	Chinese Bronze Age begins; foundation of the Xia dynasty?
2nd millennium BC: 1999 – 1000	Chinese Bronze Age	ca. 1050 BC	Transition from Xia to Shang dynasty ca. 1500 BC, Shang to Zhou 1046 BC
1st millennium BC: 999 – 0	China and Korea: Bronze Age and start of Iron Age	ca. 180 BC[c]	China: Zhou, Qin and early Han dynasties. Korea: creation of Old Chosŏn polity. 108 BC Chinese armies invade Korea
1st millennium AD: 1 – AD 999	'Millennium' Period dates from 10th century	AD 946	China: fall of Tang dynasty 906. Manchuria: fall of Parhae 926; Khitan, Jurchen attacks on Korea. Korea: Koryŏ dynasty est. 918
2nd millennium AD: 1000 – 1999[g]		1413[d], 1597[d], 1668[e], 1702[f], 1898[e], 1903[e]	1231–59 Mongols invade Korea 1592 Japanese invade Korea 1627, 1636 Manchus invade Korea 1910 Japanese Colonial Period 1950–53 Korean War
AD 2000 – 2999			

Notes from Pan et al. 2013:

a Plinian eruption

b "small-scale pulsed explosive eruption" (2013: abstract)

Notes from Wei, Liu & Gill 2013:

c Not recognized

d Not recognized

e Speculative

f Confirmed

g "We suggest that the roughly 100-year periodicity in recent eruptions may be more apparent than real. None of the post-Millennium events was long-lived, and only the one in 1702 would have made much impact scores of kilometres away" (Wei, Liu & Gill 2013: 712).

The Tianwenfeng Eruption and the Xia Dynasty in China (ca. ?2200–1500 BC)

Tianwenfeng and Qixiangzhan are districts on the rim of the Tianchi caldera where lava flows are found; they have both become the names of different eruption incidents. Pan et al. (2013) apply 'Tianwenfeng Period' to the 4th millennium BC after the first huge Holocene eruption (est. VEI 4) by Paektu at ca. 3050 BC. For the 3rd millennium BC (ca. 2050 BC), they use the name 'Qixiangzhan Period' after its next great outburst about a thousand years later. In their view all three major eruptions (Tianwenfeng, Qixiangzhan, Millennium) were of the Plinian column, explosive type. Efforts have been made to collate socio-cultural and political developments in China during this far-off era with natural events there and worldwide. But apart from 946 AD, none of the eruption dates can be affirmed precisely pending more scientific and archaeological information, and over-hasty conclusions are to be avoided.

Global climatic and environmental conditions underwent "catastrophic" changes by land and sea around 2300 BC, triggered perhaps by the Icelandic Hekla 4 eruption (Peisner 1998: 132).[12] Paektu itself may have exploded in 2160±100 uncal. bc (GVP 2013) in what has also been called the 'Tianwenfeng Eruption,' supposedly of VEI 7.[13] Reviewing previous reports, Chen et al. assign a rough date of 4~5 kya for the lowest of Tianwenfeng's four levels of pyroclastic flow units, likely to be "the product of an older pre-caldera forming eruption" (2016: 63). China was then on the cusp of the Bronze Age after its long Neolithic Period, and the uncertain beginning of its traditionally-named first named dynasty, the Xia, is commonly placed less than a century before this in ca. 2200. Its historicity continues to be questioned: Mair ends his comprehensive examination of the subject with the words, "Was there a Xià Dynasty? Not on present evidence" (2013: unpg.). But the ancient belief in it will not go away, and Pankenier proposed 1953 BC as its beginning date (1998: 189).

FIGURE 5 THE CORE REGION OF EARLY CHINESE STATES

One of the most popular stories in early Chinese mythology was that of 'Emperor' Yu, who initiated a successful irrigation scheme in the fertile soil of the Yellow River basin (Figure 5) and thereby rescued that part of the land, where Chinese civilization developed, from a great flood. Archaeologists who examined archaeological evidence of a flood at Lajia, Qinghai Province, radio-carbon dated it to ca. 2050 BC (Ye 2005). Some have tentatively associated this with the 'Emperor' Yu's work and the inauguration of the Xia dynasty (Andrews 2016: unpg.; Wu et al. 2016: 579-82). Others are sceptical (Han 2017), but Barnes (2015: 174-6) has noted that "excessive flooding" between 2200 and 2000 BC disrupted agriculture, caused heavy loss of life, and re-shaped the pattern of late Neolithic culture zones across northern and central China to usher in the new millennium. The evidence does at least begin to suggest an answer to Machida's question about the effect of such as the '4 kya event' on contemporary society (Machida 2002: 61-8). In Japan, climate change caused alterations to settlement patterns in central and northern Honshu, "dovetail[ing] with the eastern Mainland experience of site abandonment" (Barnes 2015: 176).

[12] Peisner (1998) gives the Hekla 4 date as 2350 BC; more recently, Stevenson et al. (2015) have put forward a radiocarbon date of 3826±12 for Hekla 4 [which calibrates to 2301–2204 BC at 95.4% probability for 93.3% of possible dates, using OxCal 4.3.2, IntCal 13 (ed.)]

[13] "The age of the Tianwenfeng eruption is not clear, but the carbonized wood in Heifengkou lag breccia has been dated at 4105±90 bp. This eruption covered large areas in yellow pumice and ignimbrite and released about 23.14 megatons of SO_2 into stratosphere. The bulk volume of the ejecta is at least 100 km^3, making the Tianwenfeng eruption also of VEI 7" (anon. [https://en.wikipedia.org/wiki/Paektu_Mountain]).

The rise and fall of the Chinese Shang Dynasty (ca. 1500–1046 BC)

How Xia – whether or not its political system and/or the extent of its control deserve the title of dynasty – came to be succeeded by the Shang dynasty is also imperfectly understood. Excavated remains near modern Yanshi, Henan Province, are generally believed to be those of Erlitou (Figure 5), the last capital of the polity that was ceded to the Shang people from the east around the middle of the 2nd millennium BC. That signal event in Chinese history was accompanied by "a series of astronomical/meteorological phenomena [that…] may point to repeated multiple cometary apparitions, meteor storms, and possible impacts leading to anomalous weather-related consequences on a wide scale in north China, most notably one of the severest droughts in cultural memory" (Pankenier 1998: 194). "It rained dust at Bo (the capital). For ten days it rained ash, the rain was grey…it snowed in July…frosts killed the five cereals" (Baillie 1995: 80, citing Pang et al. 1988). The date of this disaster, though still uncertain, is widely accepted as ca. 1600 BC.[14] Tree-ring evidence indicates major climatic events in 1628 and 1159 BC, perhaps corresponding respectively to eruptions by Mt Santorini (associated with an Irish tree-ring date of 1627 BC) and Hekla 3 (assigned a Greenland ice-core date of 1120±50 BC) (Baillie 1995: 80ff) and radiocarbon dates calibrated to 1121–971 BC,[15] but no suspicious activity from Paektu is recorded around the mid-2nd millennium BC.

The Shang was the first Chinese dynasty to be archaeologically authenticated, and excavations from the late 20th and 21st centuries have repeatedly demonstrated that much still remains to be discovered. Modern historians have sometimes struggled to understand the relationship between a host of newly discovered archaeological remains and early documentary sources referring to the Shang. It is understood, however, that Shang kings based their significant power on the monopolistic control of three things: the ability to control large bodies of men, the manufacture and exploitation of bronze, and use of the first written Chinese script (Chang 1988: 1-142). The latter was inscribed on tortoise shells and animal bones with records of things past and forecasts of the future. Corruption among its rulers eventually led to its overthrow by leaders of its own feudatory state, Zhou, a seminal event in ancient Chinese history because the long Zhou era that followed was distinguished by political, philosophical and cultural progress, not to mention its interest in the science of the heavens and earth.

The date when the Duke of Zhou, founder of the Zhou 'Dynasty' (1046–221 BC), led his armies to victory over the tyrannical last Shang king was traditionally placed sometime in the 12th century BC but not confirmed with more or less certainty until the late 20th century. Then, the date of the final battle, at Muye, was identified as 1046 from inscriptions on oracle bones and bronze vessels (Shaughnessy 1980-81) and confirmed by astronomical evidence (Pankenier 1998: 189). The *Bamboo Annals*[16] associated the momentous dynastic overthrow with an ominous series of natural disasters, and circumstantial evidence associating it with a large-scale volcanic upheaval around 1100 BC was discussed by Baillie (1995: 149ff.). There is no evidence of volcanic activity in Manchuria until an "uncertain" date of "1000 BCE (?) [*sic*]" (GVP 2013). But 1046 falls within the timescale provided by Hekla 3's occurrence in the radiocarbon date range of 1121–971 cal. BC, so perhaps we should not discount the possibility that growing resentment in Zhou at the profligacy of the Shang court was exacerbated by consequential crop

[14] Baillie (2008) offers a modification by a few years, newly based on tree rings, of the dates indicated by ice cores in Baillie (1995).

[15] Calculated with OxCal 4.3.2 IntCal 13 from ^{14}C 2879±34 BP given by Stevenson et al. (2015), with 95.4% probability accounting for 84.5% of possible dates (ed.).

[16] The *Bamboo Annals*: an early history of ancient China covering the Xia, Shang and Zhou era (the 'Three Dynasties'), supposedly compiled in the 3rd century BC. More than one version survives from its discovery in the 3rd century AD, and its authenticity has been questioned. However, scholars value the importance of its astronomical information. On its disputed historicity, see Nivison (1999).

failures. Nor do the *Bamboo Annals* indicate a volcanic origin either for this outburst of climatic turmoil or for any that preceded the fall of Xia previously, but descriptions of both seem to be consistent with the dusts that sometimes accompany volcanic explosions.[17]

The Chinese Han Period (206 BC–AD 220) and after

No volcanic activity related to Paektu has been recorded or suspected through the majority of the 1st millennium BC. Sometime around 500 BC, the first known state on the Peninsula, Old Chosŏn (Kochosŏn), emerged along the Taedong River basin approximately where P'yŏngyang is today. By the beginning of the 3rd century BC, the state of Puyŏ began to take shape in Manchuria, northwest of Paektu (Byington 2016: 138). In China the long imperial era was inaugurated when the First Emperor of Qin, Qin Shi Huangdi, completed the unification of the earlier feudal states (221 BC). His methods were harsh and unpopular, and when the stars were said to have been blacked out for months on end in 208-7 BC and famine occurred – part of the global climatic change indicated by Irish and German tree rings (Baillie 1995: 81) – the credulous may have read the signs as heaven's displeasure. In 206 Liu Bang succeeded in overthrowing the second Qin emperor and establishing the Han regime.

The Han dynasty was a period of intense political, military, intellectual, and scientific activity in China, and it is tempting to look for possible links between what went on in public life and meteorological disturbances: that is certainly what Han Chinese themselves did (de Crespigny 1976: 9; Ching 1993: 156). In 108 BC, Emperor Wudi's armies marched north-eastwards into the northern Korean Peninsula, now ruled by the kingdom of Wiman Chosŏn (Pratt 2005: 34), and began Chinese colonization from a capital at Wanggŏmsŏng, near modern P'yŏngyang. A reported VEI 4 eruption in the radiocarbon-dated period 255–105 BC enters into some lists of possible explosions by Paektu (Horn & Schmincke 2000: 537; GVP 2013). Paektu itself probably remained beyond the reach or interest of Chinese officialdom, but an eruption within the Changbaishan range could, pending more precise scientific dating, comfortably link Han Wudi's invasion with the eruption – if not to a sceptical modern historian then at least to contemporary Koreans of superstitious nature.

We shall look below at the question of the beliefs associated with Paektu's powers. For the moment, it is worth noting that a further series of unnatural events took place or were observed in China between 44 and 42 BC. They included harvest failures, unseasonal snow, evidence of a dust veil, and the appearance of a "red daylight comet" in May and June 44 BC (Baillie 1995: 84). Paektu seems not to have been responsible, but Baillie (Ibid.: 85) notes the eruption of Mount Etna in that year.

In China, severe weather, famine, and the collapse of the Northern Wei dynasty in AD 534 were accompanied by another dust veil event, associated with well-documented climatic global upheavals around the world in 536–540. The culpable volcano has not been definitively pinpointed, though in this case Paektu is not suspected (Baillie 1995; Larsen 2008).

The Chinese Ming Dynasty (1368–1644) and early Korean Chosŏn Period (1392–1598)

1413 AD

A meteorological event in 1413 sometimes enters lists of volcanic eruptions by Paektu, but it cannot be substantiated as volcanic. Machida, Moriwaki and Zhao note documentary mention of it (along with those in 1597, 1668 and 1702, which are now better accepted), saying that "these activities do not correspond with the major eruption [*sic*] generating voluminous tephra…, but could have been minor ones" (1990: 3). Kyo et al. call what happened an "Asian yellow sand storm" (2011: 11). This was the year in which T'aejong, the third king of the Korean Chosŏn dynasty, began the compilation of the dynastic records

[17] On records of dust storms in China and Korea and their analysis, see above and Chu et al. 2009.

Chosŏn Wangjo Sillok ('Authentic Records of the Chosŏn Dynasty'), with a retrospective survey of his two predecessors' reigns. It was also in December 1413 that he firmly ended the nineteen-year-long persecution of Koryŏ's dynastic Wang clan (*CWSTJoS* yr.13).[18] Might this sign of overdue clemency have been suggested to him by volcanic activity around Paektu: perhaps he was reminded that after Paektu's eruption back in 946, King Chŏngjong's knee-jerk response had been to grant a political amnesty? A paper by Eugene Park (2017) offers no suggestion of any such motivation for T'aejong's decree, and in any case, his own political position in 1413 was stronger than Chŏngjong's had been in 946–947. Nevertheless, the fear of a possible connection between subterranean activity and political threat was shown again in 1432, when King Sejong was concerned that recent earthquakes might portend a Japanese attack (*CWSSeS* yr.14).

1592–1597 AD

Four years after Sir Francis Drake and his fleet rescued England from the Spanish armada in 1588, events began to unfold in Korea that would earn another admiral, YI Sunsin, a reputation in his country matching that of Drake in his. But whereas Drake prevented the Spanish from setting foot in England, Yi was not yet in charge of fending off the much larger Japanese fleet assembled by Daimyo TOYOTOMI Hideyoshi, which landed on the southern coast of Korea in May 1592 and unleashed such a trail of pillage and destruction that its effects are still lamented by cultural historians and the entire Korean population. Hideyoshi's troops withdrew the following year, leaving a large occupying garrison, but they returned in August 1597. By the time YI Sunsin's famous fleet of armoured 'turtle' boats finally helped to drive the invaders away, with enormous casualties on both sides, Hideyoshi had died.

The conquest of Korea had been incidental to the Daimyo's principal objective, the Dragon Throne in Beijing, and his armies hadn't headed for the northeast, but in 1597 severe earthquakes shook parts of Hamgyŏng and Ch'ungch'ŏng Provinces and the Gulf of Bohai (Kang, Baag & Chu 2011), and according to the *Sŏnjo Sillok* (*CWSSoS* yr.30) Mt Paektu erupted ferociously. No irrefutable scientific evidence of seismic activity contemporaneous with the Japanese wars has been produced: the Smithsonian's Global Volcanism Program (2013) labels an eruption in 1597 'uncertain', and Chu et al. identify the period 1590–1690 as one of "intensive dust events in China and Korea" (2009: 108).

The Chinese/Manchu Qing Dynasty (1644–1911) and Korean late Chosŏn Period (1598-1910)

1668–1702 AD

Some researchers treat volcanic disturbances in 1668 and 1702 as separate events while others see them as part of the same movement. Kang, Baag and Chu (2011) accept the latter date as a volcanic eruption but dismiss 1668 as mere dust.[19] Conversely, Paone and Yun (2006: 170) date the Buguamiao pyroclastic flow, a dark grey trachyte ignimbrite and pumice, to 1668 and the Wuhaojie Formation, light grey comendite fine glass, to 1702. They note also that "large deep earthquakes occur frequently in the vicinity (a distance of about 200 km) of the Baekdusan volcano" (Paone & Yun 2016: 167), and they gauge that between 1668 and 1702 the mountain disgorged a pyroclastic flow of 10^9 cubic metres along a runout of 4–5 km under a Plinian column rising up to 25 km. They assign it a VEI of 4–5. Chen et al. (2016), on the basis of earlier reports, accept that the second highest layer of Tianwenfeng's pyroclastic units, coloured dark grey, might be matched with the pyroclastic flow of 1668–1702. Machida, Moriwaki and Zhao (1990) examined the devastation caused on the forestry by this eruption, which buried evidence of pine and broad-leaved trees in the pumice and ignimbrite that lie above the current tree line.

[18] See *CWS* listings under Chinese and Korean Historical Records in Reference section.

[19] See Chu et al. (2009).

1903 AD

There are different opinions about what happened around 15 April 1903 as documented in the historical literature. Kang, Baag, and Chu (2011: 11) note that the event recorded on 5 April 1903 was "a shower type of rain drop [*sic*] with hail accompanied by thunder and lightning." But Kano's fieldwork in 1936 clearly led him to think otherwise. He wrote (Kano 1937: 1144-5, my insertions):

> The explosions that occurred quite recently have made the topographical microforms quite indistinct as the result of thick accumulations of pumice exceeding 10 m in thickness… [but, he cautioned] the inner side of the caldera wall of Mt. Hakutō [Paektu] has been excavated in an extraordinary manner into a semicircular shape by some cause probably glacial erosion, rather than volcanism or normal erosion. The cirques, which are so strikingly developed, number three…. The lowest bottom of these cirques on the edge of the lake water is 2257 m.

Paone and Yun (2016) have equated the Liuhaojie tuff ring with a 1903 phreatomagmatic eruption, producing a pyroclastic flow of comendite with a runout length of 3 km and assigned a VEI of 2–3. A VEI of 2 would imply an eruption column up to 5 km, and VEI 3, a column between 3 and 15 km high. It appears to have been the most recent record of above-ground activity by the volcano. Chen et al., noting that Cui et al. (1995) had linked the uppermost black pumice with events in either 1668–1702 or 1903, conclude that the date of the uppermost layer of Tianwenfeng sediment "remains ambiguous and could be either contemporaneous with the ME or post-date the ME" (2016: 64).

The Mountain and its Ideology

Myth, Legend, and Religiosity

Humans have always feared and revered volcanoes, and in ancient times, often honoured the deities and mythic figures associated with them with tales of anthropomorphic deeds.[20] Sometimes these tales became embroiled in accounts of the emergence of societies and states. Two of nine Korean foundation myths are linked with Paektu (Pratt & Rutt 1999: 134-6), while Golmin Sanggiyan Alin (Paektu) had long been sacred among the Khitan, Jurchen, and other tribes from which the Manchu Qing dynasty would come to rule both China and Korea in 1644 (Crossley 2002: 192ff.).

Tan'gun

The story of Tan'gun is familiar to all Koreans for the part he is reputed to have played, either as their ethnic progenitor or as political founder of Old Chosŏn – spuriously dated to 2333 BC. Supposedly born through the divine union of Hwanung, son of the supreme deity Hwanin, and a she-bear, his descendants later populated states all over the Korean Peninsula. As Old Chosŏn was ostensibly the first Korean polity (see Barnes 2001: ch. 1), its history was combed by later political leaders seeking precedents to legitimize their own actions.

It is unknown when the myth originated (Grayson 1997). The monk Iryŏn's book of folk tales, the *Samguk Yusa* (compiled in 1285 AD), was the first to introduce Tan'gun, citing an earlier but now unverifiable Chinese source. Early in the Chosŏn dynasty (1392–1910), a shrine was built in P'yŏngyang to Tan'gun as the nation's progenitor, but "the Tan'gun myth never was very central to premodern Korean identity" (Seth 2013: 2). It assumed more significance through the 20th-century Japanese occupation, when nationalists argued over Tan'gun's greater value as a mythical or genuine historical figure. In 1908,

[20] See for example Birrell (1999).

historian SIN Ch'aeho determined that Tan'gun had been born on Mount Paektu, which thereby earned veneration as a holy mountain. In mid-century an archaeological stir was caused when an apparent illustration of the Tan'gun story was recognized among stone grave carvings in a 2nd-century AD shrine in Shandong, China. The identification was subsequently disproved (Pai 2000: 71ff), but the excitement it generated contributed to the growing field of nationalistic Tan'gun studies, a subject of academic curiosity that has never since disappeared.

Hogyŏng and the Value of P'ungsu *in Korea*

The Koryŏ dynasty (918–1392) was an intensely religious period when the boundaries between the state cult of Buddhism and widespread observance of shamanic and Daoist practices were blurred. The mountain god of Paektu was the most important of eight deities worshipped at the Shrine for Eight Worthies (*p'al sŏngdang*) (Ten 2017: 20). KIM Kwanŭi's 12th-century *P'yŏnnŏn T'ongnok*, quoting the *Koryŏsa sege*, tells us that WANG Kŏn's ancestral spirit, the mountain god Hogyŏng, came from the slopes of Mt Paektu before settling on Mt Song'ak. *Koryŏsa sege* was intended to justify the Wang clan's right to claim the throne and to defend the choice of Song'ak, the clan's own home, as the site for its new capital (Yoon 2006: 258 et pass.). It did so by emphasizing the importance of geomantic powers that emanated from the sacred mountain – i.e. the belief system known as *p'ungsu* (feng shui) that is still widespread among Koreans and Chinese today and may conceivably have once reflected its inhabitants' instinctive feeling for the subterranean reservoirs of magma under the volcano and recognition of patterns of lava flowing down its flanks. If it seems paradoxical that the volcano that had threatened to undermine the new dynasty in the 940s should attract such respectful recognition from a 12th-century editor, Michael Rogers provides a possible explanation (1982-3: 30):

> KIM Kwanŭi gives to Paektu Mountain the recognition that by twelfth-century perceptions (conditioned as these were by the spectacular rise of the Paektu-nurtured Jurchen) it deserved…. The idea of appropriating Paektu was not original with him…but he did give definitive expression to the myth as a basis for integration into the *p'ungsu* system, whose geographical scope was thus greatly expanded.

Today the mountain chain running from Mt Paektu in the north to Mt Chiri in the south is known by a term used since the 18th century, Paektu Taegan ('White-headed great ridge'); it is still believed by some to be the main spine of spiritual *p'ungsu* that energizes Korea, North and South (Mason 2017) – though there is little evidence that in the medieval period, despite obvious reverence, any attempt was made to activate its supposed power.[21] Whether anyone attributed Koryŏ's survival after the 946 eruption to Hogyŏng or even Tan'gun is unknown, but the pair evidently did not frighten off subsequent invaders from the north. Instead, in 1010 King Hyŏnjong tried to head the Khitan off by ordering the first great copying of the Buddhist *Tripitaka* sutras as a supplicatory protective measure, a 40-year task that evidently took too long to be effective. A similar effort was equally unsuccessful when the Mongols destroyed the sutra set stored at Puinsa Temple along with monk Ŭich'ŏn's 4740-volume supplement and conquered the Peninsula in 1232 (Pratt 2005: 111). Between times, the Jurchen claimed the volcano as part of their territory when they established the Jin dynasty in northern China (1115–1234). Emperor Shizong (r. 1161–90) said, "Only Changbai Mountain can reflect the virtue of our Golden [dynasty]; when we gaze up at its height [we recognize that it is] really a talisman for our ancestral land" (*Jin Shi* ch. 35, my additions).

[21] The rebellious 12th-century monk Myoch'ŏng did, however, name it as one of Koryŏ's eight protective spirits (Breuker 2013: 251).

The View from China

Emperor Shizong urged temple building and the performance of rites at Changbai. Later, some Koreans in the mid-Chosŏn dynasty would also have been aware that beyond the Yalu River, the Kangxi Emperor (r. 1662–1722) had made what Koreans now thought of as *their* Paektu central within the cosmic realm of the Manchu/Chinese Son of Heaven, not only by adding it to China's five sacred peaks but by actually making it *primus inter pares* of these mountains when he travelled to Changbaishan in 1682 and there performed the *fengshan* sacrifices for the first time in his reign.

From the time of the First Qin Emperor (r. 221–209 BC), the *fengshan* sacrifices were amongst the most important rituals offered to Heaven and Earth by Chinese emperors. The most sacred location for these irregular events was Mount Tai, in Shandong province. Han Wudi sacrificed here in 110 BC, two years before he despatched his armies on the campaign against Old Chosŏn. Manchurian foundation myths had long sacralized Changbai with the belief that the progenitor of Nurhaci, a late 16th-century Jurchen chieftain named Bukuri Yongson, was conceived on its slopes (Crossley 2002: 196). It was therefore revolutionary but entirely logical that Kangxi, sovereign of the Manchu Qing Dynasty, preferred to carry out the important *fengshan* sacrifices at a mountain in his homeland. According to Song (2018), Kangxi sent his surveyor, Mukedeng, to hunt out the precise source of the Tumen and Yalu Rivers and marked them with a stele at the top of Changbaishan in 1712 – an important aspect relevant to the Qing understanding of the China/Korea frontier. Kangxi is also said to have "promoted Changbai as the royal ancestral mountain, further strengthening the foundation myth of the monarch and the sacredness of Manchuria" (Ibid.: 3). Moreover, Kangxi's elevation of Changbaishan drew attention to the grip on Korea boasted by the Manchu Qing rulers following their successful invasions of the kingdom in 1627 and 1636 (Whiteman 2013: 39).

Mountains and Korean Religiosity

In East Asia mountains were associated from earliest times with immortality. Even without the patronage of Jin and Qing emperors, Changbai/Paektu already contributed to a long native tradition of mountain religion in Korea, practised in simple shamanic shrines, Daoist retreats, and Buddhist temples. Mountain spirits (*sansin*) and animals feature prominently in Korean mythology and folk art as well as in the tales of Tan'gun and Hogyŏng. Creatures redolent with symbolic meaning such as tigers, cranes and carp decorated Buddhist and Daoist temples. Hermits followed ascetic lifestyles among mountain peaks and by waterfalls, and tales were told about deserving walkers encountering [Daoist] Immortals on mountain trails, but only later realizing how they had benefited from conversing with a deity. Kangxi had said that the spirits on Changbai should "receive investiture and permanent sacrifice" (Whiteman 2013: 39), and some Korean legends go so far as to claim that two of the most illustrious Chinese cultural heroes were taught by Korean goddesses on its slopes. These were the semi-mythical Yellow Emperor (Huangdi), taught by the goddess Chabu Sŏnin (Rhee 2006: 121), and the founder of Chan Buddhism, Bodhidharma, taught by the Goddess of Heaven Ch'ŏnsŏnnyŏ, after which he became an Immortal (Winstanley Chesters & Ten 2016: 154-5). Today, many South Korean hill-based groups continue to practise physical and mental programmes dedicated to spiritual enlightenment along lines that can trace their origins to traditional devotees (Ten 2017).

Political Opportunism

In the 1930s, the Japanese again took up the challenge that had defeated them in the 1590s, using Korea and Manchuria as a launch-pad for the conquest of China. This time they encountered determined opposition not from the sea but from the mountains, specifically from MAO Zedong's communist Soviet in Shaanxi province and from guerrilla armies in the northeast where KIM Ilsŏng (1912–1994) was active. It was later claimed that his son Chŏngil was born on Mt Paektu while KIM Ilsŏng was operating there in

1941–1942. He was actually born in the USSR, though his mother, KIM Chŏngsuk, did become the central figure in a series of heroic and sacrificial deeds attributed to female guerrillas around the slopes of the volcano. In the process, she became so energized by the mountain's natural resources[22] and vital force that she attained a status equivalent to that of a mountain spirit (Winstanley Chesters 2017).

In due course KIM Chŏngil fulfilled the expectation bestowed on him by his parentage (King 2011: 270, fig. 24). When KIM Ilsŏng died in July 1994, Chŏngil succeeding him as overall ruler of the DPRK. His father was embalmed and buried in his own official residence, now converted by his son into a splendid mausoleum known as Kŭmsusan Memorial Palace. Only the year before, archaeologists had discovered a tomb near P'yŏngyang containing bones that they claimed to be those of Tan'gun. They dated them to 3000 BC,[23] well before the traditional date of Old Chosŏn's foundation, and another enormous mausoleum was built above the spot. When KIM Chŏngil visited it in autumn 1994, apricot trees burst into unseasonal flower. But the economy began to flag, exacerbated by severe floods in 1995–1996, which this time could not be blamed on any serious global volcanic eruptions but revealed government failings. In the resulting famine, half a million people may have died (Lankov 2013: 79). Now Chŏngil himself (1941?–2011) also lies in Kŭmsusan Memorial Palace. Visitors to the shrine, renamed the Palace of the Sun by his successor KIM Chŏngun, bow before marble statues of his two immortalized forebears and view a 3-D scene of them on Mount Paektu (French 2016: 1/1/16). Chŏngil was the Dear Leader under whom cooperation between DPRK and Western volcanologists first began. DPRK media reported that on his death in December 2011, Mt Paektu was cloaked in an unearthly glow (Anon. 2016).

Paektu is referred to as 'the sacred mountain of the revolution' in the DPRK Constitution (Article 169), and its image is embedded in the state seal. The words of the ROK national anthem, dating from the late 19th century and adopted in 1948, begin "Till the Eastern Sea and Paektusan dry out and wear away/Under God's protecting care, our land shall flourish for ay" (Pratt & Rutt 1999: 2). In North Korea, Paektu is the subject of paintings (Portal 2005: 152) and mosaic murals (Haufler 2011: 270), and it had an early space rocket named after it; it has appeared on postage stamps in both the DPRK (King 2011) and ROK, and it functions as a totem of reunification. North Korean artists may paint it peacefully from life (Hoffman 2011: 179), but in the 1980s, ROK students depicted its violence in polemic paintings demanding more democratization (Kim, Kollontai & Yore 2015: 134), an unexpected reminder of the *wen*:*wu* (civil:military) dualism frequently met in traditional Chinese and Korean society and culture.

Future Forecasts

The 946-7 AD Millennium Eruption measured 7 on the VEI scale, ranking it 13th among the top 25 volcanic explosions in global history. Stone reports that "only a few 7s have occurred during the last 11,500 years" (2011: 585). A survey of scientific literature relating to this eruption appears in Wei, Liu & Gill (2013). The eruption of Mt Samalas in Indonesia has recently been identified as the greatest eruption of the past millennium (Vidal et al. 2016). Another eruption of Paektu is generally anticipated, though when and of what magnitude is not known.

The minimal attention paid to the Millennium Eruption by writers of popular science is surprising, given their fascination with comparable volcanic explosions elsewhere in the world. Nor has the archaeological press been much more forthcoming, though Paektu's eruptions do not seem to have preserved physical evidence of earlier human activity – and without the 'Pompeian element', it is surely harder to arouse public interest in its story. But why should Koreans themselves continue to hallow a mountain with such

[22] "Rare medicinal plants are found in this area, e.g. *Panax ginseng* and many edible fungi" (Machida, Moriwaki & Arai 1987: 7).

[23] A date questioned by Zhou (1994).

a record of unpredictable violence? Understanding this paradox lies at the interface between the Earth sciences (geology, volcanology), the humanities (historical accounts), spirituality (myth, legend, and religious observances), and geo-politics in a region of particular sensitivity. Is such complexity perhaps the reason why, in the vast library of books on worldwide volcanology, the eruptive history of this particular volcano – one of the world's greatest continuing natural threats – still attracts little comment?

In 1996 the DPRK government set up an Institute of Volcanology; collaboration between Korean, Chinese, and Western scientists followed, subject to official authorisation and close scrutiny. In 1999 the Chinese government funded the building of an observatory on its side of Changbaishan, where frequent signals of seismic and volcanic activity were noted between 2002 and 2005, rising to a peak of 1293 incidents in 2004 (Liu, G. et al. 2011: 44-5). In 2005 a rise of ~33 mm in the Tianchi caldera floor was noted (Liu, J. et al 2015: 57). In 2011, British volcanologists Clive Oppenheimer and James Hammond travelled to North Korea and worked with Korean scientists at Mount Paektu field stations, finding no evidence of an imminent eruption but quoting the view of Liu Guoming, deputy director of the Chinese observatory, that "new evidence shows that the volcano will soon enter an active phase" (Stone 2011: 587). Two years later they returned with a larger group and again worked with Korean colleagues (Iacovino et al. 2016). In the meantime, a Chinese team had reported in 2014 that the volcano had been "more active in the last 20 ka than previously thought" and that in their estimation magma only remained for a short time in its principal chamber, so that it "may pose hazards that have previously been underappreciated" (Yang et al 2014: 112). They and other volcanologists, including Wei, Liu and Gill (2013), proposed models of what to expect depending on the scale and nature of a future eruption and the location of its major vent.

Some 60–100,000 people now inhabit the mountain region and would be at risk in the event of a blow-out, perhaps with an unknown number of tourists on the Chinese side. Wei, Liu and Gill (2013: 10) warned that:

> in the event of a large-volume eruption, pyroclastic flows pose the most serious potential hazard and could affect large areas in any direction from the volcano. Flows from the Millennium Eruption reached a maximum thickness of 100 m and extended 60 km away from the crater…. Now, there are hydropower stations, industrial and agricultural facilities, concentrated residential communities, and tourist-serving facilities near the volcano.

In the opinion of Kim Hang Myong, a former director of Pyongyang's Institute of Volcanology, another eruption on the ME scale "would be unimaginable" (Stone 2011: 584). Classing the 1903 eruption as 'small', 1668–1702 as 'intermediate', and 946 as 'large', Paone and Yun (2016) predicted the effects of the next explosion from a local to global scale, defining specific centres of population that would be at risk of destruction. Their concluding, chilling, words were: "There is not a robust monitoring system around Baekdusan volcano, especially on the North Korea side. An emergency plan must be created for Baekdu volcano" (Paone & Yun 2016: 184).

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Figure Sources

Figure 1 by Bdpmax CC-BY-SA-3.0 [http://creativecommons.org/licenses/by-sa/3.0/] via Wikimedia Commons [https://commons.wikimedia.org/wiki/File%3ABaitou_Mountain_Tianchi.jpg]; cropped
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Figure 3 based on Machida & Arai 1992: fig. 2.4.1; Suigetsu information from Suzuki 2018: fig. 2, modified by GLB
Figure 4 NASA, public domain [https://commons.wikimedia.org/wiki/File:N_Korea_sat_image.jpg]; modified by GLB
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T'aejo (1 vol., *CWSTJoS*)
Sejong (4 vols., *CWSSeS*)
T'aejong (2 vols., *CWSTJongS*)
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genealogy of WANG Kŏn. It is no longer extant but was the source of folkloristic stories about the dynasty's founder preserved in *Koryŏsa Sege.* See Yoon (2013) and Rogers (1982–3).

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CHAPTER 8

Volcanic disaster research using archaeological methods: 10th-century eruption and population movements in northern Tōhoku, Japan

MARUYAMA Kōji *

Abstract

After reviewing the current state and problems of volcanic disaster research by archaeological methods in Japan and describing the method for broader and overall development, this paper presents research on settlements in northern Tōhoku affected by widespread tephra fall in the 10th century. Although the importance of tephra detection in modern archaeology is generally acknowledged, the progress of volcanic disaster research is limited and discussion of widespread tephra fall lags behind. The reason concerns the limitations within sedimentary studies of using tephra as only a dating index. To resolve this problem, I argue that it is necessary to conduct a thorough reorganization according to a unified standard, linking naturally to broad-scale research, that is, comprehensive disaster research. This is a method that can document a volcanic eruption event as a disaster – which cannot be done by volcanology or archaeology separately; it is interdisciplinary research connecting both disciplines.

Introduction

The importance of tephra detection is generally known in contemporary archaeology and cultural property excavation surveys in Japan, but its background is largely related to the development of tephra eruption chronology. This progress made it possible to date archaeological features by the intruding tephra. Furthermore, the existence of widespread tephras allowed for comparisons of contemporaneous phenomena within the depositional range. Although there are many dating methods in the natural sciences, methods capable of presenting synchronicity over a wide area are limited, and tephrochronology is representative of them. Since the 1970s when the number of excavation investigations increased and progress was made in tephrochronology, the usefulness of tephra was noted in Japan, and cases using tephra dating increased rapidly.

For archaeological studies exploring past culture and society from a material standpoint, the existence of tephra attesting a volcanic eruption disaster is, of course, important. Still, despite the increasing use of tephra as an index for determining the age of archaeological materials, archaeological cases in Japan investigating tephra from a disaster perspective are limited. The reasons will be described below.

Study of the chronology of features and artefacts is one way to knit human history together. We are only in the middle stage of what information can inherently be extracted from tephra – information comprising the history of humanity faced with volcanic disaster. In order to contemplate this, the ‘Disaster History Approach’ advocated by NOTO Takeshi (Noto 1983, 1993, 1995, etc.) is necessarily followed here.

The author collected data on excavated archaeological sites in northern Tōhoku affected by the eruptions of two volcanoes (Figure 1): 1) Towada (a caldera now holding a lake and referred to as Lake Towada; cf. Appendix C-4), located on the border between Aomori and Akita Prefectures (cf. Appendix A-1); and

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2) Mt Paektu, located on the border of the Democratic People's Republic of Korea and the People's Republic of China (cf. Chapter 7; Appendix C-8). Tephras from 10th-century eruptions of these two volcanoes are wide-area tephras that fell during the first half of the 10th century in the Heian Period (794–1185 AD): the Towada-a tephra (To-a) and Mt Paektu–Tomakomai tephra (B-Tm). These have frequently been identified in Heian-Period remains in northern Tōhoku (cf. Chapter 6).

The Towada eruption occurred in early summer. Machida and Arai (2003) estimate that at VEI 5, it was the largest volcanic eruption in the last 2000 years in Japan. The fine-grained To-a ash was distributed 300 km towards the south. The Kemanai pyroclastic flow travelled ca. 20 km from the vent (Hayakawa & Koyama 1998), then mobilized as a lahar and flowed through the Yoneshiro River Basin to the Japan Sea, burying the alluvial lowlands and villages along the way. Many archaeological remains from that time have been discovered from under the lahar sediments (cf. Chapter 6), and legends speak of the destruction (Chapter 6: Column).

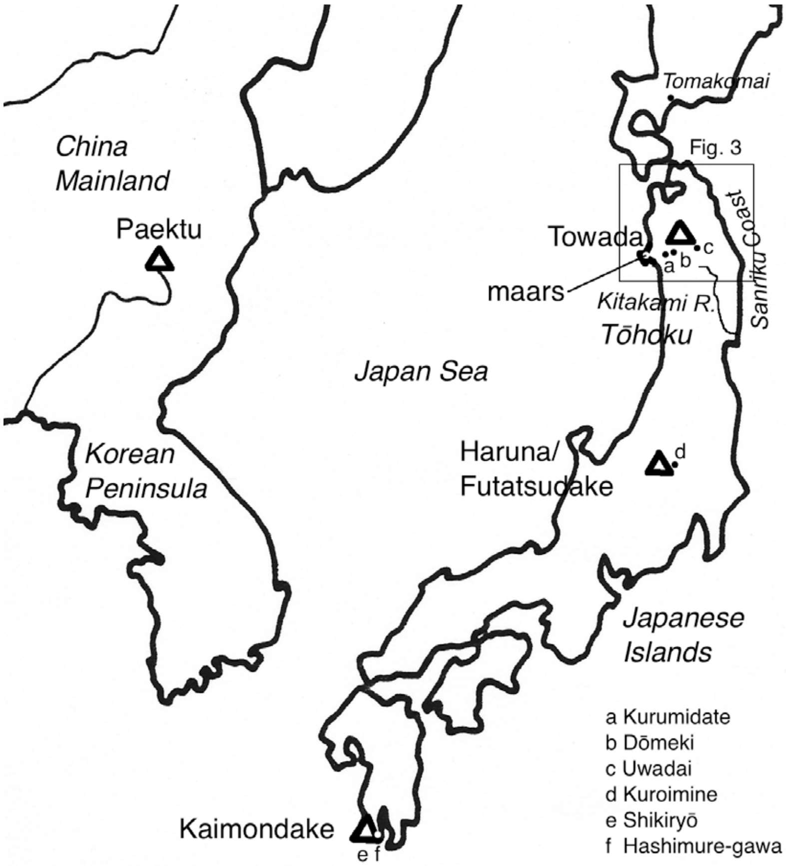


FIGURE 1 SITES AND VOLCANOES MENTIONED IN THE TEXT

The Mt Paektu eruption is estimated at VEI 7 (Pan et al. 2017) – one of the largest in the world within the last 2000 years. Two pyroclastic flows occurred, both in winter within one year of each other (Miyamoto et al. 2008). The co-ignimbrite ash that accompanied the pyroclastic flows reached Japan, where it was first discovered at Tomakomai, Hokkaido; it was later determined to be from the distant volcano Mt Paektu on the continent and is now designated as B-Tm (for Baekdu–Tomakomai) (see Chapter 7).

Some previous studies on the eruptions of the two volcanoes are dealt with in this paper. Topics covered have been studies reconstructing agricultural features (Noto et al. 2000, 2001; Takagi 2005), and detecting and discussing buildings covered by lahar deposits (e.g. Akita Kyōi 1968; Itabashi 2000; Takahashi 2006, etc.). But few studies deal with overall population movements in widespread areas.

My research focusses on collecting published data on excavated pit dwellings that contain the target tephras, To-a and/or B-Tm. From the characteristics of deposition, I have been working to estimate the time of abandonment of residences (or, in some cases, the construction time). Based on those data, I was able to research settlement dynamics before and after the To-a tephra fall in northern Tōhoku (Maruyama 2008, 2011, 2012, 2013). In this paper, I will assess the problems in doing volcanic disaster research by archaeological means, describe methods for broader and more comprehensive development, and then introduce the results of my settlement research.

The Effectiveness and Limitations of Tephra Research

Volcanic Disaster Case Studies: Geographical Limitations

Despite the fact that archaeological excavations of sites and tephra fall locations are closely intertwined, there are very few examples that can be considered from a disaster perspective. This is because the focus is on direct damage, which is limited geographically. Those sites where archaeology reveals traces of volcanic disasters are generally confined to the vast areas of damage near the source volcano, with tephra directly covering sites and features, including fields for dry crops and wet rice (cf. Chapters 12, 14). Cases where tephra buries an entire village are rare, occurring only close to the volcano. Further away, tephra fallout can easily be mobilized by rain, etc. Flowing to a lower place, it collects in hollows. If the tephra amount is small, no traces may be found.

In this paper, I use the term 'direct damage' for sites completely covered with tephra and where the settlement can be judged destroyed with one glance. In contrast, I use the term 'indirect damage' where tephra collects locally, as within features. Whether or not the site incurred direct damage may not be known; but from the presence of tephra, it can be surmised that the site was affected by a volcanic eruption relatively close by. I take as my subject matter indirect damage to sites in progressing my argument. But first, I will introduce volcanic disaster research as it is practiced in Japan.

Volcanic disasters in ancient times – from the Kofun Period (250–710 AD) to the Heian Period that I am studying – are mainly located in Gunma Prefecture (Chapters 9–11) and Kagoshima Prefecture (Chapter 12). Both areas were 'severe disaster areas' where volcanic eruptions occurred repeatedly, and where archaeological investigations of direct damage to settlements have been carried out.

Research in Gunma was led by NOTO Takeshi. A series of works by Noto proposed and set into practice a 'Disaster History Approach'. He tried to elucidate the contemporaneous social and civil responses to disasters while keeping in view the background social values. This perspective is extremely important. His research method was to assess the social situation at the time of the disaster based on differences in outcomes: discontinuation, redevelopment, or restoration of the buildings, paddy fields and related facilities, etc. affected by the disaster (e.g. Gunma Maibun 1983, 1991; Noto 1983, 1989). In this same prefecture, numerous disaster sites have been excavated, beginning with the Kofun-Period Kuroimine site (Figure 1d) which was buried in the mid-6th century AD by two metres of Ikaho tephra (Hr-FP) from the Futatsudake vent of Mt Haruna (Komochi Kyōi 1986). The results of the Kuroimine excavations cannot be detailed here, but see the brief outline by Tsude (1992).

In Kagoshima, a series of excavations revealed tephra from Kaimondake (Km). The Hashimure-gawa site in Ibusuki City (Figure 1f), which encompasses the volcano, was a settlement buried at the end of the 7th century by Km-11, and then again in 874 by Km-12, both tephras originating from Kaimondake. After the first eruption, reconstruction of the pit dwelling and continued shellmound formation suggest immediate restoration, but after the latter, the village was abandoned. The researchers attribute the different reactions to background differences in eruptive influence as well as differences in the characters of the disaster victims (Shimoyama 1990; Kamada et al. 2009). In addition to the Hashimure-gawa site, there is continuing investigation and report on the Shikiryō site also in Ibusuki City (e.g. Takano & Nitta 2008) (Figure 1e).

In both Gunma and Kagoshima, there have been many volcanic eruptions (Appendices C-5, C-7), and each time both landscape and settlements were damaged, attested by archaeological excavation. But how did people respond to each event? Indeed, if the events followed closely in time, how did people deal with both? Research from this disaster perspective can be carried out, based on cooperation between excavators and natural scientists in taking the 'tephra point of view'.

Assessing Volcanic Disasters by Indirect Archaeological Methods

As described above, studies that assess disasters from tephra mainly deal with archaeological sites located around volcanic sources. In order to conduct this discussion over a broader area, it is necessary to use widespread tephra as a key layer. However, setting aside direct damage from pyroclastic flow sediments, tephra fall is less likely to become a factor that disrupts human activity in an instant; the farther away from the volcano one investigates, the more difficult it is to judge the relationship between archaeological phenomena and tephra effects. As a result, cases that can be perceived as evidence of disaster decrease.

First of all, 'disaster' is a concept that is established only after human involvement. Even if a tephra is interposed in human constructions, if it cannot be determined how it relates to human activity in terms of time, then it is only tephra – simply a substance, a natural phenomenon. Conversely, if the temporal relationship with the archaeological event becomes clear, the relevance to the disaster can be considered. But there are various problems inherent in the judgment of chronology from the sedimentary aspects.

Analysis of tephra deposit modalities is the basis of this study. In order to use tephras as chronological indicators, it is required to investigate and record in detail how tephras with absolute ages intrude into sites and features from a sedimentological viewpoint. However, when dealing with archaeological features, all excavation directors encounter the limitations of repeated burial processes involving extremely diverse factors. After all, many of the tephra layers are only the aforementioned 'tephras as natural substances' – that is, purely sedimentary with no cultural implications. In addition, understanding of the burial process is affected by the knowledge, recognition and consciousness of the investigator to a large extent, resulting in individual differences in interpretation. This situation does not change even now in the 21st century. And, after the completion of the archaeological excavation, the materials analyzed will only exist in the form of the report; basically, it is impossible to reinvestigate the original materials. As a result, it is difficult to uniformly evaluate individual report examples as they are, and most of them remain at the level of coarse age indicators while comparative examination between sites and regions is not explicitly made. A disaster history approach is nothing without a proper chronological approach, and the research will stagnate.

Traces of direct disaster are only partial aspects of the volcanic eruption event as a whole. Damage by tephra fall that is not manifested on the land surface – for example, material and social changes due to climate variability and environmental change – are difficult to recognize; they are, so to speak, 'invisible damage' and should be inherently larger. Exploring this is necessary to intimately understand a volcanic eruption disaster. A wider area in terms of space must be considered. By taking indirect damage traces as a research objective, changes before and after the eruption season can be assessed from cultural modifications and population movements. Volcanic activity has increased in various parts of the Japanese archipelago since the Great Tōhoku-oki Earthquake in 2011. Now that it has become urgent to explore past disasters and their response behaviours, the need for this kind of research is increasing.

Methods of Reading Society from Tephra

Here I describe the basic methods for assessing more broadly volcanic disasters from archaeological phenomena. The methods are simple, and the tasks are the following three:

Assemble Data on Sites and Features Intruded by the Target Tephra

A comprehensive organization of data will increase the accuracy of analysis. Identification of tephra in archaeological features from previous excavations is based on the description in the excavation report. However, there are obstacles such as the "individual differences" mentioned above. This will be discussed in the next section.

For identifying the type of tephra, the basic and most important observation records are geological studies such as the strata and stratigraphic relationships, sediment colour, grain size, etc. Furthermore, by accumulating physical and chemical identification analyses and repeatedly comparing these, we can hope to increase accuracy in identification from individual volcanic products. It should be noted that the methods of physical and chemical analyses are diverse, involving advantages and disadvantages; we must recognize that none are perfect. Even EPMA analysis[1] that can measure trace elements makes no sense unless there are basic comparative data. We must steadily accumulate data in future.

There are many instances during excavation when one is troubled by whether a sediment is a tephra or not. It should be minimally required that the excavation director have the knowledge to be able to judge the sediments for taking a tephra sample (see Appendix E-2, E-3).

Analysis of the Tephra Intervention Conditions and Specific Timing of Building Destruction

There are few cases where it is possible to entirely elucidate the deposition process and factors of the sediment accumulated in individual features. Investigation of sedimentation conditions of those materials described in excavation reports can be done from text descriptions, actual measurement charts, soil layer notes, photographs, etc. However, as these were filtered through each excavator's 'point of view', individual differences in interpretation probably occur. In order to make use of tephra for time estimates by eliminating this influence, it is necessary to consider the tephra deposition modes by the least common multiple factor at a level that does not need to take into consideration various factors related to the burial process of the remains and individual interpretational differences. Such factors to consider are those in Table 1 on sedimentary position and condition of deposit. Interpretation of indirect phenomena can thus be achieved. Naturally, since the amount of information obtained from the indirect phenomena is smaller than from direct phenomena, one must analyze and compare as many phenomena of both kinds in order to establish this work statistically.

In considering the timing of tephra deposition, it is also important to decide whether it is a primary deposition or a redeposition. In archaeological reports, there are many distinctions between natural deposition and artificial deposition of artefacts, but few judge whether a natural sedimentary layer is a primary deposit or has been redeposited. Since the timing of deposition depends on whether the tephra is primary or redeposited, there is a problem in handling them indiscriminately. But for tephras that are not distinguished, discrimination can be made by mutual comparison of sedimentary modes within subregions that have the same terrain environment. At least for stratified materials, it is possible to identify tephras that occurred in the same period as the eruption based on archaeological chronology.

[1] EPMA = Electron Probe Micro-Analysis

Temporal and Spatial Differences According to Time-specific Features and their Accompanying Artefact Assemblages

Here we will examine the temporal and spatial differences among the collected data for features whose timing was determined according to the procedures described above and their accompanying artefacts. Accordingly, this makes it possible to estimate the extent of the cultural area in each period and to monitor the material culture dynamics framed by the eruption event. Determining absolute age is important, but even more so, this is a unique method for examining dynamics based on the eruption event over a broad area.

Case Study: Major Eruptions of the 10th Century and Northern Tōhoku

Target Tephra

Towada-a tephra (To-a)

The scale of the Towada eruption event is judged the largest in Japan during the past 2000 years (Hayakawa 1994), and its tephra distribution reached as far as 300 km southward (Machida & Arai 2003). The Kemanai pyroclastic flow generated at that time flowed down the Ōyu River / Yoneshiro River Basin, becoming a volcanic mud flow (lahar) which reached the Sea of Japan. In that river basin, buried pit-dwellings have been found frequently from within muddy sediments, and the remains of the Kurumidate site (Akita Kyōi 1968) (Figure 1a), also known as 'Pompeii of Japan' in Kita-Akita City, are representative.

The eruption date of 915 AD is considered most likely, based on records in the *Fuso Ryakki* text written during the Heian Period (Suzuki 1981; Machida et al. 1981; see also JMA n.d.) and on dendro-chronological analysis of wood excavated from the volcanic mudflow at the Dōmeki site in Ōdate City, Akita (Akaishi et al. 2000) (Figure 1b).

Mt Paektu–Tomakomai Tephra (B-Tm)

Distribution of tephra emanating from Mt Paektu on the continent into Japan extends from Hokkaido to northern Tōhoku (from about N40° northwards) (Chapter 6; Machida & Arai 2003). The eruption scale is considered to be the largest among volcanic eruptions anywhere on Earth in the past 2000 years (Hayakawa & Koyama 1998).

The eruption age is slightly different depending on the analytical method, and there is no agreement. Kamide et al. (2010) insist that it is 929 AD, based on lake bottom varves (annually laid sediments) at Ninomegata and Sannomegata maar lagoons in Akita. Hayakawa & Koyama (1998) argue – from the contents of the *Kōrai-shi* history, the *Kōfukuji Nendaiki* chronicle, and the *Teishin Kōki* chronicle – that it should be 946. There are also several estimates for the latter half of the 930s (Fukuzawa et al. 1998; Nakamura et al. 2011, etc.). However, all agreed that it was in the second quarter of the 10th century, and recent interdisciplinary work fixes its eruption date as 946 AD (see Chapter 7).

The time difference between the two tephra falls (To-a and B-Tm) is estimated at about ten to thirty years. By using both these widespread tephras occurring close to each other in time, finer chronology of archaeological materials can be determined.

Target Area

The target area for this study is the area in which To-a and B-Tm tephra accumulated, particularly the area where the distribution of the two tephras overlap: from Aomori to the northern parts of Akita and Iwate

Prefectures (north of latitude 40°N), excluding the northern Tsugaru and Shimokita regions. Focussing on this area of overlap, I investigated the features published in archaeological reports through March 2010 in all three prefectures to assess the regional conditions.

In the 9th to 10th centuries, this area was a frontier between the Ritsuryō state, i.e. the central government, and *emishi* society in the north. *Emishi* is not an ethnic designation but a term applied to all northern peoples beyond the administrative jurisdiction of the Ritsuryō state. 'Ritsuryō' refers to the adoption of aspects of the Tang Chinese administrative system in the mid-7th century and characterizes the Nara (710–794) and Heian (794–1185) periods. However, the exact boundary of the Ritsuryō state is not clear. The ultimate purpose of this research is to find out how communities in this buffer area reacted when universally faced with these huge eruptions; this is done by assessing differences in material culture across the region synchronous with the tephra falls.

Targeted Features for Analysis

I limited my study to pit-dwellings (semi-subterranean residences) for the following four reasons:
1. As features comprising sites of that region and period, they exist everywhere.
2. They are highly uniform and are suitable for classification work using the same standard. It is common for them to be recorded via two cross-section diagrams using the quartering method – so that the stratigraphy on all four pit-dwelling walls is represented.
3. In addition to the sedimentary cover, the soil into which the pit-dwelling was dug is recoverable and becomes data to indicate the time of building or repair.
4. It is possible to study the chronology and regional differences of the structures and their associated artefacts.

Standards for Classifying Modes of Tephra Deposition

The stratigraphy and condition of tephra and the presence or absence of burning are used as classification indicators (Table 1). When several conditions occur together, they are notated together, as in Figure 2 captions. Burnt dwellings provide a variety of information such as estimation of the buildings' structures in addition to easy specification of the timing of their destruction. If tephra is present in these cases, it is also possible to estimate the timing of destruction more precisely and to better understand architectural structures from the sedimentary relationships of the burned layer (the collapsed roof) and tephra layers.

The stratigraphy of the sedimentary fill encompasses everything above the floor and is numbered in layers from upper to lower. The height from the floor surface of any particular stratum is an important indicator reflecting the time of its accumulation; but since sedimentation process and speed are different between individual features, any further subdivisions must be undertaken by detailed examination at the fieldwork stage, otherwise it will not make sense. As designated in Table 2, Floor 'a' tephra touches the floor in the centre of the structure but not where the floor and walls join; Floor 'b' exhibits a pattern in which tephra exists where the floor and wall meet or in the sedimentary soil of the channel by the wall. Classification was carried out by compiling the conditions and stratigraphy of these tephra remains. When both To-a and B-Tm exist, they are individually classified.

The thickness of the tephra layers is not discussed here. Although the stratum thickness may reflect the amount of tephra fallout, thickness and tephra fall amount cannot be equated because it is a sediment accumulated in the dwelling pit. Here, attention is focussed on whether or not it formed a laminated deposit.

Depositional Pattern and Phase Classification

Based on these laminations, Figure 2 illustrates a model of sedimentary patterns for possible estimates of tephra deposition phases and consequently building construction and destruction phases, while Table 2 shows the timeline and phase divisions. Six phases are recognized: from period I before the fall of To-a to the period VI after the fall of B-Tm.

TABLE 1 CLASSIFICATIONS OF TEPHRA DEPOSITIONAL STRATIGRAPHY AND CIRCUMSTANCES, AND RELATION TO BURNED MATERIALS

Position of tephra deposition	**Conditions of tephra deposition**
Fill strata	tephra layer(s) occurring in fill deposits but not touching the pit-dwelling floor
House floor 'a'	tephra partially touching the pit-dwelling floor but not filling the corners, where there are underlying strata
House floor 'b'	tephra deposits that lie on the pit-dwelling floor in the corners and along the edges of walls
Ubiquitous	tephra that is scattered everywhere
Incorporated into architectural constructions	tephra that has been incorporated into floor linings or clay hearth constructions
Circumstances of deposition	**Conditions of tephra deposition**
A	stratigraphically deposited
B	forms intermittent layers
C	grainy or includes blocks
D	only recorded as ‘intrusive’, or evidence is unclear due to lack of concrete descriptions
Burned conditions	**tephra layer (if multiple layers, the lowest one) and its relationships to burned construction materials or burned earth**
1	one or more sedimentary layer above the burned stratum with tephra above it
2	tephra directly above burned material
3	tephra directly below burned material
4	on top of tephra layer, one or more sedimentary layers, with burned stratum above that
5	tephra occurs in same layer as burned material
6	unclear

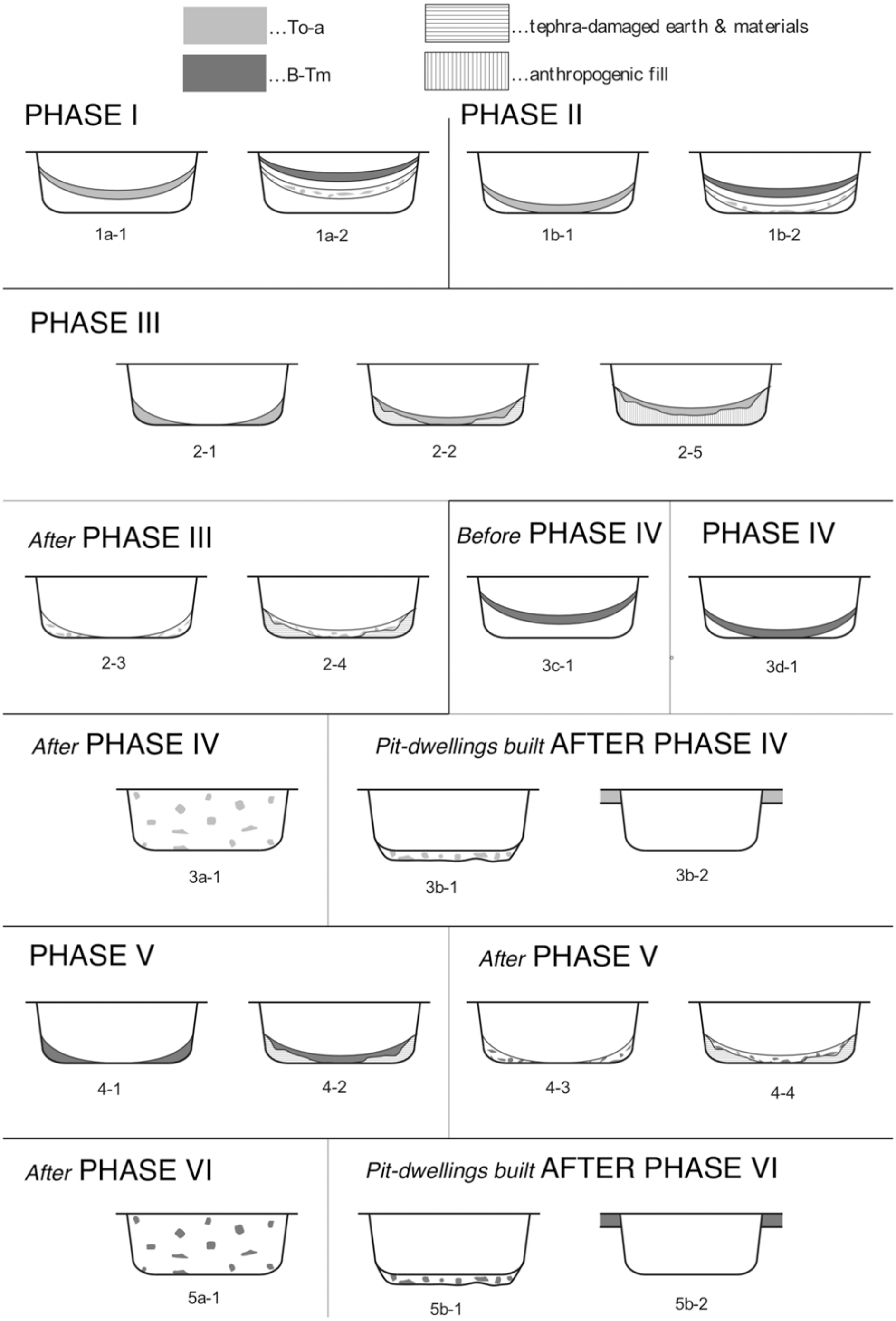


FIGURE 2 DEPOSITION MODELS OF TEPHRA (TO-A, B-TM) IN PIT-DWELLINGS AND DWELLING ABANDONMENT TIMES

Phase divisions (I–VI) match Table 2
Models (1a–5b) match captions right
Deposition descriptions ('a'–'b', A–D, 1–5) as in Table 1

Figure 2 *captions continued*

PHASE I

1a-1 To-a stratigraphically or intermittently deposited (Deposition Types A and B) in pit-dwelling fill (without touching house floor)

1a-2 To-a in pit-dwelling fill as coarse, blocky material (C) or unclear (D) deposition, with B-Tm occurring above it

PHASE II

1b-1 To-a as house floor mode 'a', stratigraphically (A) or intermittently (B) deposited

1b-2 To-a as house floor mode 'a' in coarse/blocky (C) or unclear (D) deposits, B-Tm above it

PHASE III

2-1 To-a as house floor mode 'b', stratigraphically (A) or intermittently (B) deposited

2-2 To-a either as house floor mode 'a' or in the fill above, stratigraphically (A) or intermittently (B) deposited, either directly above burned material (2) or together with burned material (5)

2-5 Dwelling pit sediments resulted from resident activities; To-a deposited directly above anthropogenic fill in stratigraphic (A) or intermittent form (B)

***After* PHASE III**

2-3 To-a as house floor mode 'b', coarse/blocky (C) or unclear (D) deposits

2-4 To-a as house floor mode 'a' or in an upper layer, as coarse/blocky (C) or unclear (D) deposits, either directly above burned material (2) or together with burned material (5)

***Before* PHASE IV**

3c-1 B-Tm in pit-dwelling fill, stratigraphically (A) or intermittently (B) deposited (without touching floor)

PHASE IV

3d-1 B-Tm as house floor mode 'a', stratigraphically (A) or intermittently (B) deposited

***After* PHASE IV**

3a-1 To-a in anthropogenic fill

Pit-dwellings built *after* PHASE IV

3b-1 To-a is incorporated into building structures (clay-lined floors or clay hearths)

3b-2 To-a strata cut by digging operations

PHASE V

4-1 B-Tm as house floor mode 'b', stratigraphically (A) or intermittently (B) deposited

4-2 B-Tm either as as house floor mode ‘a’ or in the fill above, stratigraphically (A) or intermittently (B) deposited, either directly above burned material (2) or together with burned material (5)

***After* PHASE V**

4-3 B-Tm as house floor mode 'b', coarse/blocky (C) or unclear (D) deposits

4-4 B-Tm as house floor mode ‘a’ or in an upper layer as coarse/blocky (C) or unclear (D) deposits, either directly above burned material (2) or together with burned material (5)

***After* PHASE VI**

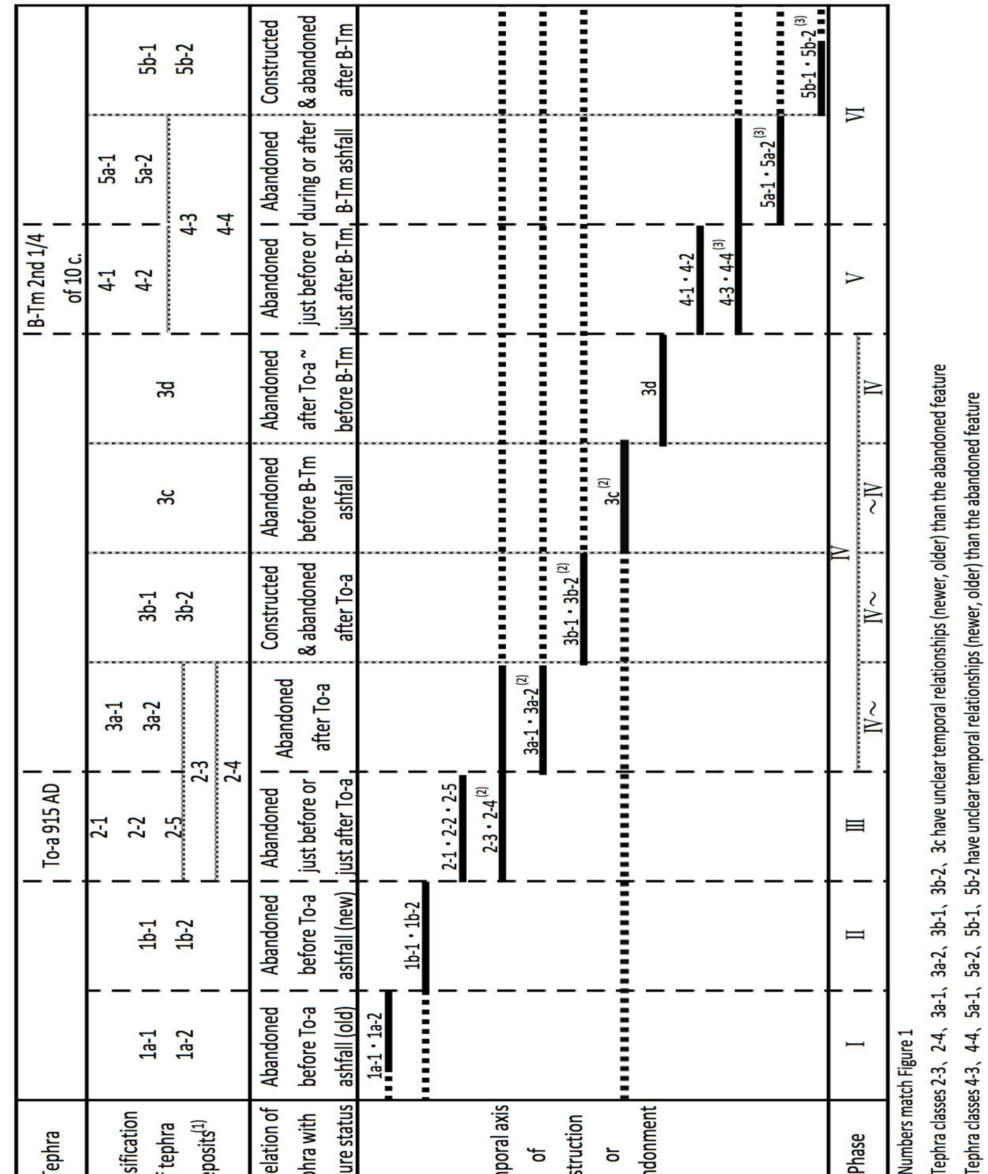
5a-1 B-Tm in anthropogenic fill

Constructed *after* PHASE VI

5b-1 B-Tm mixed into construction material (clay-lined floors or clay hearths)

5b-2 B-Tm strata cut by digging operations

TABLE 2 TEMPORAL DISTRIBUTIONS OF TO-A AND B-TM TEPHRAS ACCORDING TO CLASSIFICATIONS IN FIGURE 2



(1) Numbers match Figure 1

(2) Tephra classes 2-3, 2-4, 3a-1, 3a-2, 3b-1, 3b-2, 3c have unclear temporal relationships (newer, older) than the abandoned feature

(3) Tephra classes 4-3, 4-4, 5a-1, 5a-2, 5b-1, 5b-2 have unclear temporal relationships (newer, older) than the abandoned feature

What is noteworthy is that B-Tm is an example of class 3d sedimentation, where it forms a layer on Floor 'a' or accumulates intermittently. With this single sedimentary layer, the earliest limit cannot be determined; it can only be said that it was before the B-Tm ash fallout. However, as a result of careful examination of all confirmed 3d class samples, there were no natural stratigraphic deposits of To-a layers below the B-Tm layer – though some existed due to anthropogenic manipulation. These indicate that they were discarded after the To-a ash fallout. As a precaution, all the floor ‘a’ patterns not having the stratification / intermittent layer were also examined, but there were no stratigraphic deposits of To-a. Therefore, at least according to the existing data, class 3d / stage IV may be limited to destruction after To-a but before B-Tm. This makes it possible to understand change occurring during for a certain period (10 to 30 or so years) after the To-a depositt and to elucidate changes after the B-Tm tephra-fall by comparing phase VI data. This case is also thought to be meaningful in terms of sedimentological studies.

Results

Movements of Communities

An outline of the regional movements as illustrated in Figure 3 and confirmed by this analysis is as follows. In stage IV, corresponding with the To-a tephra fall, villages suddenly decreased in population in the central Mabechi River drainage in Iwate and in the Oirase River basin in Aomori. Conversely, villages suddenly increased in population in the Appi River Basin of Iwate and the middle to upper basin of the Yoneshiro River in Akita, and around Sanbongi-hara to southern Ogawara Lake and around Noheji Bay to northern Ogawara Lake. In addition, in Phase VI after the B-Tm tephra fall, settlements increased rapidly around Noheji Bay to northern Ogawara Lake in Aomori, while settlements on the Aomori plain to the west, which had continued intermittently until Phase IV, began to decline.

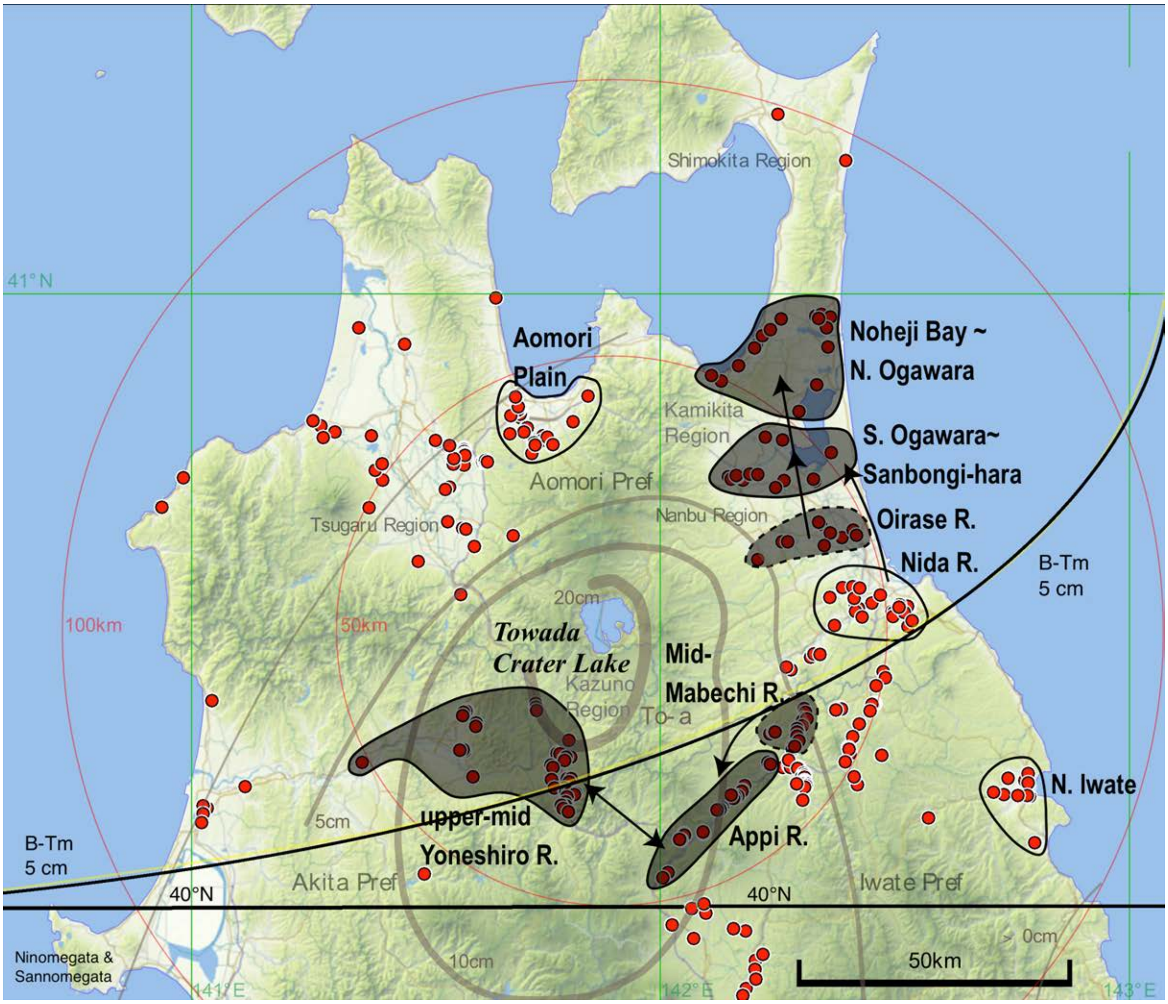


FIGURE 3 REGIONAL DYNAMICS IN NORTHERN TŌHOKU IN PHASE IV
AFTER TO-A TEPHRA FALLOUT BUT BEFORE B-TM TEPHRA FALLOUT

- ● sites with pit-dwellings yielding To-a and/or B-Tm tephra
- — grey areas with solid boundary: rapid population *increase* compared to Phases II–III
- --- grey areas with dashed boundary: rapid population *decrease* compared to Phases II–III
- ➔ directions of population movements

The basis for determining population movements was comparison of pit-dwelling numbers belonging to Phase II and III with those for Phase IV within the different sites. If Phase IV pit-dwellings number fewer than II-III, then the settlement is interpreted to have shrunk in population; if they increase over the numbers for Phase II-III pit-dwellings, then the settlement is interpreted to have grown in size. To translate these trends into population movements, geographical factors and artefact distributions were taken into account.

The datings of the pit-dwellings themselves as presented in Figure 2 are based on the relationship of tephra to dwelling occupation: both the position of tephra deposition and its circumstances of deposition must be taken into account. For example, in pit-dwelling 2-1 (Figure 2), To-a tephra lies in floor mode 'b' and was stratigraphically (A) or intermittently (B) deposited; but there is no evidence of continued human presence after the tephra fallout, so it is assigned to Phase III. In contrast, pit-dwelling 2-3 has the same mode of floor deposition 'b', but the tephra was deposited in coarse/blocky fashion or unclear. It is possible that the dwelling was ruined just before or just after the tephra fall, but it cannot be determined which. However, it could not have been any earlier, and there is no limit on how late the occupation could have continued. In fact, the dwelling could have been built after the tephra-fall. Therefore, this dwelling is assigned to post-Phase III. The defining factor here is that 'coarse/blocky' or unclear tephra deposits may indicate clean-up activities; however, it is difficult to prove that.

Regional Differences and Morphological Change in Artefacts

Although associated artefacts were all subject to collection, earthenwares form the data for comparative analysis in this report. Regional differences in vessel assemblages and morphological styles, and their temporal changes have been variously recorded, but here we will look at the Hajiware pot commonly used in the area for boiling food. Hajiware is an unglazed earthenware fired at 800–900 °C.

In Phase III, a type of Hajiware cooking pot with a particular shape (Figure 4, right) appeared where it had not existed before: in the Appi River basin and farther south in the upper Kitakami River drainage, both Iwate Prefecture, and in the Yoneshiro River drainage of Akita Prefecture. The rim on this pot is shorter than the native type (Figure 4, left) and is of coarse construction. In Phase IV, the number of these pots increased dramatically, with the Niida River drainage in Aomori Prefecture showing the same trend. They also spread into the Noheji Bay~northern Ogawara Lake district of Aomori Prefecture but did not outnumber the indigenous pots there. In contrast, in the Tsugaru area of Aomori and the northern coast of Iwate, no pots of the new type appeared.

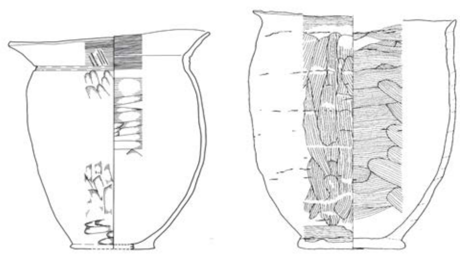


FIGURE 4 HAJIWARE COOKING POTS

(scale = 1/8); Left: Phase II, Right: Phase IV

At this time, in the area governed by the Ritsuryō state, pots made on the fast wheel were mainly used. These pots were exported into the *emishi* areas before the Towada eruption, but they were subsidiary there. This same trend continued in Phase IV, but in the mid-Yoneshiro River drainage, they had a different appearance. Directly after the Towada eruption, wheel-thrown pots began to appear at many sites where they were used as the main ceramics. This lasted only a short time, reverting back to mainly using pots not made on the wheel.

In Phase VI, the new model also spread to the Tsugaru region of Aomori; in areas where it appeared in Phase IV, the adoption rate was shortened with the new vessels becoming proportionally predominant. Additionally, in these areas, the number of bucket-shaped pots with inward-sloping attenuated rims increased, and some appear in the inner bay region. This shape change is thought to derive from the new model in terms of shortening and simplifying the rim.

It has previously been pointed out that the morphology of the rim of the Hajiware pot changed greatly in the 9th to 10th centuries in northern Tōhoku, but the temporal and spatial aspects have not always been clear. By using tephra data as a filter, at least the timing and regional differences of these changes could be elucidated. Accordingly, the way that Hajiware was greatly transformed after both volcanic eruptions strongly suggests that the two are not unrelated.

Putting together these factors, let us consider the relationship of ceramic change with movements following volcanic eruptions (Figure 3). It is highly likely that the increases and decreases in settlement population after the To-a tephra fall are reciprocal. Specifically, people moved from the central drainage of the Mabechi River in Iwate to the Appi River basin, and around the Oirase River basin in Aomori to the area around Sanbongi-hara and north of southern Ogawara Lake.

From the Nara period to early Heian, the central drainage of the Mabechi River was a place where large settlements existed – it was a long-term base area. However, this area is geographically close to Towada volcano. There are examples in which stratified To-a tephra is confirmed outside the confines of archaeological features, as at the Uwadai site in Ninohe City (Iwate-ken Maibun 2000) (Figure 1c); there, the inside of a pit building is filled with To-a tephra to a thickness exceeding 80 cm. Moreover, this is not one located on the alluvial flats but on a gently sloping terrace. Not all of it is a primary deposit, but this is an easy-to-understand case demonstrating the large amount of ash falling in the area. Compared with other regions, there is no doubt this area endured great damage, and that is probably the main reason for the rapid decrease in settlement population.

In terms of distance from the source, the Appi River basin is of comparable distance from the volcanic source as the central Mabechi River drainage. However, even though damage was not as bad as in the latter area, it was worse than in the Ritsuryō state regions south of latitude N40° and the Sanriku coast to the east of the Kitakami mountains. I believe that this was due to the policies of restoration and revival on the side of the Ritsuryō state. The Appi Basin was a major hub north of the Ritsuryō state in Phase IV. That area was a buffer zone between the ruling nation and *emishi* society; the increase in settlements can be envisioned as resulting from the efforts of the state to gain rights and rule over that area. There was a Buddhist temple Tendaiji, now in Ninohe City, which was a symbolic building exhibiting ties to the Ritsuryō state. Ōya (2006) points out the link between reconstruction and this temple. Despite various theories about its date of construction, foundation stones for the building's pillars sit on a razed surface that existed before the To-a tephra fall (Jōbōji Kyōi 1981); there is considerable possibility that this was a site of recovery and reconstruction. In addition, although this area has the characteristic of being an eastern entrance to the Kazuno area of Akita in terms of population geography, similar movements are seen also in the Yoneshiro River drainage as described later. From an artefactual perspective, both areas have common characteristics and there is no doubt that there was contact between them.

It is easy to imagine that the Oirase drainage, which is the source of water for Towada Lake, became an uninhabitable place after the eruption. Villages in the area had already declined before Towada eruption, but the eruption dealt a final blow. From the increase in population in the Kamikita region (Figure 3), it can be hypothesized that there was a large evacuation or migration from all the southern regions northwards. This is supported by artefactual characteristics. This major evacuation or migration behaviour contrasts with the restoration and reconstruction efforts in the Appi Basin and implies a certain degree of freedom.

Another area where settlement sites increased rapidly was the middle to upper Yoneshiro Basin; but from the previous phase, movements there were rather complicated. In that river basin, the proportion of discovered features belonging to Phase III, when Towada eruption is confirmed to be larger than in Phase

II before the To-a tephra fall. Since the timespan of Phase III is narrower than that of Phase II, the detection ratio of features in this region for Phase III is usually low. Thus, the high detection rate indicates that the number of settlements was rapidly increasing in the period just before the Towada eruption. In addition, after the eruption in stage IV, the location of settlements shifted and rapidly proliferated on high ground.

Regarding this trend, the increases in Phase Ⅲ have been explained as resulting from policies toward the *emishi* since Gangyō no Ran (a rebellion by the *emishi*) that occurred in 878, while those increases in Phase IV after the eruption resulted from recovery policies dealing with volcanic disasters (Takahashi 2010). The results of this study are in harmony with Takahashi's findings. Particularly regarding the trend in Phase IV, the increased number of settlements cannot be explained by simple evacuation or movement from the river basin to higher ground nearby; there must have been influx of people from other areas. Consequently, the transect described above from the Appi Basin to the Yoneshiro Basin became a focal area for restoration and recovery from the volcanic disaster, aided by assistance from the Ritsuryō state. The result was an increase in settlements.

Although the Appi–Yoneshiro area is a geographical environment in which stratified B-Tm tephra deposits exist, the number of detected strata is small; so it is considered that the structures abandoned or destroyed in Phase VI comprise the majority. Moreover, in areas where the amount of To-a tephra fall was small – on the northern Iwate coast or in the Tsugaru region of Aomori – great changes in Hajiware pots cannot be seen; this must reflect a general lack of movement of people into these regions.

Regarding the changes in settlement numbers after the B-Tm tephra fall, increases around Noheji Bay to northern Ogawara Lake in Aomori and decreases around Aomori Plain are poorly explained without considering their geographical relationships. However, from the similarities in food vessels and the spread of the new type of pot, it is understood that these areas were mutually influenced by each other. Study of the effects of the Mt Paektu eruption is a task for the future.

Concluding Remarks

In this paper, I described a method to explore the influence of volcanic eruption based on the sedimentary aspects of tephra intruding into archaeological features. In all modesty, it is a method requiring a lot of work, but it is an effective means for considering the relationship between volcanic eruption events and human beings and their society across a wide geographical area. Depending on one's viewpoint, tephras can be both simple natural products as well as products revealing human activities; and of course, they are indicators of absolute age and comprise traces of volcanic disasters. Essentially, the existence of tephra lends itself to interdisciplinary studies: it is the key to answering questions that cannot be solved by either volcanology or archaeology alone.

In this instance, I have interpreted settlement dynamics from evidence of settlement abandonment and regional changes in ceramic morphology. By analyzing the nature of tephra deposits within pit-building fill, it is possible to hypothesize whether the building was abandoned (undisturbed tephra layers) or whether efforts were made to clean up the tephra (blocky or unclear tephra deposits), allowing continued occupation of the building. These results then facilitated estimates of mass movements from collation of pit-houses at many different sites. The timings of abandonments in some settlements correlated with increases in size of other settlements. The types of ceramics followed these movements, with previously unknown ceramic types spreading into new areas.

However, it was discovered that movements were not the same in different regions. Figure 3 illustrates that south of the Towada volcano, the mid-Mabechi River occupants moved to the Appi River catchment, which also exchanged populations with the upper-mid Yoneshiro River region. The centripetal influx of people into the Appi Basin, where the Ritsuryō state maintained a presence, was predicated on state assistance in recovery and reconstruction. Conversely, in the far northeast, residents of the Nida and Oirase River catchments moved even further northwards, increasing the population densities in the area from Noheji Bay through Ogawara to Sanbongi-hara. These movements can be interpreted as being less reliant on state assistance and recourse to kin and trade networks in times of hardship. Thus, reactions of the local *emishi* population were partly determined by their proximity to state institutions and the type of assistance that might have been offered.

For elucidating even more detailed population movements, similar research investigating pit-dwelling morphology is necessary. Progress is ongoing. However, with these methods alone, it is impossible to imagine the living conditions which were greatly influenced by the environment. Such influences are difficult to elucidate, but the minute plant and animal remains recovered by the flotation method are key to solving this puzzle. Flotation is also an interdisciplinary approach, and though it may be a common method, there is still much research to be carried out.

Figure & Table Sources:

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CHAPTER 9

TephroArchaeology in the Gunma Region: an Overview

HORAGUCHI Masashi *

Introduction

Gunma Prefecture is situated in central Honshū, largest of the Japanese Islands (Figure 1); it hosts several active volcanoes such as Mt Haruna and Mt Asama (cf. Appendix C-5). On the one hand, the volcanoes provide beautiful scenery and hot springs, but once a volcano begins erupting, it begets severe damage lasting over a very long time. For archaeologists, sites buried by tephra from volcanoes are a very valuable resource.

FIGURE 1 LOCATIONS OF HARUNA AND ASAMA VOLCANOES IN GUNMA PREFECTURE

Mt Haruna sits in the middle of the prefecture. It is a stratovolcano consisting of a series of lava domes, the highest among these being Kamon-ga-take at 1449 m. Nearby, the Futatsudake vent erupted at the end of the 5th to early 6th centuries (depositing Hr-FA tephra: first ash, followed by a pyroclastic flow) and in the mid-6th century (spreading pumice Hr-FP, which was accompanied by a lahar) (Sōda 1989).

Mt Asama is in northern Gunma on the border with Nagano Prefecture; it too is a stratovolcano, 2568 m high. From before 13,300 years ago, large eruptions have occurred from time to time, and currently it is emitting a steam plume. Recent eruptions have produced the late 3rd-century As-C tephra, the As-B tephra of 1108 (Kamitsuke 2004), and the As-A tephra of 1783.

Tephra from five large eruptions of these two volcanoes have been documented across a broad area of Gunma Prefecture (Machida & Arai 1992, 2011; Sōda 1989), and many damaged settlements have been excavated (Gunma-ken Maibun 2013) (Figure 2). Several have been nicknamed 'Japanese Pompeii' (Table 1) (Kamitsuke 2006). Additionally, throughout the prefecture, paddy-fields for wet-rice cultivation and ridge-and-furrow fields for dryland cultivation were damaged by eruptions of Mt Asama in the 3rd and 12th centuries (Noto 1983). Thus, there are multitudes of 'Pompeii' sites of different periods. The activity of excavating these on a daily basis has bestowed a special character on Gunma archaeology (Arai 1993).

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Table 1 Major Sites in Gunma Prefecture Buried by Tephra
Locations in Figure 2; see Appendices A-2, A-3 for periodizations

Site	Location	Period	Date AD	Tephra	Thickness
Dōdō	Takasaki	Kofun	late 3rd c.	As-C pumice fall	10–20 cm
			early 6th c.	Hr-FA ash fallout, lahar, flood	3–8 cm
			mid-6th c.	Hr-FP lahar, flood	60–100 cm
		Heian	1108	As-B airfall pumice	20–30 cm
Hamagawa-nagamachi	Takasaki	Kofun	early 6th c.	Hr-FA ash fallout, lahar, flood	50–100 cm
			mid-6th c.	Hr-FP lahar, flood	120–140 cm
		Heian	1108	As-B pumice fallout	20–30 cm
Shimo-shiba sites	Takasaki	Kofun	early 6th c.	Hr-FA ash fallout, lahar, flood	163 cm
			mid-6th c.	Hr-FP lahar, flood	187 cm
		Heian	1108	As-B pumice fallout	15–20 cm
Kanai sites	Shibukawa	Kofun	early 6th c.	Hr-FA ashfall, pyroclastic flow/surge	30 cm
			mid-6th c.	Hr-FP pumice fallout	200 cm
Nakasuji	Shibukawa	Kofun	early 6th c.	Hr-FA ash fallout, pyroclastic flow	72 cm
Kuroimine	Shibukawa	Kofun	early 6th c.	Hr-FA ash fallout, pyroclastic flow	30 cm
			mid-6th c.	Hr-FP pumice fallout	200 cm
Shiroi sites	Shibukawa	Kofun	early 6th c.	Hr-FA ash fallout, pyroclastic flow	8–40 cm
			mid-6th c.	Hr-FP pumice fallout	40–190 cm
Kanbara	Tsumagoi	Edo	1783	As-A pyroclastic flow/debris avalanche	650 cm
Higashimiya	Naganohara	Edo	1783	As-A pumice fallout, flood	100 cm

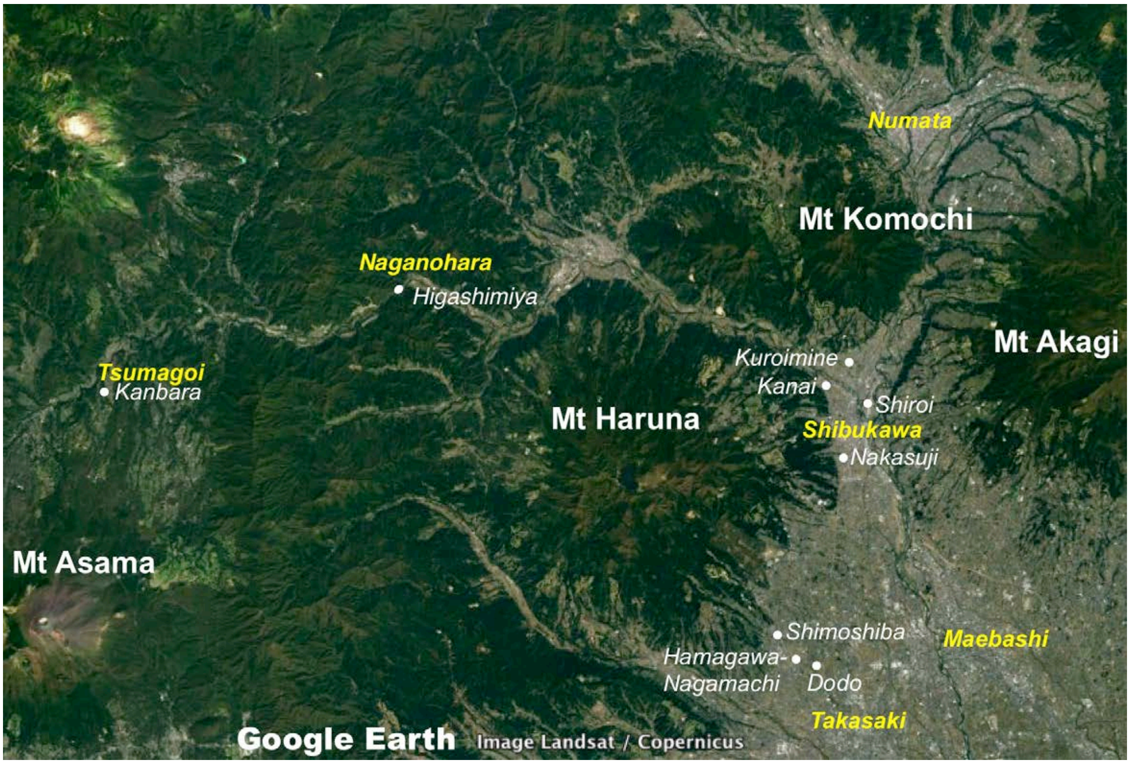

Figure 2 Locations of Sites and Cities/Townships Mentioned

The Utility of Tephra in Archaeology

The three benefits of tephra for archaeological investigation can be identified as follows:

Key Strata for Indicating Chronology

Tephra deposits are used as key strata that are spread over wide areas, forming boundaries between stratigraphic layers. Particularly in assessing the chronology of the Palaeolithic Period, such key layers are indispensable. In addition, from the absolute dating of tephra layers, the relative dating of artefacts and features above and below key strata can be inferred in what has become a standard archaeological method.

Key Strata Indicating Contemporaneous Land Surfaces

For example, if Mt Haruna were to erupt today, volcanic ash would be deposited on the surrounding area virtually simultaneously. Even if it took several days to fall out in the more northern Tōhoku region, this can be considered contemporaneous on the archaeological time scale. That is, even though land surfaces are in different areas, those covered by tephra would appear as a continuous landscape of the same moment (cf. Chapter 4). Tephra provides us with a widespread temporal surface representing the same slice of time in different places.

Preservation of Palaeo-surfaces

This is perhaps the greatest advantage of tephra. If it is the case that tephra destruction is total, then enormous damage is visited on the land surface. However, tephra covers past landscapes like a blanket, often saving features underneath from later disturbance. New discoveries are often revealed via tephra preservation. These can be divided into aboveground and underground remains:

Preservation of Aboveground Structures

Our archaeological investigations have usually been focussed on underground structures such as pits and pit-houses (cf. Chapter 8) – Japanese archaeology is often characterized as 'post-hole archaeology'. Thus, we have obtained relatively rich information about holes in the ground! However, information about aboveground structures, commonly constructed in Japan with organic materials (timber posts, reed thatching, etc.), is surprisingly rare. Preservation of land surfaces provides many clues to what these structures might have consisted of:

Soil-based low-level features: the bunds of paddy-fields (Chapter 11) or raised-ridge field systems (see Chapter 14).

Structures of organic materials: pit-buildings with thatched roofs (cf. Chapter 6), surface houses with wattle-and-daub walls, fences woven of reeds or branches (Chapter 10). Information on these architectural aspects is usually garnered from carbonized remains or impressions of structures when they fall over. Under good conditions, information can be had from cavities within the tephra or from concentrations of tephra contaminated by deterioration. Such finds complement wet-preserved organic remains.

Fragile or ephemeral constructions: collections of pottery and other special goods related to ritual activities. Under normal circumstances, these are broken up and become piles of fragments; but if they are covered by tephra, they are frozen in their position of use (Chapter 10).

Preserved Transformations and Alterations of the Earth's Surface

Even on paved roads, surfaces become rutted with use; on prepared sports grounds, the surface becomes roughened by the end of the game. Nature, of course, is changed whether by conscious or unconscious human actions, and the landscape is disturbed in various ways. Tephra can preserve these minute transformations:

Human and animal footprints: Many footprints of people revealing their modes of work (Chapter 11) are recovered from rice paddies and other surfaces, covered by ash fallout. Examples are pastures, where multitudes of horse hoofprints remain (Chapter 14), and lines of footprints belonging to horses and people walking away to escape ash fallout (Chapter 10).

Recovery and demise: Bioturbation, where the roots of shrubby bamboo and grasses appear at the top of tephra surfaces, indicates the gradual recovery of an area. Such plants are protuberant and can also mark the edge of cultivated land. Trees that grew and house posts that were erected during recovery may be toppled by subsequent volcanic blasts and pyroclastic flows, signaling their demise (Chapter 10). Uprooted trees leave concave hollows, half in the underlying sediments and half in the overlying tephra. The activities here are not due to human interference but constitute natural adjustments of the landscape.

Natural and anthropogenic markings: Scraping or cutting marks by agricultural tool use and marks of fingers dragged through a puddle have been recovered. The troughs and impact holes of rocks in pyroclastic flows on underlying volcanic ash surfaces are evident (Chapter 10).

Alterations: Humification and colour changes due to the decay of plant material are monitored; especially, traces of rice stalks in paddy-fields are identified this way. At Kanai Higashi-ura site, colour changes in the tephra around human bones are suspected to reflect flesh, clothing, and footwear (Chapter 10).

Application of Tephra Advantages in Archaeological Investigations

Archaeological research is like fitting together an incomplete jigsaw puzzle from fragmentary materials to make one version of one facet of the past. Using tephra for an archaeologist is like having several pieces in hand to challenge the puzzle. The discovery of the 6th-century settlements buried by tephra had an especially great impact on Japanese archaeologists. Until then, settlements of that time were thought to consist of pit-buildings with very few pillared surface buildings. This is understandable since the pits of pit-buildings are large archaeological features while the latter only leave small holes in the ground. However, with the excavation of Kuroimine (Horaguchi 2005) and Nakasuji (Shibukawa-shi Kyōi 1988), suddenly settlements were found to have, together with pit-buildings, not only many surface buildings of various functions including storehouses and animal stables but also gardens and seed beds – all surrounded by fences to form individual households. Several of these households made up a settlement, and around the edges were both paddy and dry fields, horse pastures, burial grounds, spring water collection points, ritual spots, and narrow paths to connect them all. Such a rich settlement landscape, appearing from underneath the tephra, far exceeded anyone's expectations.

At the Kanai Higashi-ura site (Chapter 10), starting with a warrior wearing lamellar armour, the bones of four people were found who died in the Hr-FA pyroclastic flow. But there were also lines of hoofprints and footprints of people and horses who managed to escape beforehand by walking calmly away. From these kinds of data, the moment disaster strikes becomes real to us.

In the alluviated regions of central Gunma Prefecture, large tracts of rice paddy features were discovered under the tephra blanket (Chapters 11, 14). From the inspection of the preserved field surfaces, the methods of field construction and cultivation and the irrigation networks could be analyzed. Footprints within the paddy-fields and elsewhere were used to reconstruct the activities of the farmers. By matching these with ethnographic research on the agricultural cycle and farming practices, researchers are able to assess the seasonality of volcanic eruptions (Chapter 11) – something not usually recorded in historic documents (Harada & Noto 1984). Paddy-fields in different areas which had been covered with the same tephra blanket become the resources for investigating regional variations in cultivation practices, land-divisioning strategies, and land-use systems.

The jigsaw puzzle's picture, which until recently had been invisible, has suddenly became apparent in fine detail. The advantages that tephra cover offers are multitudinous, as illustrated in Gunma. Moreover, once these various regional pictures are brought together out of isolation and animated, we will surely be able to see movement and change across the landscape.

For example, at the Dōdō site (Gunma-ken Maibun 1983), paddy-fields have been successively buried by tephras As-C (late 3rd century), Hr-FA (turn of the 6th century), Hr-FP (mid-6th century), and As-B (1108 AD) (Chapter 14). As they were excavated, archaeologists recorded minute details about every paddy-field. Beyond this, however, they observed the relationships of successive paddies to each other, bringing in a different viewpoint than just documenting the paddy-field regime under one tephra blanket. Paddy-fields stacked up in layers under recurring tephra strata can be read as traces of people's reactions to successive volcanic disasters – themselves making mutual relationships between the stratigraphically separated paddies. For example, in response to the damage caused by the As-C tephra-fall in degrading the paddy's ability to hold water, paddies were reconstructed in very small sizes. When these were buried by Hr-FA tephra, the basic paddy pattern was maintained and production immediately restored. Then, the central government instituted nationwide land-divisioning, the *jōri* system, superseding local partitioning. The square paddy-field system that appeared in Gunma, and was subsequently covered by As-B tephra, is hypothesized as a result of this government directive. Whether this is correct or not does not reduce the value in pioneering investigations from a volcanic disaster perspective: assessing people's adaptations to volcanic damage in the context of the time period's socio-political backdrop.

Again, by connecting trends in archaeological feature construction with individual fall units during eruption trends, ever shorter time periods can be observed. For the relatively recent eruption in 1783 of Asama As-A, many historical records document the eruption. Consequently, we can compare the eruption event resulting in several tens of tephra units with the documents and with the results of archaeological excavation, putting together a detailed picture of how people coped with the eruption duration – for example at Kanbara (Chapter 2: Figure 6). For the early 6th century eruption, Hr-FA tephra has been divided into 15 fall units. At the Nakasuji site, successive damage to buildings has been visually illustrated for every Hr-FA tephra-fall from unit #1 to the pyroclastic flow of unit #7. We have the opportunity to widen the application of fall-unit-based archaeological analysis.

Volcanic Disaster and Settlement Transition Seen in Damaged Sites

At the sites damaged by Hr-FA and Hr-FP tephra from Mt Haruna, we can assess people's reaction to volcanic disasters. The sites can be divided into those suffering from tephra deposition on the direct axis of lobate tephra distribution, and those subject to lahars in the many streams flowing off the flanks of Mt Haruna. Let us first look at the cluster of sites in the northern area where sites suffered heavy tephra pyroclastic flows of ash and pumice: Kuroimine, the Shiroi site cluster, and the Kanai sites in Shibukawa City. Then we will progress to sites off Haruna's southeastern flank struck by lahar disasters: Dōdō, the Shimo-shiba sites, and Hamagawa-nakamachi, all in Takasaki City. Sites on the eastern edge of Haruna were also affected by lahars (see Chapter 11). See Figure 2 for site locations.

Northern Sites

The Kuroimine site sits at the north head of the basin between the Agatsuma and Toné Rivers, about 10 km east of the Futatsudake vent (Komochi-mura Kyōi 1991; Tsude 1992; Ishii & Umezawa 1994; Horaguchi 2005). It was covered twice in the 6th century by Haruna tephra: Hr-FA and Hr-FP. As the first site in Japan to have been properly excavated from underneath tephra cover, it is extremely important; it can be described as a typical agricultural village of its times (Horaguchi & Ishii 1990). After the Hr-FA ashfall and associated pyroclastic flow, the settlement was briefly restored. If the next eruption of Hr-FP in the mid-6th century had not occurred, the village would have continued as normal. However, nearly two metres of Hr-FP pumice were deposited on the site, destroying the village. Not until after the 12th century was this area reopened for occupation. Kuroimine was a village that was restored after the Hr-FA eruption only to be destroyed by the Hr-FP disaster.

The Shiroi site cluster is slightly south of Kuroimine, also approximately 10 km east of the Futatsudake vent (Gunma-ken Maibun 1997). Before the Hr-FA eruption at the beginning of the 6th century, this area was hardly used. From traces of many trees toppled by the pyroclastic flow accompanying the eruption, it is thought to have been a forest environment. However, once covered by Hr-FA ashfall and devastated by the pyroclastic flow, the vegetation was 'reset' (cf. Chapter 13), changing to a grassland environment populated by Chinese silver grass / Japanese pampas grass *susuki* (*Miscanthus sinensis*), shrubby bamboo *nezasa* (*Pleioblastus chino*), and Lamb's quarters *shiroza* (*Chenopodium album*).

This change in environment was probably then utilized for new purposes at the Shiroi sites until the Hr-FP eruption. Employing the opportunity provided by the Hr-FA destruction of the forest, people redeveloped this newly created landscape as pasture. Multitudes of hoofprints have been excavated from under the Hr-FP pumice that fell in the mid-6th century (Chapter 14). Thus, between the two eruptions, this area seems to have been used as pastureland. The pumice layer that eventually covered the pasture was about 1.5 m deep. The first activity thereafter was the construction of a pit-building in the early 7th century. It took about 50 years for the vegetation to recover to the point of allowing redevelopment of a village there. Once re-established, this village continued its existence throughout the centuries. Thus, preserved in the archaeological record was the development of pastureland afforded by the Hr-FA disaster, and the re-colonization and continued existence of village life after the Hr-FP disaster.

Kanai site cluster is on the northeastern foot of Mt Haruna, 9 km as the crow flies from the Futatsudake vent (Chapter 10). There, the Kanai Higashi-ura settlement was covered with Hr-FA ash fallout and pyroclastic flow. It was the home of a technically advanced group, evidenced by horse-raising and manufacture of iron goods. Judging from the features thought to constitute a ritual centre, it was undoubtedly a regionally important core settlement. During the lull following the deposition of the first Hr-FA airfall tephra unit, people and their horses evacuated the settlement in a line, according to their footprints (Chapter 10: Figure 17). Unit S3, consisting of the pyroclastic flow, enveloped four people including a warrior wearing armour, according to the bones found under the tephra. No further features or evidence of human activities are found at this site after the first Haruna eruption, but the two metres of Hr-FP pumice deposited in the mid-6th century preserved hoofprints of horses made between the two eruptions. Hr-FA tephra spelled the end of this settlement for all human purposes.

Sites to Haruna's Southeast

The Dōdō site is located off the southeastern foot of Mt Haruna, 14 km south of the Futatsudake vent (Gunma-ken Maibun 1983; Noto 1989). Although the site sits in the opposite direction of the axis of dispersion of volcanic ash and pumice fallout, it hosts lahar sediments that flowed off the volcano. Paddy-fields that are covered by the Hr-FA-associated lahar have the same field divisioning as those above it covered by Hr-FP tephra (cf. Chapter 14); this situation is interpreted as efforts to recover the same field system in the intervening time period. Nearby at the Shimo-shiba Tenjin site, efforts to revive cultivation in dry-fields involved digging in Hr-FA volcanic ash and mixing it with the soil.

Nearby, Hamagawa-nagamachi site was inundated by a 5-metre-thick lahar associated with Haruna's mid-6th century eruption (Gunma-ken Maibun 1998). When plants began to grow again after the eruption, new homesteaders used this new growth to build their houses and make a new community. Excavations revealed that an early 7th-century pit-building was dug into the lahar sediments. Among the architectural members of the pit-building were many pieces of *yashabushi*, Japanese green alder (*Alnus firma*). This tall deciduous tree is a representative pioneer species, being quick to colonize disturbed ground. Despite these new forest resources enabling energetic rebuilding of the community, the site was buried again under yet another lahar.

At the neighbouring Shimo-shiba Kamitaya site, seven layers (Strata 5 to 11) of the lahar associated with the early 6th century Hr-FA eruption have been identified (Gunma-ken Maibun 1998). Stratum 7 consists of paddy-fields at 40 cm depth from the top of the lahar. Stratum 9 consists of dry-fields 80– Employing the opportunity provided by the Hr-FA eruption, people redeveloped this newly created landscape.90 cm below the top of the lahar. It is not yet clear what the timing is of these different layers, but despite the repeated deposition of lahar sediments, people kept taking up the challenge of redeveloping or reclaiming their fields.

Volcanic Disaster and Human Reactions

Here I would like to make some distinctions between different words used to describe human reactions to volcanic disasters.

Definitions

- When people are able to resume their same activities in the same place as before the volcanic disaster, this is 'RECOVERY' (*fukkyū*), such as at the Dōdō and Shimo-shiba Tenjin sites affected by Hr-FA tephra damage.
- When there is a relatively short gap and activities have to be restarted, this is 'RESTORATION' (*fukkō*), as at Kuroimine site after the Hr-FA disaster.
- When the gap is fairly long and different activities are instituted, this is 'RE-DEVELOPMENT' (*saikaihatsu*), as at the Shiroi site cluster and Hamagawa-nagamachi after the Hr-FP disaster.
- When the volcanic disaster is used as an opportunity to change direction, this is a 'NEW DEVELOPMENT' (*shinki kaihatsu*), as at Shiroi site cluster after the Hr-FA eruption.
- When people leave the land for good and stop all activities there, this is 'ABANDONMENT' (*haizetsu*), as seen at the Kanai site cluster after the Hr-FA eruption and at Kuroimine after the Hr-FP eruption.

Discussion

'Recovery' did not happen only at the sites mentioned above; regardless of whether it was Hr-FA or Hr-FP tephra, if we move out from the axis of volcanic ash and pumice deposition, or if we move far away from the eruption vent, we can see that light damage was incurred in broad regions. It is also apparent that 'restoration' took place even when there was not much damage; that is, occupation or activities were discontinuous but re-started after a gap. Finally, after the As-B (1108) and As-A (1753) disasters, core areas where bureaucratic facilities were located were quicker to recover and be restored than surrounding areas (Chapter 14).

'Re-development' generally took place in areas where much time was needed for the recovery of the damaged flora until it could support new settlements. As preserved under the lahar at Hamagawa-nagamachi site, there was evidence of many repeated efforts for re-developing the paddy-fields. Conversely, it was possible for 'restoration' at the Kuroimine site after the Hr-FA eruption and 'new development' at the Shiroi site cluster precisely because the fine Hr-FA volcanic ash was easier to convert into soil than the Hr-FP pumice, and so the recovery time for the flora was short.

'Abandonment' takes place when damage is severe. However, in the above examples, heavy damage cannot simply be concluded to result in abandonment. The Kanai Higashi-ura site was abandoned after the Hr-FA ashfall and pyroclastic flow, but the Kuroimine site underwent restoration. The Kuroimine site later was abandoned after the Hr-FP pumice-fall, but the Shiroi site cluster underwent redevelopment. Even though the Kanai Higashi-ura site was the most advanced in the area, the Kuroimine settlement – a simple farming village – outlived it. What these different constitutions imply for disaster studies needs a lot more thought. For example, the Kuroimine site sits on the upper part of a terrace where soil is more likely to be eroded than accumulated. Regeneration of the plant life on the terrace after the 2-metre pumice inundation must have been more difficult than at the Shiroi site cluster located in the flatlands subject to further alluviation. Is this the reason that Kuroimine was abandoned? Specific environmental circumstances other than tephra fallout depth at individual sites must have conditioned differences in human responses to disasters (cf. Chapter 15).

Conclusions

Damage that accompanies large volcanic eruptions spreads across wide areas. Some damage lasts a very long time, and some damage is extremely grave. But the story does not end with humans just being beaten down: it consists of initiatives in recovery, restoration, and new development, or the abandonment of disaster areas and gaining new territory, or sometimes even using the disaster as an opportunity to open new land for new purposes. Such disasters are met with various forms of adjustment, and it is the archaeological sites buried under successive tephra deposits that bring the details of those adaptations to our eyes.

We have seen above various responses to volcanic disaster by focussing on settlement dynamics. However, several studies extend our investigations in Gunma to the actions of individuals and communities that bore the damage (cf. Chapters 10 and 11) – such as near the Kuroimine site where a mounded tomb named Naka-no-mine Kofun was built by people living in the area before it was buried by Hr-FP pumice. The settlement associated with this tomb was destroyed, and the people moved somewhere else. However, relatives celebrated the deceased and dug away the pumice to re-open the tomb chamber to inter a new burial. Though their homeland had been abandoned, they maintained their burial grounds. Where did they go, what kind of life were they living?

Gunma archaeologists continue their excavations under tephra equipped with a new consciousness of such questions.

Figure & Table Sources

Figure 1 by Lincun (国土交通省 国土数値情報(行政区域) CC-BY-SA-3.0 via Wikimedia Commons, [https://commons.wikimedia.org/wiki/File%3AMap_of_Japan_with_highlight_on_10_Gunma_prefecture.svg]; modified by GLB
Figure 2 modified from Google Earth by GLB

Table 1 compiled by the author

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CHAPTER 10

Investigations into the Kofun Period Disasters Caused by Mt Haruna Eruptions

SUGIYAMA Hidehiro *

Introduction to the Kanai Sites

Approximately 1500 years ago, Mt Haruna erupted two times in the 6th century, causing extraordinary damage along the northeastern foot of the volcano by tephra fallout, followed by pyroclastic flow, lahar, and pumice inundation. Two sites which reveal the realities of this disaster, referred to as Kanai Higashi-ura and Kanai Shimo-shinden, are in Kanai, Shibukawa City, Gunma Prefecture. Below, as well as noting the conditions of damage that obtained, I will document the special investigative techniques and findings uncovered below the volcanic damage and how people recovered from this double disaster visited on them by Mt Haruna's eruptions. The focus will be on the Kanai Higashi-ura site, as it yielded the most extraordinary remains (Sugiyama & Sakuraoka 2014; Sugiyama 2016b, 2017b; Ōki et al. 2017), and secondarily on the Kanai Shimo-shinden site with similar findings.

The Kanai site cluster is located in the northern part of the Kantō Plain of eastern Japan, on the south bank of the Agatsuma River just before it meets the Toné River (Figure 1). It sits at the edge of an alluvial fan formed by the Noborisawa stream as it flowed off of Mt Haruna; the front edge of the fan forms a 20 m terrace scarp cut by the Agatsuma River.

FIGURE 1 TOPOGRAPHY OF THE KANAI SITE CLUSTER, SHIBUKAWA CITY, GUNMA

* Gunma Archaeological Research Foundation

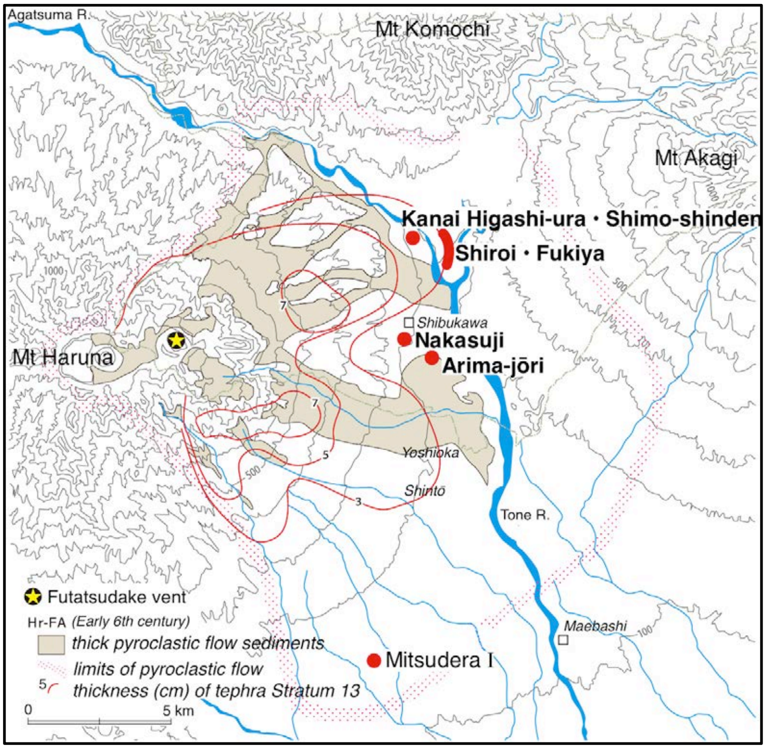

FIGURE 2 Hr-FA SHIBUKAWA TEPHRA DISTRIBUTIONS (EARLY 6TH CENTURY)

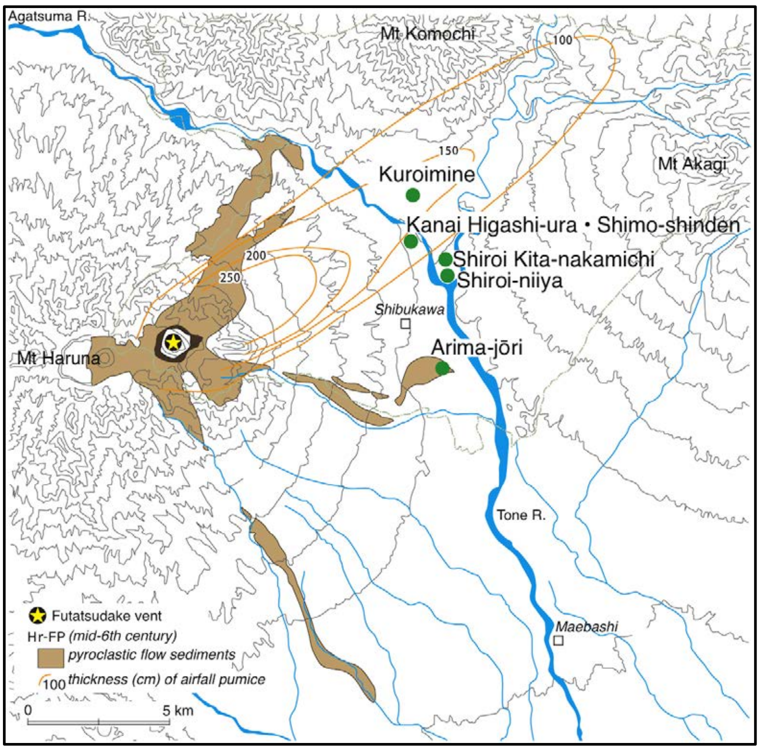

FIGURE 3 Hr-FP IKAHO TEPHRA DISTRIBUTIONS (MID-6TH CENTURY)

Mt Haruna has erupted periodically from several hundred thousand years ago; the latest eruptions that are reported here emanated from the Futatsudake vent of Mt Haruna (Sōda 1989). The first of these, at the beginning of the 6th century, was the phreato-magmatic eruption of Haruna Shibukawa tephra (Hr-FA) (Sōda 1989), which inundated the east–northeastern foot of Mt Haruna (Figure 2). Fifteen tephra strata have been identified (Sōda 1996, 2003); seven were present at Kanai Higashi-ura site (Sōda 2017). The significant events were, first of all, a volcanic ash fallout resulting in tephra Strata 1 and 2, followed by a pyroclastic surge (tephra Stratum 3) that killed humans and horses and destroyed buildings directly in its path; following that, a large pyroclastic flow (tephra Stratum 7) delivered a bombardment of rocks and had the strength to alter the shape of mounded tombs.

The second eruption 20 to 30 years later in the mid-6th century created the Haruna Ikaho tephra (Hr-FP) (Figure 3), resulting in large amounts of pumice fallout. At the time of the second eruption (Hr-FP), there were only a few horses present and no indication of human activities; the area was covered by about 2 m of pumice.

Both large eruptions from the Futatsudake vent caused enormous damage to the east-northeastern foot of Mt Haruna, with many sites almost completely obliterated. The Kani sites, on the southwestern bank of the Agatsuma River were destroyed.

After the ash fallout of Hr-FA at the beginning of the 6th century (Figure 2), the pyroclastic surge and then pyroclastic flow and lahar were very destructive to the entire region. Especially, the Nakasuji site (Ōtsuka 1988) and Kanai site cluster at the northeastern foot of Mt Haruna were in the direct path of the pyroclastic flow and completely destroyed by it. Only a few people likely survived the onslaught or made a timely escape. Along the northern bank of the Agatsuma River where damage from the pyroclastic flow was light, villagers carried on with life and were able to farm their fields and build new tombs at the foot of Mt Komochi. At the Arima-jōri site, further south on the west bank of the Toné River, dry-fields were completely buried by a lahar (cf. Chapter 11; Sakaguchi 1989, 2013); but the lahar leveled out the topography and replenished the soil, so there are places where paddy-fields were built anew. Many dry-fields were established in areas of less water on the less-affected mountain flanks, and new mounded tombs were built along the Toné River, with some at the foot of Mt Akagi. A new cluster of pastures for horses was created on the lower terrace where the Agatsuma and Toné Rivers join, for example at the Shiroi–Fukiya site cluster (Inoue 1997; cf. Chapter 14).

The deluge of pumice Hr-FP in the mid-6th century again affected the northeastern foot of Mt Haruna (Figure 3), where the fields, pastures and villages at the Kuroimine site (Ishii 1991; Tokue 2013) and Shiroi–Fukiya site cluster were buried by 1.8 m of pumice. Where the pumice cover was only about 1 m deep, people began to clear the pumice within a few decades, establishing residences as at the Shiroi-Niiya site (Kuroda 1994) and building new tombs with mounds of the collected pumice as at the Shiroi Kita-nakamichi site (Sugiyama 2009). Thus, recovery was underway by the early 7th century.

The impact and destructive forces of the two Mt Haruna eruptions particularly affected the northeastern foot of the volcano. The areas that received direct hits by the pyroclastic flows and pumice fallout were almost completely destroyed. Recovery was demanding, but where the tephra cover was relatively thin, some recolonization efforts began within a few decades. However, where damage was severe in areas of heavy pumice fallout, farming was difficult in both dry-fields and paddy-fields. We would like to think that the residents may have turned to make a living by handicrafts. But because recovery was difficult, there were probably people who left the region altogether (Sugiyama 2017b). These options might be reflected in the continued construction of chiefly mounded tombs as at Shiroi Kita-nakamichi, or the sudden increase in late 6th-century mounded tomb construction in the southern Yoshioka-Shintō district (located on Figure 2). Thereafter, especially in the 7th century, multitudes of small mounded tombs were built; those in the northern Numata district north of Mt Komochi have outstanding numbers of horse trappings, indicating the high proportion of horse ownership there. We must consider that area also to have been a destination for people to move to after the volcanic disasters of the 6th century.

Tephra is well known as a great preserver of cultural remains, freezing in time human (and animal) activities, settlement structures, and field systems. Three sites in Gunma Prefecture have provided exceptionally detailed glimpses into past lives: Kuroimine, previously discussed in Chapter 9 (see also Tsude 1992), and the Kanai sites of Higashi-ura and Shimo-shinden, recently excavated between 2012–2014. In the following sections, the extraordinary remains at the Kanai sites will be presented, followed by the results of several specialist analyses, some of which represent cutting-edge research in geotechnic engineering.

Unfortunately, the Kanai sites did not survive, though some residents may have escaped. On top of the FA tephra, before the FP pumice fallout, a thin layer (1–3 cm) of humus developed; this topsoil is imprinted with horse hoofprints. There are no other signs of life at Kanai between the two tephra fallouts, and after the mid-6th century eruption, the area was not reoccupied until the 17th century.

Finds from under the First Haruna Eruption (Hr-FA), Early 6th Century

Human and Animal Remains

The remains of six individuals and three horses were recovered. At Kanai Higashi-ura site, one man wearing armour, a woman wearing a necklace, and an infant lay in a ditch (Figure 4); another child lay on the hillside above. They all perished in the pyroclastic flow. At the Kanai Shimo-shinden site, two children in their teens and three horses were found.

The man wearing armour was a man in his 40s, 164 cm tall. His lamellar armour suit consisted of more than 1800 iron pieces laced together with kumihimo braiding (a mark of elite manufacture) and some leather thongs (Ōki 2017; Uchiyama 2017; Okuyama 2017; Sawada 2017). Fabric within the armour is presumed to have been his clothing (Sawada 2017). The helmet he was wearing had been taken off at the moment of the pyroclastic surge; it was a keeled helmet comprised of five horizontal iron bands (Figure 5a). At his waist, he wore a knife with a deer antler hilt and a pendant whetstone (Figure 6). To the west of him lay another set of lamellar armour of 951 pieces (Figure 5d) and 50 lamellae made of deer antler that may have comprised a chest plate (Figure 5c); additionally, 25 iron arrowheads with antler fixings were unearthed (Sugiyama 2015). These are exceptional in having globular decorative devices made of deer antler attached to the arrows (Figure 6). The arrows had been placed points up in quivers and stood on either side of the armour suit; when the pyroclastic flow hit, they were toppled over and carried along with it a little ways. At a slight distance, a long-hafted iron socketed spear was discovered decorated with silver and antler fixings around the haft join (Figure 4) (Sugiyama 2016a).

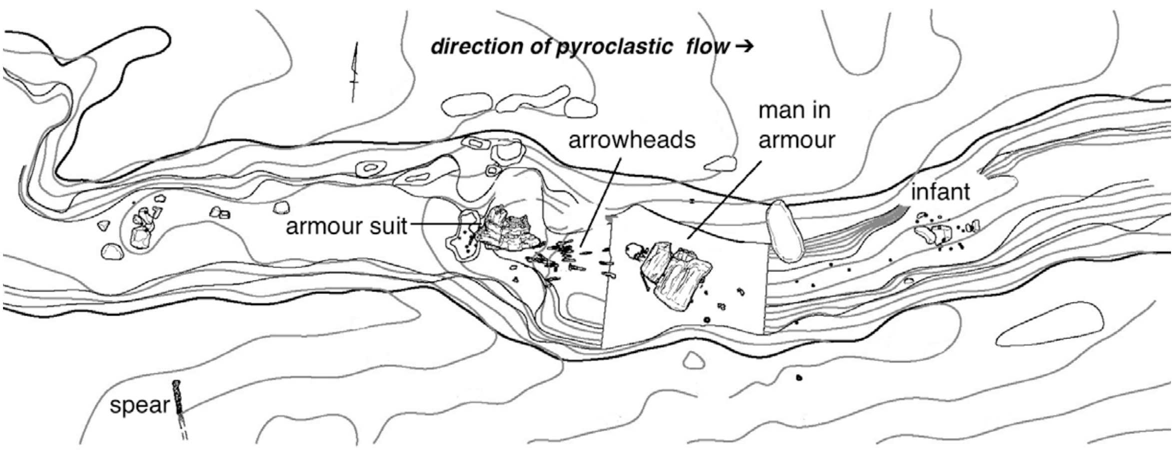

FIGURE 4 PORTION OF DITCH CONTAINING TWO INDIVIDUALS AND ARMOUR AT KANAI HIGASHI-URA

The arms and weapons are all thought to have belonged to the man wearing armour. They are outstanding in their generous use of deer antler and are extremely rare examples – perhaps the first or second to be known in Japan. The fact that this person had two suits of armour and a long spear suggests that he was a very high-ranking individual. Around him he had placed the second suit of armor and two quivers. Before the pyroclastic surge, he had knelt down facing the mountain, removed his helmet, turned it around 180° so that it faced himself, spread out the flaps and placed it on a small flat stone. He then rested his forehead on the helmet with his hands beside the helmet before the surge consumed him. By these acts, it is thought that he tried to placate the volcano and died doing so (Sugiyama 2017a).

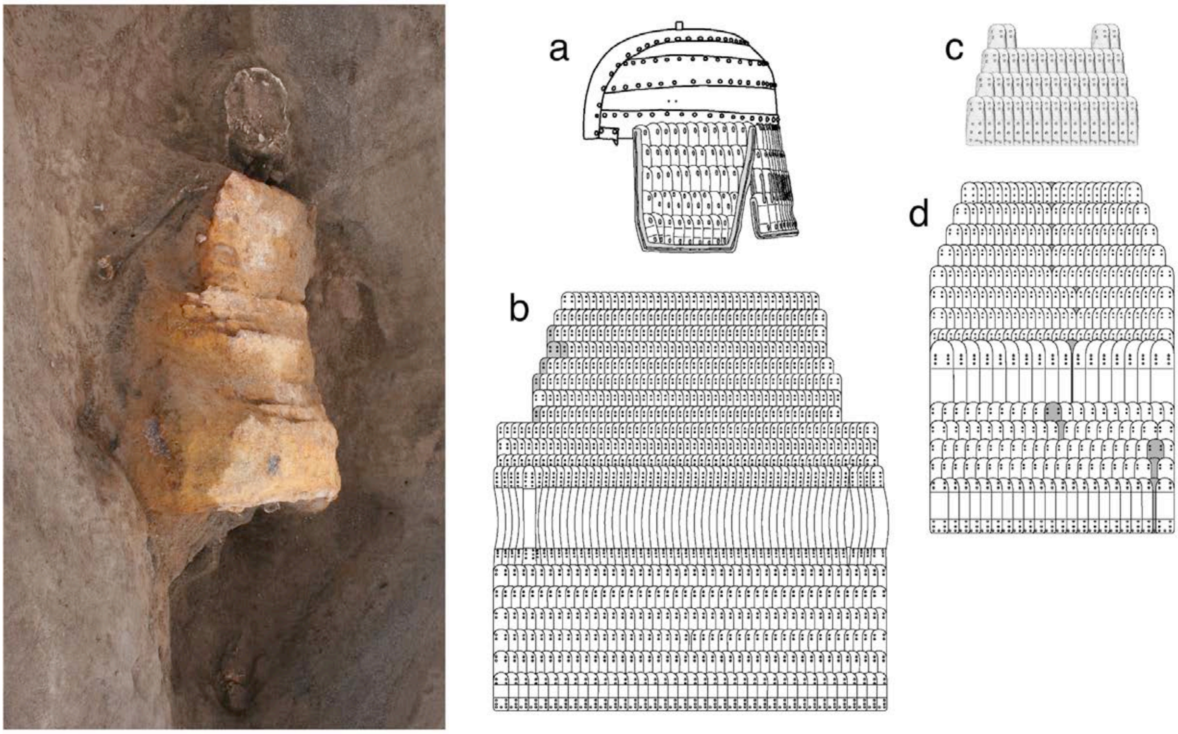

FIGURE 5 THE ARMOUR FOUND ON AND TOGETHER WITH THE MATURE MALE

(man in ditch turned sideways for comparison)

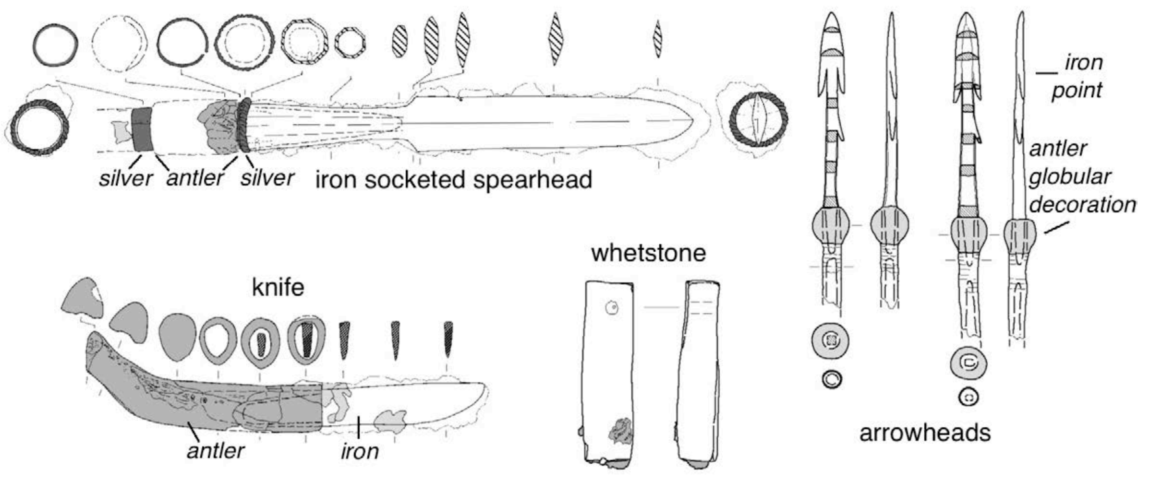

FIGURE 6 TOOLS AND WEAPONS RECOVERED

The woman wearing a necklace (Figure 7) was discovered further to the west in the ditch (not shown in Figure 4). She was a petite 143 cm tall in her 30s. Her necklace was strung with cylindrical beads of jasper and green tuff plus small round glass beads. It is possible that she had suspended from her waist a bag containing 27 small disc beads made of talc, probably for ritual purposes.

FIGURE 7 SKELETON OF A MATURE FEMALE AT KANAI HIGASHI-URA SITE

Only fragments of the infant's crown remained, found in the ditch. And the child on the hillside was a 5-year old of undetermined sex, represented only by a portion of the skull.

At the Kanai Shimo-shinden site, the remains of three horses and two children in their teens were uncovered. The sex of the latter is unclear, but from their position near the horses, it is possible they acted as grooms. Just the skulls of the horses were relatively well preserved, with only traces of post-cranial remains confirmed. Two of the horses were young, so they are thought to have been raised in the area.

Site Structures

Kanai Higashi-ura Site

The Villa

In the early 6th century, there had been a villa at Kanai Higashi-ura (Figure 8), of which we were able to investigate the eastern half. Within a compound marked off by a simple fence-like structure, there were three buildings – a pit-building, a pillared building, and a surface structure – in addition to ridged-fields of square and rectangular shapes. All of these were in use at the time of the pyroclastic surge.

The pit-building, interpreted as a house because of its clay-built hearth and storage pits, yielded over 50 stone weaving weights bearing traces of red pigments of dyed cords wrapped around them. They must have been being used to weave something very special. The pillared building yielded around 100 balls of red earth, set to dry; these consisted of silt, sand and clay pigmented with iron oxide (Shiga 2017) – a colour used for face paintings and in rituals. Inside the surface structure, a large Hajiware jar had been embedded in a pit for stability; it probably was used for some kind of storage. The garden plots were constructed of ridge-and-furrow with rather tall ridges. There were more ridged-fields just outside the villa boundaries on the north side, but there the ridges were lower and are thought to have lain fallow.

The Ritual Area

A ritual area existed at Kanai Higashi-ura about 20 m south-west of the large pit-house; close to 900 pieces of Haji pottery underlay the tephra fallout (Figure 9). The area comprised a circular space ca. 5 m dm in which ritual objects had been buried, while Haji jars and bowls were piled in stacks. Very large jars and pots stood in a wing-shaped pattern that opened to the south, and 700 small ceramics (mostly bowls) formed stacks of 2 to 20 pieces in the southwest area. These dishes are likely to be the remains cleared up after ritual feasting. Activity continued in the ritual area right up to the time of the eruption.

In order to discover the sequence in which the Hajiware were stacked in this ritual area, sediment from the bowl interiors was recorded. In some bowls, volcanic ash lined the interiors, and after some time, black soil accumulated, then another layer of ash was deposited. This indicates old and new relationships among the stacked bowls. By examining the stratification of the fine sediments, potentially minute human activities can also be illuminated because they are preserved at an instant in time.

South of the large jar, excavators recovered 10,000 talc disc beads, 210 glass beads, 80 other various bead shapes, 160 small stone imitations of things like bronze mirrors, etc., and 180 iron objects. These all seem to have been intentionally buried in the ground. Aside from the pottery,

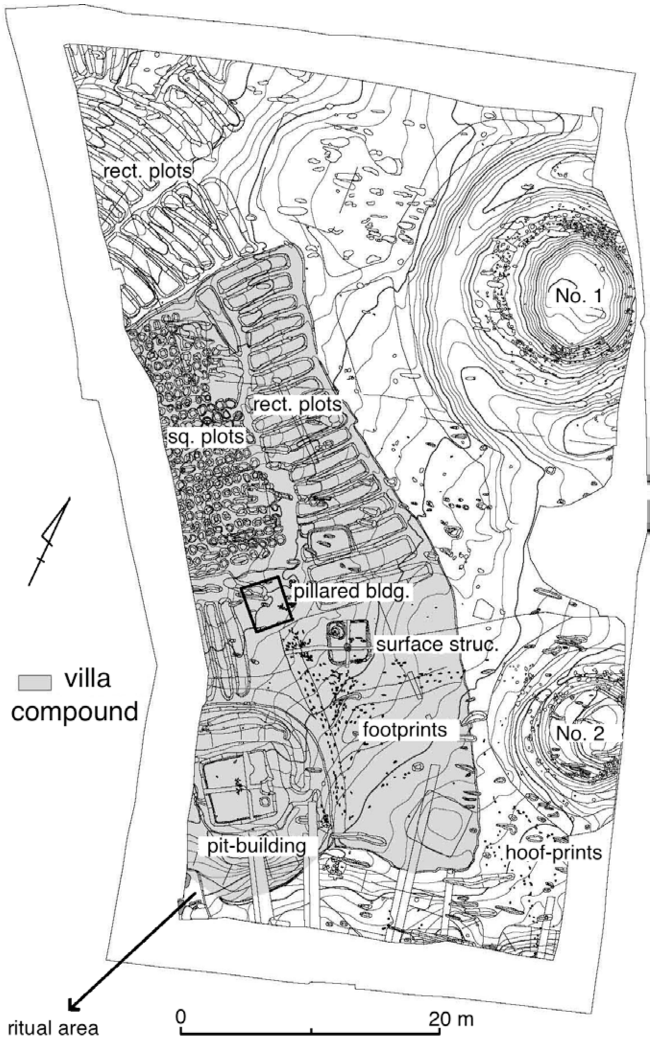

FIGURE 8 EXCAVATION SECTOR KANAI HIGASHI-URA SITE
The villa compound, square and rectangular garden plots, three buildings and two mounded tombs

FIGURE 9 EXCAVATING THE RITUAL AREA AT KANAI HIGASHI-URA

there is no other ritual site in Japan that has yielded so many ritual goods. For that reason alone, the ceremonies carried out here are viewed as extremely important.

Kanai Shimo-shinden Site

Another potential ritual area was discovered at the Kanai Shimo-shinden site. A rhomboidal area measuring ca. 48.5 x 56 m on a side was surrounded by a woven fence 3 m tall (Figure 10), with wooden posts marking off bays 1.8 m in width.

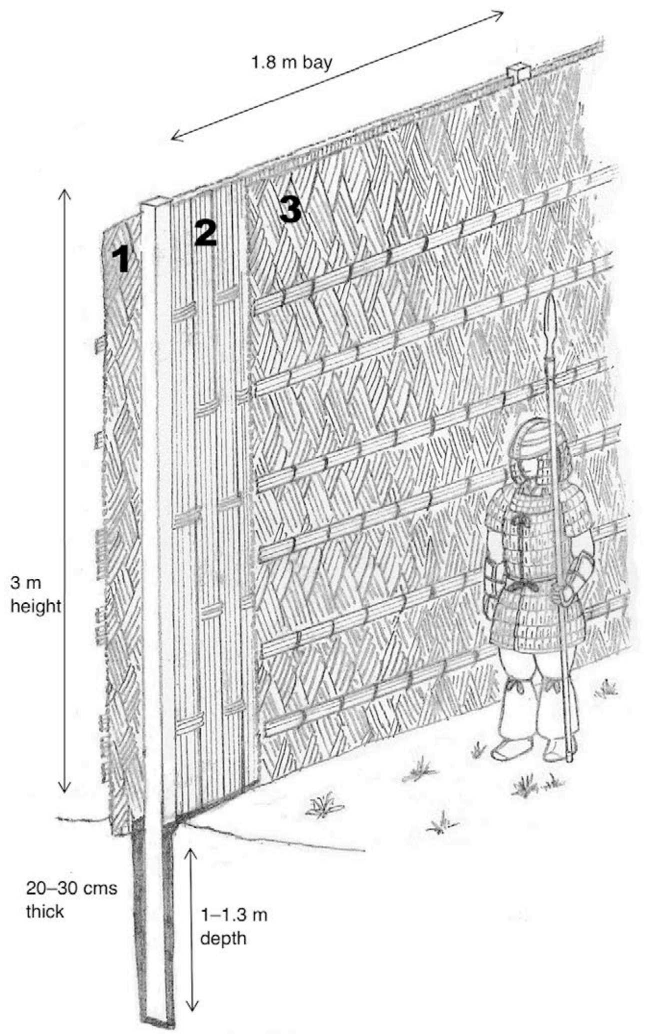

FIGURE 10 FENCE STRUCTURE AT KANAI SHIMO-SHINDEN

The fence had been knocked down and carbonized during the pyroclastic surge, but its structure has been reconstructed from these prostrate carbonized remains. Three layers of woven plant materials comprised the fence walling of 20–30 cm in thickness; reeds and bamboo were alternately woven on the diagonal for the outer surfaces, and vertical bundles of reeds formed the centre fill. The left side of the drawing shows the cut-away view, from the left: the matting on the far side (inner wall) reinforced with horizontal reed bundles **1**, vertical bundles of reeds in the centre **2**, and the nearside matting (outer wall) lashed to horizontal reed bundles for stability **3** (Hara 2017).

Within this fenced enclosure stood two pillared buildings (Figure 11-4,5), one with multiple underfloor post supports (usually interpreted as a storehouse), and two pit-buildings (Figure 11-1,2) interpreted as residences because of their hearth facilities. The larger residence measured 9 m on a side with the roof supported by 6 wooden posts. The pillared building had no roof, but the pillars withstood the pyroclastic surge and rotted in place.

Volcanic ash from before the pyroclastic surge covered the interior and exterior of the large pit-house, indicating that the roof had been previously removed but the pillars remained where they were. They had been pushed off vertical by the pyroclastic flow and were carbonized as they stood. Because these structures were damaged in this state, it is known that the facilities were no longer being used at the site at the time of the first eruption. There were few artefacts within the fenced enclosure, but more than ten pieces of deer antler were discovered beside one of the pillars of the storehouse. These probably constituted the leftovers after making antler tools and fixings. From the Kanai sites, over one hundred antler objects have been recovered, and the finds at Shimo-shinden indicate they were made locally.

In the southwest corner of this fenced enclosure was a small pit; on the shoulder of the pit were found several talc imitations of double-edged swords; further towards the fence corner, two more sword imitations, and a small bronze mirror were unearthed. Closer to the house but still within the south-western sector was a smaller circular area 3 m across, suspected to have been surrounded with walling made of reeds. It seems that ritual activities were conducted towards the southwest, which may have had some reference to spirit orientations in yin/yang philosophy though it is not known whether these ideas were present in the Kofun Period.

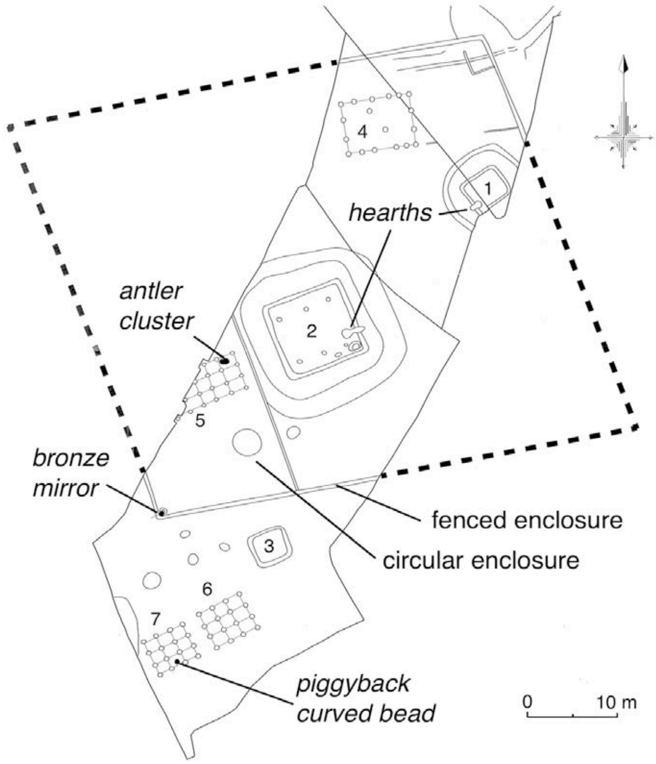

FIGURE 11 SITE PLAN OF KANAI SHIMO-SHINDEN FEATURES

Outside the fenced enclosure still to the southwest were a pit-building (Figure 11-3) and two multi-post storehouses (Figure 11-6, 11-7); near the latter were found several disc beads and a 'piggyback' curved bead (*komochi magatama,* 4.3 x 8.2 cm), so-called because of the protuberances on the upper side (Figure 12).

FIGURE 12 *KOMOCHI MAGATAMA* AND DISC BEADS

Specialist Analyses

Bone Preservation and Strontium Isotope Testing

Japan has characteristically acidic soils due to the leaching of base metals from tephra fallout, so the proportion of human bones preserved in tephra-derived soils is extremely low. Thus, we needed to discover why some skeletal remains were relatively well preserved at the Kanai sites. The densities and the grain size distributions of some strata collected were measured; these are conventional parameters in soil mechanics. Measured values depended on each stratum and described quite different properties. We hypothesized that the boundary from dense sediments to less dense sediments formed a barrier to capillary action of water.

This was tested by taking sediment samples from two positions. In the first position, a stable layer of black soil developed on top of the Hr-FA pyroclastic flow sediments that buried the man in armour. The soil

FIGURE 13 FEMALE (LEFT) AND MALE (RIGHT) ADULT SKULLS FROM KANAI HIGASHI-URA SITE

layer comprised of coarse grains was less dense than the compact pyroclastic layers comprised of fine grains. The degree of saturation of the fine-grained tephra layers was less than that of the black coarse-grained soil, so that even when two layers received precipitation due to rainfall, the soil might become water-logged; but the compact pyroclastics formed a capillary barrier that prevented percolation of soil moisture into the remains below and protected the buried bones. In the second position tested, the man in armour was engulfed in Stratum 3 of the pyroclastic surge; above that lay Stratum 7 of coarser-grained pyroclastic flow sediments. The water retention activity of Stratum 7 was considerably lower and had higher suction potential than that of Stratum 3. As a result, there was little seepage into Stratum 3. In both cases, results of the grain-size analysis informing on water retention demonstrated that a capillary boundary formed which prevented the percolation of water downwards and kept dry the layers in which the bones were embedded (Nishimura 2017).

Various means were used to assess the origins of these people (Tanaka et al. 2017). From the shape of the skull (Figure 13), it is known that the man wearing armour descended from immigrants from the Korean Peninsula, while the woman wearing a necklace has the morphology of a person from the Japanese Islands (cf. Barnes 2015: Box 11.2). Moreover, strontium isotope analysis revealed that both the man and woman were not locally born but spent their childhood in an area of geologically very old bedrock; they had probably moved to this region from the west. The child, however, had indeed grown up locally.

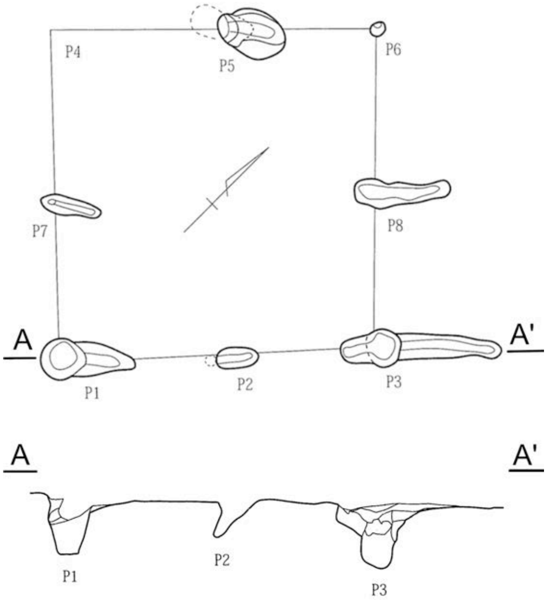

FIGURE 14 DEFORMED POSTHOLES FROM TOPPLED HUT PILLARS IN PLAN AND SECTION

Damage Variability and Assessment

Surge Damage

Buildings in use at the time of the eruption survived the initial tephra fallout, but they were destroyed by the next pyroclastic surge. Pillars of a small hut bent with the flow (Figure 14). Their deformation has been used to estimate the strength of the surge. Pillars belonging to a building undergoing renovation, however, were left standing; it is thought that because they presented no breadth to the surge, they suffered little damage.

In collaboration with geotechnical engineers, the destructive power of the pyroclastic surge on these toppled posts was assessed through 3-dimensional analysis using the section profiles of building post-holes and data obtained from soil analysis. The 3D dynamic response analysis based on the elasto-plastic finite element method was performed to evaluate the impulse given from the pyroclastic surge body to a small wooden hut at the time of the volcanic eruption (Kameyama et al. 2017). The material parameters of soils in the ground for the analysis were determined from the results of the laboratory tests. The results indicated that a speed of 108 km/hour or an impact of 250–500 kg of material would have the same effect.

Impact Traces

Over 1000 linear indentations were discovered in the grounds of the Kanai sites; these were revealed to be traces where rocks in the pyroclastic flow dug into the earth (Figure 15). They are oriented in the direction of the pyroclastic flow (arrow in Figure 15), wedging into the ground rather deeply but bouncing out as they headed due east, leaving behind a ridge of soil on the out-going eastern edge of an indentation.

Figure 15 Sectioned Impact Trace, Filled with Tephra

Mound Erosion

At Kanai Higashi-ura site, two mounded tombs were hit from the west by the pyroclastic flow. The stone pavements covering the tombs (Figure 16), on the sides directly exposed to the flow, were blasted off, and the mound shapes were changed by earth being shaved off. They endured quite a bombardment. Around the tomb can be seen many linear impact traces of rocks in the pyroclastic flow.

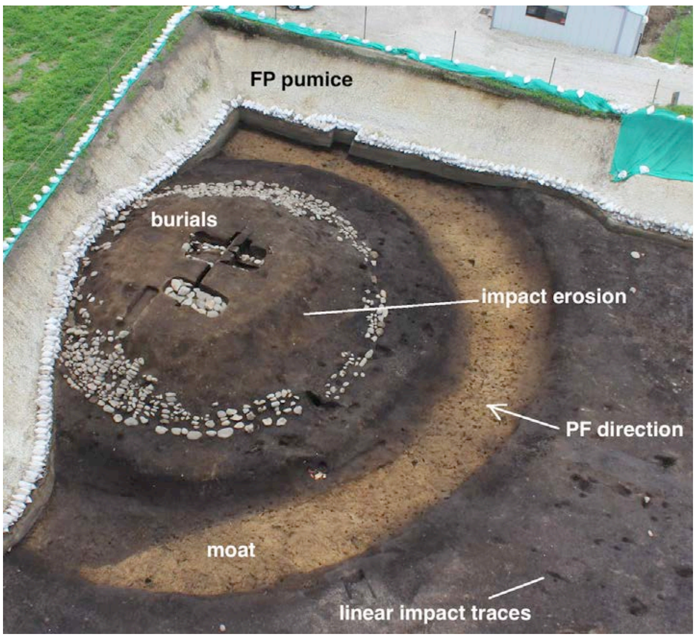

Figure 16 Detail of Damage to Mounded Tomb

The indentations were identified in collaboration with volcanologists and interpreted as the flow having proceeded directly west to east without following a valley. It appears that the rocks were carried by a very large pyroclastic flow after the initial pyroclastic surge that killed the people and horses and destroyed the buildings. In contrast, the ceramics at the ritual site were left in their stacked positions probably because the strength of the flow was different at various locations and according to its own depth of flow.

Investigating Pre-eruption Conditions

In the late 5th century, village numbers increased in this region, proliferating from slightly raised areas on the plain onto terraces and alluvial fans. Rice paddies were constructed in the low-lying areas, and where water was scarce, dry-fields were maintained. Using new-style iron agricultural tools, areas were opened up for agriculture. Mounded tombs of the elite were built primarily on small rises in the Agatsuma and Toné River drainages, but some were on alluvial fans and hills.

Use of Horses

Considerable evidence relating to horses has been recovered from features and artefacts under the tephra, informing on customs as well as land use patterns. Hoofprints occur in isolation (cf. Chapter 14) or together with human footprints (Inoue & Miyazaki 1997; Inoue & Sakaguchi 2004); the latter are interpreted as a person leading a horse (Figure 17). From the analysis of teeth, young horses were present; they were most likely reared in this area. From the evidence of agricultural tools and hoofprints, it appears that horses were mainly used as pack animals, but decorated horses for ritual and military horses were important as well. Two teenagers whose remains were found together with three horses were probably grooms. Horse trappings made of iron and laminated with gilt bronze were excavated from within the pyroclastic flow sediments; they indicate both that high-status individuals rode lavishly decorated horses and that there was such a person at this site (Sugiyama 2017a).

Prior to the pyroclastic surge, nearly 1000 human footprints were made in the initial wet ash fallout from the phreatomagmatic eruption cloud. Various footprint sizes indicate there were adults and children, and people's movements can be reconstructed, for example leading in and out of houses, before the pyroclastic surge occurred. Most walked barefoot, and none could be seen running (Miyashita & Suda 2017). This attests to calm evacuation of the area after the tephra fall.

FIGURE 17 RECOVERING HORSE HOOFPRINTS AND HUMAN FOOTPRINTS IN THE VOLCANIC ASH

Plant Uses

Various plant remains shed light on the natural flora, crop species, and architectural members. They survived embedded in the ash fallout or pyroclastic sediments or carbonized; then they were fully covered by the second eruption of pumice. Because of the compact nature of the tephra where contamination was limited, analyses were conducted on plant opal, pollen, and the identification of seeds. Cultivated dry-rice, wheat, and foxtail millet formed the major crops; peaches and plums were used for food and ritual.

Analyses of carbonized wood from 15 pit-houses revealed the use of deciduous oaks (*konara, kunugi*) and chestnut (*kuri*). These three types were taken from the neighbouring mountains and were the primary building materials for constructing houses, but some other houses had a greater variety of woods used. Within pit-houses, architectural materials were carbonized by the intrusion of hot pyroclastics; the different woods can be identified and their patterns of use clarified. Thatched roofs were damaged by the pyroclastic flow on some structures, and others could be reconstructed from various data. Non-cultivars identified were a variety of deciduous trees, bamboo and meadow plants (Table 1). Very few trees had been felled by the pyroclastic flow; only two could be identified from stratigraphic sections. Apparently, trees growing in the area had earlier been cleared right up towards the mountain; the site was surrounded by grasses.

Table 1 Non-cultivars Identified at Kanai Sites

deciduous oak	*konara*	*Q. serrata* Thurnb.
sawtooth oak	*kunugi*	*Q. acutissima* Carruth
chestnut	*kuri*	*Castanea crenata* Sieb. et Zucc.
horse chestnut	*tochinoki*	Aesculus
Chinese hackberry	*enoki*	Celtis
Amur corktree	*kihada*	*Phellodendron amurense* Ruprecht
fir	*momi*	Abies
Japanese cedar	*sugi*	*Cryptomeria japonica*
dandelion subfamily	*tanpopo*	Cichorioideae
monopodial bamboo	*medake*	Pleioblastus
blue stem grass	*ushigusa*	Andropogoneae
Japanese pampas grass	*susuki*	Miscanthus

Summary

At the Kanai sites, footprints of horses and humans revealed a calm exodus after the first light tephra fallout of Hr-FA; those caught by the following pyroclastic surge/flow are preserved in various acts of activity (two teens in charge of three horses), distress and death (10-year-old child on the mountainside, and a female in a ditch), and reverential acceptance of his fate by the man dressed in armour. In addition to the armour and weaponry, decorative elements suggest elite status, with lavish deer antler and silver fixings on the weapons, and beads possessed by the woman.

Structural remains at Kanai Higashi-ura tell of an elite housestead comprised of several buildings situated next to mounded tombs and surrounded by ridged garden plots. When pillared and surface buildings occur together with pit-buildings, the latter are usually common work spaces; the pit-building at Higashi-ura contained balls of loam mixed with hematite, suggesting craftworks related to ritualized face-painting and weaving red fabrics. A specialized area in which almost 700 bowls were discovered in stacks are interpreted as the remains of ritualized feasting; these were accompanied by thousands of beads, iron objects and stone imitations of bronze mirrors – all these are indicative of ritual activities.

The Kanai Shimo-shinden site was unusual in having a housestead contained within a 3-m-high fence woven of organic materials; the survival of such organic remains is extremely unusual and provides a much more impressive character to the site than usually seen from mere post holes. A pit-house and two pillared storehouses stood outside the fenced enclosure, while inside the fenced area were four buildings including two pit-houses, a pillared building, and a pillared storehouse. Posts of the storehouse were discovered in association with a cluster of deer antler pieces, probably for making antler objects and fixings as found on the weaponry of the Higashi-ura site. Two ritual deposits were also discovered. Within the fenced enclosure, a small pit in the southwest corner of the fence yielded stone imitations and a small bronze mirror. Outside the fenced enclosure near one of the storehouses were found more beads, including a large 'piggyback' curved-bead-shaped object.

The distribution of volcanic ash revealed that the housestead at Higashi-ura was in use when the tephra fallout began, but the housestead at Shimo-shinden had already been abandoned previously. The reason for the vacated premises is not known. Both housesteads were comprised of similar building varieties, suggestions of craftworks, and elite occupation. Unlike other sites in the Gunma region (cf. above and Chapters 11, 14), there was no indication of recovery or resettlement at these Kanai sites after their destruction.

To fully utilize the potential of volcanic preservation, we must continue to devise methodologies and preparations that can capture that information. This chapter has revealed that human and horse bones, which are not usually recoverable in Japanese soils, were protected by tephra layers that formed capillary barriers that kept moisture from assisting the decay of the bones. Geotechnic calculations of pyroclastic flow speed were calculated from toppled pillars and rock impact traces. Cooperation among archaeologists, palaeobotanists, geologists, and engineers at the Kanai sites recovered heretofore unparalleled data, showing the way forward for future research.

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Figure & Table Sources

All figures created by GARF, GPEB & modified by GLB

Figures 1, 5 (photo), 7, 9, 12-15, 17 courtesy of Gunma Archaeological Research Foundation
Figures 2,3 after Sōda 2003: figs. 52, 53
Figures 4-6 after Ōki, Sugiyama & Miyashita 2017: figs. 5, 39, 47, 72, 85, 87, 94, 95, 106, 108 and Sugiyama 2017a fig. 1
Figure 8 from Sugiyama & Sakuraoka 2014: fig. 4
Figure 10,11 after Hara 2017: appendix, p. 7
Figure 16 after Kameyama, Wakai & Sugiyama 2016: fig. 2

Table 1 after Sugiyama 2016b: table 1

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All sources in Japanese unless otherwise noted

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CHAPTER 11

Archaeological Investigation of the Seasonality and Duration of the 6th-century Eruptions from Mt Haruna

SAKAGUCHI Hajime *

Abstract

Volcanic eruptions greatly affect human society. Particularly in agricultural societies, ash fallout can directly damage crops and transform landscapes and affect soil profiles. In order to assess the effects of volcanic disasters in pre-historical periods without written records, archaeological investigation of the timing and seasonality of eruptions is essential. This chapter examines three sites in Gunma Prefecture, where tephra from two eruptions of Mt Haruna have buried 6th-century agricultural fields in the Kofun Period (250–710 AD). The seasonalities and durations of each eruption are assessed through archaeological data.

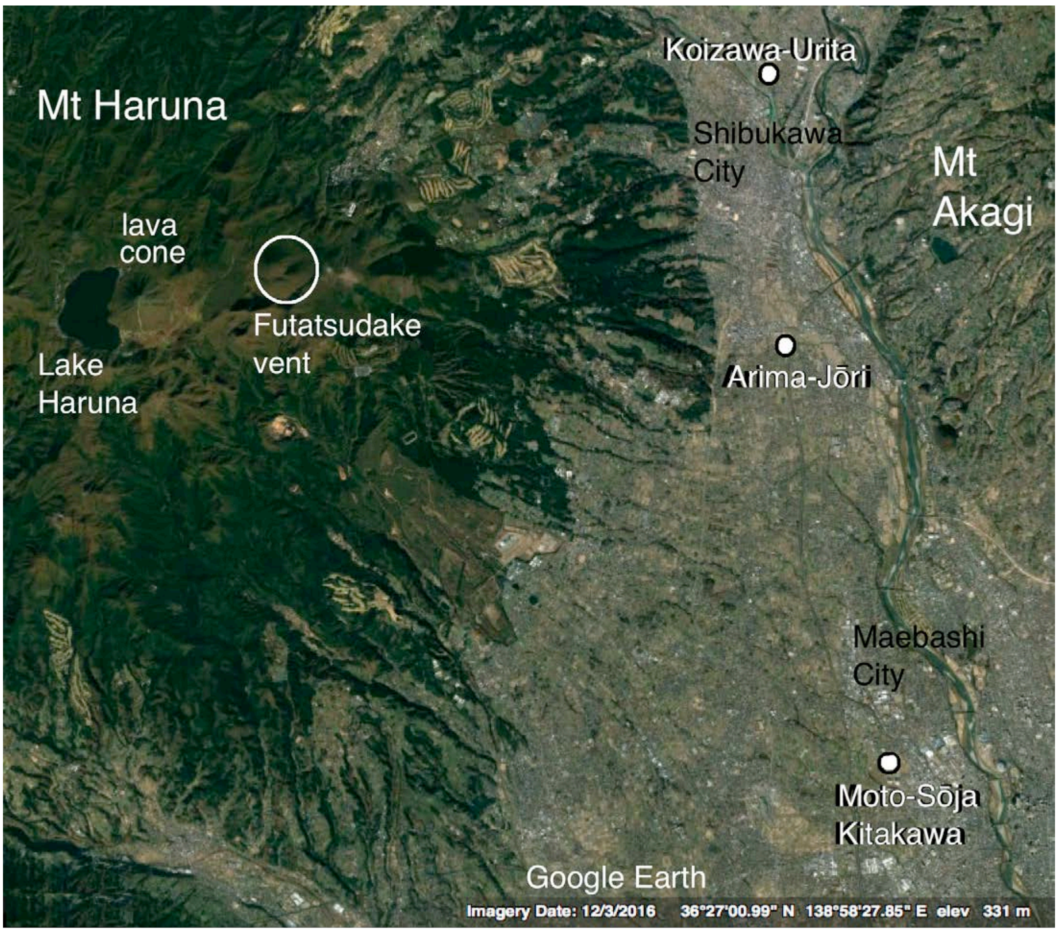

FIGURE 1 LOCATIONS OF SITES DISCUSSED AROUND MT HARUNA IN GUNMA PREFECTURE

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Introduction

Mt Haruna, positioned in central Japan in Gunma Prefecture (Figure 1), erupted twice in the 6th century during the Kofun Period. Tephra that erupted at the beginning of the 6th century from the Futatsudake vent is termed the Shibukawa tephra (Hr-FA, Machida & Arai 1992) or just FA; it is characterized by phreatomagmatic eruptions and pyroclastic flows associated with lava dome formation. Tephra that erupted in the mid-6th century from the same vent is termed the Ikaho tephra (Hr-FP, Machida & Arai 1992) or just FP; it is characterized by Plinian eruptions and pyroclastic flows. There are no historical documents whatsoever recording these eruptions. However, the dates and seasons of these eruptions have been estimated from the ceramics found above and below the tephra strata and from the conditions of buried rice paddy features (Harada & Noto 1984; Sakaguchi 1993). FA tephra has been divided into 15 strata (S_1~S_{15}), while FP tephra is divided into 19 strata (I_1~I_{19}) (numbered from bottom up: $_1$ is earliest) (Sōda 1996, 1998). Despite these fine divisions, however, there have not been any materials until now by which the duration and seasonality of these individual layers could be assessed.

In recent years, excavations at the Moto-Sōja Kitakawa site in Maebashi City (Figure 1) have uncovered paddy fields and associated features such as irrigation canals directly below each of the FA and FP tephras and their accompanying lahars (Gunma-ken Maibun 2007). Within the stratigraphic relations of tephras and lahar sediments covering these agricultural remains, data have emerged to shed light on the heretofore unclear sedimentary duration of the fine layers making up FA and FP. Consequently, we will investigate the duration and seasonality of these fine layers, based on the practices of modern wet-rice agriculture, by comparing the Moto-Sōja Kitakawa site with other sites in the surrounding area.

Procedures and Seasonality for Cultivating Wet-rice

The procedures for growing wet-rice in modern Japan can be divided into four categories as seen in Table 1. Since Japan stretches longitudinally over a great distance, the timing of the above tasks will vary by region. Table 1 gives a generalized schedule of activities. These procedures in their relevant seasons form the basic materials for assessing the seasonality of Kofun-Period paddy fields buried by tephra.

TABLE 1 PROCEDURES AND SEASONALITY OF MODERN WET-RICE CULTIVATION

	April	May	June	July	August	September	October
1. Prepare the paddy field a. plough the field b. add irrigation water and stir the lumps out of the ploughed soil c. rebuild bunds between fields	———	—— (first half)					
2. Plant the rice		———	—— (first half)				
3. Maintenance tasks, such as weeding		———	———	———	———	———	—— (first half)
4. Harvest						—— (second half)	—— (first half)

Moreover, there are two methods of planting: growing the rice in seed beds (*naedoko*) and then transplanting the seedlings, or instead, planting seeds directly in the paddies themselves. Currently, planting seedlings is most common; but in the Kofun Period, it is not yet known whether one or the other method or both were used. Figure 2 illustrates several stages of the procedures: planting seedlings by hand in an upper terraced paddy field, with a flooded semi-circular paddy below awaiting planting. These are surrounded by newly built bunds, which as yet bear no weeds. Three paddies on a lower terrace in mid-picture have been flooded, with one ploughed field on the left. Today, both ploughing and planting are mostly accomplished using small machines, and mechanization has caused paddy fields to be enlarged to accommodate them. The sizes of the lower paddy fields shown here can be compared to the tiny fields common in the Kofun Period at Moto-Sōja Kitakawa site, discussed below.

Figure 2 Planting Rice Seedlings by Hand

Figure 3 Excavated Ushi'ike River

Loc. A: Irrigation canal
Loc. B: Paddy fields

The FA Eruption Affecting Moto-Sōja Kitakawa Site

The Moto-Sōja Kitakawa site in Maebashi City comprises a small valley carved by the Ushi'ike River (Figure 3), one of several small streams sourced from the southeastern flank of Mt Haruna. It is located on a terrace at 114–120 m msl, 3 m above the Ushi'ike River and 5 km from its source. The Futatsudake lava dome that formed at the end of this eruption series is 15 km distant to the northwest. This site was affected by both 6th-century eruptions of Mt Haruna, but only the early 6th-century remains will be discussed here; the mid-6th-century eruption is dealt with in the next section.

Excavations at the site covered 26,700 m^2, revealing tephra, lahar, and flood deposits as well as Early Kofun rice paddies, irrigation intake dams, paths; Middle Kofun irrigation canals, paths; Late Kofun paddies, irrigation wells, and pit-houses; Heian Period paddies, dry fields, pit-buildings, paths, and streams; and Medieval pillared buildings, irrigation canals, etc. (see Appendix A-2, A-3 for period dates). The paddies fed by the dam in Loc. A are discussed further in Chapter 14 (see Chapter 14: Figure 11).

FA ash fallout comprised the 11th stratum at ca. 3.3 m below the present-day ground surface; it was 10 cm thick, containing S_1 and S_7 micro-layers. Above that stratum lies 2.5 m of FA lahar, reaching 3.5 m at its thickest; this lahar can be divided into perhaps 5 layers based on colour differences.

Paddies, irrigation canals, and streams directly underlay the S_1 microstratum of FA tephra, which was about 1–2 cm thick; above that was 6–8 cm of S_7, then the FA lahar. Between the strata, there were no palaeosols and no FA tephra above the lahar sediments. However, we were able to identify one aberration in the sedimentary deposition attributable to human activities that informed on the season and duration of the FA lahar.

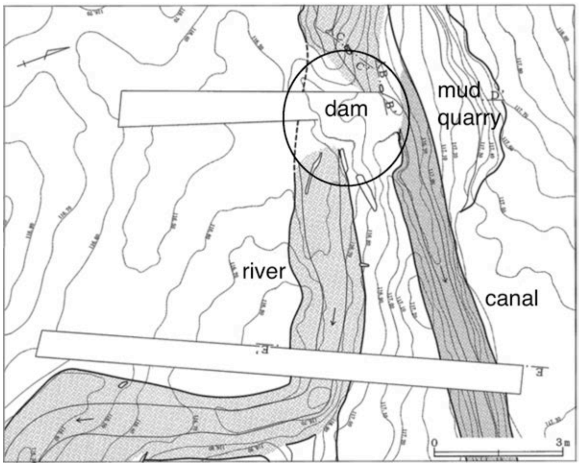

FIGURE 4 DIVERSION OF WATER FROM USHI'IKE RIVER INTO AN IRRIGATION CANAL

A dam in the river, funnelling water into an irrigation canal leading to the paddy fields, was revealed in excavation (Figure 3-A, Figure 4). To make a simple mechanism for diverting the water into the canal, the riverbed had been lined with fragments of reeds and wood, and then mounded with earth to form a dam. Sectioning the dam revealed the following stratigraphy: the organic materials on the riverbed had been directly covered by sedimentation of S_1 and S_7, and then directly on top of those layers was earth fill of the dam comprised mainly of black mud containing blocks of mixed S_1 and S_7. These were covered by FA lahar. The lack of earth fill between S_1 and S_7 indicates that these airfall tephras occurred close in time, otherwise there would have been time to continue the dam-building between them.

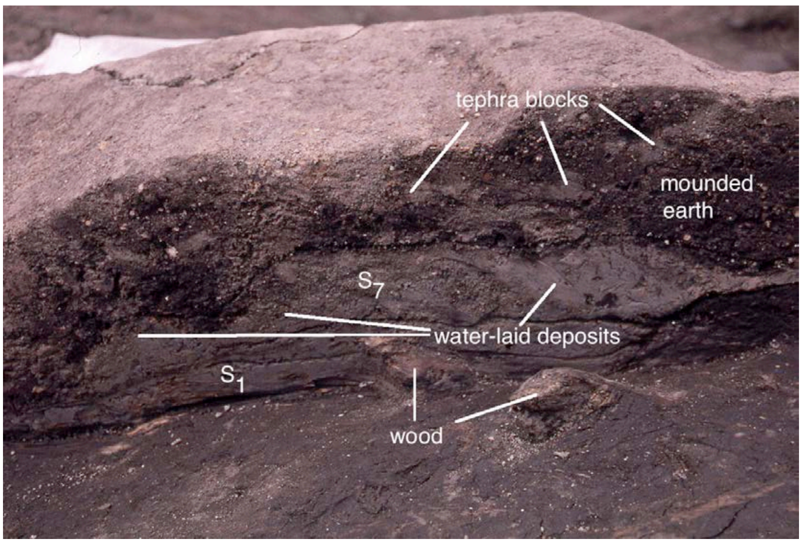

FIGURE 5 THE DAM STRATIGRAPHY AT CANAL DIVERSION POINT

In addition, the inclusion of both S_1 and S_7 blocky sediments (Figure 5) in the mud mound forming the dam indicated it had been mounded using those two airfall units. Judging from water-laid sediments in the canal on top of the FA tephra layers, the task of building the dam appears to have been completed. We can thus estimate that there were at least several hours after the S_7 fallout in which the farmer(s) could then work mounding the dam and diverting water before the lahar struck.

Furthermore, many footprints were excavated from the riverbed sediments and around the branching canal. Some footprint depressions were covered with S_1, some with S_7; then there were some instances of overlap of S_1 and S_7 footprints (Figure 6). And of course, all these were covered by the FA lahar.

From these overlapping sequences, we know that work was being done there before the S_1 fallout and between the S_1 and S_7 fallouts. The activity of the person(s) is not completely clear, but there are absolutely no footprints farther upriver. Judging from three footprints that head from the river to the slope on the north side of the canal, it is clear the activity involved canal construction. On the north bank there is a cutting ca. 5 m long and 1 m deep into the river bank (labelled 'mud quarry' in Figure 4). There is no evidence of S_1 and S_7 here – having been removed by quarrying; the cut marks are irregular and directly covered by FA lahar. This was where the worker(s) obtained the mud for the dam and the work was carried out after both ash fallouts, accounting for the blocky inclusions of S_1 and S_7 in the dam mound.

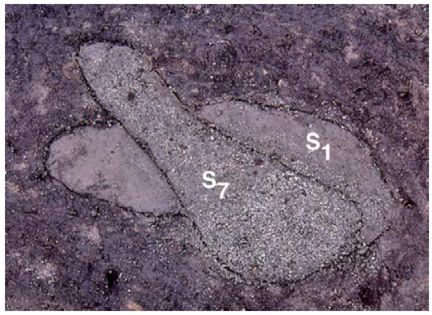

FIGURE 6 FOOTPRINT HOLLOWS FILLED WITH SUCCESSIVE TEPHRAS
S_1 in the lower, S_7 in the upper

Next, let us examine closely the bunds of paddy fields directly below S_1 at Loc. B (Figure 7). These fields are approximately 1.5 x 2 m in size each and are characteristic of the later Kofun Period. It was customary each year to first destroy (flatten) last season's bunds, then completely rebuild them anew. The top third of the paddy fields in the photograph are different from the bottom two-thirds in both orientation and condition. Among the top third, the paddy areas are clearly defined and the bunds are relatively tall; in contrast the bottom two-thirds of paddies are unclear and the bunds are relatively low – they exhibit overall erosion.

FIGURE 7 EARLY 6TH-CENTURY LOC. B PADDIES

These differences illustrate the progress in rebuilding the bunds in the year of FA eruptions. That is, in the upper area, ploughing the fields had already been accomplished, and FA S_1 fell at the point when bund repair had been finished. In the lower area, the eroded fields and bunds surviving from a previous year's agricultural cycle indicate that ploughing had not yet started in the year of the FA fallout. However, in the lower area can be seen lots of footprints and small holes; it seems that work had started on the bunds in this area but was not finished. Both areas were directly covered by S_1, then S_7, and there is no evidence of them having been worked any further after those ash fallouts before they were covered by the FA lahar.

All these features were covered by the FA lahar in the last instance, and there are no indications in the strata above them that reclamation or restoration was carried out. On the other hand, because there was no sedimentation of FA tephra above the lahar, the lahar itself is understood to have been the last activity after emplacement of the FA tephra. From the above data, it can be thought that the time interval between S_1 and S_7 was a matter of a few days. If, for example, the FA lahar had occurred a month later or even the next year, we would be able to see that bund-construction would have been finished after the S_7 tephra fallout, and the lahar would have buried completely prepared paddy fields. However, there was little time between S_7 and the lahar; consequently, the interval between S_1 tephra fallout and lahar initiation after the eruption stopped must have occurred in the stage between ploughing and bund repair. Thus, the FA volcanic activities from eruption to lahar initiation must have taken place within a month between May and June.

It is interesting to note that the fields at Moto-Sōja Kitakawa appear to have been temporarily abandoned after the 10 cm FA fall unit deposition even though work continued thereafter at the dam. After the tephra fallout, the farmer(s) turned their attention to building the dam, so they clearly did not anticipate the lahar. And they would not have bothered to fix the canal if they did not intend to return to deal with the tephra layer and finish constructing the fields. The lahar which subsequently destroyed everything travelled down the river course, covering it in 2.5–3.5 m of lahar sediments. Nevertheless, directly above these is a thin layer of paddy field soil (Stratum 9) which was subsequently inundated by FP ash fallout and lahar. This means that in the half-century between Mt Haruna eruptions, the area had been reclaimed for wet-rice production (cf. Chapter 14).

The FP Eruption as Known at Three Sites

Moto-Sōja Kitakawa

Half a century after the FA eruption, the Moto-Sōja Kitakawa site in Maebashi City was again buried by FP tephra (Stratum 8) and then FP lahar (Stratum 7). The FP pumice fallout unit at 70 cm depth was only 1 cm thick (Figure 8, white layer), containing the I_{19} micro-layer. Above this stratum was approximately 40 cm of FP lahar composed of more than 10 layers, but these comprised only two layers by colour. The lower of these two layers was 5 cm thick and the upper 30 cm thick.

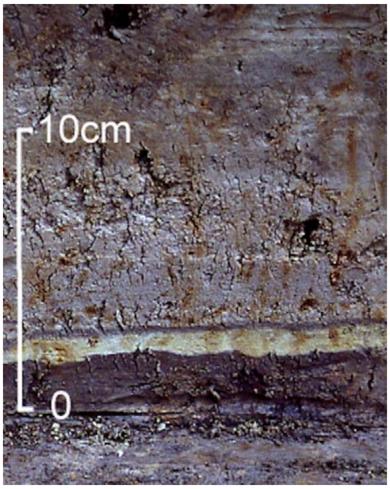

FIGURE 8 FP STRATIGRAPHY AT THE MOTO-SŌJA KITAKAWA SITE

FP tephras I_1~I_{18} did not exist at this site – only I_{19}. Excavations revealed paddy fields and irrigation facilities (Figure 9), their surfaces covered first by 1 cm of FP-I_{19} tephra (white layer), then 5 cm of a first lahar flow and finally 30 cm of a second lahar. Between these sedimentations there were absolutely no indications of palaeosols. However, in the paddies subject to these sedimentations, data were recovered for a) plough marks covered by I_{19}, b) bund construction and field ploughing after the ash fallout and first lahar, with volcanic materials incorporated into the bund structures, and c) ploughed paddy surfaces at the beginning of the upper lahar flow.

In contrast to the earlier paddy fields at this site covered by FA tephra and lahar, these mid-6th century paddies show a different manner of construction. Only longitudinal bunds had been emplaced by the time they were overwhelmed by the second lahar; the intervening short connecting bunds, demarcating individual paddies were not completed. Three longitudinal bunds (outlined in white in Figure 9) were excavated, each showing a different stage of construction. The mounded bunds of the first contained no tephra or lahar sediments; thus, they were finished before volcanic activity commenced. In contrast, the second and third bund mounds had no volcanic materials in their lower levels, but upper levels contained I_{19} tephra and yellow-orange sediments thought to belong to the first lahar mixed with paddy soil. Moreover, the first bund had loaded on its top chunky blocks of I_{19} while the second and third did not. These variously indicate efforts at continuing construction or re-construction between tephra fallouts.

The fact that agricultural activities continued from before the FP tephra fallout to the beginning of the upper lahar flow is supported by footprint evidence. Several footprints were recovered at various sedimentary stages: 1) footprints lined with I_{19} (and therefore made before the ash fallout); 2) footprints

Figure 9 Longitudinal Paddy Field Bunds
Excavated below mid-6th century FP sediments at Moto-Sōja Kitakawa
Arrow marks area of three longitudinal bunds

impressed into I_{19} and subsequently filled with the first lahar sediments; 3) footprints in first lahar sediments then covered by second lahar sediments; and 4) footprints on top of those covered by first lahar and then themselves covered by second lahar sediments.

Arima-Jōri and Koizawa-Urita

The Arima-Jōri and Koizawa-Urita sites are located in Shibukawa City, about 10 km north of Moto-Sōja Kitakawa and 10 km from the Futatsudake vent to its direct west (Figure 1) (Komochi-mura Kyōi 2000; Gunma-ken Maibun 1989). These are only two of several sites on the eastern flank of Mt Haruna where rice paddies buried by FP have been discovered. In accordance with differences in agricultural preparations below the FP tephra cover, three different types of paddy field surfaces were identified:

1) surfaces with no bunds at all but areas of deep footprints,
2) areas where the longitudinal bunds had been started but not completed (Figure 10), and
3) leveled field surfaces where stirring of the paddy soils was taking place within completed surrounding bunds.

In comparison with the seasonality of modern wet-rice agriculture, these field conditions indicate that the FP eruption took place in early summer during bund construction and rice planting.

Seasonal Comparisons

FIGURE 10 VERTICAL BUNDS UNDER CONSTRUCTION AT ARIMA-JŌRI

At the Arima-jōri and Koizawa-urita sites, the earliest tephra fall unit consisted of FP-I_1; just prior to that, constructing bunds commenced, and these bunds were subsequently inundated by a thick layer of I_1 pumice. Consequently, the *beginning* of the eruption can be seen in the bund-construction stage at these Shibukawa City sites. In contrast, the Moto-Sōja Kitakawa initiation of bund-construction occurred just prior to its first tephra fallout of FP-I_{19} at the *end* of the eruption sequence. In other words, the duration between I_1 and I_{19} is illustrated by the difference in agricultural task initiation in these two areas. This temporal gap cannot have been as much as one month even with the 10 km distance between the site areas, especially taking into account the effect on the harvest if the planting season is delayed. Judging from today's planting schedule, that gap was probably around one week. Thus, the time from the beginning of the FP pumice fallout to its end can be estimated as between one day and one week.

The interval between the FP lahars can be calculated in a similar manner. Bund construction at Arima-Jōri began before I_{19} but included both I_{19} and some of the initial sediments of the first lahar (remembering that the two lahars together had 10 constituent strata). Between the two lahars, there is evidence of paddy restoration, as indicated by the inclusion of first lahar sediments in the bunds. This work was most likely carried out by several people. One person can be hypothesized to mound 100 m of bund in one day; thus it may have taken a few days for the three vertical bunds to be constructed. Reclaiming the fields from the first lahar is estimated to have taken between a few days and one week.

In summary, the duration of the FP fallout from I_1 to I_{19} is calculated to be between one day and a week. The subsequent interval from I_{19} fall unit to the first lahar may have been one to a few days, while the interval from the first to second lahar might have been a few days to a week. All in all, from the beginning of the FP eruption to the end of the second lahar must have occurred within a few days to a few weeks within the season of paddy preparation.

Conclusions

From the evidence at Moto-Sōja Kitakawa site, the duration of FA ash fallout (from S_1 to S_7) is estimated at a few days or at most a month. At the same site, the duration of FP pumice fallout (I_1 to I_{19}) is estimated as one day to a week. Thus, including the lahars, these events must have taken place during a few days to a few weeks' time. As at the Kanai Higashi-ura site (cf. Chapter 10), evidence at the Moto-Sōja Kitakawa site reveals that the activities of people between tephra fallouts can be recovered through the analysis of individual tephra deposition units. Research on the timing between such micro-layers will become an important topic in future.

The seasons in which the FA and FP tephra fallouts took place were coincidentally both in early summer during rice paddy preparation. In the years of these eruptions, the many people who lived on the eastern flank of Mt Haruna, having suffered inundations of tephra and lahars, without a doubt were completely unable to harvest any crops from either rice paddies or dry fields. This must have impacted on the activities of political leaders who ruled this region. In such a way, the effects of volcanic eruptions on local societies are severe.

Figure & Table Sources

Figure 1 courtesy of Google Earth
Figure 2 author's own
Figure 3 modified by author after Gunma-ken Maibun 2007: fig. 40
Figure 4 modified by GLB after Gunma-ken Maibun 2007: fig. 89
Figures 5, 6, 7, 8, 9, 10 courtesy of the Gunma Prefectural Board of Education

Table 1 compiled by author

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CHAPTER 12

Restoration of Agricultural Assets after Volcanic Disasters in Southwest Japan

KUWAHATA Mitsuhiro *

Introduction

This paper discusses sites excavated in the Miyakonojō Basin of Miyazaki Prefecture in the southeastern region of Kyushu Island, Japan (Figure 1). The volcanic disasters following the historic eruptions of Sakurajima and Kirishima resulted in consequent efforts at restoration of rice fields. Miyakonojō Basin has an elliptical shape, measuring about 30 km north-south and about 15 km east-west. Its major river, the Ōyodo, attracts many tributary rivers through the central axis of the basin from south to north. The basin is surrounded by the Kirishima volcano group in the northwest, the Morokata Colline in the northeast, and the Wanitsuka mountain range to the southeast; only the southwest is open, facing Ōsumi Peninsula (Figure 2).

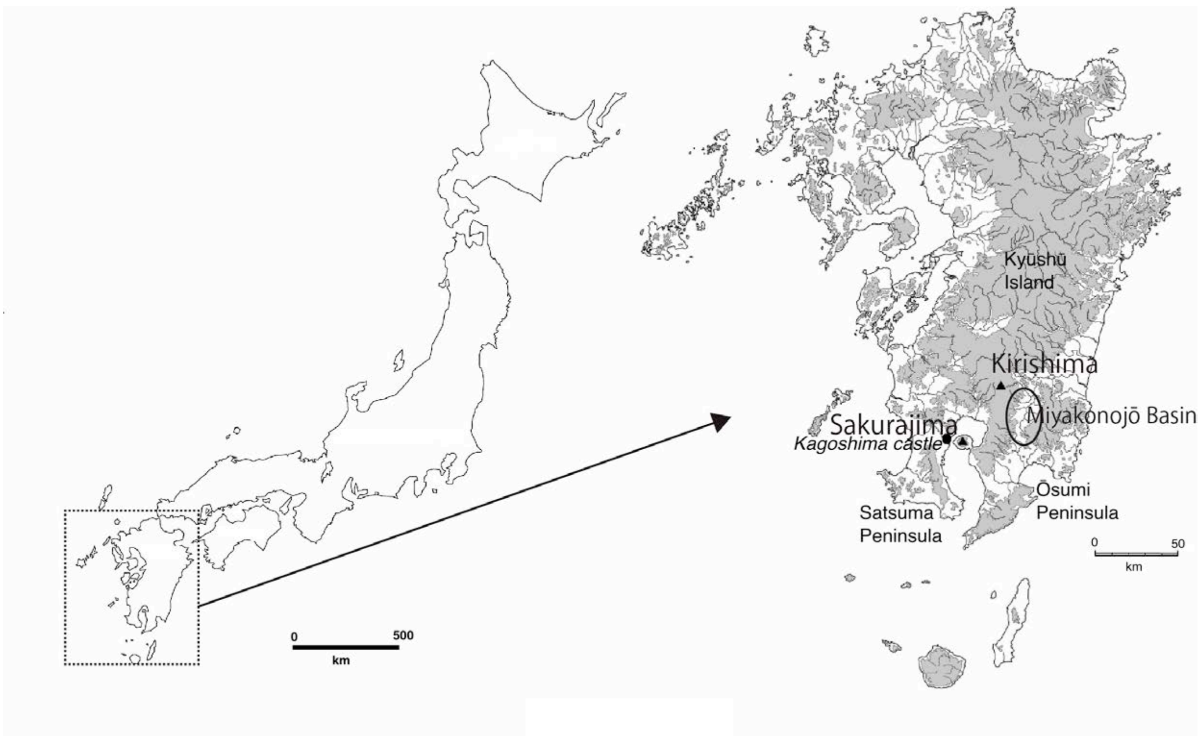

FIGURE 1 RESEARCH AREA IN SOUTHEASTERN KYUSHU

Even now the Miyakonojō Basin suffers from the descent of ejecta by the Kirishima volcano group (see Appendix C-7). The damage caused by the eruption of Shinmoe-dake that occurred at the end of of January 2011 is fresh in the memories of the people of Miyakonojō City. Ejecta from Mt Sakurajima also descend regularly on this area, though Sakurajima is located about 40 km southwest of the basin.

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The Kirishima Eruption of 1716–1717

The Kirishima volcano group is situated northwest of the Miyakonojō Basin on the border between Kagoshima and Miyazaki Prefectures (Figure 2). The Kirishima–Shinmoe Kyōho eruption occurred between 1716 and 1717 in the Edo Period (1603–1868); it was a Plinian-type eruption, with a volcanic explosivity index (VEI) of 4.

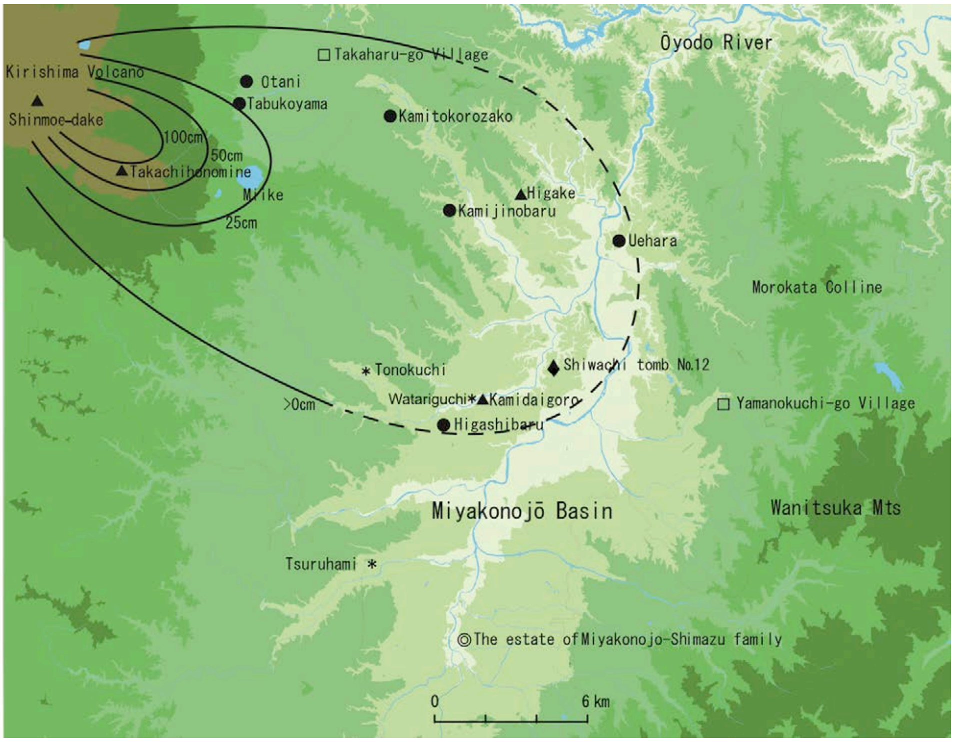


FIGURE 2 THE DISTRIBUTION OF KIRISHIMA–SHINMOE KYŌHO TEPHRA-FALL OF 1716–17

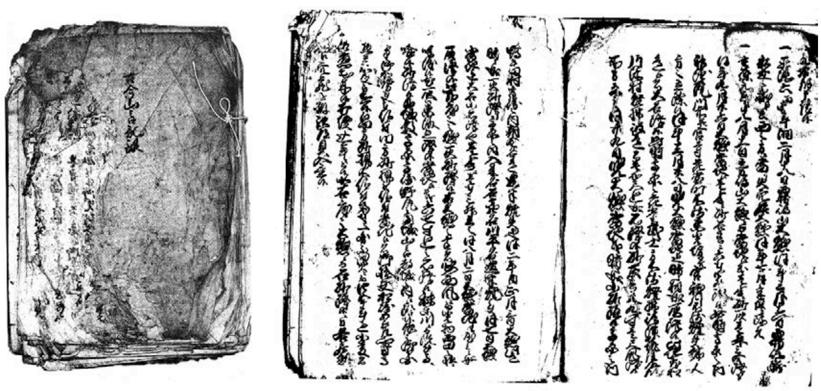


FIGURE 3 THE HISTORICAL TEXT ENTITLED "ANCIENT DOCUMENTS OF YAMA-NO-KUCHI-GO"

The progress of the eruption and its local effects during those years on Yama-no-kuchi Township, located on the east side of the basin at the foot of the Wanitsuka Mountains, were recorded in a historical document (Figure 3). The village officers reported to the government of the Kagoshima Domain at Kagoshima Castle (cf. Figure 1) just after the eruption climaxed, and the government sent investigators to record the actual situation. It is documented that the village officers and farmers removed the volcanic ash which fell in the cultivated areas in an attempt at field restoration. During the restoration of the affected areas, the Kagoshima Domain government provided people with rice.

The Sakurajima Eruption of 1471

Sakurajima volcano is situated between the Osumi peninsula and the Satsuma peninsula in southern Kyushu. The Sakurajima-Bunmei eruption occurred in 1471 during the Muromachi Period (1333–1573). It was a Plinian-style eruption of pumice fallout, with a volcanic explosivity index (VEI) of 4, forming the largest eruption in the history of Sakurajima. The quantity of pumice ejected was more than double that of the Edo-Period eruption (1779) or the Taishō-Period eruption (1914) of the same volcano. The pumice fallout angled in the east-northeast direction (Figure 4).

At the Tsuruhami site (#6 on Figure 4), the depth of sedimentation of the Sakurajima-Bunmei tephra (Sz-3) in the Miyakonojō Basin is clearly ascertainable (Figure 5). The thickness of the upper layer, composed of grayish-white coarse-grained volcanic ash, is 2 cm. The lower layer thickness of grayish white pumice is 7 cm. Both strata were formed during the 1471 Sakurajima-Bunmei eruption, and there is no humus layer between the two.

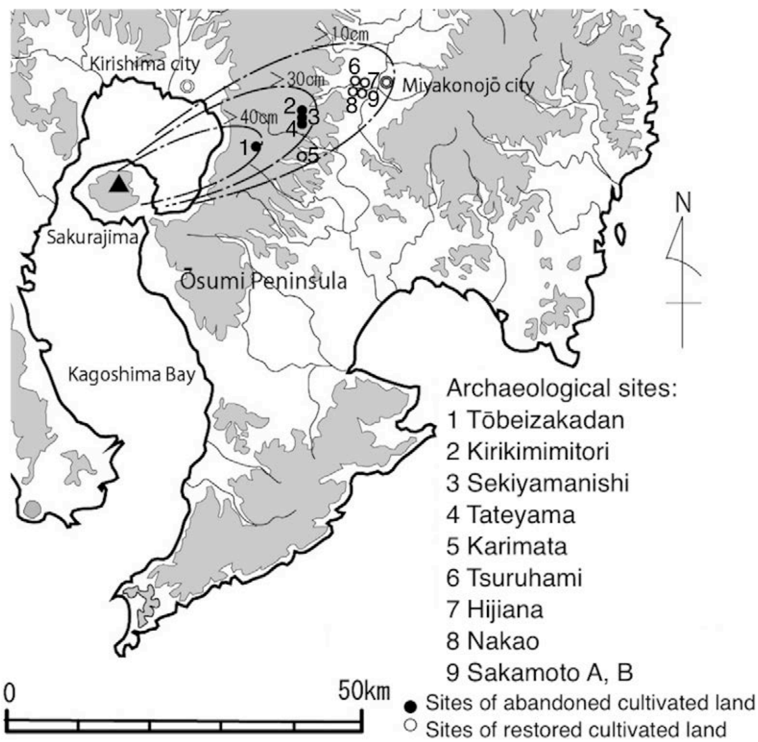


FIGURE 4 DISTRIBUTION OF SAKURAJIMA-BUNMEI TEPHRA (1471 AD)

FIGURE 5 TEPHRA STRATUM (9 CM THICK) AT TSURUHAMI SITE

The distribution of tephra across the Miyakonojō Basin is shown in Figure 6; within this lobe, however, tephra thicknesses were generally greater than 10 cm. Under this pumice deposit lie the remains of many medieval-period rice fields.

Post-eruption Medieval Fields: Restored or Abandoned

Examples of cultivated field restorations following the Muromachi-Period (1333–1573) eruption of Sakurajima in 1471 are known from several sites in Miyazaki Prefecture and eastern Kagoshima Prefecture. In excavating different sites, we could see two patterns in the tephra deposits: one where tephra has fallen and remained undisturbed indicating abandonment (sites #1-4 in Figure 4); and the other where humans have attempted to remove the pumice, thus disturbing the tephra layers and indicating efforts at restoration (sites #5–9 in Figure 4). Below, we will discuss three restored sites (Sakamoto A, Tsuruhami, and Nakao) and one abandoned site (Tōbeizakadan). Moreover, the remains at Sakamoto A and Tsuruhami sites were rice paddies for wet-rice agriculture, while at Nakao and Tōbeizakadan the fields were ridge-and-furrow (*une / unema*) for dry-field cultivation (cf. Chapter 14).

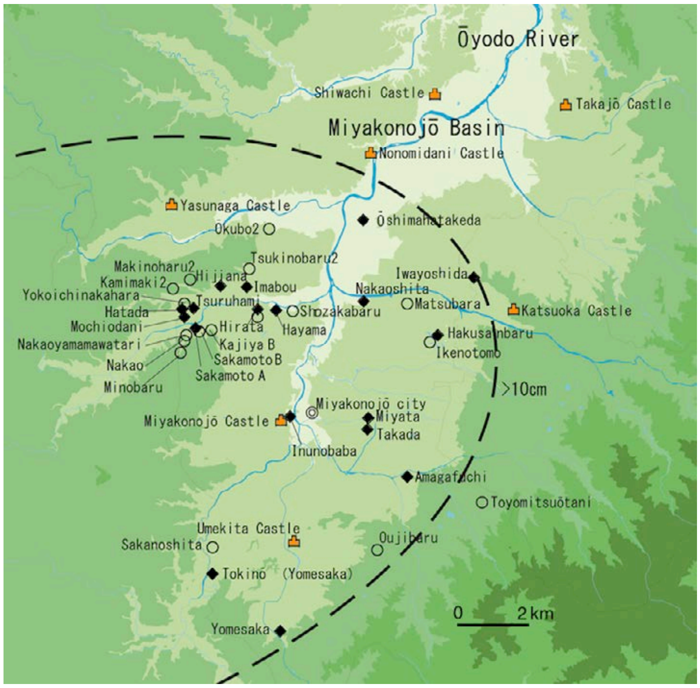


Figure 6 The Remains of Ancient Fields Covered by the Sakurajima-Bunmei Tephra in 1471

– – – 10 cm isopach   ⌂ medieval castle

◇ dry field   ○ wet-rice field

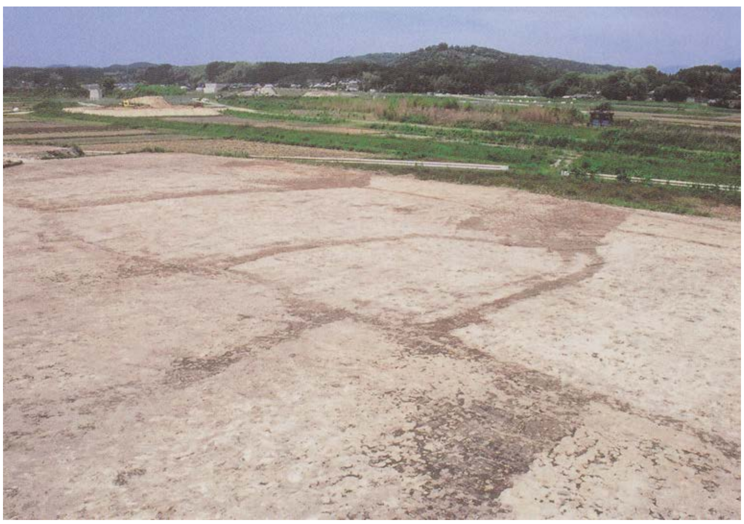


Figure 7a Excavation of Tephra-covered Rice Paddies at the Sakamoto-A Site

Paddy-field Remains

The Sakamoto A Site

Sakamoto A is located in the western side of Miyakonojō Basin on the south bank of the Yokoichi River, a tributary of the Ōyodo River (mapped as Figure 4 #9, and in Figure 6). Medieval wet-rice fields were covered in Sakurajima-Bunmei tephra, with the field bunds clearly visible (Figure 7a). Sediments on both sides of the field bunds ('balk' in Figure 7b) were heavily disturbed by digging (Figure 7c). These digging hollows are interpreted as efforts at removing the tephra. The trench excavation allowed sampling for agricultural remains in both the trench wall and a mid-trench section.

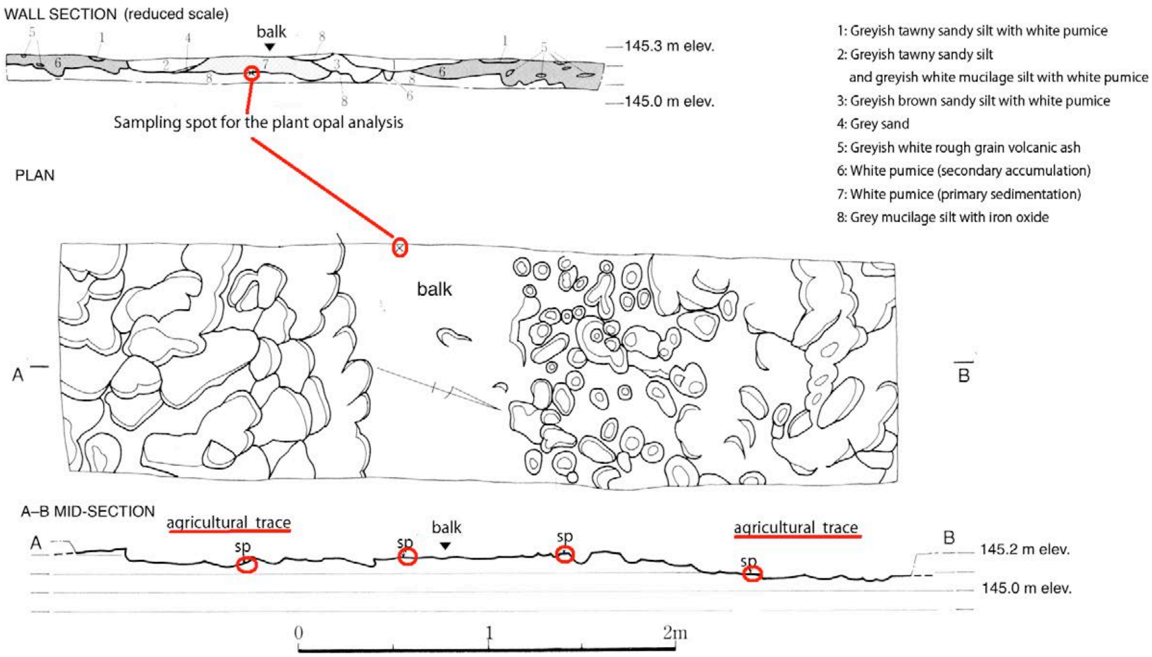


FIGURE 7b TRENCH EXCAVATION PLAN AND SECTION AT SAKAMOTO SITE

FIGURE 7c DETAILS OF DIGGING HOLLOWS
on both sides of balk as shown above

The Tsuruhami Site

The neighboring Tsuruhami site on the north bank of the Yokoichi River (mapped as #6 in Figure 4 and in Figure 6) also yielded clear evidence of wet-rice fields before the eruption, the in-situ tephra layer, and evidence of restoration after the eruption. Figure 8 shows the site section, trenched down below the paddy-field surface on the left. The tephra layer is visibly disturbed in the wall section; detail of the disturbed tephra (Figure 8, upper right) indicates attempts at field restoration, with spade-like digging of soil into the tephra (cf. Chapter 14).

Figure 8 Excavation of the Tsuruhami site

Left: overview of wall section extending below paddy surface
Upper: detail of disturbed tephra layer

At both sites, coarse-grained volcanic ash and black soil are mixed with the pumice layer, indicating that the stratum was disturbed after the tephra fallout. The quantity of rice phytoliths (plant opal) directly above the tephra layer is less than half that in the layer directly below the tephra (Table 1). These sums reveal that harvests decreased and production capacity dropped following the eruption, but farming was continued despite the 10 cm of tephra cover.

Table 1 Comparisons of Phytolith Counts in Pre- and Post-eruption Layers

Site	Pre-tephra-fall	Post-tephra-fall
Sakamoto A	13,500/gram	6800/gram
Tsuruhami	6600/gram	2800/gram

Dry-field Remains

The Nakao Site

The Nakao site lies on the south bank of the Yokoichi River in the Miyakonojō Basin (#8 in Figure 4, lower left in Figure 6). A broad area of dry-field ridge-and-furrow features was uncovered by excavation (Figure 9). The aerial photograph (Figure 10) shows a field system laid out in squares, much like the 8th-century *jōri* system for rice paddy which took the form of gridded squares (of 1 *chō* = ca. 1 ha size). However, the fields here have been converted to dry fields, indicated by the ridge-and-furrow arrangement highlighted by tephra, which can be seen as white strips much like those at Tōbeizakadan. The furrows were filled with pumice, coarse-grained volcanic ash, and lumps of the underlying soil layer. Such a mixture indicates that the cultivated fields were reworked at the Nakao site and continued to be used. In Figure 11, there are two sequences of agriculture visible: the paddy soil is grey, covered by disturbed tephra. Above that are the humps and hollows of ridge and furrow, covered again by tephra.

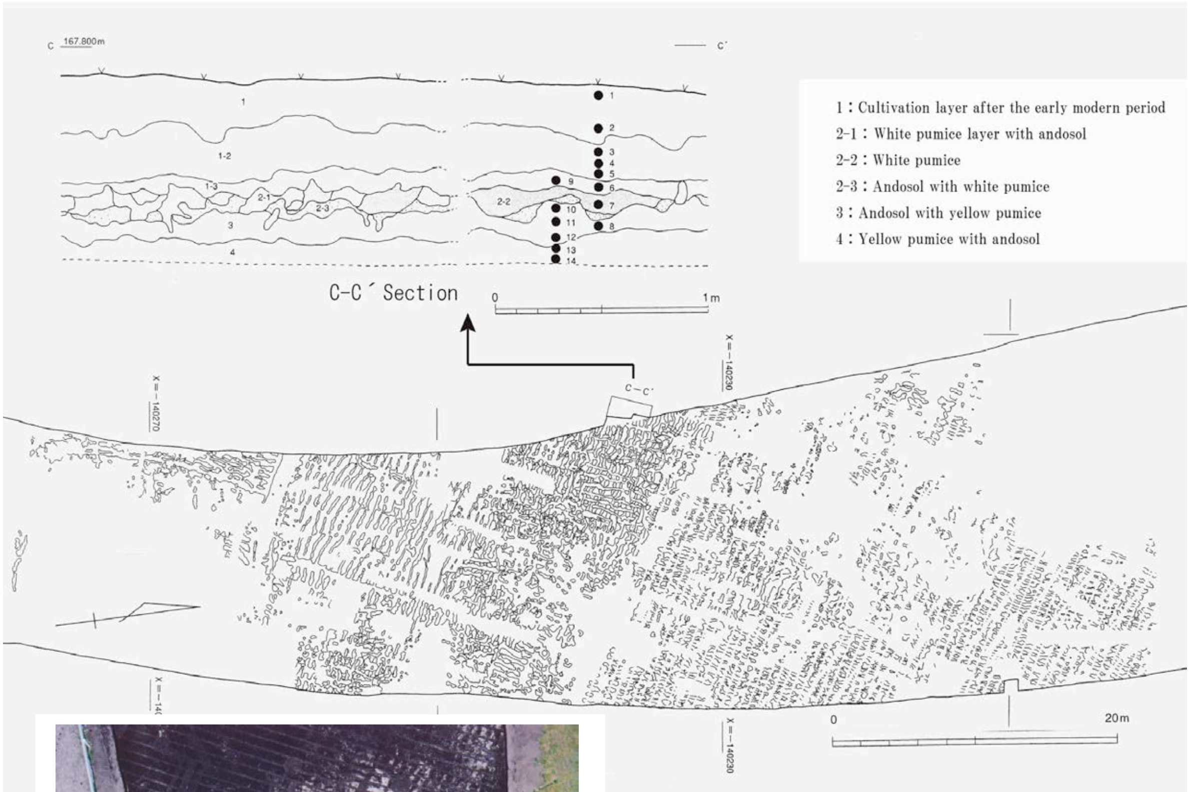


FIGURE 9 NAKAO SITE EXCAVATION PLAN AND SECTION

FIGURE 10 NAKAO SITE AERIAL OVERVIEW

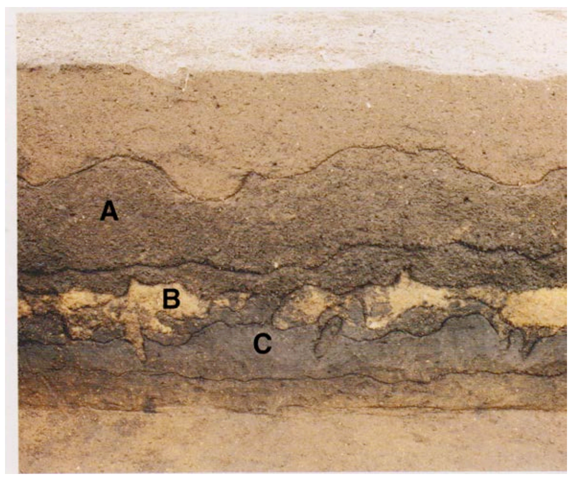


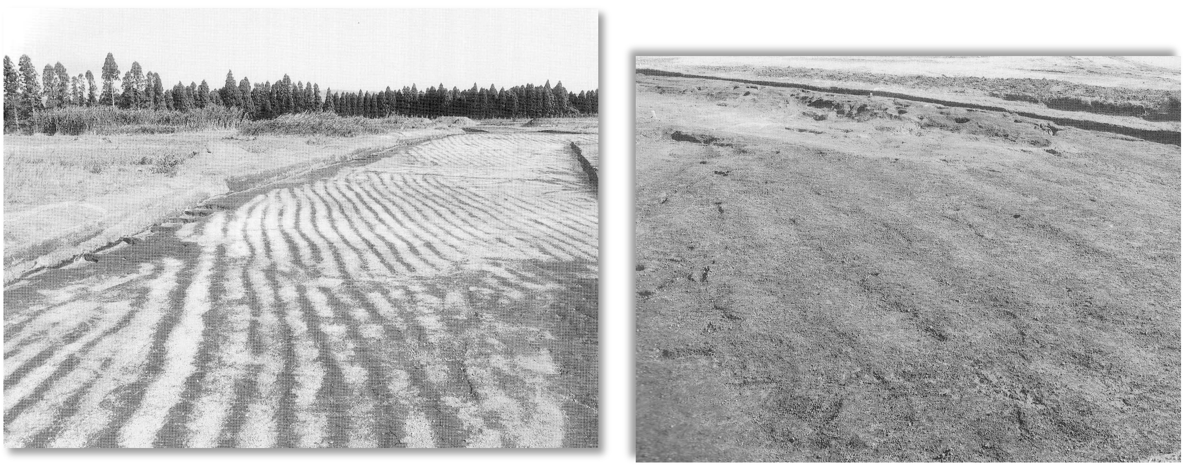
FIGURE 11 SUCCESSIVE FIELD REMAINS AT NAKAO SITE

A: ridge & furrow (brown)
B: tephra (yellow)
C: paddy (grey)

The Tōbeizakadan Site

The Tōbeizakadan site in Kirishima City, Kagoshima Prefecture (#1 in Figure 4) (Fukuyama Kyōi 1997) had been covered by 50 cm of Sakurajima-Bunmei pumice. Removal of this pumice during the excavation exposed the ridges of a ridge-and-furrow field system (Figure 12a). The consecutive shallow ditches (furrows) stood in a row; still filled with tephra, they are easily seen in the open excavation (Figure 12b, left). After removal of all the tephra, the field system is clearly visible (Figure 12b, right).

Figure 12a Excavation of the Tōbeizakadan site Revealing Ridge-and-furrow Dry-field Agriculture



Figures 12b Photos at Different Stages of Excavation of the Tōbeizakadan Site

Conclusions

In this chapter we have demonstrated that within the 30 cm isopach (Area II in Chapter 3: Figure 1) of Sakurajima-Bunmei tephra distribution, there were no paddy-fields but only dry-field features; all of the latter were abandoned and cultivation was not resumed until the modern period. Area II was described as “Hard to Adapt / Endure”, and from this evidence, it seems that no efforts were made to do either. This may have been because the actual tephra fallout is estimated to be at least two to ten times as much as that discovered in excavation – from 60 to 300 cm (Kobayashi & Esaki 1996; Kobayashi & Tameike 2002) – due to compaction over time. Conversely, within the 10 cm isopach, both paddy-fields and dry-fields were restored. As presented by Noto (2000) and discussed in Chapter 14, various ways were conceived for the removal of pumice from the fields; here, the fields were restored by digging in the tephra – a strategy also pursued in the Kantō.

The 1471 eruption of Sakurajima occurred in the late Muromachi Period during great unrest throughout Japan and within Miyakonojō Basin, as domain lords and powerful families fought for political gain (Kuwahata 2014). This situation may account for two things: that there are few written documents about the volcanic disaster, and that there was little help by the local governments to re-establish farmlands. In the later Edo Period (1603–1868), restoration of fields occurred just after the tephra fallout where Kirishima tephra layers were less than 10 cm thick. In these cases, the tephra was removed; during this process, food was paid for on this occasion by the government of the Kagoshima Domain. However, unlike the assistance afforded in the 10th century by the Ritsuryō state (Chapter 8) or by the Kagoshima daimyo in the Edo Period, Miyakonojō farming families were left to their own devices after the 1471 eruption.

Already in 1990, Tokui had emphasized that the level of damage borne by people during volcanic disasters was due to both natural and anthropological factors: the style and strength of the eruption and the distance from the volcano as well as how many people there were and the forms of their subsistence economy and social organization. Both Tokui (1990) and Shimoyama (2005) demonstrated methods for obtaining information regarding the distribution of tephra and the thickness of its deposition. Their methods were based on observations of primary deposits on stable flat land. However, farmers must also deal with tephra redeposited by floods (and lahars) which threaten their livelihood. Also, attitudes towards the disasters by political masters affect recovery attempts. The above examples of the 1471 disaster clearly demonstrate that despite living under hierarchical political regimes in the medieval period, local farmers garnered less help than those living almost five centuries earlier under a centralized state (see Chapter 8). This, however, was due not to the nature of the political system but to its stability, with medieval warfare interfering with ensuring peasant well-being.

Acknowledgements

I owe a great debt to Professor Eiji NITTA, whom I first met as a second-year undergraduate in 1983. Together with my classmate SHIMOYAMA Satoru, now deceased, I would visit his office where a wooden container bearing alphabet writing hung outside. I now think that Prof. Nitta must have carried his research materials in that case when doing his work in Southeast Asia. To me, who had never been abroad, this was like peeping through a fence to the outside world – a fresh impression that has never left me. Prof. Nitta published the NOA: “Newsletter Of Archaeology” or “New Oriented Archaeology”, as one wishes. Reading the issues, I felt connected to the academic world outside and still treasure them. Recently I have had the opportunity to work with Prof. Nitta on the Kaimondake volcanic disaster and have received much valuable training. I dedicate this chapter Prof. Nitta in gratitude for his opening a door to the wider world.

Figure & Table Sources

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Figures 10, 11, 12 courtesy of the Miyazaki Archaeological Center; Figure 12 modified by GLB

Table 1 compiled from text by GLB

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All references in Japanese

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CHAPTER 13

Tephrogenic Soils of Japan in Comparative Context

Gina L. Barnes *

Abstract

*Around the world, soils derived from volcanic ash are judged to be fertile and good for agriculture. Japan, however, seems to be an anomaly in that tephra-derived soils have traditionally been avoided because they were classed as 'infertile' soils (*yasechi*). Granted, the major crop in Japan is wet rice – which is generally grown in lowland regions where alluvial (redeposited) soils are fashioned into rice paddies. And if paddy fields are located in upland regions, they still involve irrigation which brings in nutrients and silt to enrich the paddy soil. But only the modern application of lime and phosphate have allowed the growing of crops with good yields in upland dry-field areas. There are several variables that determine land-use patterns on tephrogenic soils, and soil chemistry plays a large part. This chapter comprises the first foray into sorting out some of these variables, challenging some of the myths about the fertility of volcanic ash soils, and hopefully laying the groundwork for further investigation of tephra-derived soil use in prehistory.*

Tephrogenic Soils

In Chapter 1, it was stated that, like all rocks, tephras weather to clays through two different processes: via simple water/rock interaction over time, *or* through the activity of plants (Velde & Meunier 2008). Whereas buried rocks (including tephra) may be transformed to clay over millennia via the first process (think granite → kaolinite), the surfaces of tephra strata are not only exposed to plant activity but to further sedimentation by loess, floodwater, or even subsequent tephra fallout, etc. Thus, the tephra becomes diluted with other materials including organic matter, and with chemicals generated by those plants or deposited through sedimentation including aeolian loess. Nevertheless, the basic natures of the soils developing on tephra are influenced by the mineralogical content and glassy fragments of the tephra.

The term 'tephragenic' is used by some to describe volcanoes producing tephra (e.g. tephragenic volcanoes or tephragenic eruptions, Kittleman 1979: 51; Machida & Arai 1983: 159; Hotes et al. 2004) or the products of explosive eruptions (e.g. tephragenic clasts, Ehlmann et al. 2017: 2511); the term is adopted here with the spelling modified to 'tephrogenic' to match the sense of 'originating in' (as in 'neurogenic'). Tephrogenic soils are thus those that develop on or include substantial amounts of tephra.

Andosols

The major soil type that is formed from volcanic ash is variously called an andosol, or andisol, or andept depending on the scheme; these terms all derive from the Japanese word *ando* meaning 'dark earth', but in Japanese such soils are more often known as *kurobokudo* 'black fluffy earth'. In this chapter, the 'andosol' spelling is used because it retains the Japanese descriptive, *ando*. In contrast to less than 1% of the Earth's landmass covered by andosols, they are estimated to cover 17% of Japan's land surface (Ōmura 1993: 247) (Figure 1). The commonly accepted characteristics of andosols are listed in Table 1.

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Table 1 Andosol Characteristics

* a high phosphate (P) retention of ≥85%
* low bulk density of ≤0.90 kg dm^{-3} (FAO) / ≤0.9 Mg m^{-3} @ 33 kPa water retention (USDA)
* Al_{ox}½Fe_{ox}^{2} value of ≥2% (FAO) / Al_{ox} 0.5Fe_{ox} content ≥20 g kg^{-1} (USDA)
• highly stable soil aggregates
• "an abundance of non-crystalline minerals such as allophane, imogolite and metal–humus complexes" (Imaya et al. 2010: 454)
• variable charge
• high water retention
• friable consistency
• excellent tilth
• a high humic content

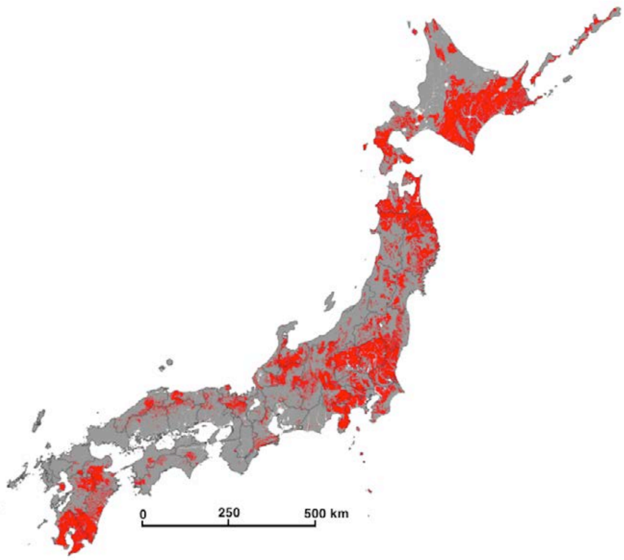

Figure 1 Distribution of Andosols in Japan

Before proceeding further, it is useful to consider two dimensions of soil research: definition and classification. Every discipline has created its own definition of soil for its own purposes (Hartemink 2016). Soil scientists, however, develop classifications on one-metre deep sections from the surface where at least A and C horizons can be detected, even if a B horizon is not apparent. A single sediment – such as freshly deposited tephra or alluvium or a paddy field – is not a 'soil' according to this view. Moreover, any sediments that occur at levels deeper than one metre are not included in these classifications.[1] In this chapter, 'soil' is used in its pedological sense: sediments defined according to their genetic horizons (Schaetzl & Thompson 2015). However, Sase and Hosono (1995) have coined a term *kuroboku-dosō* (black 'fluffy soil' stratum), which does not refer to a soil profile but to a single layer (*sō*). This definition might be useful in archaeology if black andic layers are discovered, for example, as palaeosols buried more than one metre deep or when individual layers rather than profiles are discussed.

Most extant systems of soil classifications have been produced with an eye to agricultural potential, and soil scientists in several countries have created their own national classifications (Gerrard 2000: ch. 5). Takahashi and Shoji (2002) compare domestic classifications in Japan and New Zealand with worldwide classification schemes, illustrating many differences in scope and definition. The US Soil Taxonomy of the United States is often used as a referent (USDA Soil Survey Staff 1999); but the FAO-UN (2015) scheme integrates local soil types where feasible. The above terms for volcanic ash soils are used variously in the different schemes, for example 'andosol' in the FAO-UN scheme; 'andisol' in the USDA Soil Taxonomy, previously referred to as 'andept'; and 'andisol' in the New Zealand national classification (Katō 1983: 8). Most of these schemes are hierarchical, with global, regional and local foci of increasingly fine distinctions, but commonalities do exist. The *starred items in Table 1 are given by the FAO-UN (2015: 63) as diagnostic properties of 'andic' soils that must co-occur; the USDA taxonomy gives some of these in different units of measurement (Imaya et al. 2010: 461). A useful comparator is given in Morisada et al. (2004: table 1).

[1] Based on a discussion of 'soil' definitions with Ohkura Toshiaki, NIAES (National Institute for Agro-Environmental Sciences, Tsukuba), pers. comm. 23 Oct 2018.

Japanese soil classifications have historically been developed within three categories: ando soils, paddy soils, and upland soils (Obara et al. 2015). Instead, Obara and associates have proposed a new classification using criteria that are defined quantitatively and qualitatively across all land categories (Figure 2). Andosols (Figure 2-D) are one of ten proposed 'Great Soil Groups'; andosols are further divided into six 'Soil Groups': regosolic, gleyed, wet, fulvic, non-allophanic, and allophanic andosols (Ibid.: table 2).[2] Among these, allophanic andosols "are the central concept of Andosol great group and are characterized by the dominance of allophane and imogolite formed by the weathering of volcanic ash under well-drained conditions and accumulated humus" (Obara et al. 2015: 222).

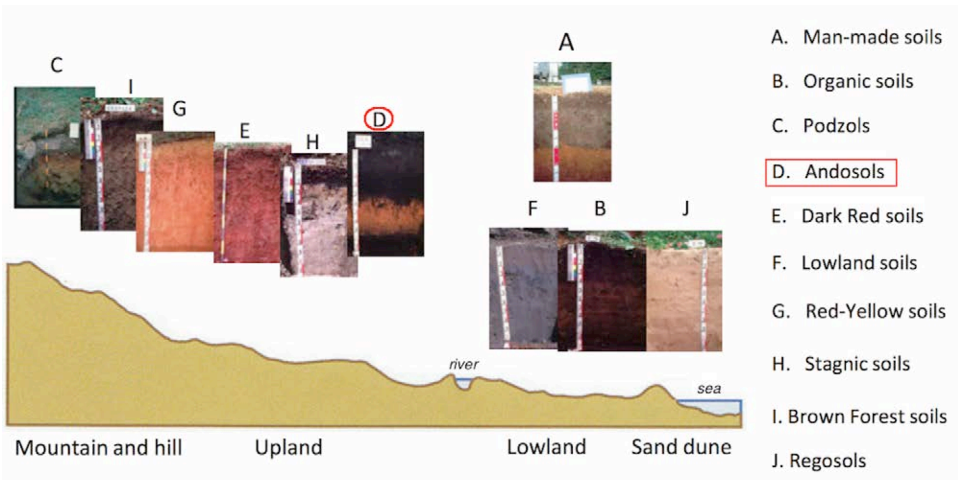

FIGURE 2 THE PROPOSED TEN GREAT SOIL GROUPS OF JAPAN DISTRIBUTED IN DIFFERENT ECOLOGICAL ZONES

Thus, we have a situation where allophanic andosols "are the central concept of Andosol Great Group" (Obara et al. 2015: 222), but they are only one of six andosol Groups. One of these, non-allophanic andosols, were only recognized in 1978 (Takahashi & Shoji 2002). Mapping these two types illustrates the dominance of allophanic over non-allophanic andosols (Figure 3). Moreover, tephra can be found in other Great Groups such as Brown Forest Soils. Beyond Japan, volcanic ash soils are present in several orders (Entisols, Ustivitrands, Spodosols, Mollisols, Alfisols, Ultisols, Vertisols, Inceptisols, Oxisols as seen in Ugolini & Dahlgren 2002: table 3; Dahlgren et al. 2004: table 1). Many of these are transformations to and from andosols with changing climatic conditions.

The essential differences between allophanic and non-allophanic andosols are presented in Table 2 below. These two types of andosols form under different pH conditions: allophanic andosols, which are characterized by allophane, imogolite and ferrihydrite, preferably form under pH values >5.0; non-allophanic andosols are characterized by Al-humus complexes and opaline silica and are dominant under pH<5.0 conditions. Fe prefers formation of ferrihydrite rather than incorporation into Fe-humus complexes because ferrihydrites are more stable (Ugolini & Dahlgren 2002). When aluminium is complexed with humus in low pH (acid) soils, it prevents Al from forming the alterite clays,[3] and the excess Si precipitates as opaline silica; this is termed the 'anti-allophane effect' and operates to produce non-allophanic andosols (Shoji et al. 1993: 113). The presence of excess Al makes non-allophanic

[2] Takahashi and Shoji (2002) name the fourth group 'forest' instead of 'fulvic', and the sixth group simply 'andosols' rather than 'allophanic andosols'. 'Fulvic' is sometimes misspelled as 'fuluvic', primarily in East Asia (see e.g. Ge & Cheng 2001, etc.).

[3] The term 'alterite' follows usage by Bauer & Velde 2014: 130, indicating minerals altered through weathering.

andosols very acid and contributes to Al toxicity. Allophane and imogolite are both forms of alterite clay minerals which have active Al and Fe components; they will be discussed more fully below.

TABLE 2 COMPARISON OF THE TWO MAJOR ANDOSOL GROUPS

	Allophanic andosols	**Non-allophanic andosols**
Recognized in	1947	1978
% of Andosols	70%	30%
Termed by WRB (2014)	silandic (silica dominant) "typically gives a strongly acid to neutral soil reaction"	aluandic (aluminium dominant) "gives an extremely acid to acid reaction"
humus	ca. 3–11% of soil matter; Japan = 33%; low content of complexing organic compounds	ca. 4–22% of soil matter; Japan = 55%; rich in organic matter
Active Al/Fe	allophane imogolite ferrihydrite Al/Fe humus complexes	Al-humus complexes (with opaline silica by-product)
pH(H_2O)	pH 5.2–6.0 in humus-poor soil due to H from carbonic acid in water; pH 5.0–5.7 in humus-rich soil due to humus complexing	4.8–5.3; H from organic acids
base metal presence	base-rich andesitic basalt and basalt coloured glass	base-poor volcanics: rhyolite, dacite, andesite non-coloured glasses
clays	ca. 33%(wt) allophane / imogolite ca. 23%(wt) crystalline clays (mainly 2:1)	ca. 2%(wt) allophane / imogolite ca. 42%(wt) 2:1 crystalline clays
precipitation	<1000 mm/yr	>1000 mm/yr
tephra age	younger volcanic materials	older more weathered volcanics

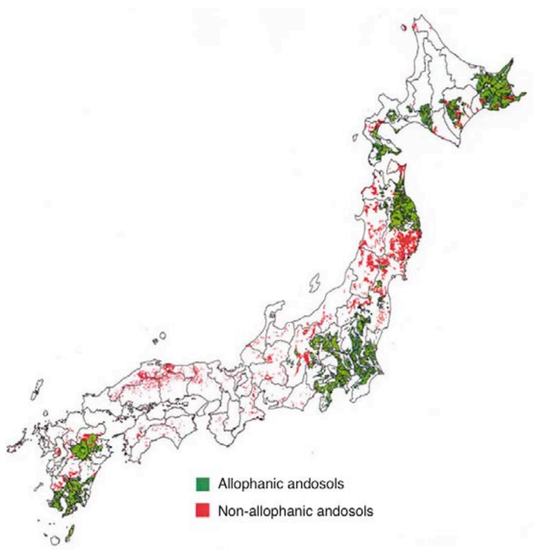

FIGURE 3 DISTRIBUTION OF ALLOPHANIC AND NON-ALLOPHONIC ANDOSOLS IN JAPAN

It will be noted that many of the differences between the two andosols in Table 2 are mainly due to the age of the tephra because older tephra has had longer to be transformed into clays, accounting for the decrease of the transitional clays allophane and imogolite and the increase in 2:21 crystalline clays in non-allophanic andosols. Precipitation rates can also increase weathering. The amount of humus in each also reflects time expended since the tephra deposition. An unstated similarity in Table 2, however, is that both andosols are highly deficient in P, which is one of the basic attributes of andic soil (Table 1).

Figure 3 clearly shows the locations of active Quaternary volcanoes in green, from left to right: southern Kyushu Island, Mt Aso in central Kyushu, the Kantō region, northeastern Tōhoku, and areas of southern and eastern Hokkaido Island.

Tephra in Other Soil Classes

Andosols are not the only soils that contain tephra. Two other Great Soil Groups in Japan have members with a significant tephra-derived component.

First, Regosols (Figure 2-J); compare:

> Volcanogenous *regosols*: "Soils in which the cumulative thickness of un-weathered pyroclastic materials with phosphate absorption coefficient of less than 300 and organic carbon contents of less than 3%, is 25 cm or more within 50 cm of the mineral soil surface" (Obara et al. 2015: 223).
>
> Regosolic *andosols*: "Soils belonging to the Andosol great group and with vitric [coarse] soil materials 25cm or more within 50cm of the mineral soil surface" (Obara et al. 2015: 222).

The general definition of regosols applies to any rock altered through weathering (producing alterites); it is potentially composed of three zones from bottom up: the structurally coherent altered rock, a structurally coherent but friable and porous zone, and a friable structurally incoherent zone that is usually unconsolidated but may be cemented (Velde & Meunier 2008: 115). Often termed an 'immature' soil, regosol does not contain any significant organic material and is composed mainly of minerals. When and how a volcanogenous regosol of pyroclastic materials becomes a regosolic andosol is not discussed, but a reasonable deduction is that it does so by the action of plants.

The tephrogenic soils of Indonesia may be offered here in comparison. Based on regosols, they are not very black (contain little humus) and they do not contain allophane – both conditions due to the young age of the tephra; but they do have andic properties (T. Ohkura pers. comm. 23 Oct 2018).

Second, Brown Forest Soils (BFS) (Figure 2-I) may contain tephra; these soils correspond to Udepts in the USDA system and to Cambisols and Stagnosols in the FAO-UN taxonomy. BFS cover 53% of Japan's land area (NDHG 2015: 22). According to Kubo (1982), they can form from mountain ridges down to the lowlands, in dry to wet conditions; six different BFS sub-types were devised to accommodate this variability. However, Imaya et al. (2010) argue that instead of the traditional classification of BFS by moisture and slope conditions, BFS can be better characterized by their varying 'andic soil properties', particularly the amount and vertical distribution of aluminium oxylate (Al_{ox}), plus gravel which represents bedrock weathering. The focus on aluminium oxalate, written variously as $(NH_4)_2C_2O_4$ *or* $C_2H_8N_2O_4$, is due to its role in the formation of allophane, which is a "unique clay mineral of volcanic ash soils" (Imaya et al. 2010: 461) taking a hollow sphere morphology at 35–50Å (Wada & Wada 2014). Imaya et al. state that although 70% of forest soils in Japan are brown (BFS), contrasting with black forest soils (andosols), BFS may incorporate varying amounts of volcanic ash either through direct tephra fallout or soil creep, mixing with and changing their chemical compositions.

Implications

The above distinctions in soils were not apparent to prehistoric and historic peoples, who had to judge the fertility of soils merely on their apparent productivity. We now know that upland tephrogenic soils were generally avoided for three main reasons: the lack of P, soil acidity, and Al toxicity. Without knowing the causes of infertility, however, direct solutions – such as the modern addition of phosphorous and lime (which ameliorates acidity and therefore conceals Al toxicity) – were not feasible. Instead, indirect solutions such as short-term cultivation (swidden) or green manuring were undertaken to greater or lesser effect (see Chapter 14). The andic characteristics of, and colloidal clay presence in, a soil can today be tested by scientific means, but we may be limited in prehistory to judging land use practices today as a proxy.

Tephra Transformations

Tephra-derived soils have a particular weathering sequence that soil scientists classify as a progression from tephric (initial tephra weathering) → vitric (coarse, still containing large amounts of unweathered glass) → andic properties (having the properties listed in Table 1 above) (FAO-UN 2015: 62). The FAO-UN provide quantitative descriptions of soils with 'tephric' and 'vitric' properties (Table 3) where glass* refers to volcanic glass, glassy aggregates, and other glass-coated primary minerals. The transformation of newly deposited tephra into andic soils (andosols) takes time, with the negative aspects (P retention, acidity, and Al toxicity) gradually increased through the process.

• Tephric properties (tf) particularly belong to 'tephric material' (tephra of all sorts), but the tephra may be "reworked and mixed with material from other sources…tephric loess, tephric blown sand and volcanogenic alluvium" (Ibid.: 84).

• Vitric properties (vi) develop in tephra "which contain a limited amount of short-range-order minerals or organo-metallic complexes"; when tephric material acquires vitric properties through weathering, "it is then no longer regarded as tephric material" (Ibid.: 74, 84). Vitric properties are "closely linked with andic properties, into which they may eventually develop" (Ibid.: 74). Hence the tephric→vitric→andic sequence (andic as *starred in Table 1) (see Shoji et al. 1996 for precise specifications).

TABLE 3 COMPARISON OF TEPHRIC & VITRIC PROPERTIES OF SOILS

	Tephric (tf)	**Vitric (vi)**
glass*	≥30% grains in the sand fraction	≥5% grains in the sand fraction
Al_{ox}½Fe_{ox}[2]	low	≥0.4%
phosphate retention	none	≥25%
carbon (C)	none	<0.5% C_{py}/OC[3] or C_i/C_{py}4
organic C	none	<25% by mass

The transformation from tephra to andosol entails two different processes: rock weathering and soil formation; these are "independent open systems" (Velde & Meunier 2008: 114), though they may occur simultaneously; moreover, clays may form during both or either of these processes. Weathering of rock into clay takes "hundreds *of* thousands of years", whereas clay mineralization in the soil horizon stabilizes within "hundreds *to* thousands of years" (Ibid.: 242, emphasis added). Weathering is studied by geologists and soil by pedologists, and never the twain shall meet! Velde and Meunier propose that this is because "pedologists study the soil downward…while geologists begin their investigation upward from the unaltered rocks" (2008: 113). But Eash et al. (2016: 11) are clear that "microorganisms are involved in rock weathering from the start." Volcanic ash soils are exceptional because research into their formation has incorporated rock weathering, unlike research on soils of other lithologies (Ugolini & Dahlgren 2002).

Weathering has been mentioned above in terms of regosol zones, but the product of weathering – clay formation – will be investigated below. The weathering of tephra involves all three components of tephra – volcanic glass, mineral crystals and lithic fragments – which weather at different rates, providing inorganic substances (the elements and minerals) for clay formation. The treatment here is necessarily brief, doing little justice to the multitudes of work written on the subject (e.g. Ugolini & Zasoski 1979; Shoji et al. 1993; Yamanoi 1996; Sase & Hosono 1997; Ugolini & Dahlgren 2002; Dahlgren et al. 2004; Hosono & Sase 2015; Shindo & Nishimura 2016; and bibliographies therein).

From Tephra to Clay

As stated above, all rocks weather to clay over time due to the action of water – whether atmospheric, hydrothermal or oceanic water – upon silicate materials.[4] However, the weathering of tephra is unique in having intermediate stages where the amorphous clay mineral allophane and/or tubular-structure imogolite are some of the first products. As used by Velde and Meunier (2008: 3), the term 'clay' refers to phyllosilicates (Greek *phyllon* 'leaf'+ Latin *silic* 'flint') rather than being used as a size category. Despite the etymology, however, they also include non-leafy aluminosilicate phases (e.g. imogolite and allophane) in the phyllosilicate / clay category.

Crystalline clays are generally divided into groups depending on the numbers and types of their 'sheets' as 2:1 and 1:1 clays. One type of sheet is formed of silicate tetrahedra SiO_4^{4-} (Appendix B: figure in Table B-2) or aluminate tetrahedra AlO_4^{5-}, which are linked together by their oxygen atoms; a second type is an octrahedral sheet containing metals, e.g. Al^{3+}, Fe^{3+}, Fe^{2+} or Mg^{2+}, bonded to O^{2-} (oxygen) or OH^{-} (hydroxyl). These electrically charged atoms are ions: cations are positively^{+} charged while anions are negatively^{-} charged, with the number (valence) indicating the capacity of the atom to form chemical bonds, as in the clay sheets. These sheets are then organized into layers, with 1:1 clays containing one each of a tetrahedral and an octrahedral sheet, and 2:1 clays in which one octrahedral sheet is sandwiched between two tetrahedral sheets (see Velde & Meunier 2008: ch. 1.1.1. for details). Kaolinite (as well as the serpentine mineral lizardite) are examples of 1:1 clays, while 2:1 clays include smectites, illites, micas, vermiculite, chlorite (and the metamorphic mineral talc). When the octrahedral sheet is found alone, it constitutes the non-clay mineral gibbsite (aluminium hydroxide); gibbsite is often the last product of the clay weathering cycle.

Numerous clays, by-products, and detritus are produced during the weathering process. Only a few are relevant here (Appendix B: Table B-3), but it is important to note that clay species are inherently unstable; depending on changes in their environment, a particular clay may undergo transformation into another type of clay in different clay group altogether. Thus, the information given in Appendix B: Table B-3 does not represent all the varieties and possibilities that are inherent in clay minerals.

Weathering of Tephra

Tephra is composed of three components: volcanic glass, mineral crystals, and rock fragments. All these are forms of or collections of minerals, and therefore mineral weathering is the most important process. However, volcanic glass has its own problems, which will be discussed separately.

Minerals crystallize from magma melt in a given order (Appendix B: Figure B-2); the mineral species depends on the chemical composition of the magma. The felsic minerals are the last to crystallize and dominate intermediate and felsic tephras; in order of abundance, these are: noncoloured volcanic glass, plagioclase, other silica minerals (e.g. quartz–Q), and mica. Heavy mafic minerals are less common: coloured volcanic glass, hypersthene, augite, hornblende ssp., and other minerals (Shoji et al. 1993: 105). These various minerals weather in order from least stable (glass and olivine) to most stable: coloured > non-coloured glass = olivine < plagioclase < augite < hypersthene < hornblende < ferromagnetic minerals (Ibid. 1993: 112). The major elements provided by these rock-forming minerals are Si, Ca, K, Na, Mg, K, Al, Fe, and Ti – unsurprisingly the same elements tested for quantities in Quaternary tephras in Japan (Machida & Arai 2011). The rock-forming minerals also provide minor and trace elements. Minerals of non-volcanic sources may be present in tephra, deriving from aeolian dust (particularly quartz), or having undergone hydrothermal alteration. The products of this weathering are then available for clay formation.

[4] This section is heavily based on Velde & Meunier 2008.

Weathering of Volcanic Glass

The weathering of tephra begins as it is exposed to volcanic gases during eruption; sulfuric, hydrochloric, and nitric acids condense on the glass particles in tephra which, after deposition initiate chemical changes producing soluble compounds of Na^+ and Ca^{2+} with SO_4^{2-}, Cl^-, and NO^{3-} (Ugolini & Dahlgren 2002). Further interaction occurs between water and volcanic glass fragments. The glass particles are composed of so-called 'amorphous' silica: vitreous silica SiO_2 tetrahedra organized randomly (Figure 4) rather than in a crystalline structure like quartz. Ions of several types of impurities may also be incorporated into the glass (Al, boron-B, alkalis and alkaline earth elements), while the water itself most commonly contains sodium–Na ions (Icenhower & Dove 2000). Volcanic glasses in Japanese Quaternary tephras are characterized by quantities measured by EPMA of silicon–Si, titanium–Ti, aluminium–Al, calcium–Ca, manganese–Mn, magnesium–Mg, potassium–K, sodium–Na, iron–Fe and then presented as oxides (Machida & Arai 2011: app. 2). Upon the dissolution of volcanic glass, these various elements enter into the circulating solution from which clay minerals can form.

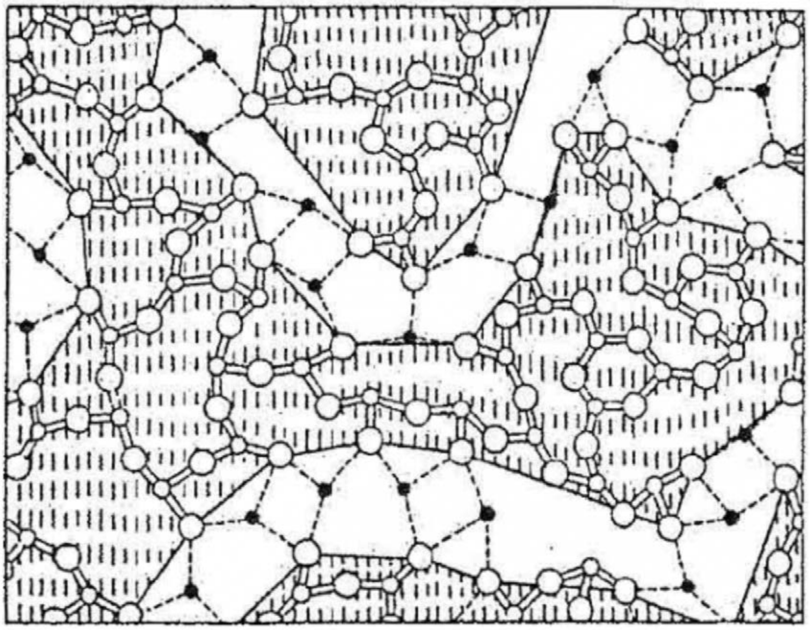

Figure 4 Proposed Structure of Vitreous Glass

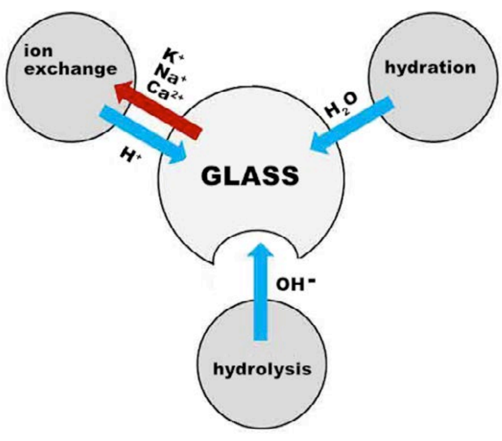

Figure 5 Corrosion of Glass by Water

The dissolution of amorphous silica has been a puzzle, but it appears that the uneven surface structure of silica tetrahedra links provides sites for the detachment of individual tetrahedra (Dove et al. 2008). Moreover, recent research proposes that amorphous silica (greyed in Figure 4) may have greater surface area than previously imagined, with channels formed through the glass matrix by links to ionic impurities (the dots • in Figure 4) (Anaf 2010). These channels are opened up through ion exchange during leaching, exposing internal silica tetrahedra as well as surface silica tetrahedra to hydrolysis. Previous studies on crystalline quartz dissolution have shown that rates can be increased to 50x by the presence of NaCl (sodium chloride, common salt) in water (Dove et al. 2008: 9904), and it is hypothesized that ions of other metals (K, Mg, Ca) in solution will also increase dissolution rates up to 26x (Icenhower & Dove 2000: 4202). The removal of these ions weakens the linkages between silica tetrahedra (Shoji et al. 1993: 110-111), allowing the formation of silicic acid $Si(OH)_4$ which is unstable in water and quickly combines to form other minerals such as clays or taken up by plant growth (Belton et al. 2010). Water can act on the glass fragments in three ways (Figure 5):[5]

• Rainwater and even morning dew act on minerals via *ion exchange*, facilitated by carbonic acid H_2CO_3 (carbon dioxide dissolved in water); since Al is a large atom with a high charge (Al^{+3}), it is generally difficult to replace through exchange and is thus left behind.

• Water may be chemically bonded into the volcanic glass upon eruption, but further *hydration* of the glass is possible by absorption of water on fragment edges; this is the same process as obsidian hydration, obsidian being a volcanic glass extruded like lava rather than explosively like tephra.

• *Hydrolysis* causes a chemical reaction between hydroxols (negatively charged OH molecules) in water and solid silica to form silicic acid: SiO_2 $2H_2O \rightarrow Si(OH)_4$ *or* H_4SiO_4, the major ingredient for building clays.

Clay and Alterite Formation

Rock weathers to clay varieties as constrained by several variables: temperature/climate, rock types, and then for igneous rocks: magma types, chemical compositions, soil pH, etc. For felsic igneous rocks, the weathering of feldspars produces illite-mica and smectite – the clay of alluvial soils (T. Ohkura pers. comm. 23 Oct 2018; Odom1984); further weathering transforms these into kaolinite and gibbsite (Figure 6 left). The major clay species of the smectite group is montmorillonite (Appendix B: Table B-3), but in Japan, montmorillonite is almost exclusively formed by hydrothermal alteration from rhyolite tephra in the Green Tuff zone of Miocene date (Takeshi 1978; Barnes 2003). In this same region, other clay minerals, such as vermiculite and mica, as well as quartz are also present; their presence in non-allophanic andosols is attributed to aeolian deposition of loess from the continent on the windward side of Japan (Shoji et al. 1993: 122). It is notable that allophanic andosols do not have the vermiculite component (T. Ohkura pers. comm. 23 Oct 2013)

The rapid weathering of volcanic glass in Quaternary tephra produces more Al, Fe and Si than can be quickly built into crystalline clay minerals (Ugolini & Dahlgren 2002), and template minerals for clay formation (chlorite and mica) are generally absent in tephra (Shoji et al. 1993: 101-102). Consequently, so-called alteration (alterites) form instead:[6] the amorphous allophane and imogolite colloidal clays (Figure 6, right), plus ferrihydrite, Al/Fe-humus complexes, and opaline silica. Which of these form or dominate is determined by soil acidity; in acidic andosols, aluminium prefers combination with humus rather than forming the colloidal clays (Table 2). Most alteration products stem from felsic minerals, while ferrihydrite is an iron hydroxide that forms from volcanic glass and minerals of mafic composition.

Allophane and imogolite are formed of hydrous aluminosilicate colloids – that is, they comprise gels made of silicon and aluminium with water, and their structures are not detectable by X-rays. Some refer to them as short-range-order clays (SROCs) (Neall 2006), but Shoji et al. (1993: 101) prefer the term ‘non-crystalline’ for allophane and ferrihydrite as they “show no repeat of structural units in any of the three dimensions”. A combination of infrared spectroscopy, thermal tests, and chemical analyses reveal the components of allophane to be hollow spherules 35–50Å in diameter; imogolite forms tubes of even smaller scale: 6.4–21.4 Å. Allophane develops in volcanic ash, whereas imogolite develops on pumice – particularly fibrous pumice so that the structure of the fibers is retained in tubular crystalline structures through “incongruent precipitation” (T. Ohkura pers. comm. 23 Oct 2018).

[5] This diagram should not be confused with the silica tetrahedron (see Appendix B: Table 2 figure)! For details on the weathering of volcanic glass, see Shoji et al. (1993: ch.5.2.4).

[6] Formation processes and conditions are quite complicated for each colloid; see Shoji et al. 1993: ch.5.3, 5.4.

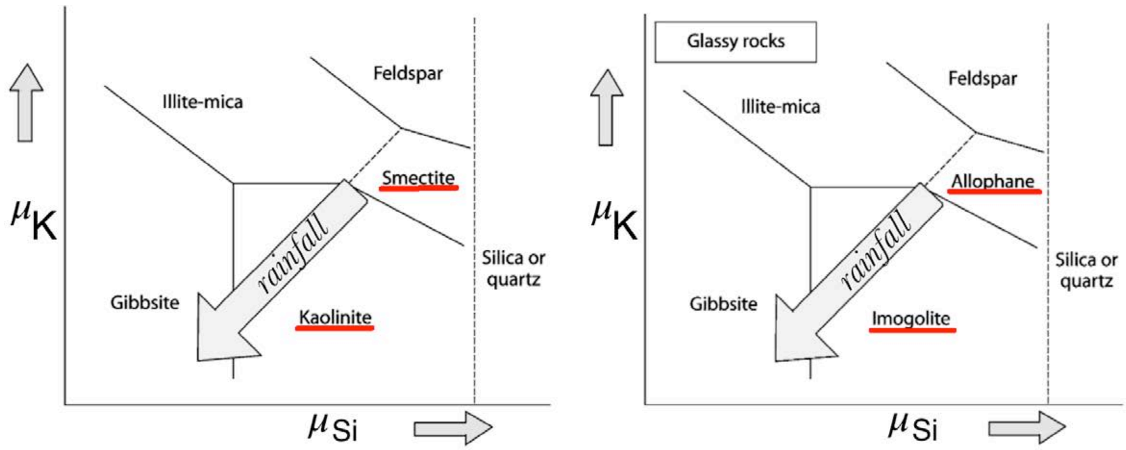

FIGURE 6 'NORMAL' CLAY SUCCESSIONS (LEFT) AND GLASSY ROCK CLAY SUCCESSIONS (RIGHT)

Allophane is dependent on slightly higher pH and Si concentrations, while imogolite forms under lower pH and Si concentrations. As long as Si is available in higher pH value soils, colloid precipitates of AlSi will preferentially form over Al/Fe-humus complexes. Intermittent tephra airfall may interject new supplies of Al and Si; but when these elements decrease in availability as volcanic glass weathers out, the nature of the soil will change from andosol to other soil types. However, Harsh (2005) emphasizes that both allophane and imogolite are not confined to volcanic ash soils and can form in soils derived from a variety of different rocks (gneiss, loess, and other igneous and sedimentary rock), while allophane can occur in six of the twelve soil orders. The high water content of colloidal clays makes them dependent on humid conditions with constant moisture; thus, they are characteristic of areas with high rainfall, and if the soils dry out, they destabilize and convert to various clay minerals: imogolite→halloysite (hydrated kaolinite), and allophane →smectite. If further dessicated, the halloysite will lose its hydration and convert to kaolinite. More will be said about these colloidal clays in a section below as they relate to plant growth.

Lest one think that the process is a quick one, the full transformation of tephra to clay takes thousands of years, and although the alteration products are seen as somewhat temporary or transitional, they can exist for similar time periods. The rate of tephra transformation has been documented to depend on the chemical composition of the parent magma and morphology of the extruded tephra. In New Zealand, andesitic tephra has been found to decay to allophane within 300 years, but rhyolitic tephra took 3000 years to decay to allophane; then it took 7000 years for rhyolitic allophane to crystallize to halloysite, but andesitic allophane persisted for up to 100,000 years (Kirkman & McHardy 1980). Parfitt (2009) notes allophane ages of 250,000 years.

Turning Tephra into Soil

Plant Activity

Only deeply buried rocks are affected by water interaction without influence from plants. Any rocks (including tephra) near the Earth's surface are subject, first, to colonization by bacteria and spore-producing plants (mosses, lichens, algae, and fungi). Thereafter, vegetative regeneration occurs by a variety of means, via wind-blown seeds or the "resprouting of buried branches"; plants may benefit by tapping into buried palaeosols for nutrients (Shoji & Takahashi 2002: 114). Lahars and debris flows provide exceptionally good bases for new growth as they often contain much previously developed soil, its micro-organisms, and plant roots and seeds. The rate of revegetation will depend on temperature and moisture regimes, with climate stress limiting recovery (del Moral & Grishin 1999).

A review of plant regeneration on volcanic rocks and sediments revealed complicated and idiosyncratic patterns of recovery around the world; an extreme example was provided for Krakatau: "Each island of the group was developing differently as a result of unique colonization events and subsequent disturbance" (del Moral & Grishin 1999: 145). In contrast, "Although successions in New Zealand are endlessly varied, some patterns emerge" (Wardle 1991: 554). The pioneer species colonizing each area depended on the present ecosystem flora, type of volcanic product both in form and chemistry, climate, precipitation, altitude, animal presence, etc. Thus, is it very difficult to generalize about or predict floral communities – each case needing investigation anew.

Nitrogen N

The one constant, however, is that pioneer plants need nitrogen to grow. It is the building block of proteins and DNA, etc. and is usually provided in soils from decaying plant and animal matter. However, if organic N is unavailable, as in fresh tephra cover, pioneer species find other ways to obtain the N they need. Several opportunities exist for obtaining N from rock material itself or assisted by bacteria or fungi.

It has long been known that atmospheric nitrogen N_2 could be fixed (transformed into nitrate NO_3^-) by bacteria in the soil. These belong to plant growth promoting 'rhizobacteria' (PGPR), from Greek *rhiza* 'roots', and are categorized by root proximity: around roots (rhizosphere), on roots (rhizoplane), in root tissue (endophytes), and in special root nodules (Gopalakrishnan et al. 2015). The last group includes the well-known legume-associated Rhizobia as well as Frankia, which form actinorhizal symbiosis within vascular plant nodules. While 1700 species of legumes (family Fabaceae) are involved in rhizobia-legume symbiosis, actinorhizal plants number about 220 species and are mainly trees and shrubs in the Rosid I lineage of angiosperms (see Wall 2000: fig. 2). The other nitrogen-fixing bacteria "do not induce the formation of observable plant structures" (LMIL 2018: n.p.). One particular genus of nitrogen fixer bacteria, Azospirillum, is known to be associated with Graminae species (Steenhoudt & Vanderleyden 2000).

Among pioneer tree species, there is evidence of symbiosis with soil fungi of the ECM (ectomycorrhizal) type. Like PGPR, the fungi remain outside the plant root system, and many have long root sheaths themselves that bring up water to the plants in exchange for carbohydrates in 'obligate symbiosis'; they also can provide up to 86% of the nitrogen needed by host plants (Peay et al. 2007). Obase et al. (2007) note that endomycorrhizal fungi (arbuscular mycorrhizas, AM) were also present, but they were not consistently associated with the woody pioneer species.

It is notable that N is not part of the standard formulae for 'rock-forming minerals' that are common in tephra (Appendix B: Table B-1, central column). But these formulae do not take account of variations in the crystal lattice where other ions may be substituted in. The ammonium tetrahedron (NH_4) is found in decreasing amounts in biotite, muscovite, K-feldspar, and plagioclase; its distribution is "quite systematic, suggesting that NH_4 is one of the stable geochemical components in high temperature processes" (Honma & Itihara 1981: abstract). Research since the millennium has revealed that there is much nitrogen incorporated into bedrock and circulating thermal waters: sedimentary and metasedimentary rocks may contain up to 1000 mg N kg^{-1} organically bound nitrogen in ammonium-rich bedrock, or it may be available from thermal waters (Holloway & Dahlgren 2002). This non-atmospheric nitrogen may be very important in supplying plants with the N needed for growth (Morford et al. 2011).

Plant Regeneration

As mentioned above, plant regeneration patterns on newly deposited volcanic products are very diverse; del Moral and Grishin (1999) emphasize the randomness of which species will be colonizers. They also make a distinction between survival and succession (not always clear from other reports); others distinguish between primary succession on a sterile sediment and secondary succession after a disaster (Brewer n.d.). Arnalds (2013) emphasises that the height of plants affects recovery. If plant life has not been completely extinguished, then recovery is possible via survivors, including those pushing through tephra from below or from root bundles caught in lahars; quick erosion of tephra often exposes underlying plant matter that is then able to grow again. In contrast, succession relies on transport by wind or birds of spores and seeds from nearby survivors. Importantly, 'snags', dead tree branches serving as bird perches, may allow the seeds of far distant trees and shrubs to be carried to new areas. And the geomorphology of the area may determine what species colonize which terrains.

Only a few examples can be offered here of case studies in plant regeneration on tephra or tephra-derived soils.

• An experimental study conducted on bare ground of an already developed andosol in Japan also confirmed that *aki-no-enokoro-gusa* and *mehi-shiba* grasses were the first to colonize (respectively: *Setaria faberi*, Japanese bristlegrass, and *Digitaria adscendens*, crabgrass); these were succeeded by wildflowers (Erigeron, daisies) (Ebinger 1962).

• Shoji and Takahashi (2002) report on revegetation on Mt Usu in Hokkaido after the eruption in 2000. *Populus maximowiczii* (Japanese poplar, *doronoki*), *Betula platyphylla* var. japonica (Japanese white birch, *kabanoki*), and *Salix sachalinensis* (Sakhalin willow, *onoe yanagi*) were early colonizers. By 2004, 14 tree species were documented (Obase et al. 2007); and after 25 years, forests were established on extremely thin soils, ca. 10 cm, with regosolic properties persisting below.

• Dahlgren et al. (2004: 151) identify lupine (Lupinus spp.) as a nitrogen fixer and colonizer of Mt St Helens pyroclastic flows, creating "islands of soil fertility" by supplying nitrogen, capturing aeolian sediments, and incorporating organic matter. They also mention alder (Alnus spp.) as an N-fixer.

• In the Philippines, *Saccharum spontaneum* (wild cane) was able to colonize Mt Pinatubo tephra in the Philippines within seven years (Shoji & Takahashi 2002), and it remained the dominant grass among four types 15 years later when much tree growth (*Parasponia rugose,* belonging to the hemp family) had developed (Marler & del Moral 2013). The hemp trees and wild cane favoured flat terraces, while the minor grasses and ferns preferred talus slopes.

• In Kyushu, the evergreen shrub *Ardisia japonica* (coralberry, *yabukōji*) can form "a stable pioneer scrub community in southwest Japan that resists invasion [by trees] indefinitely" (del Moral & Grishin 1999).

• From New Zealand, is it known that beech forests supress the growth of grasses and establish thick stands of climax forest within 300–400 years (Wardle 1991: 556). Neall (2006) comments that forest litter improves soil fertility, but certain trees may have acidic litter, contributing to the acidification of the soil (Jobbágy & Jackson 2003). In northern Japan, fulvic andosols develop under beech forests (*buna*; *Fagus crenata, Fagus japonica*) (Shoji et al. 1993: 8) with an understory of bamboo grass.

Studies of plant regeneration in clear-cut forest areas are also instructive:

• Clear-cut laurel forest growing on allophanic andosols in the Canary Islands were first colonized by the pioneer species heather (*Erica arborea*) and the native firetree (*Morella faya*), the latter having the ability to fix nitrogen in the soil and thus having the "capability to change entire ecosystems" (HEAR 2017 n.d.). Regrowth of an intermediate mature laurel forest occurred within 50 years (Arévado & Aboal 2015). This latter information is relevant to western Japan where the indigenous Holocene forest system was laurilignosa, though now replaced by secondary red pine.

• Another case of clear-cutting, however, provides a different perspective: andosols in northwestern North America were colonized by bracken, which acidified the soil and prohibited the regrowth of forest (Johnson-Maynard et al. 1998).

Such studies have yet to be carried out routinely at archaeological sites in tephra-affected areas to monitor the recovery of plant species. Dahlgren et al. introduce the important concept of "disturbance gradient" in assessing the amount of tephra cover ranging from "complete obliteration of the landscape near the mountain to a mere dusting of volcanic ash hundreds of kilometers from the vent" (2004: fig. 1, 115). Not all tephra fallout is damaging, as they note that dustings can rejuvenate soils and increase their fertility.

FIGURE 7 THE MISCANTHUS FIELDS OF SENGOKUHARA, JAPAN

Andolization

Andolizer Species

The progression tephric→vitric→andic is basic to this discussion, as we are particularly interested in andosols rather than other soil types. After initial colonization by bacteria, fungi, and the pioneer species, the transformation of tephric to andic volcanic ash soils begins with 'andolizer' species which convert volcanic ash to andosols; these include bamboo grasses, particularly *sasa* (Sasa spp.) and *nezasa* (Plioblastus variegatus Makino) (cf. Stapleton 2006-2018); Cortaderia (pampas grass, of the subfamily Arundinoideae); *Miscanthus sinensis* (*susuki*, eulalia or Chinese silvergrass, sub-family Panicoideae) (Figure 7); and *Saccharum spontaneum* (wild cane, family Poaceae). In Japan, Miscanthus is the major andolizer in the cool-temperate zone, while Miscanthus and Plioblastus colonize the warm-temperate zone (Shoji & Takahashi 2002; Nanjyo 2004). Andosols are not just formed on fresh tephra: bluejoint grass (*Calamagrostis Canadensis*) has also been noted to be an andolizer by converting tephra-derived spodosols into andosols after forest fires (Shoji et al. 1993: 49).

The andolizers named above all belong to the Poaceae (aka Gramineae) family of grasses. Because grasses need silica to form the phytoliths / plant opal in their plant parts, especially to keep themselves stiff and upright, the silica of dissolving tephra is a perfect source to exploit. Kubo (1982) notes that great amounts of plant opal from grasses (Graminae phytoliths) are found in kurobokudo soils, indicating that they develop under the colonization of grasses and herbs rather than forest; such heavily humic soils can be radiocarbon-dated, providing an indirect age determination for the volcanic parent material (Chigakudan 1981: 313a). Miscanthus aids and abets the formation of colloidal clays by biocycling alkali/alkaline base metal ions, maintaining higher pH values and base-rich soils (Shoji et al. 1993: 131). Also, since grass parts (leaves, stalks, husks) contain much plant opal, returning phytoliths to the soil every year as the plants die keeps up the supply of silicon (Si) available for further colloid formation.

Andosol Soil Profiles

Soils are defined by having particular stratigraphic horizons (Figure 8, left), in general designated O through C; these are termed 'genetic horizons' relating to their formation, in contrast to 'diagnostic horizons' that are used in soil classification (Schaetzl & Thompson 2015: chs. 3, 8). The O horizon is comprised of dead plant matter (humus), A is topsoil, B is subsoil, and C is the regosolic substratum; not shown are E (an eluviated stratum with loss of minerals) and R (bedrock). In the andosol class, the A horizon is much thicker than usual; compare the genetic sequence depths (Figure 8 left, in both centimetres and inches) with the andosol in Ibaraki Prefecture (right, in cm), with the A horizon reaching more than 1 m depth. For Japan, development of a deep A horizon depends on the time lapsed and the climate; one containing at least 10% humus and measuring 30 cm deep generally takes 1000 years to develop, and for a full ABC profile to develop takes 1500 years (Kato 1983: 20, 22). The dark humus layer is commonly referred to as *kurotsuchi* (black earth) and the underlying yellow-red sediments as *akatsuchi* (red earth). The upper dark layer has virtually the same composition as the underlying red layer, only differing in the addition of plant remains (T. Noto & T. Soda pers. comm. Sep 2018).

Six major diagnostic soil profiles have been established for northeastern Japanese andosols (Figure 9), beginning with the 'vitric' stage (a) as designated in Table 3; the A horizon contains humus, while the C horizon is the weathering tephra. The 'buried' tephra column (b) illustrates the repetition of soil formation after repeated tephra fallout; the buried portion (indicated by the numeral '2') existed long enough for the development of an A horizon and a weathered B horizon (Bw), but the new tephra on top (C) has only developed an A horizon. The 2A layer may become a source of nutrients for deep-rooted plants. Sometimes, the periodic deposition of volcanic ash does not even allow the sequential A layers to develop melanic or fulvic profiles and remain regosolic andosols (Shoji & Takahashi 2002).

FIGURE 8 SOIL PROFILES FOR GENETIC SEQUENCES (LEFT) AND AN ALLOPHANIC ANDOSOL (RIGHT) IN EQUIVALENT SCALE

However, fulvic andosols can also be quite dark and can only be distinguished from melanic andosols by laboratory analysis determining the ratio of humic acids to fulvic acids (Honna et al. 1988) (Table 4). These humic substances are discussed more fully in Appendix D together with other nutrients. These colour-types of andosols can occur in either allophanic or non-allophanic andosols. The characteristics and productivity will vary with each combination.

TABLE 4 PROPERTIES OF THE TWO MAIN DIAGNOSTIC ANDOSOL HORIZONS

	MELANIC ANDOSOLS	**FULVIC ANDOSOLS**
Maturity	andic (see Table 1)	andic (see Table 1)
Colour	both: Munsell colour value and **chroma of ≤ 2**, moist, *and* a **melanic index of < 1.7**	either or both: a. Munsell colour value or **chroma of > 2**, moist b. a **melanic index of ≥ 1.7***
Organic carbon	weighted average of ≥ 6% *soil organic carbon*, and ≥ 4% *soil organic carbon* in all parts	weighted average of ≥ 6% *soil organic carbon*, and ≥ 4% *soil organic carbon* in all parts
Thickness	a combined thickness of ≥ 30 cm with ≤ 10 cm non-**melanic** material in between	combined thickness of ≥ 30 cm with ≤ 10 cm non-**fulvic** material in between
Humus	**humic acids (HA) A-type dominant** over fulvic acids	**fulvic acids (FA) dominant** over humic acids (mainly P-type)

* The melanic index is the humic / fulvic acid ratio in the organic fraction of the soil (USDA Soil Survey Staff 1999: 860).

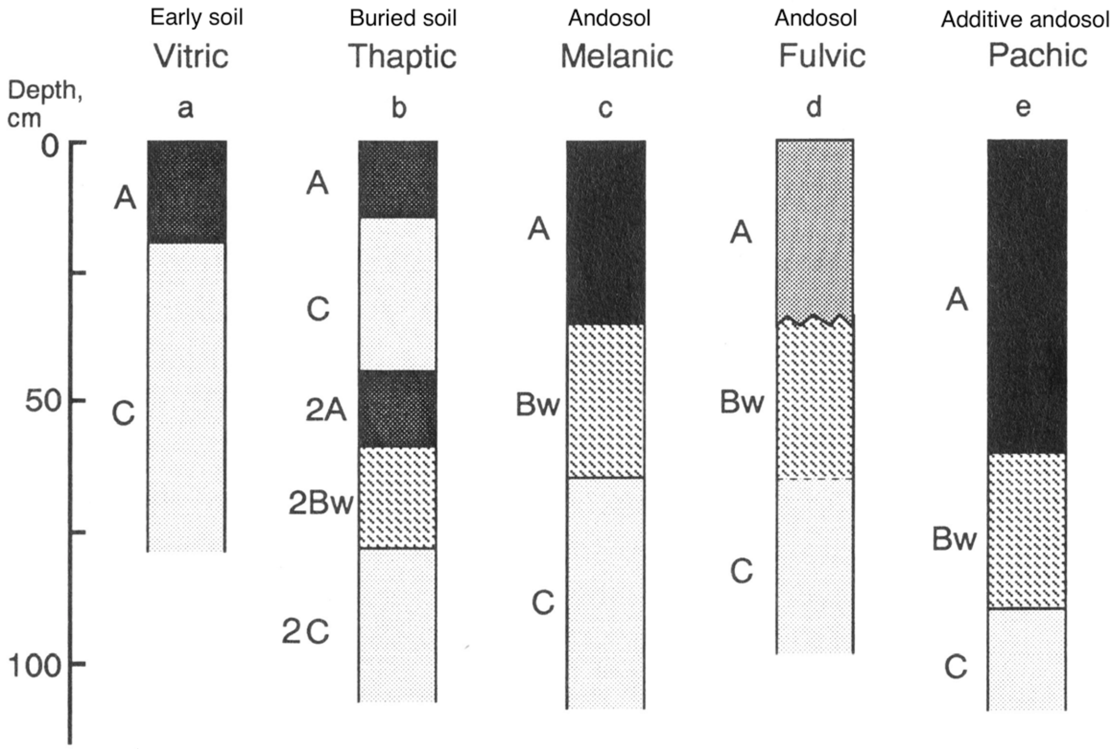

FIGURE 9 SELECT ANDOSOL PROFILES AS FOUND IN JAPAN

Grassland Longevity

Although the natural succession of plants is from colonization of open ground by grasses and herbs to shrubby growth and the eventual invasion of forest, pioneer growth can last a long time: centuries for bracken (Johnson-Maynard et al. 1998), and thousands of years for grasses. Long-lived grasslands occur worldwide: North American prairies, South American plains, African savannahs, Eurasian steppes, and Australian bush. A variety of conditions have been named as maintaining these grasslands: climate, precipitation, soil-rooting depth, fire, and clearance activities; but tephra-derived soils are not a precondition for grassland growth.

One critical aspect of grasslands in general is maintenance of their boundaries with forests. Existing forests provide seeds and roots for colonization of areas of tephra fallout grassland recovery among others. Studies around the world report increasing encroachment of forest on grassland, though the rate may be decadal (Cuni-Sanchez et al. 2016). The reasons given are varied: increase in precipitation, increase in global CO_2 and other growth-promoting factors, and fire. Many of these 'fires' are intentional: "in the Congo basin, it has been suggested that forest is expanding into savannas because of urban-migration and a consequent reduction in fire frequency" (Cuni-Sanchez et al. 2016: 2, 5). Conversely, in Brazil, fire is rejected as a single cause but is treated in conjunction with precipitation and tree-rooting depth (Langan et al. 2017).

Archibald et al. (2013) have developed the concept of a 'pyrome' that differs from 'biome', a plant community; they use five criteria to establish five pyromes (Table 5, top half) and then classify different biomes as potentially hosting the different pyromes (Table 5, bottom half). A negative correlation is noted between fire frequency and intensity, reflecting the fact that fires occurring at frequent intervals do not allow the build-up of fuel to support intensive fires. Another factor is precipitation: despite the high productivity of high rainfall climates, the fuel is usually too wet to burn. With few exceptions, all the biomes are subject to all five pyromes but in varying percentages.

The ICS pyrome in Table 6 correlates with deforestation and agricultural regimes and is therefore indicative of human activity; its fires are "fairly small" with "intermediate return time" and have significant occurrence in all biomes except boreal forests. Grasslands that have a higher risk of fire other than in ICS are in FIL, FCS, RIL, and RCS pyromes to varying degrees. The colours denoted are keyed to a map (Archibald 2013: fig. 2), which has no datapoints for Japan. This is not to say that Japan is not subject to fires: Zorn et al. (2002) present data that shows the number of forest fires has been decreasing from avg. ca. 4000 incidents per annum in the 1980s to avg. ca. 3300 in the 1990s, and between 2004 and 2013 declining from ca. 2600 to ca. 2000 incidents (FDMA 2014: fig. 1-4-1). The Fire and Disaster Management Agency specifies early spring as forest fire season. In 1933 there was an interesting article published about natural causes of seasonal forest fires initiated simultaneously across the archipelago by approaching cold weather fronts (Editorial 1933), but it seems more likely that the FDMA is correct in assessing that the fires are due to weather being relatively dry with strong winds in early spring and also that people are more likely to be in the mountains collecting wild vegetables or taking hikes. Data on anthropogenic fires are contradictory. Zorn presents data from the Forestry Agency Japan dated to 2000 that indicate ca. 70% of forest fires were human-induced, but they also quote a 1987 study that states 99% of forest fires in Japan were caused by humans; the FDMA states that anthropogenic fires are very predominant. In any case, the majority of fires indeed seem to be human-induced; however, what were the fires set for? That is the conundrum of kurobokudo in Japan.

TABLE 5 CHARACTERISTICS OF THE FIVE PYROMES IDENTIFIED BY MODEL-BASED EXPECTATION MAXIMIZING CLUSTERING

Characteristic	FIL (yellow)	FCS (orange)	RIL (green)	RCS (purple)	ICS (blue)
Mean burned area, %	14 (8–36)	9 (3–17)	1 (0–2)	0 (0–0.5)	0 (0–1)
Estimated FRI, y	3 (1–4)	1 (1–2)	>50	>50	12 (6–19)
Max FRP, MW	473 (350–660)	197 (156–253)	476 (283–844)	187 (108–334)	224 (143–352)
Max fire size, km^2	414 (155–1437)	25 (15–43)	83 (38–214)	4 (2–9)	9 (5–17)
Length of fire season, mo	4 (3–4)	3 (3–4)	2 (1–2)	1 (0–1)	3 (3–4)
Tropical moist broadleaf forests	2	10	5	**28**	**56**
Tropical dry broadleaf forests	3	21	6	16	**53**
Tropical coniferous forests	0	10	13	17	**59**
Temperate mixed forests	1	2	11	**41**	**45**
Temperate coniferous forests	2	0	**26**	**45**	**26**
Boreal forests	1	0	**46**	**47**	6
Tropical grasslands and shrublands	**29**	**33**	9	6	**23**
Temperate grasslands and shrublands	10	3	21	**29**	**37**
Flooded grasslands	**46**	17	8	5	**24**
Montane grasslands	6	15	13	**31**	**36**
Mediterranean vegetation	1	3	**25**	**36**	**35**
Xeric vegetation	18	1	**31**	**24**	**26**

The median and 25th to 75th quantiles of each fire characteristic are reported (parentheses), as are the percentages of 12 World Wildlife Fund biome classes that fall into each pyrome (values greater than 20% are bold)

Kurobokudo as a Pyrome

Above we saw that andosols in Japan occur in two general colours, melanic and fulvic (Tables 4, 5); these correlate with different biomes: deep melanic profiles are assessed to form under grasslands (mainly by *Miscanthus sinensis*), but fulvic profiles form under beech forests (by *Fagus crenata,* Japanese beech *buna*) (Shoji et al. 1993: 45-47). Both of these have high organic matter contents, but the difference in colour is attributed to the presence in melanic andosols of minute pieces of charred plant matter which supply black humic acids. Thus, melanic andosol formation hinges on the burning of plant matter.

Other deep black soils around the world, however, may or may not be related to fire. For example, plaggen soils in Europe are known to have been formed by the addition of heather or grass topsoil slabs to the fields, thus building up deep dark humic anthropogenic layers (Blume & Leinwether 2004), and loess in China has been modified by adding earth mixed with manure containing much humic matter (Gong 1994). On the other hand, the deep black *terra preta* soils of the Amazon clearly contain great amounts of biochar; Glaser et al. (2001: 39-40) propose that rather than burning forest to create this biochar, it was added as hearth residue from the "low-heat smouldering domestic fires commonly used by the native population for cooking and heating". *Terra preta* soils are limited in distribution and have now been proven to be midden deposits, containing household refuse, pottery, plant and animal remains as well as hearth debris (Schmidt et al. 2014). The *terra preta* soils are anthrosols, not andosols; they are not andic as they did not develop on tephra.

Since phytoliths coming from grasses are very prominent in kurobokudo, and since Miscanthus is a known andolizer, it has been assumed that the humic content of melanic andosols in Japan mainly comes from Miscanthus. However, further investigation of carbon stable isotopic ratios ($\delta^{13}C$) in Japanese andosols revealed that only half of the plant material is contributed by C4 plants (Hiradate et al. 2004); this is still a large proportion, as C4 plants comprise only 3% of all terrestrial plants, though 79% of C4 plants belong to grass or sedge families (Bareja 2013). C3 plants such as woody plants and trees among others contribute the other half. In fact, C4 plants like Miscanthus have been found *inessential* to the formation of andosols (Takahashi & Dahlgren 2016), though it seems that Japanese kurobokudo do mainly form under grasses, whether Miscanthus or bamboo.

Thus, the picture of andosol formation is rapidly changing, but one important ingredient for melanic andosols is recognized to be FIRE; however, some scholars are deeply sceptical that fire is the *only* cause (T. Ohkura pers. comm. 23 Oct 2018), especially given the fact that kurobokudo can be formed without Miscanthus, as noted above. Nevertheless, research in North America demonstrates that melanic andosols result from frequent forest fires in Alaska and northern California's Cascade Range (Takahashi et al. 1994); and Dahlgren speculates that charcoal, from Native American's management of grassland over thousands of years, contributes to the dark colour of prairie soils (pers. comm. 17 Feb 2018). Schmidt et al. (2002) have discovered black carbon in chernozem soils of central Europe, challenging the traditional understanding of chernozem development and suggesting fire as an inalienable formative component. Finally, the biochar found in Amazonian *terra preta* soils, though not from grassland fires but from charcoal added to the soil, is still an important component in the formation of those black soils.

Two external factors in the longevity of melanic andosols are 1) rejuvenation of volcanic ash layers through repeated eruptions (Figure 9-e), and 2) potential impact of human activities. If grasslands are not maintained (either naturally or artificially as indicated in the signboard of Figure 7: "managed land"), they are subject to forest succession. In a humid climate like Japan, succession from grassland to forest is a certainty except for the results of human intervention. Suga et al. (2011: 114) note that grasslands that became disused at the beginning of the 20th century have been colonized by white birch (*shirakaba, Betula platyphylla*) forest within the century.

Today, grasslands account for less than 1% of Japan's land surface (as opposed to two-thirds being forested). It is well-known in Japan that these current grasslands such as Sengokuhara in Kanagawa Prefecture (Figure 7), Wakakusa-yama in Nara Prefecture (Figure 10), or the Akiyoshi karst landscape of Yamaguchi Prefecture are maintained by annual firing. Even the name *wakakusa* means 'young grass'. From maps of the Meiji Period (1868–1912) marking land use patterns, Ogura (2011) notes that grasslands were more widespread than today and that there is documentary evidence of their management by firing them in early spring; this is a traditional practice called *hi-ire* ('setting fires').

This, however, is only one method of maintaining grasslands. Suga et al. name two other methods: cutting and grazing (2011: 101-102, 108). They propose that specialized grasslands date back to the Jōmon Period, when hillsides are thought to have been intentionally fired – an idea examined below; and in the Kofun Period (in the 5th century AD) grasslands were maintained for fodder for horses and cows after these were imported from the continent. Finally, harvesting grass for green fertilizer and thatch for roofing dates back to at least 800 AD, intensifying around 1500 AD, with the acreage then increasing exponentially.

FIGURE 10 THE ANNUAL CELEBRATORY FIRING OF MT WAKAKUSA BEHIND KOFUKUJI TEMPLE IN NARA CITY

Such dense grasslands are different from the seven grasses of autumn (*aki no nanakusa*) that are praised in poems of the 8th-century *Manyōshu* poetry anthology – among which Miscanthus was the only Poaceae, accompanied by a flowering shrub (*hagi*, Lespedeza) and several wildflowers. Suga et al. note that such mixed grasslands could be seen in disturbed areas around settlements until quite recently.

But it is a mistake to think that even the maintained grasslands were comprised only of Miscanthus; two varieties of bamboo have also been prominent: ground-hugging bamboo grass (*sasa*) and the taller dwarf bamboo *nezasa* (Figure 11). The phytoliths of these bamboos and Miscanthus are found in kurobokudo in varying quantities; moreover, the humic acids in kurobokudo match these plants (Suga et al. 2011: 113). Very little evidence of wood has been found in kurobokudo soils despite the prominence of beech forests on andosols.

The sequence of grassland development in the Kantō Plains has been first, colonization of new tephra by Miscanthus, the andolizer species. If these plants are not subject to fire renewal, the land is gradually reforested; the shade kills the Miscanthus, and bamboo grass species colonize the understory. If the forest is cut, bamboo grass remains as the ground cover. Thus, the dwarf bamboo, *nezasa*, has been the main grassland species of the Kantō region (NOTO Takeshi pers. comm. 1 Oct 2018).

FIGURE 11 TWO BAMBOO GRASS TYPES: *SASA* ON LEFT, *NEZASA* ON RIGHT

Because of the high humic acid content of melanic andosols, the humic material itself can be radiocarbon dated; it has been known since 1988 that these black andosols can date back to 30,000 years ago, with most of them clustered between 5000 and 1000 years ago (Takahashi & Dahlgren 2016). But now, kurobokudo have been found together with Palaeolithic stone tools well below the AT marker tephra of 29,000 years ago. Hosono and Sase (2015) report that on the flanks of Mt Ashitaka, just south of Mt Fuji, six sequential palaeosols (of the Ashitaka loam) have been recovered,[7] with the earliest associated with stone tools at 40,000 BP. This date is close to that currently known for the peopling of Japan (Barnes 2015: 65); thus, Hosono and Sase conclude that as soon as Palaeolthic peoples occupied the islands, they began to transform the landscapes using fire. They underwrite this by noting that grasslands in New Zealand also started to appear only after colonization by Polynesian peoples (the current Maori). However, archaeologists in Japan are very reluctant to accept the interpretation that all kurobokudo soils are due to anthropogenic interference (NOTO Takeshi pers. comm. 1 Oct 2018).

Together with the confluence of human activities and volcanic deposits, three environmental conditions were essential for grasslands to develop in Japan (Hosono & Sase 2015: 325):

- annual average temperatures greater than 0°C
- warmth index (WI) >30~35°C
- a wet environment with a Köppen index of K>18

It follows that for kurobokudo to have been formed in the latter half of MIS 3 (which lasted from 60 kya to 24 kya), there must have been warmer humid interludes; Hosono and Sase note that two expansions of *medake* bamboo have been found in the lower Tachikawa loam in the southern Kantō district which may correlate with the formation of kurobokudo via human activities. And kurobokudo have been found in Kyushu by 30 kya as mentioned above. However, conditions were not favourable in Hokkaido until the Holocene. Moreover, the areal coverage of kurobokudo in the late Pleistocene and early Holocene was limited by the small population densities of hunter-gatherers. Most kurobokudo date to Initial and Early Jōmon (10,550–3520 BC), but Hosono and Sase puzzle over the lack of such soils at the height of occupation in Middle Jōmon (3520–2470 BC) at the Sannai Maruyama site in Aomori Prefecture, concluding that the village was built on grasslands whose kurobokudo soils were disturbed by large-scale urban earthworks; but in the Late Jōmon (2470–1250 BC), the Sannai Maruyama site area reverted to grasslands, building up another thick kurobokudo soil; the area was used for hunting and cutting thatch through the 10th century AD.

But what were these grasslands used for in the prehistoric period? In the mid-1960s a hypothesis for Jōmon agriculture was proposed for the area around Mt Aso in Kyushu based on tool types (Shimomura 2011: 133), and in the 1980s, it was hypothesized that the Jōmon grew buckwheat in mountain swidden fields based on charcoal and buckwheat pollen found together (Tsukada et al. 1986; Barnes 1986b). Buckwheat grains have been recovered from several prehistoric sites, but they could be contaminations from above and are not fully accepted with clear dating (Nakayama 2010). Buckwheat (*soba*, *Fagopyrum esculentum*) is not a grass but belongs to the Polygonaceae. It is native to the Himalayan region of Yunnan Province, having been domesticated in the San Jiang region bordering Yunnan, Sichuan and Tibet; molecular DNA studies indicate that it spread from southern to northern China, through the Korean Peninsula to the Japanese Islands (Gondola & Papp 2010). Its arrival date is unknown, but it may have accompanied dry rice arriving in the Late Jōmon Period. Nevertheless, it is rarely found in flotation samples despite having a very distinctive shape of grain (Gary Crawford pers. comm. 21 Oct 2018). By the 9th century, it is mentioned in government documents encouraging planting, so we know that it formed one of the non-rice grain staples for peasant farmers (von Verschuer 2016: 25).

[7] These would be *kuroboku-dosō* rather than kurobokudo, as explained above.

Currently, there is no firm evidence of swidden in the Jōmon Period, though burned-field (*yakihata*) cultivation was known in Japan up into the 1990s. Such fields were part of the *satoyama* ('village mountain') complex (Barnes 2010; Berglund 2014), whereby hillslopes behind villages were managed for various resources. Some villagers are now trying to revive the practice, for example at Itsuki Village in Kumamoto Prefecture, where one field was fired for the third time in 2012; the fired field was then sown with buckwheat for the first year, then millets and barnyard grass in the second, with beans and soybeans in the third.[8] Research on southern Kyushu has revealed a pattern of firing bamboo forest rather than trees. The first year after firing, foxtail millet (*Setaria italica*) was sown, then the second year, bamboo roots were harvested; thereafter the bamboo forest was allowed to grow back, ready for firing again in ten years' time (Kawano 2008). This pattern does match the build-up of graminae phytoliths in the deep kurobokudo soils but not of Miscanthus *per se*.

Other uses of grasslands have been suggested. Suga et al. (2011) propose that the firing of grasslands from the Late Palaeolithic Period in Japan related to hunting practices to keep forest growth down as the climate warmed. This would probably also obtain in the Jōmon phases when deer and boar were the major terrestrial protein; deer are not forest animals but like open clearings near the forest edge where they can graze and then escape to tree cover. Their preference for parkland is exemplified today by the Nara deer park in Japan, the Raby Castle deer park in England, and on the golf course of Estes Park, Colorado. Boar and deer continued to be hunted in the medieval period (despite Buddhist prohibitions against eating the meat of four-legged animals), and Nakazawa (2011) has specified 'rough meadows' (*kōya*) as the hunting grounds.

Above it was mentioned that Miscanthus was an important roofing material in historic times, with Miscanthus fields maintained for cutting thatch. However, it has not been emphasized enough that the basic residence of prehistoric times (and existing through the first millennium AD) was the pit-house, thatched from roof tip to ground. With growing populations and the need to thatch houses every generation, the demand for Miscanthus must have been high. Much more research is needed on these possibilities.

Andosol Productivity

> Volcanic ash soils or Andisols are among the most productive soils in the world…. In contrast, volcanic ash soils or Kurobokudo in Japan were originally regarded as impoverished soils because of high amounts of active aluminium, very low contents of available phosphate, low concentration of exchangeable bases and strong acidity. (Shoji et al. 1993: 209)

How can both of these statements be true? We have seen that there are at least six types of andosols alone, with a clear distinction between allophanic and non-allophanic andosols, plus other soil types that incorporate volcanic ash. Moreover, there is tremendous variation in the chemical and mineral compositions of tephra-derived soils, with some clay products and by-products affecting those compositions. Agricultural productivity is said to depend "primarily on the degree or intensity of pedogenic development", which in itself is governed by soil composition, climate, precipitation, and temperature, etc. (Dahlgren et al. 2004: 115, 122) Thus, it is difficult to generalize, as the soil of any location has its own characteristics, thus deficiencies must be identified for mitigation.

[8] See the two videos from Itsuki Village, first the firing of the fields then sowing buckwheat: youtu.be/pRF4GQVuhuU , youtu.be/o8WmdA8j1s4

Andosol Properties

The properties of tephra-derived soils have been described in detail by several authors (e.g. Ugolini & Zasoski 1979; Shoji et al. 1993; Shoji & Takahashi 2002; Takahashi & Shoji 2002; Ugolini & Dahlgren 2002; Dahlren, Saigusa & Ugolini 2004; Lowe & Palmer 2005; Parfitt 2009; Takahashi & Dahlgren 2016; Taylor et al. 2016). Complicated chemical reactions are involved in producing these properties and conditions; here we can only present those properties inherent in andosols (Table 6) without reference to climate, tephra age and composition – factors which will further affect fertility. Appendix D addresses some of the issues concerning nutrients. Table 6 does not distinguish between allophanic and non-allophanic andosols, where some of the greatest differences in fertility arise; this division is the most important for soil management and depends on the electric charges of materials in each type of andosol (Dahlgren et al. 2004). Within the tephric→vitric→andic sequence discussed above (cf. Table 3), there is a gradation of productivity.

TABLE 6 ANDOSOL PROPERTIES

	Advantages	**Disadvantages**	**Mitigation**
Water supply	Good water retention if pumaceous	Strongly hydrated → low bearing capacity & stickiness = waterlogging	Drainage
Colloid clays	High water-holding capacity; plant available	Can dehydrate	
Texture	Highly friable → good rootability; stable soil aggregates	If too porous → water loss	add bentonite /montmorillonite
Base metal supply	Fertile if basic or andesitic	Leaching of base metals; low exchangeable base-holding capacity leading to soil acidity	liming to add Ca; add gypsum or phosphogypsum to increase subsoil Ca
Phosphate	Major nutrient, from apatite	Active Al and Fe lead to P fixation; adsorb P from solution thus high P retention at >85%	add lime, gypsum, silica, green manuring, and P fertilizer
Potassium	Major nutrient, from weathered glass	Depleted in allophanic andosols; used for 2:1 clays in non-allophanic andosols	add K fertilizers
Nitrogen supply	small pool of easily larger pool of slow release	Gradual decrease of N with continued glass weathering	green manuring
Toxicity		potential Al, Na, and Io toxicity	liming, green manuring

Shoji et al. (1996) describe these progressive levels of productivity (Table 7, with my interpolations). Vitr-andic transitional andosols, which have not completely acquired andic properties, are often lowest in productivity because colloids which hold water and nutrients have not yet developed thoroughly; conversely, PO_4 is generally available for the same reason. Aluandic or Non-allophanic soils have variable productivity; the deficiency of P needs to be overcome with fertilizers, then non-allophanic andosols may be very productive as long as Al-toxicity does not develop. The main drawback of allophanic andosols is the low availability of P, which again can be mitigated with fertilization. For tropical andosols, Shoji et al. describe other problems and solutions.

These authors emphasize that the non-crystalline contents of andosols (allophane, imogolite, Al/Fe-humus complexes, ferrihydrite) are major contributors to the productivity of andosols, as they have "variable charge, high water-holding capacity, high phosphate retention, low bulk density, high friability, weak stickiness, formation of stable soil aggregates, etc." (Shoji et al. 1996: 606). High phosphate retention is obviously a negative andosol property, but what about colloid clays and humus complexes?

As we have learned, allophane and imogolite are "mutual solid solutions of silica, alumina, and water and minor amounts of bases" (Parfitt 2009, quoting Ross & Kerr), and the ratios vary from Si-rich to Al-rich (Al:Si = 4:1 max). Water molecules may occupy the internal spaces of allophane spheres or be chemically adsorbed to the AlOH component, accounting for their water retention properties.

TABLE 7 COMPARISONS OF PRODUCTIVITY AMONG ANDOSOL TYPES COMMON IN JAPAN

	Vitr-andic	**Alu-andic = Non-allophanic**	**Sil-andic = Allophanic**
Productivity level	low	variable	high when fresh
Colloids	not yet fully developed	fully developed	fully developed
Phosphorus	not yet bound to colloids ∴plentiful	strong fixation capacity	strong fixation capacity leadi to lower productivity
Humus retention	low	high, bound to Al	high, bound to colloid clays
Al		potentially toxic from 2:1 clays	adsorbed by humic materials
Base metals		low exchangeable base content	high nutrient retention but decreases with weathering
Acidity		increases with weathering	

Allophane is a kind of clay, and it can comprise up to 60% of an andosol (w/w); it is thus useful in pottery production. Allophane heated to high temperatures (900–1000°C) will begin to form the mineral mullite from the aluminium content (Parfitt 2009); and mullite is the hallmark of stoneware pottery, in contrast to earthenware which will melt at those temperatures due to the fluxing agency of the iron content (Barnes 1992/2001). Thus, areas that have volcanic soils with considerable Al content are prime areas for stoneware and porcelain production as well, since kaolin clay is dehydrated halloysite.

Because the colloidal clays have variable surface charges (both positive and negative), they can bind individual ions, such as those of phosphate, as well as humic substances. Organic matter that is bound to allophane or imogolite decomposes only very slowly (Parfitt 2009); thus, although the soil looks fertile because of its black humic content, much of that is bound to the colloidal clays where the humic and fulvic acids are not available for plant use. Dahlgren et al. (2004: 146) describe one way that allophane and other non-crystalline colloids in soil hinder organic matter decomposition: their high adsorption of P deprives micro-organisms from using it themselves so that they cannot act to decompose organic matter; the authors also note that carbon is also 'protected', with decreased rates of mineralization from C to CO_2. Phosphorus which is bound into these complexes is thus said to be 'retained' and not available for plant nutrition.

Al–humus complexes form preferentially in acidic soils, leading to the formation of non-allophanic andosols. These complexes perform the same function as the non-crystalline clays: adsorbing various metal ions and humic substances. In doing so, they stabilize the soil organic matter and 'protect' it from microbial decomposition, thus denying its use by plants (Takahashi & Dahlgren 2016). Andosols characterized by a predominance of Al–humus complexes exhibit the 'anti-allophane' effect of competition for Al between the humus and allophane, meaning that more Al-humus complexes will form rather than allophane. Non-allophanic soils have low base concentrations, high exchangeable Al content, and strong acidity – all of which contribute to Al-toxicity (Dahlgren et al. 2004).

The fact that there is a continuum between allophane/imogolite formation and Al–humus complexing means that local conditions will determine which direction and how much of each form. These different products have different dissolution rates, with allophane/imogolite dissolving more slowly than Al-humus complexes, with the ratios tending towards equilibrium (Dahlgren et al. 2004: fig. 9). However, both can be broken down by tilling, when the micro- and macro-aggregates of soil particles stuck together with these colloids are broken apart and the SOM is exposed to microbial action; dehydration may also promote microbial action which cannot take place while soil particles are saturated by water (Takahashi & Dahlgren 2016: 113), but with the loss of water-holding colloids, soil particle aggregates become unstable, leading to higher bulk density and less friability.

General Cropping

Different crops have different nutritional requirements so that one may grow in a regime that is unsuitable for another; both Neall (2006) and Uchida (2000) discuss specific crops grown on andosols in terms of deficiencies and some mitigation procedures, while Shoji et al. give a brief survey of worldwide agricultural tephras (1993: ch. 8.2). Today, Miscanthus stands in Japan are artificially maintained and form only a minority of growth on andosols. By recent accounts, 34% of Japanese andosols are dry-fields (*hatake*), 28% are in paddy (*suiden*), 22% is pasture, and 17% is orchard (NARO/NIAES 2010). These statistics indicate that at least 78% of these 'impoverished soils' have been overcome by intensive mitigation and are producing crops for human consumption.

Neall (2006) gives a general overview of what crops grow best volcanic ash soils of different countries and what deficiencies might develop due to local conditions. For example, iodine toxicity is common in northern and central Honshu in newly constructed paddies. Mg and S may limit grass growth on andesitic or rhyolitic soils; lack of mafic mineral elements may lead to nutritional deficiencies (Cu, Ca, Iodine, or Mb and F toxicity. A boron–B deficiency is noted for lettuce in Japan.

Surprisingly, some plants such as tea and buckwheat (in addition to hydrangea!) actually accumulate Al in chelated form; internal chelation is accomplished by various organic complexes (e.g. citrate, oxalate) and acts to detoxify absorbed Al (Yokel 2002). These plants may be said to be Al-tolerant, and it is no surprise that they are major crops grown on tephra-derived soils in Japan. Takahashi and Dahlgren (2016) report that higher levels of aqueous Al^3 in non-allophanic soils can protect against root rot in common bean and potato crops. Other Al-tolerant plants grown in Asia include wheat (*Triticum aestivum*, grown in Hokkaido), sickle senna (*Cassia tora*), soybean (*Glycine max*), and taro (*Colocasia esculenta*), while western Al-tolerant crops include rye, oats, maize, rapeseed, and snapbean (*Phaseolus vulgaris*) (Ma et al. 2001). These crops mainly exude organic acids around the root tips which then chelate Al and protect the roots. The tree, *Paraserianthes falcataria* (batay, Peacock's plume) indigenous to island Southeast Asia, is a pioneer species that is not only Al-tolerant but can fix nitrogen (Krisnawati et al. 2011).

Interestingly, flooding the soil in rice paddies dissolves P from its bound forms and makes it available for plant use – but this does not help in upland dry fields. One crop that is tolerant of low P levels is the sweet potato: as an introduced crop to Japan, it was farmed extensively in the volcanic soils of southern Kyushu to the extent that it is known by its regional name *satsuma-imo* (potato from the Satsuma Peninsula).

Tephra-derived soils, if sufficiently fertilized and fine-grained at depth, are excellent for long root crops such as the large *daikon* radish (mooli) and edible burdock (*gobō*) in Japan. The soils are light and fluffy, amenable to extensive cultivation of buckwheat (Figure 12).

More and more, 'precision agriculture' in either low-tech or hi-tech forms is being practiced. Low-tech involves recognising spatial differences in soil development (using lobate tephra fallout pattern and micro-climates) and applying specific fertilisers to micro-environments. Hi-tech relies on instrumentation such as "sensors, robots, GPS, mapping tools and data-analytics software to customize the care that plants receive" (Ling & Bextine 2017: n.p.).

Figure 12 Ploughed Andosol Field in Gunma Ready for Sowing Buckwheat
Buckwheat is used to make soba noodles, a Gunma specialty

Summary

This review, though not comprehensive, is indicative of what happens to tephra after its deposition on the Earth's surface, especially under the climatic conditions characteristic of Japan. Thus, the focus has been on andosol formation and use, but the story will be quite different for tephra in arid regions or the tropics.

Lesson 1: The soil types and clays formed from tephra vary depending on parent material, climate, altitude/slope, temperature, precipitation rates, and vegetation, etc. Thus, it is difficult to make a blanket statement about tephra-derived soils, and doubly difficult because their characteristics modify over time depending on changes in all the above variables. Investigation into prehistoric land use patterns must take account of or reconstruct the relevant variables in the time slice being dealt with, which may even have changed seasonally.

Lesson 2: Not all andosols are created equal, though they must qualify as 'andic' (Table 1) to be considered an andosol. Within this category, however, there are differences in colour (melanic vs fulvic) that reflect their genesis under the influence of burned grasses and forest cover, respectively; there are also differences in the formation of non-crystalline clays and Al-humus complexes, the former being typical of allophanic andosols and the latter of non-allophanic andosols. This is the basic difference in tephras that determines fertility and aluminium toxicity levels.

Lesson 3: We do not know enough about plant regeneration after tephra eruptions, particularly how humans dealt with the changes in soil characteristics and plant communities. The gross categories of responses to volcanic eruptions (extinction – abandonment – making do – recolonization) need finer evaluations in the latter two categories. More studies of off-site macro- and micro-botanical remains are needed to understand the timing of plant recolonization of tephra and the potential human use of the plants available or how crops are re-initiated in areas covered by tephra.

As for the kurobokudo soils of Japan, these melanic andosols are now known to have formed under grasslands which were generally maintained by periodic firing. The fact that they first appear at the same time as colonization of the archipelago ca. 40,000 years ago speaks volumes for the possibility of human manipulation of the environment using fire. Kurobokudo soils can belong to either allophanic or non-allophanic andosols, with far less potential for agriculture in the latter category. These melanic andosols have developed under grassland, but if not continuously maintained, the land is soon subject to forest encroachment.

We know a considerable amount about current cultivation practices in overcoming some of the deficiencies of andosols, but as yet we know almost nothing about relative problems in using tephra-derived soils versus non-tephrogenic soils in prehistory. The special conditions of rice paddy agriculture have been the focus of much archaeological work in Japan, with paddy field and irrigation complexes excavated at many sites. What we do not yet know is how tephra-covered uplands were integrated into the agricultural regime. Judging from statistics for 2007, despite the amount of land devoted to paddy fields (2.53 million ha) being slightly more than dry fields (2.1 2 million ha), paddy only contributed 22% of agricultural output in the form of rice, while dry fields contributed 25% in the form of other grains, vegetables, and fruits (MAFF 2008; MLIT 2008). If this is the case in a fully mature wet-rice agricultural system, then how were uplands exploited in pre- and proto-historic Yayoi and Kofun Period times[9] while wet-rice technology was being developed and expanded? At several archaeological sites, ridge-and-furrow plots have been recovered from underneath tephra cover (see Chapters 11, 12, 14). More detailed analysis is needed of the soils from these plots and the plant remains therein to assess dry-field agriculture in times of paddy-field reliance.

Before agriculture, we have the Palaeolithic and Jōmon peoples who seem to have managed their environments with fire in order to exploit the plants and animals that inhabited grasslands. The Jōmon are known horticulturalists who domesticated several species of plants, including the herb Perilla (*shiso*) and *hie* barnyard grass (*Echinochloa crus-galli* → *E. utilis/esculenta*), during their long habitation of the archipelago (Crawford 2011); middens have been proposed as the locus of initial domestication (Matsui & Kanehara 2006). But it is also suspected that late Jōmon peoples also cultivated buckwheat and dry rice, crops imported from the continent; where and how did they manage the soil and field systems for these crops? There are many questions to answer regarding the use of tephra-derived soils in prehistory, not least how grasslands were used for hunting.

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[9] See archaeological periodizations in Appendices A-2, A-3.

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Table 1 compiled from Obara et al. 2015; Imaya 2010; FAO-UN 2006: 42; Takahashi & Dahlgren 2016
Table 2 compiled from Shoji et al. 1993; Ugolini & Dahlgren 2002; WRB 2014; FAO-UN 2015 (quotes from p. 62); Takahashi & Dahlgren 2016
Table 3 compiled from FAO-UN 2015: 74, 84
Table 4 extracted from FAO-UN 2015: 35-6, 39-40
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Table 6 compiled from FAO-UN 2006: 70-71; Shoji et al. 1993: ch. 5
Table 7 compiled from Shoji et al. 1996.

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CHAPTER 14

Farming Tephrogenic Soils in Gunma: Before and After Volcanic Eruptions

NOTO Takeshi * & Gina L. BARNES **

Abstract

This chapter is essentially divided into two themes. The first deals with the nature of Japanese agriculture in general through time but with reference specifically to Gunma Prefecture, home to three active volcanoes. How agriculture developed and was carried out in this volcanic region makes for a slightly different history and practice than in many other parts of Japan. The second theme investigates how farmers in the region dealt with volcanic disasters – including ash and pumice fallout, pyroclastic flows, lahars and floods – through several periods. Many examples showcase resourcefulness and ingenuity in restoring fields to productivity or creating fields anew in areas devastated by volcanic deposits. Others illustrate why fields were abandoned or restoration efforts failed. Combinations of climate, seasonality, tephra type and depth of cover, in addition to social practices, political development, and civil engineering skills all determine the reactions of people to volcanic disasters at different times. This makes it difficult to predict future reactions, and the people of Gunma live in hope that no new disasters are imminent.

Introduction

The Japanese Archipelago extends from sub-tropical Okinawa through the temperate zone comprised of Honshu, Kyushu and Shikoku Islands to sub-arctic Hokkaido (Figure 1). It is an area of high humidity, so crops can be grown all year round as long as there is no snowfall. In the elbow of Honshu lies Gunma Prefecture, comprising the northwestern sector of the Kantō Plains replete with several active volcanoes: Mt Asama, Mt Haruna, and Mt Kusatsu-Shirane (Figure 2). The Toné River, having the largest drainage area of any river in Japan, encompassing the entire north Kantō Plains, flows from Gunma Prefecture. Many small tributaries flow into the Toné River, cutting complicated paths across the terraces and depositing the eroded terrace sand and gravel on both banks of the Toné – making for a complex topography.

FIGURE 1 MAIN ISLANDS OF JAPAN WITH TŌHOKU AND KANTŌ (CIRCLED) DISTRICTS

Archaeological investigations in Gunma have greatly progressed the various sub-disciplines of disaster archaeology relating to volcanic eruptions (including flooding), typhoons (including flooding), and earthquakes (including flooding). They have also revealed much information about farming practices, since Japanese laws require archaeological investigation of all land (public and private) that is to be disturbed in construction; this means that public archaeology in Japan is not site-oriented but includes great swaths of off-site areas which are often found to be farmland. Except for the *jōri* system of land-divisioning created in the 7th century and still

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existing in the landscape in many places today, it is axiomatic that field systems can only be known if they are preserved under tephra or flood deposits. Otherwise, constant tilling and/or field reorientation tends to destroy previous layouts. Thus, our knowledge of past agricultural systems is limited by both arbitrary temporal preservation constrained by nature, and arbitrary discovery, as construction sites are not chosen with archaeological targets in mind.

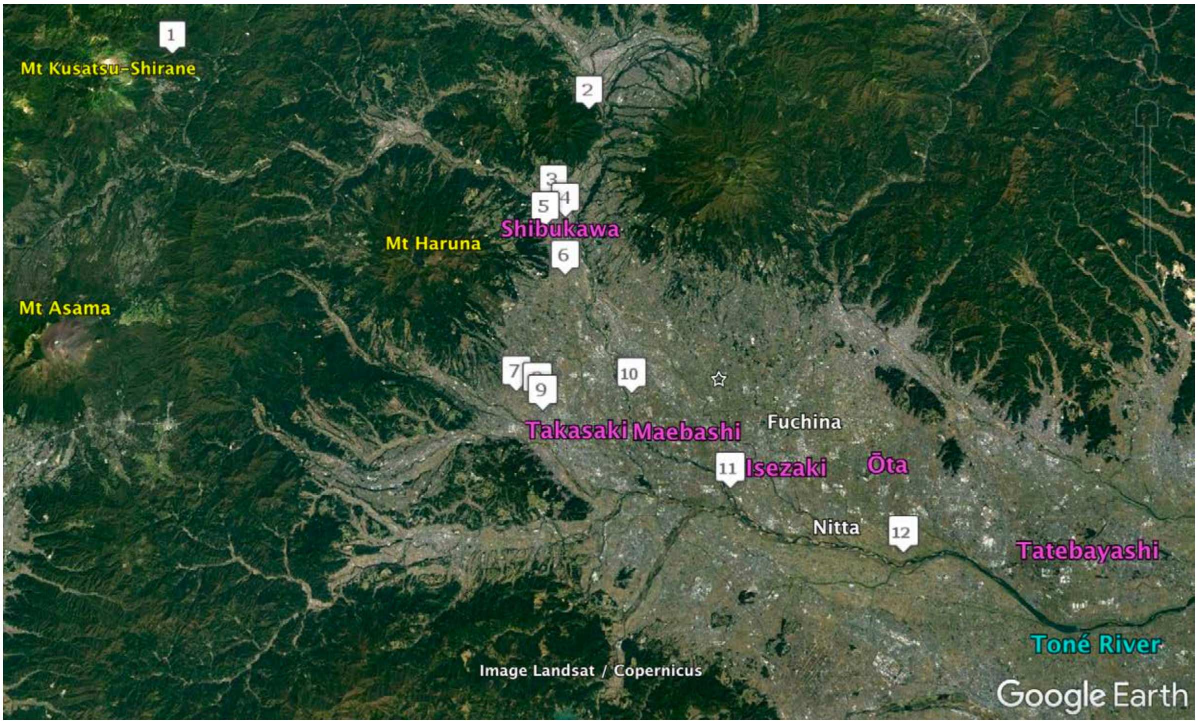


FIGURE 2 PLACES MENTIONED IN THE TEXT

Archaeological Sites (numbers), cities (red), volcanoes (yellow), and the major river (blue)

1 Kumakura	7 Shimo-shiba Tenjin
2 Shimo-kawada Hirai	8 Dōdō
3 Kuroimine & Nishigumi	9 Ashida-Kaito
4 Shiroi site cluster	10 Hidaka
5 Shimo-shinden	11 Miyashiba-mae
6 Arima	12 Mitsugi-Saranuma

Nevertheless, two field systems have been revealed in site stratigraphies: paddy-fields for growing wet-rice, and dry-fields for growing dry grains and vegetables. Wet-rice agriculture was instituted in the southwestern Kantō area from between 200 and 100 BC in the Middle Yayoi Period (phase III) (Kanagawa Kyōi 2012), and in Gunma Prefecture as known by being buried under Asama (As-C) tephra dated to the late 3rd century AD (Sakaguchi 2010; Barnes 2019). Wet-rice became the staple of historic society and eventually obtained throughout the Japanese Islands except Hokkaido. During the Yayoi (ca. 800 BC–AD 250) and Kofun Periods (250–710 AD) in general, paddy-fields were constructed on lowland alluvium, while dry-fields occupied higher ground on levees, terraces, alluvial fans, and footslopes. The soils of these two regimes are different and have divergent potentials for cropping. Much agriculture is conducted on alluvium and also lahar sediments; both are redeposits of upland sediments and are more nutrient-rich than tephrogenic soils (cf. Chapter 13). Furthermore, soils derived from volcanic ash differ from those derived from pumice.

In contrast to the fine divisioning of soil profiles created by soil scientists (Chapter 13: Figure 2), farmers in Gunma Prefecture are only interested in three types of 'soil' (here meaning sediments or layers): red earth (*akatsuchi*) – the original tephrogenic loam layers (cf. Chapter 2); the black humic soils (*kurotsuchi*) that develop on them to greater or lesser degrees; then among the black soils is recognized a third category, *kurobokudo*, the dark black but light and fluffy soils known as andosols. In Chapter 13: Figure 1, the Kantō region is seen to be included almost in its entirety within the distribution of allophanic andosols (*kurobokudo*); although this is generally true, there are black soils (*kurotsuchi*) in the area that are not allophanic because they are so young and have not had time to develop. The distinction between *kurotsuchi* topsoil and *kurobokudo* layers is the major one that farmers in upland areas are concerned with. In the lowlands, for farming on alluvium, the crucial factor involves the water supply, not soil type.

This chapter will investigate generally how tephrogenic soils in Gunma are farmed within the overall context of agriculture in Japan. First, we describe the separate wet- and dry-field systems, and then look briefly at the historic development of agricultural improvements in order to understand more about farming challenges in times before record-keeping began. In the final section, archaeological examples of field restoration or re-development through time will be given. These are important for learning how previous occupants of a high-risk area maintained their livelihoods through the ages.

Paddy-fields and Dry-fields and Their Products

Paddy-field technology in Japan was transmitted from either the Korean Peninsula or the China Mainland first to northern Kyushu, and its presence defines the Yayoi Period (Miyamoto 2017). There are some who maintain that dry-field agriculture developed independently in the Archipelago, but others who believe that wet-rice technology and dry-field crops were introduced together (Nasu & Momohara 2016, and references therein). Debates about agriculture in the preceding Jōmon Period (13,500–400 cal. BC) began early in the 20th century and are still continuing today among Japanese archaeologists (Noto 1987 and references therein; Kuwabara 2015; Kaner & Yano 2015). Previous reports of staple grains such as rice, wheat, barley, and buckwheat appearing in the Late and Final Jōmon archaeological records have been ranked for their accuracy, with few wholly accepted (Nakayama 2010). But these designations are now being superseded by grain impression/void identifications in pottery (e.g. Obata 2011, 2016; Shitara & Takashe 2014).

Jōmon peoples managed, cultivated, and domesticated several types of plants, ranging from sweet chestnut and lacquer trees to hemp plants, legumes such as soy and adzuki beans, beefsteak plants (Perilla, *shiso*) and barnyard millet (*Echinochloa utilis*). Some show size changes that relate to domestication processes (Obata 2011; Crawford 2011), and it is argued that chestnut seedlings were transplanted into the settlements (Suzuki 2016). None of these plants, however, became staples on which an agricultural society – with its attendant changes in calendric tasks, production of surplus, and craft specialization – could be founded (Bleed & Matsui 2010).

The introduction and expansion of wet-rice agriculture throughout most of southwestern archipelago occurred in several stages:

- Wet-rice technology was initially imported in the early 1st millennium BC as a coherent package with three necessary components: 1) techniques to build *short* irrigation canals to divert water from rivers onto nutrient-rich alluvial lowlands on both sides of a river; 2) techniques to build bunds to contain the irrigation water in the fields; and 3) techniques to make 'level cultivated fields' for growing rice. These conditions obtained at the earliest Yayoi sites such as Nabatake (Final Jōmon/Initial Yayoi)[1] in Saga Prefecture in Kyushu (Karatsu Kyōi 1982), though contemporaneous rice cultivation in areas further east

[1] But not in Late Jōmon at Nabatake, as originally stated in the excavation report.

(technically among Final Jōmon peoples) may not have benefitted from these facilities in their first manifestations (Nasu & Momohara 2016). By the time wet-rice cultivation began in the Gunma region in the Middle Yayoi Period (or possibly earlier), it was a fully developed technology as seen in Kyushu. The first paddy-fields excavated in the Kantō region were at the Late Yayoi Hidaka site (Gunma Kyōi 1982; Takasaki-shi Kyōi n.d.). These were situated in alluvium along a small stream. In 2018, Middle Yayoi paddies were excavated at the Ide site cluster (as yet unpublished).

• During the Kofun Period around the 5th century AD, new civil engineering technology for building *long* irrigation canals was transmitted again from the Korean Peninsula. This allowed for the delivery of water to terrace surfaces as opposed to alluvial flats, as at the Dōdō site discussed below. These engineering works depended on improved iron technology for making large iron tools such as spade shoes for digging in gravelly ground.

• In the Kodai (Nara~Heian) to medieval periods (i.e. 8th~12th centuries)[2], wetlands were drained to expand the rice-growing area; this required constructing drainage canals in addition to irrigation canals.

Several of these stages were precipitated by the immigration of refugees from the continent, particularly the Korean Peninsula, who were escaping from wars in their homelands. Not only peasants but craftworkers, aristocrats, and nobles took refuge in the Japanese Islands, bringing their knowledge and skills with them. Waves of refugees arriving at the beginning of the 1st millennium BC introduced wet-rice technology to the Islands (Miyamoto 2017); in the 4th~3rd century BC, they introduced bronze- and iron-working; and in the 5th and 7th century AD, their skills transformed elite crafts and state administration (Inoue 1990; Ueda 2013; Migishima 2006).

Paddy-field and Rice Types

Paddy-fields constructed under the initial technological scheme are referred to as 'wet-paddies' (*shitsuden*); these are paddies constructed on the alluvial flats and are moist all year round. Paddies on terraces or flat upland areas are referred to as 'dry-paddies' (*kanden*); these are paddies that dry up without irrigation (cf. Chapter 11: Figure 2).[3] Those that are constructed in wetlands are called 'wetland paddies' (*kyōshitsuden*) and must be drained to be viable. There are some *kanden* on sloped surfaces dating to the Kofun Period at the Shimo-kawada Hirai site in Gunma that may be predecessors of paddy-field terracing (GARF 1993a); these necessitated a source of water which came from natural springs. At least short canal construction was needed to bring the water to the fields, but the slope of the fields was very small (<10°). Constructing stone- or earth-walled terraces up steep slopes did not begin in earnest probably until the early 12th century (Heian Period), with the first written reference to them as *tanada* ('shelf' paddies) in 1338 (Katsuragi-chō 1983–2006). Such terraced paddy-fields are generally built on slopes greater than 10° (cf. Chapter 11: Figure 2). *Tanada* constructed on tephra can be washed away in typhoons, so not until walled terraces were built could slopes greater than 15° be effectively terraced; such terracing became widespread from the 15th century or so (Nakajima 1990).

Japanese people favour growing rice over any other crop and so will grow rice as a dry-field crop as well. This gives rise to the phrase *suiden shikō* (wet-rice preference) describing Japanese food preferences. Rice grown in paddies is referred to as wet-rice (*suitō*), while that grown elsewhere is dry-rice (*rikutō,* or more commonly, *okabo*). Since the Japanese favour rice, the flavour is very important; wet-rice is considered the tastiest, while dry-rice is not very flavourful. However, since even a little poor-tasting rice is preferable

[2] Period dates can be found in Appendix A2, A3.

[3] The latter term is somewhat unfortunate as it may be confused in English with dry-field agriculture; *kanden* are used mainly to grow wet-rice, while many other crops are grown under dry-field cultivation. Moreover, some *kanden* are used in winter to grow dry crops such as barley or vegetables. The terms dry-field and dry-paddy are not interchangeable.

to none at all, dry-rice continues to be grown. *Suitō* rice is eaten either as steamed rice (*uruchi*) where the grains stick together, or as *mochi*, made by pounding steamed rice into a sticky paste for making rice cakes. The difference between these depends on the relative ratios of starch types (amylose:amylopectin). Amylose accounts for 70–90% of the starch in *uruchi* but amylopectin is 100% of the starch in *mochi* (Anon. AIA n.d.). Analysts have determined that the most palatable 'stickiness' of rice in Japan is governed by the relative proportions of amylose and protein, the ideal ratio being 16.5% amylose and 6.0% protein (Iwama et al. 2009: 2-11); amylose percentages usually range from 15–35%, so this is the lower end of amylose inclusion. The more amylose in a grain, the drier and more indendent (non-sticky) the grains become when cooked. Dry-rice in Japan has an amylose content of 25%, making it less palatable; thus, *okabo* is mostly used these days to make *senbei*, savoury rice biscuits.[4]

Dry-field Agriculture

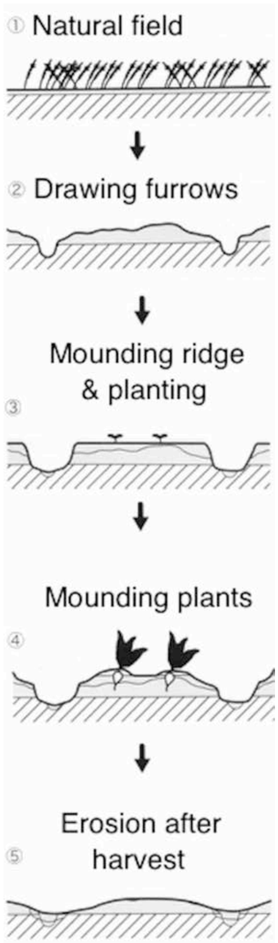
Until the introduction of wheat-farming under extensive agriculture regimes (*sohō nōgyō*) in Hokkaido in the 19th century (Iwama et al. 2009), dry-field crops were produced in very small areas near villages. Up into the Kofun Period, dry-crops were cultivated on upland riverine terraces; included were *mugi* (wheat/barley), barnyard millet (*hie*, *Echinochloa esculenta*), foxtail millet (*awa*, *Setaria italica*), common millet (*kibi*, *Panicum miliaceum*), soybeans, and azuki beans plus many vegetable varieties. When construction of long irrigation canals allowed paddy-fields to be opened on terrace surfaces in the Middle Kofun Period (5th century), dry-field cultivation moved upwards to slopes of less than 10°. These upland areas remained under dry-field cultivation as long as they were not near rivers that could be drawn on for irrigation water or as long as they were on slopes where paddies could not be constructed. Noto considers that the terracing of dry-fields probably began from the early 17th century in the Edo Period (1603–1868); such fields are referred to as *dandan-batake* (stepped dry-fields). None have been excavated for any period in Gunma, suggesting that the originals are still in use. Terracing in order to construct flat land, however, is not essential for growing dry crops, unlike the need to keep water level in paddy-fields. Figure 3 provides an idea of modern hillside farming without terracing.

FIGURE 3 HILLSIDE GARDENS IN THE YOSHINO MOUNTAINS, SOUTHERN NARA PREFECTURE

There is no archaeological evidence of unstructured dry-fields; however, from at least the Kofun Period onwards, garden plots that were tilled have taken a characteristic form of ridge + furrow (*une* + *unema*) that is still practiced today in vegetable gardening (Figure 4). The first stage of preparing a modern dry-

[4] Personal communication (October 2018) from Gunma farmer KURIHARA Taketsugu (b. 1944), who confirmed that *okabo* is not very palatable.

field every year is *sakutori*; this name may have been taken from the character *saku* (see Glossary) because of its shape 卌, as can be seen in Figure 4: right. With the incising of the furrows in the earth, the farmer has two choices depending on the desired crop. Bulbs, korms, and tubers can be planted within the first-dug furrows and then mounded over with earth to form a ridge with secondary furrows from the mounding activities on either side. Or the furrow can serve as drainage for earth mounded between the furrows to form ridges where seeds are planted. Half a month after planting on the *une*, furrows are deepened and more earth is mounded over the plants. In this way, the ridges *une* are the desired end product of field construction with the adjoining furrows a by-product.



Above: Seasonal sequence of field preparation

Upper right: Ridges formed with a spade evidenced by spade marks and deposits

Lower right: Various ridges in different planting stages

FIGURE 4 GROWING CROPS IN MODERN RIDGE-AND-FURROW GARDENS

The 927 AD *Engishiki* document quantified the requirements for growing vegetables in the Imperial Gardens (von Verschuer 2016: 16-20, 25-26). The crops grown on ridges *une* in the gardens were: soybeans, azuki beans, cowpeas, chives ('wild' and 'Chinese'), spring onions, ginger, melons, lettuce, mallow, coriander, colza, nothosmyrnium, aubergine, and taro. Obviously, many of these crops were delicacies, and von Verschuer comments that "The rural population may simply have sown soybeans by the wayside, on the rice-field ridges and in the cereal fields, as was done in the 17th–18th centuries" (2016: 27). It is interesting that barley was one of the crops grown in the Imperial Gardens, though not on ridges.

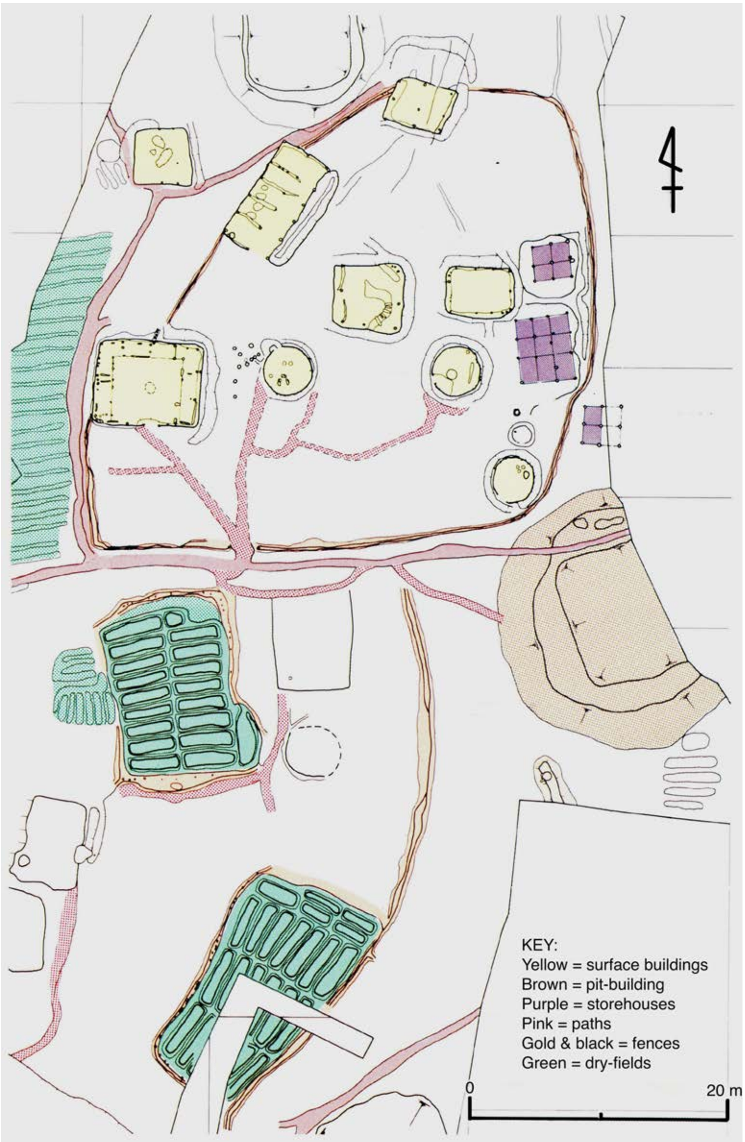


FIGURE 5 DRY-FIELDS AT NISHIGUMI SITE, GUNMA

Garden plots preserved under tephra at Kuroimine and Nishigumi sites (Figure 2: #3) are seen to cluster around houses within the village precinct. Both dry-field grains and vegetables could be grown on such plots, supplementing rice which would be grown in paddy-fields located in low, wet areas nearby. At Nishigumi, two kinds of *une-unema* field systems can be seen: one with long narrow ridges and furrows (Figure 5: upper left), and one of broader, shorter *une* separated by wider *unema* (Figure 5: lower half). Perhaps different types of crops were sown in these different structures: grains in the former and vegetables in the latter? Much more work needs doing to recover evidence of plant remains from these various dry-field systems.

Swidden vs Field Firing

Swidden Slash-and-Burn Agriculture

The 8th-century *Man'yōshū* poetry anthology contains a poem that von Verschuer thinks "seems to allude to direct sowing, without tillage, on waste ground" (2016: 27):

The millet that I sow on Sanatsura hill, even if my beloved's horse grazes on it, I will not say to him: go away

This may be a reference to swidden agriculture, as sowing on a hillside would logically require removing the natural growth first, with burning it a means to provide fertilizer. The idea that swidden agriculture (*yakihata nōkō*) was practiced in the early Holocene by Jōmon peoples is a product of ethnographical thinking after the post-war introduction of the concept of the Laurilignosa forest zone extending from southern China into western Japan by Nakao (2006) and Sasaki (1982, 2007) (Noto 1987: 18-21). By evaluating the socio-economic position of swidden in southeastern Asia as a "primitive" technique (even though it was practiced in 20th-century Japan), ethnologists naturally assigned it to the period preceding the introduction of wet-rice technology, considered the "real agriculture", in the Yayoi Period. This type of thinking ignores the complementary role swidden can play under various socio-economic conditions and in different periods.

The case study of Heian-Period Kumakura site below illustrates some of the problems in interpreting evidence for swidden in the archaeological record, but one must also take note of the observations of Gunma archaeologists who have noticed that Kofun-Period settlements seem not to have been occupied for more than one or two generations rather than having long stratigraphic development through time. They suspect that people might have been moving their village locations to open new dry-fields even though their paddies were permanently cultivated in the nearby lowlands. Whether this can be termed swidden agriculture is up for debate. It may have involved burning forest cover to fertilize the land, using the land for short cropping periods, and fallowing it to enhance forest regrowth – but, this technique, if it existed, was an adjunct to the mainstay of wet-rice agriculture and did not provide the only means of subsistence.

It is not unreasonable to think that swidden was practiced in pre-historic Japan, but it is a mistake to assume so without firm evidence. No examples have yet been discovered *archaeologically* that *unequivocally* illustrate swidden practices in early Japan. The historical texts from the Nara and Heian Periods, as reviewed in detail by von Verschuer (2016: ch. 2; quote on p. 133), did not deal outright with swidden but "implicitly acknowledged its existence in the administrative regulations" beginning in 701 AD. These particularly addressed the use of fire in burning grasslands for pasture and prohibited fires on sacred mountains and shrine grounds – presumably allowing them elsewhere. Table 2.1 in von Verschuer (2016: 134-135) catalogues vocabulary in the early historical texts and poetry anthologies relating to burning land, while Table 2.2 (2016: 139) catalogues the vocabulary and characters used to designate different kinds of dry-fields, including swidden, in the 10th to 12th century dictionaries. By that time, swidden was well established, as referenced in poetry, and by the Edo Period it was discussed in the agricultural treatises.

Two of the poems in the 8th-century *Man'yōshū* anthology refer to sowing *awa* (foxtail millet, *Setaria italica*) on hills or mountains; but von Verschuer notes that bracken is the most-often referenced plant in poems, described as collected from burned areas (2016: 148). In the 14th century, the land holdings of one shrine were listed as 50% paddy-fields, 40% swidden fields, and 10% permanent dry-fields; half the swidden fields were "idle", while the other half grew *awa* (foxtail millet, 67.9%), dry-rice (*no-ine*, 17.1%), soybeans (14.7%) and red beans (*azuki*, 0.3%). These were taxed crops, but barnyard millet (*hie*, *Echinochloa utilis*), taro (*sato-imo*) and yams (*imo*) were not taxed (von Verschuer 2016: 140). For the Edo Period, there are about 18 to 20 ethnographic examples of swidden in deep mountains (cf. von Verschuer 2016: 130-132). Thereafter, swidden was particularly practiced in the Inland Sea area up into the 1970s, and it is now undergoing a small revival in western Japan (cf. von Verschuer 2016: 124-130). Sasaki's map of swidden in the 1950s (1972: 23) shows it was practiced in northern Tōhoku, San'in, Shikoku, Kyushu, and even in the Kantō region (cf. Appendix A-1 Map).

Fired Fields

Swidden also brings Japanese soil classifications into the discussion, since swidden, like all dry-field agriculture, was carried out on upland soils, and many of these are tephrogenic. Today, almost half of dry-fields (NDHG 2015: fig. 1) are located on *kurobokudo* (黒ボク土) soil, the pyromes discussed in Chapter 13. Some pedologists and archaeologists take the view that *kurobokudo* soils began with Jōmon peoples making swidden fields, but the appearance of these soils far pre-dates the Jōmon Period. Hosono and Sase (2015) have identified two major epochs of *kurobokudo* formation: during the latter half of MIS 3 (57–28 kya), a generally warm period before the last glaciation (MIS 2), and MIS 1 (basically, the Holocene from 11.6 kya to the present). The early *kurobokudo* soils coincide with initial human occupation of the

Japanese Islands from ca. 42,000 years ago but are represented mainly in western Japan. The Holocene *kurobokudo* soils are particularly represented in Tōhoku and Hokkaido, where earlier development of such soils had been suppressed by lower temperatures. Hosono and Sase acknowledge that there are earlier black palaeosols, but these have not yet been proven to be *kurobokudo*; if they prove to be so in future, then the authors are willing to consider that *kurobokudo* can form under natural conditions, as already demonstrated by bamboo grasslands where trees are prevented from growing by strong winds. But the role of fire in their creation would still have to be demonstrated.

Though the *existence* of *kurobokudo* within human history in Japan is so attested, its *causes* and the *roles* it played in early societies is not clear. Forest fires (*yamakaji*) are a common occurrence during the Japanese winter, and possibly some of these fires were inadvertently caused by humans in the past as they are in the present. Fire is a crucial ingredient to *kurobokudo* formation, but swidden is not the only way fire is used intentionally in the uplands. Several other terms such as *hi-ire* ('setting fire') and *yaki-harai* ('controlled burning') are used for grassland maintenance (see von Verschuer 2016: Table 2.1 for historical terms). The uses of the grassland may have been for pasturage, or for allowing the natural growth of Miscanthus stands. In traditional Japanese agricultural villages, Miscanthus (*susuki*) was a valuable product, used dried for thatching roofs or fodder. Thus, *susuki* fields were considered as common-use areas (*iriai-chi*) for all villagers. If *susuki* fields were left unattended, they would naturally become re-forested; thus, annual fires were set to kill the tree seedlings and insects. As *susuki* regrew in the field, the area was often used for pasturage. This practice is only attested historically from the 12th century onwards (Yasuda 1959), but one possible example from the Kofun-Period site of Shiroi-Ōmiya in Gunma is described below.

In conclusion, it must be emphasized that *yakihata* (swidden) and *hi-ire* or *yaki-harai* (clearing by fire) are very different customs: *yakihata* was a means to open forested land and grow crops, while *hi-ire* aimed at maintaining Miscanthus fields keeping the hillside from regenerating forest, and finally, *yaki-harai* was used to keep fields cleared which were often used as pasture. It may be that prehistoric peoples practiced hill-firing for hunting purposes or to grow thatch for their pit-dwellings. This would not be unusual as fired fields have been documented wherever humans have intruded, especially clear in the case of the Maori in New Zealand as well as in Japan (Hosono & Sase 2015: fig. 4). Given the various uses and causes of upland fires, however, the presence of *kurobokudo* in and of itself cannot be taken as specific evidence of past swidden agricultural practices.

Kofun-Period Fire-cleared Pasture?

One possible example of field firing is at the Shiroi site cluster, inundated by mid-6th century Hr-FP pumice from the Mt Haruna eruption. It was discovered through a roadway pre-construction excavation, and as a transect, the excavation is divided into placename land units. The pumice fallout at the Shiroi-Ōmiya site preserved many horse hoofprints impressed in mud (GARF 1993b), so there must have been rain immediately before the eruption. The site area had land-division bunds which are inferred as belonging to a previous paddy-field system, but there were no ridge-and-furrow features indicating dry-field cultivation. Thus, the field was interpreted as pasture, perhaps fallowed paddy. Moreover, the hoofprints ranged over the entire area, including the bunds, walking in a random manner, indicating that the bunds were not confining movement in the field. According to the presence of both large and tiny hoof sizes, the eruption season was calculated as foaling season, May or June (Noto & Asou 1993).

In the site stratigraphy were identified three different black layers, 0.5–1 cm thick, containing charred plant remains, and some burned earth was recognized. Noto considers this as possible evidence that the field was burned (*yaki-harai*) to encourage new green growth as fodder for the horses; the field is estimated to have been fired once every ten years during the 30 years it lay fallow. Phytolith analysis on one macro-botanical remnant proved it to be Miscanthus; the stalk was only 30–40 cm long and so was in its early growth period in late spring.

At the nearby Shiroi Kita-nakamichi site (Noto & Sugiyama 2002), phytolith analysis at 916 sampling points across a field yielded evidence, in descending order of densities, of Miscanthus, Echinochloa, *sasa*, Oryza, and *mugi* (either wheat or barley) (Figure 6). *Sasa* (bamboo grass) covered the field fairly evenly. As a shrub that grows as a forest understory, it is interpreted as originating with the initial forest cover. Clearing the forest encouraged colonization by Miscanthus. Concentrations of Miscanthus phytoliths at certain spots is interpreted as representing stalk bases and root balls; by their size, it is estimated that the Miscanthus plants were at most five years old. The Echinochloa genus includes several weedy grasses as well as cultivars; these could not be distinguished as phytoliths. The random distribution and occasional clumping of phytoliths in the field suggest that they grew wild and were not intentionally planted. Both rice (*Oryza sativa*) and *mugi* (wheat/barley) phytoliths were very sparse, with the former concentrated on a path worn through the field; thus their presence is interpreted as deriving from horse droppings, especially by horses fed straw in stables and then led along the path.

These excavated fields from the Shiroi site cluster thus suggest a fallowing system that lasted up to five years in duration. During that time, the fields were used for pasturing horses, which could feed on the Miscanthus and Echinochloa that grew there naturally. Since the fields were preserved in this state by the thick layer of FP pumice, we do not have information whether these pastures were intended to be turned (back) into croplands at a later date.

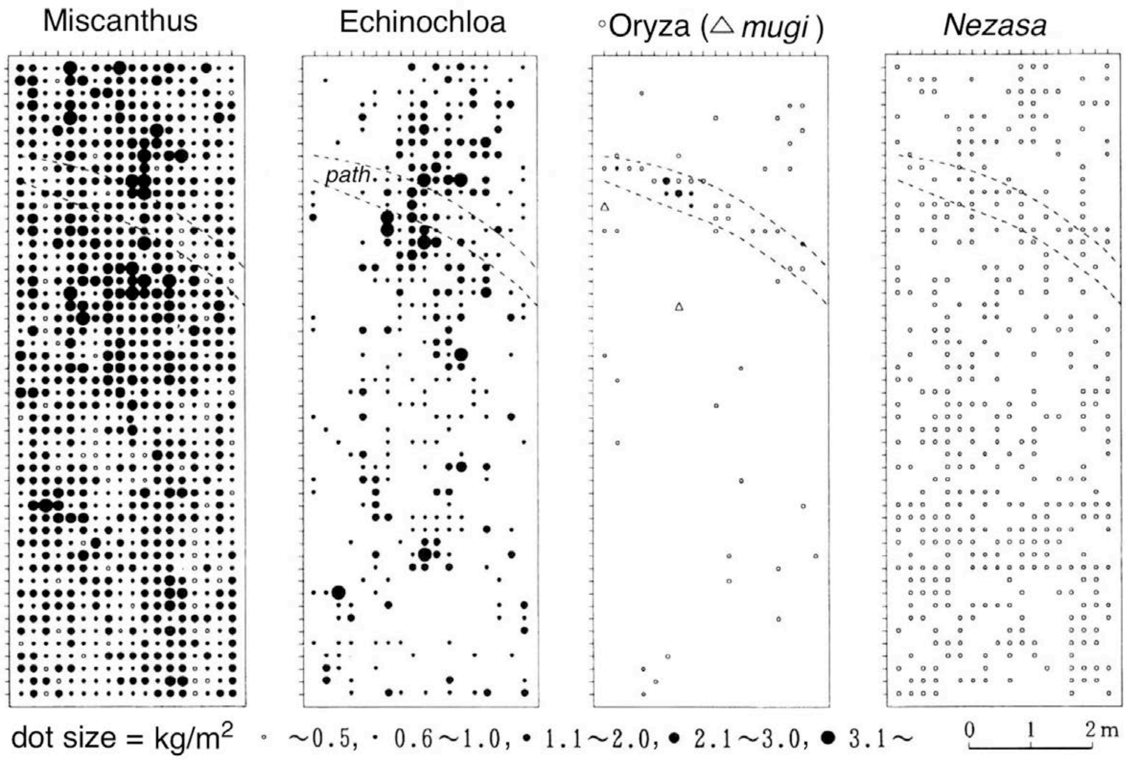


FIGURE 6 PHYTOLITH DENSITIES IN ONE EXCAVATED FIELD AT SHIROI

Rice (*Oryza sativa*) clearly clusters on the path, indicating horse defecation en route from being fed grain staw in stables. Other species are randomly distributed; *nezasa* bamboo was probably the original ground cover, invaded by Miscanthus and Echinochloa during use as pasture.

Swidden at Heian-Period Kumakura Site?

Divergent interpretations of the Kumakura site (Figure 1: #1) shed light on the difficulties in identifying swidden agriculture in early periods. Located in the deep mountains of Gunma Prefecture near Mt Kusatsu-Shirane, the site sits at 1140 m m.s.l. on gently sloping land (3°) of the eastern flanks of Mt Kusatsu-Shirane; this area was once completely forested in evergreen oak (*mizunara*, *Quercus crispula* Blume) and/or beech (Fagus, *buna*). The excavated site yielded several Heian-Period houses (Ichimura & Yamamoto 1984), occupied for one or two generations in the late 10th century; Kumakura is one of twelve or thirteen Heian sites dating between 950 and 1050 AD located in the vicinity of the volcano.

The stratigraphy of the site was composed of several volcanic ash deposits alternating with deep *kurobokudo* soils (Figure 7). Phytolith samples were analyzed from fourteen core locations, showing variable stratigraphic distributions of several Poaceae: bamboo, Miscanthus, and Paniceae (Figure 8). Paniceae tribe phytoliths (45% from seeds) were most evident in the surface layer (#1-1, 0–10 cm depth); they decreased rapidly with depth and disappeared two layers above stratum #4a which contained pumice identified as As-C (late 3rd century AD) from Mt Asama. The phytolith data above stratum #4a are unequivocally interpreted by the excavators as resulting from swidden agriculture by the Heian-Period inhabitants; the crop being grown is assumed to be *hie* (Japanese barnyard millet, *Echinochloa esculenta/ utilis*), which was also the modern crop being grown at the site but not in the area sampled for phytoliths. The phytolith analyst, FUJIWARA Hiroshi, also suggested that Echinochloa was being grown earlier in time (Fujiwara in Ichimura & Yamamoto 1984; Fujiwara 1987), as indicated by the same patterning if not same quantities

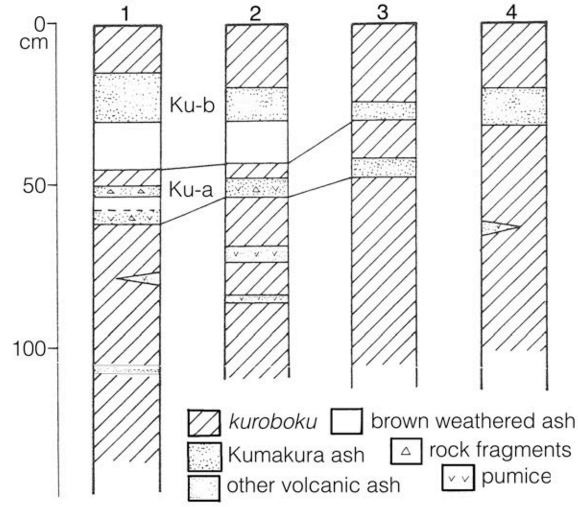


FIGURE 7 KUMAKURA SITE STRATIGRAPHY
Loc. 3 is at Kumakura site, Locs. 1, 2 & 4 nearby

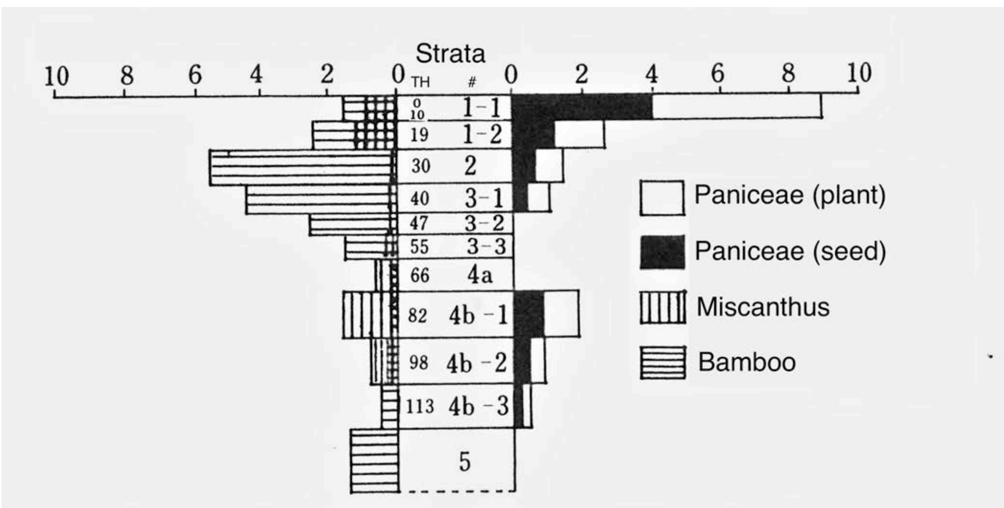


FIGURE 8 PHYTOLITH ANALYSIS FROM KUMAKURA #4 CORING
Right: Paniceae plant matter and seed phytoliths
Left: natural cover of Miscanthus and bamboo phytoliths

of phytoliths occuring below stratum #4a. This possibility is hotly rejected by the excavators (including Noto) on the grounds that 1) no earlier settlements have been found in the region, 2) no early ceramics are found at the site, and 3) it is not clear whether the Paniceae phytoliths came from cultivars or weeds. In the absence of clear archaeological data, the combined testimony of the ecology, the stratigraphy, the patterning, and the *kurobokudo* soils is thus dismissed. In favour of Fujiwara's interpretation are the understandings that *kurobokudo* soils are very likely anthropogenic, that burned areas may have been used for hunting or for growing thatch rather than cultivation, that if the Paniceae phytoliths cannot be identified to species level, then they cannot be used to surmise Heian-Period agriculture either. Of course, the Heian residents had to have some means of supporting themselves deep in the mountains, but one cannot apply a double standard to interpreting the upper and lower phytolith distributions.

Farming Upland Soils

Soil Varieties

FIGURE 9 NOTO & BARNES CONDUCTING FINGERWHORL TEST
Kurobokudo at Tsumagoi, Gunma,
ca. 1000 m msl west of Mt Haruna

Interviews with farmers in Gunma revealed they are not interested in nor concerned with formal soil classifications developed by soil scientists. Instead, they have an intuitive classification that informs on productivity. They distinguish between black soils (*kurotsuchi*) and red soils (*akatsuchi*); these essentially correspond to topsoil (Chapter 13: Figure 8 left, Horizon O) and parent materials (ibid., Horizon C). The black layers have exactly the same inorganic contents as the red parent materials but with the addition of decayed plant matter, loess deposits, alluvial wash, etc. They are considered 'immature' (OHKURA Toshiaki pers. comm. 23 Oct 2018) compared to a sub-set of the black soil category, *kurobokudo* (called *kuronoppo* in this region). While normal *kurotsuchi* is very good for cropping, within limitations, *kurobokudo* soils are avoided due to the disastrous lack of phosphate (P) (see Appendix D-3). These two soils can be distinguished by a fingerwhorl test: *kurotsuchi* is rather sandy when rubbed between the fingers (indicating the residual presence of volcanic ash) but can be rubbed clean off the fingers; *kurobokudo*, however, is so fine-grained and clayey (due to the conversion of volcanic glass into colloidal clays) that it enters the whorls of the fingerprints and cannot be wiped away (Figure 9).

In the Kantō region, the tephrogenic topsoil can be anywhere from 15 to 70 cm thick; the red sediments below derive their colouring from oxidation of the iron content. *Akatsuchi* is commonly referred to as 'Kantō loam'; it is not pure volcanic ash as some archaeologists think, but comprises a mixture of tephra, loess, and clay – best termed *kazanbaido* ('volcanic ash earth') (cf. Chapter 2). The volcanic ash may not be direct fallout but can be eroded from nearby barren volcano slopes to be deposited elsewhere (cf. Chapter 2: Figure 2). When organic matter is added to the *akatsuchi*, it becomes *kurotsuchi* with the same basic inorganic components. *Kurobokudo*, however, is lacking in volcanic ash because the glass component has dissolved, releasing silica and other elements from dissolved minerals (see Chapter 13). These are the ingredients for forming amorphous clay colloids and which can become fixed to humic acid complexes (cf. Appendix D-2). These not only deprive plants from taking up P as a nutrient but also 'protect' P from use by soil bacteria so that the latter cannot break down plant matter – one reason why *kurobokudo* soils have such high humic content.

In addition to the black and red soils, there is also white pumice, which discolours when exposed on the surface. Pumice layers in Gunma are alkaline, ranging from weak to middling values (pH 8–9). Both black and red horizons are acid (pH 4.5–6) due to the leaching out of nutrients in a heavy rainfall regime; acidity increases with yearly cropping because any alkali elements are taken up by the plants and removed from the soil, making it more acid in composition through time. *Kurobokudo* soils need seven times as much phosphate fertilizer to grow crops as regular *kurotsuchi* topsoil.[5]

It is generally thought that crops cannot be sowed directly on the *akatsuchi* loam or pumice; but this is exactly how the black soils began, with plants rooting in the tephra and the decayed remains of successive generations of plants then contributing to the build-up of the black soils. Chapter 13 describes the role of Miscanthus as an andolizer, critical in turning *akatsuchi* into *kurotsuchi*. This problem will be revisited below in relation to new tephra fallout. The deep humic profiles characteristic of tephrogenic soils serve as carbon sinks, with Andosols containing an average of 20kg/m^2 and Brown Forest Soils averaging 14kg/m^2, compared to less than 10kg/m^2 for non-tephrogenic red, yellow, and profile-less soils in Japan (NDHG 2015: fig. 1).

Crops can be grown directly on pumice under certain conditions. The benefits of growing crops on pumice include good drainage so that roots/bulbs/corms do not rot; and yet pumice itself is porous so that it contains much moisture that is available to plants. Because pumice is a rock, not a soil, it affords some protection against disease since, unlike humic soils, it has little or no micro-organisms. Vegetables with long roots such as *daikon* radish and burdock *gobō* are not suited to pumice; but those with round bulbous corms and/or shallow rooting systems, such as *konnyaku* (*Amorphophallus konjac*) or buckwheat do well. Buckwheat (*soba*, *Fagopyrum esculentum*) is an interesting crop in that it can be grown on soils with a poor nutritional component such as pumice; moreover, it has a short growing season, with grains being available 65 days after sowing. Its root system is comprised of a short (10 cm) taproot and "densely fibrous superficial roots" that are efficient in mobilizing and absorbing Ca and P (Bugg n.d.<1997). However, if it is grown on soils with good nutrition, energy goes into producing copious leaves and stalks, but the grains are few and small. Buckwheat is currently grown in large fields without ridges (cf. Chapter 13: Figure 12),[6] and it is now one of the major crops of Gunma, used to produce its famous local product, *soba* noodles.

How these soils/sediments relate to farming practices in the past is explored in the following sections.

Historical Practices & Archaeological Evidence

To understand past practices, some historical texts and a series of documents called *Nōsho* ('Agricultural Treatises') can be consulted; the latter are discussed in Tsukuba (1987). Especially useful are the *Engishiki* records (927 AD) directing the planting of the imperial gardens as discussed above (von Verschuer 2016). The first *Nōsho*, the *Seiryōki* produced between 1546 and 1629 (Mizunari 1980), provides a baseline for judging advances in agricultural technology. The *Seiryōki* was written by a daimyo in Awa (now Tokushima Prefecture on Shikoku Island)[7], based on Chinese agricultural knowledge and his own experience.

In the early Edo Period, agricultural manuals were written by the heads (*nanushi*) of agricultural works in a daimyo's domain; the *nanushi* were responsible to their daimyo for increasing the yields of the domain

[5] As related in an interview with farmer ŌSHIMA Kesahachi, age 86, Komochi-mura, October 2018.

[6] According to an interview with farmer GOTŌ Hisashi, age 71, Shibukawa City, October 2018.

[7] Prefecture locations are given on Appendix A-1 map.

and were in a position to give instructions and advice, sometimes through pictures or songs for illiterate farmers. In late Edo, 'experts' emerged among these *nanushi* and also independently; these experts wrote treatises to *preserve* farmers' knowledge rather than telling them what to do.

The earliest use of human excrement as fertilizer in Japan is much debated (Kyūma 2013). Special toilet features are known from the 8th century (Matsui 1992; Matsui et al. 2003), and anyone who has used such a traditional toilet knows it has to be emptied out periodically – or many successive holes dug (which are not found archaeologically). OHKURA Toshiaki of NIAES[8] (pers. comm. 23 Oct 2018) rightly points out that most people who live close to the earth will realize that manure deposits will increase floral growth. From that realization, it is a short step to using human manure in the fields. Kyūma estimates that the practice started sometime between the 8th and early 12th century, and by the late 16th century it had been incorporated into the agricultural treatises (2013: 85-6). In the Edo Period during the growth of the Edo urbanopolis, symbiosis developed between Kantō Plains farmers and night-soil purveyors.

The fertilizers mentioned in the *Seiryōki* were all organic: green manure (leaves and twigs), horse and cow manure, and wood ash. Others were included, but it is not known how widely they were used. However, once commercialized in the Edo Period, they became widespread: these included human excrement (night soil); chicken droppings; soybean and rapeseed pressings after oil had been extracted; compost (*taihi*) as opposed to green manure, made from Miscanthus or rice stalks processed through animal digestive systems; and fish. Two kinds of fish were commercially available: Hokkaido herring dried and ground into powder, and dried Kantō sardines. The latter were obtained from fisheries along the coasts of modern Chiba and Ibaraki Prefectures; while not ground up for shipment, they were certainly crushed before using. Both kinds of crushed/ground fish were sluiced onto the plants in water – rather than being buried whole as in some other cultures – because it was more economical. Nevertheless, a contemporary farmer in landlocked Shibukawa City, Gunma, stated that it was the practice through generations in his region to use whole dried herring and sea-oak kelp (Eisenia) for fertilizer.

Despite knowledge and existence of these various fertilizers, in fact they were not used very effectively during the Edo Period (Tōhata 1973). This was made clear in the Meiji Period (1868–1912) by the arrival of the German agricultural technician Max Fesca, who came to Japan at the age of 36 and stayed for 12 years (1882–1894) as a lecturer at the Komaba Agricultural School in Tokyo (formerly Edo) and was director of the Agricultural Division of the Geological Research Institute. Some consider Fesca "the 'father of modern Japanese agriculture' through his introduction of new farm implements, deep tillage methods, crop rotation and new seeds" (Anon. n.d., unpg.). Fesca is noted for his insistence on field studies and quantitative soil analyses – and for inspiring young scholars, though he met with considerable resistance among the 'experts' of traditional methods (Tōhata 1973: 103-108). One of three nationally famous 'experts' (*rōnō*) was FUNATSU Denjibei from Jōshū (Kōzuke) Province (now Gunma Prefecture). Unlike the other two famous experts, Funatsu concerned himself with dry-field agriculture as well as wet-rice. He taught at the Komaba Agricultural School between 1878 and 1886, overlapping with Fesca. Funatsu is said to have instituted many of Albrecht Thaer's "Principles of Rational Agriculture", and he devoted much effort to instituting high-yield mulberry crops for silkworm fodder (Tanaka 2013). Funatsu was thus instrumental in reviving silk production in Gunma, as related by Ma (2005), and mulberry trees were the major crop grown on the volcanic flanks from Funatsu's time into the 1980s when the silk industry in Japan collapsed.

Fesca's approach to discovering the nature of soils in different areas of Japan through testing and then mapping led finally to understanding the problems of soil acidification from continuous cultivation. Such soil testing is still undertaken periodically (Table 1), and local offices will test any soil brought to them by a farmer for advice on how to increase yields. The Dissemination Advice Offices operate on a district

8 National Institute of Agri-Environmental Sciences (NARO), Tsukuba

basis, somewhat like the Agricultural Extension Services run by the NIFA in the United States (https://nifa.usda.gov/extension). Acidification was cured by adding calcium carbonate $CaCO_3$ which replaced the alkali elements lost in leaching and plant uptake. In Japan today, dry-fields are limed at least once a year.

TABLE 1 ONE SURVEY RESULT FOR CATION EXCHANGE CAPACITY, AND BASE SATURATION IN GUNMA SOILS

Soil locations:	**pH**	**CEC in me*** **Ca2+, Mg2+, K+, H+**	**base saturation**
paddies	5.9	13.9	
hatake (dry-fields)	6.0	14.9	
kurobokudo (volcanogenic pyrome soils) >1000 m m.s.l uncultivated	5.1	30	
broad-leafed forest	5.3	24	27%
needle-leafed forest	5.6	30	50%
under cedar			
1. live needles in shrine grounds	5.9	35	67%
2. dead needles in shrine grounds or on *kurobokudo*	4.7	30	18%

* presumably milliequivalents (me) per 100 grams of soil, now usually notated as meq/100g, the measurement of Cation Exchange Capacity (CEC) = exchangeable base metals

By the mid-Meiji Period, therefore, the problem of yields declining from continuous cultivation was recognized, and advice drawing on Fesca's experience took three forms: 1) rotate crops, 2) add fertilizer, and 3) if unproductive, then leave fallow. Fesca was particularly concerned with the fertilizer problem: he noted that many farms did not have animals, and even those that did were not utilizing their manure to great advantage (Tōhata 1973: 130). This is exemplified by a calculation that 25,000 Gunma Prefecture villages maintained horses in 1894 (Meiji 6) versus only ca. 850 that had cows (NAKAZAWA Satoru pers. comm. 20 Sept 2018); from the Edo into Meiji Periods, these horses were used as pack animals in the northern part of the prefecture and (warrior) mounts in the south. None were used for milk or meat and only incidentally for fertilizer. Fesca encouraged the ploughing of fields using draft animals, which would naturally fertilize the soils en route, and the rotation system that developed under Fesca's urging included having cows or horses graze in fallow fields. Typically crops were rotated for three years and the field was left fallow the fourth year. This was still not ideal because 25% of the potential agricultural yield was not realized by having one-quarter of fields under fallow in any one year. The only way fallowing could be avoided was to dose heavily with P or introduce new soil into the field.

However, the problem of decreasing yields from lack of P was not yet understood in Fesca's time. These concerns apply mostly to dry-fields, as P-binding colloids (e.g. allophane) and humic complexes (cf. Chapter 13) tend to dissolve in irrigation water, releasing the phosphorus for wet-rice growth. In tephrogenic soils, such colloids and complexes have a lifespan of over 1000 years. By then they are buried deep in the soil profiles, because *kurobokudo* soil profiles increase upwards rather than downwards like non-andosol profiles. This impedes plant growth by making P unavailable to the dry-field crops – except on the exposed surface where oxidation and crushing may release some P. Crops planted on allophanic *kurobokudo* soils may give a reasonable yield the first year, but yields rapidly fail after that. On other andosols, Al-toxicity and Fe-toxicity are also a problem. Unproductive fields were known as *iyachi* (despised land) and may have been susceptible to these toxicities, exhausted through continuous planting or being water-logged.

Fertilizers

In the early 20th century, fertilizing with soybean cakes – residue from processing soybean oil – became highly economical as great quantities could be imported from Manchuria (Higuchi 2015). Soybean meal has "considerable amounts of phosphoric acid and potash, a large proportion of which is 'available', but it is principally valued in fertilizers as a source of nitrogen" (Piper & Morse 1923, quoted in Shurtleff & Aoyagi 2016: 751).

Other fertilizer techniques are attested in the *Seiryōki* (14th century); but prior to that, fertilizer is suspected to have been used, but from when is not clear. Arguments based on ethnographic analogy that special wooden *geta* sandals were employed to stamp green matter into prehistoric paddy-field soils are particularly popular (Kinoshita 1985; Terasawa 1986). In a present-day experiment (NDHG 2015: 88-89), AISAWA Akira collected evergreen oak leaves from a forest, composted them for two years and spread them on a paddy-field to calculate increased yields. The amount of green manure for one hectare of paddies was ethnographically determined to be 4.4 metric tons of leaves, or 3.7 t of compost, obtainable from one hectare of forest. He established four paddies: one to use the leaves directly, one to use the composted leaves, one to use modern chemical fertilizer, and one to go without fertilizer altogether. The relative yields of brown (unpolished) rice per hectare were 4.1±0.1 t, 4.0±0.1 t, 5.0±0.3 t, and 3.8±0.6 t. The green manured fields thus achieved 80–82% yield of the chemically fertilized field, while the unfertilized field achieved 75% of the latter. This was, however, lower than the national level of unfertilized field yields at 4.3 t (90% of chemically fertilized fields). Thus, farming with green manure necessitated equal acreages of forest and paddy, and the amount of fertilizer added was of considerable mass. It is unlikely that prehistoric farmers collected four metric tons of leaves every year to add to their paddies.

Excavated paddy-field soils at the Dōdō site discussed below have been found to contain considerable amounts of *sasa* (bamboo grass) phytoliths (Fujiwara 1983), presumably as part of the original ground-cover. But it is not clear whether *susuki* (Miscanthus) stalks and leaves were added intentionally as fertilizer or whether these also derived from the landscape prior to paddy construction. Paddy- and dry-field soils dating to the Kofun Period have yielded phytoliths of several bamboo varieties, but again, it is not clear whether these were added intentionally as fertilizer or whether they derive from the cleared landscape.

Excavations of the 6th-century Kuroimine and Nishigumi sites recovered building traces thought to be a partitioned stable block (Figure 5: upper middle); these were probably used for horses, since multitudes of horse hoofprints have been found preserved under tephra in Gunma but no bovine prints at that time. Whether or not the stable detritus was used as fertilizer, however, is not known. Green manure contains relatively little P compared to excrement, thus this would have been a great improvement (T. Ohkura pers. comm. 23 Oct 2018).

Crop Rotation

In either of the red and black soil types, planting continuously with the same crop in dry-fields results in soil exhaustion; paddy-fields, however, do not require rotation and can be cultivated continuously due to the nutrients provided in irrigation water. To avoid soil exhaustion in dry-fields, crops can be rotated through different fields each year, or some fields can be left fallow once every three years or so.

This is a worldwide practice, and it can be seen in some dry-fields of the Kofun-Period Shiroi site cluster discussed above (Noto & Sugiyama 2002; Noto & Asou 1993). As discussed above, plants growing in the fallow field at Shiroi-Ōmiya were used for horse pasturage, attested by multitudes of hoofprints in the soil; in return, the horse droppings probably fertilized the field for the next round of cropping. Miscanthus (*susuki*) root-ball traces were discovered in excavation; their large size suggests that the field was left fallow for five years as pasturage. At Shiroi Kita-nakamichi, rice phytoliths were found clustered on the path, presumably from droppings made en route from the stables. But both rice and *mugi* phytoliths were recovered from elsewhere in the field, suggesting that grazing took place in a fallow field.

Field Restoration

In this section we move on to a very different topic: that of human activities relating to field recovery after burial by tephra.

Dōdō Site Paddy-fields: Yayoi~Kofun

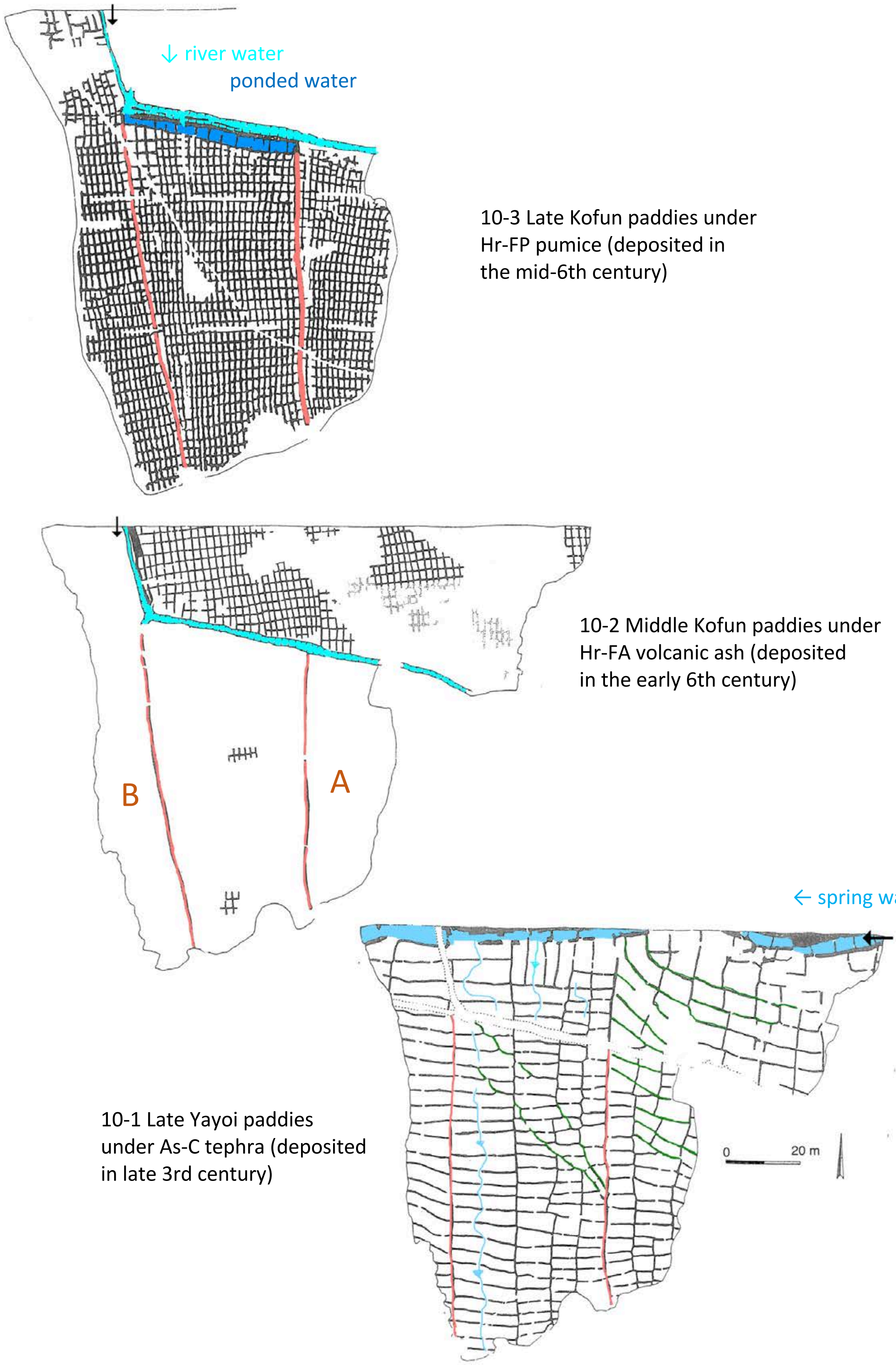
The excavated paddy-fields at the Dōdō site attest to rapid restoration of the fields after a tephra fallout. The method used was not to remove the tephra (though there is one example elsewhere from the Edo Period where that was done) but to rebuild the paddies in exactly the same location.

The Dōdō site is located off the edge of the Sōmagahara alluvial fan at the foot of Mt Haruna in Gunma. At this spot, natural springs emerge from the alluvial gravel of the fan once they hit the tephrogenic clay underneath. Excavations have revealed a series of paddy-field landscapes that have been stratigraphically preserved under three different tephra layers (Figure 10).

The lowest stratigraphic level of paddy-fields recovered in excavation were blanketed with As-C pumice from Mt Asama (Figure 10-1); once assigned to the mid-4th century, this tephra is now dated to the late 3rd century (Sakaguchi 2010; Takasaki-shi Kyōi n.d.) or even earlier (Yasui et al. 2018). In archaeological periodization, this would make these fields Late Yayoi in date. They were covered by ca. 15 cm of As-C pumice when excavated – or ca. 30 cm when newly fallen. The next stratigraphic layer of fields was preserved by tephra fall of Hr-FA, volcanic ash from Mt Haruna at the turn of the 6th century (end of Middle Kofun Period) (Figure 10-2). These were then buried by deep pumice fall of Hr-FP from Mt Haruna in the mid-6th century (Late Kofun Period) (Figure 10-3). Thereafter the area was abandoned until the early historic era when the paddy-fields were laid out according to the gridded *jōri* system; those fields were buried by the eruption of As-B tephra in 1108. The important thing to note about these field systems is that there was continuity in the layout of the field boundaries through the first three stratigraphic levels. These will be described in turn using their tephra cover as a time designation, e.g. ~As-C fields to indicate those buried under As-C tephra, ~Hr-FA for fields buried under the Futatsudake ash, and ~Hr-FP denoting those buried by Futatsudake pumice.

The ~As-C fields (Late Yayoi) are rectangular (some as narrow as 17 x 3 m) and are oriented with their long sides parallel to the irrigation canal which carries the spring water from east to west (Figure 10-1, arrow). Each of the fields has a water gate on its northern side, parallel to the canal, and water is drawn down through each column of fields towards the south. Some of the fields are oriented to sloped ground (northeastern section), and some accommodation of topographic disruption of the field layout can be seen in the central section (green lines). These are constructed on 5° slopes and so are not considered to be *tanada* ('shelf fields') There are two darker bunds beginning at the north and running southwards. These are the clues to understanding how the fields were rebuilt following the As-C pumice fallout.

The ~Hr-FA paddies (Middle Kofun) have a completely different orientation (Figure 10-2), but the darker bund (A) of the underlying field system is preserved in the new layout; the other major bund (B) can be seen to begin in the same place as before the Hr-FA tephra fallout, but it veers off course further south. This indicates that the bund (A) was visible for its entire length through the As-C pumice and served to anchor the new paddies in the landscape. There may be as much as a 250-year time difference between the ~As-C and ~Hr-FA paddies; thus, it cannot be ascertained when the ~Hr-FA field layout was instigated. But in order to have used the bund for reconstruction, reclamation of the area must have begun within three years of the As-C tephra fallout, otherwise the bunds would have eroded and become invisible in the landscape.



10-3 Late Kofun paddies under Hr-FP pumice (deposited in the mid-6th century)

10-2 Middle Kofun paddies under Hr-FA volcanic ash (deposited in the early 6th century)

10-1 Late Yayoi paddies under As-C tephra (deposited in late 3rd century)

FIGURE 10 SUCCESSIVE PADDY FIELDS (1–3) EXCAVATED AT DŌDŌ SITE, GUNMA

The system preserved under Hr-FA (Figure 10-2) is very different from that preceding it (Figure 10-1). The squarish fields are tiny by comparison (max 2 x 4 m), and the irrigation canal structure shifted to bring in water from the nearby river instead of the spring (10-2 arrow). Because these paddies suffered from water leakage, as they were constructed directly on the As-C pumice, more water volume was necessary and could not be supplied from the springs. Reasons for the small paddy size may have been to prevent erosion of the pumice through strong water flow from the river and also to slow the water speed to try to keep the water ponded. In the 19th century, one technique (colmatage) for building new paddy soils was to load topsoil into the irrigation canal which would then deposit the silt in the paddies, as discussed below; there is no evidence of this practice occurring earlier, but one hypothesizes that it might have been useful.

Only 50 years or so passed before the great eruption of Hr-FP pumice; the field system preserved under this tephra layer resembles the ~Hr-FA paddies with some modifications that suggest technological advances (Figure 10-3). First, the two main bunds are maintained in the field divisioning, but the shape and orientation of the paddies have changed: the fields are more rectangular and oriented with their short side to the canal (exact opposite of the ~As-C paddies). The irrigation canal drawing water from the river continued to function (arrow), but small reservoirs (dark blue) were constructed along the length to allow the water to pool before being sent into the paddies to the south. The entire area was divided up into smaller parcels of paddies (three districts are identified) and fed by multiple canals of the same nature.

A similar irrigation system was discovered at the Moto-Sōja site (Figure 11), under the Hr-FA tephra deposits of the early 6th century. The construction of the dam in Loc. A was presented in Chapter 11, but this figure reveals the entire situation whereby a very short canal was built to draw river water into a pond and then distribute it to small paddy-fields in the backmarsh beside the river, confined by earthen dikes (GARF 2013: 7). This excavation from under the Hr-FA tephra suggests that: 1) even in the 5th century AD, civil engineering works for irrigated rice agriculture were very limited in this region, requiring neither sophisticated technology nor large corvee labour groups; and 2) the landscape still determined the logistics of irrigated rice farming. Wholesale transformation of landforms under paddy agriculture were yet to come.

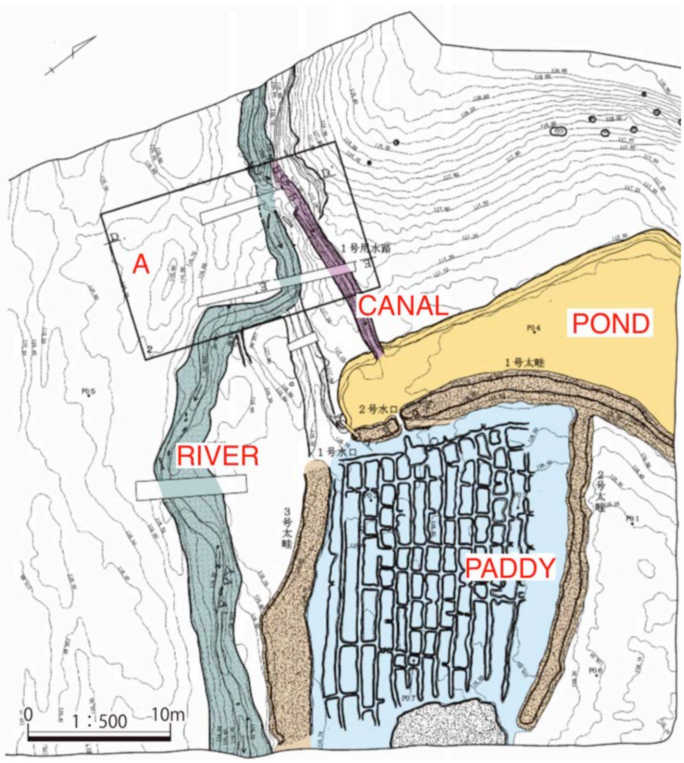


FIGURE 11 MOTO-SŌJA SITE PADDY AND CANAL SYSTEM (EARLY 6TH CENTURY)

Until the excavation of the Dōdō site, it was thought (following the Pompeii example) that farmland covered by tephra would have reverted to wasteland because it was so difficult to reclaim. However, the early Middle Kofun-Period ~Hr-FA paddies, which were constructed on As-C pumice, are a counter-example that clearly shows people were willing and able to devise ways to resuscitate their fields. Although Dōdō is located off the edge of the alluvial fan, it is still on sloped land, and the field orientations illustrate that the farmers were knowledgeable in using gravity to feed water into their fields when they were first constructed in the Late Yayoi Period. The good paddy soils of ~As-C fields had a clay base which provided a hardpan for keeping water ponded in the fields. The disaster of the As-C pumice fall must have exercised the farmers' ingenuity to provide enough water to fields constructed on pumice: pumice is extremely porous and lets water drain straight through it. To make reasonable paddy-fields, a base had to be laid that stopped water drainage. This might have been accomplished by adding upland soil, either directly into the paddy-field or into the irrigation water upstream, as seen in modern times on the Kurobegawa alluvial fan in Toyama Prefecture (Kagose 1952). This technique is referred to as *ryūsui kyakudo* 'flowing-water guest soil', a process known as colmatage in which "solid particles suspended in dispersing fluid [are] trapped in porous medium" (Litwiniszyn 1967: 1315). This same technique was used at the Ashida-Kaito site at the turn of the 6th century (Takasaki-shi Kyōi 1980). We can see the results of their efforts in the early Middle Kofun ~Hr-FA fields. Further advances were made after the Hr-FA tephra fallout, as seen under the Hr-FP tephra unit. However, this last pumice fallout of up to 2 m was the final straw that led to the area's abandonment until the early historic period.

Dry-field Ridge Reconstitution

Contemporaneous with the paddy-fields used to grow wet-rice, permanent dry-fields (*jōbata*) were constructed to grow a variety of vegetables and grains. As described above, these used ridged constructions. Excavations at the Mitsugi-Saranuma site in Isezaki City, Gunma (GARF 2000), have revealed clear evidence of such ridged fields from the Heian Period that were repeatedly flooded through over-banking of the Hayakawa River. The outstanding feature at this site is the construction of new ridges in clear relationship to previous ones (Figure 12), indicating the continued value of these field locations despite repeated flooding.

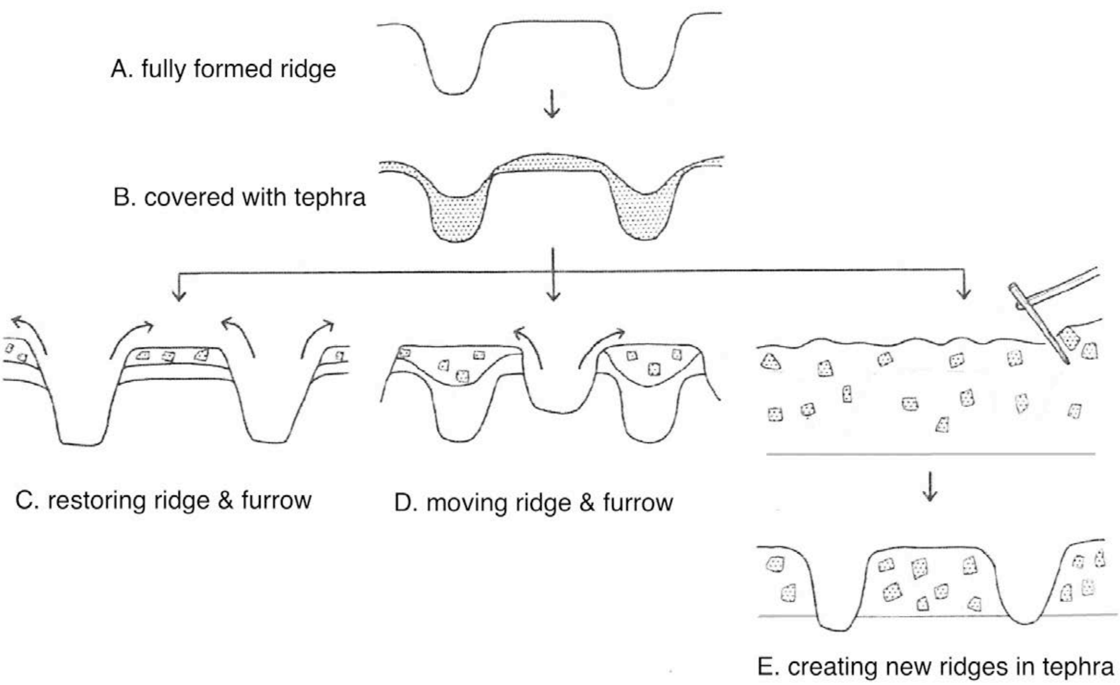


FIGURE 12 POSSIBLE STRATEGIES IN RECOVERING DRY-FIELDS AFTER TEPHRA DEPOSITION

Because the digging of new furrows at Mitsugi-Saranuma was oriented exactly on top of the old ridges (Figure 12-D), the excavators surmise that the flood deposits were not deep enough to completely obscure agricultural soil to be mounded over the flood deposits to create new ridges; thus, the stratigraphy shows the offset of ridge and furrow through time. As attested by the layering of fields, this recovery system was employed from the late 8th century through the early 9th century; correlation of strata from neighbouring sites revealed eight flood layers, though the Mitsugi-Saranuma site itself only has evidence of three. Nevertheless, from the datings of house remains within these layers, these field recovery techniques are known to have been used between the early 8th and early 9th centuries.

A similar technique also occurred earlier in Gunma in direct relation to Hr-FA tephra cover at the Shimo-shiba Tenjin site (GARF 1998). Site section drawings illustrate that the field of ridges was covered with FA ash, but that restoring the field involved digging out the furrows deeper and piling the soil from below on top of the ash. Thus, this disaster mitigation strategy was executed as a response to tephra damage but was later applied to flood disasters. The technique may have originated in a normal turning over of field soils as discovered at the Arima site in Shibukawa City (GARF 1990). There, ridges aligned with earlier ones had their soils renewed from digging the furrows out and mounding the soil on top of the ridge – a technique referred to as *unekae* 'remaking the ridges' (Kojima 2000: 513).

Heian Period Paddy and Dry-field: Divergent Reconstruction Histories

The 12th-century eruption of Mt Asama in 1108 deposited pumice over the entire Gunma plains area; proximal areas such as in present-day Maebashi and Takasaki Cities received 30–45 cm of pumice (excavated thickness 15 cm), while Ōta and Tatebayashi Cities in distal areas received ca. 10–15 cm (excavated thickness 5 cm). In reverse of expectations, paddy-fields in the proximal areas were reconstructed while those having less damage in the distal areas were not. The reasons were purely political, not technological.

The office of Kōzuke Province under the Ritsuryō government was located near today's Maebashi City. The governor duly sent notice to the Heian capital (Kyoto) about the eruption and damage to the tax-paying rice fields; instructions were sent back to have the fields immediately restored to productivity. The governor, however, was anxious to return to the capital himself after his 3-year term of service and was not keen to over-exert himself, so he just had the paddy-fields surrounding the provincial office restored and then sent a notice to Heian that work was completed. When an inspector came out from the capital, he was only shown the restored paddy-fields around the provincial office and returned satisfied with the work done (Noto & Minegishi 1989).

Restoring paddy-fields covered with pumice must have been facilitated by the visibility of the *jōri* land division bunds, marking off hectare squares, since the *jōri* field system is still evident on the plains of Gunma. However, with such deep pumice cover, there is the overriding problem of how one grows rice on pumice. Noto is of the opinion that they must have used a system of adding new topsoil to the paddies, either by hauling it in from elsewhere or feeding it into the irrigation water to be deposited as silt (the *ryūsui kyakudo* system described above). Pumice is very porous in two senses: it is large-grained so that water can drain freely through it, but pumice grains themselves contain voids that can hold moisture for plant use. Some plants, such as *susuki*, may be able to root directly in pumice, but rice requires at least three months of inundation by gently flowing water during the growing season; such ponded water is unlikely to be effected directly on top of pumice. Grown as dry rice, however, it might have been feasible, but the preference is always for wet-rice whenever possible.

The paddy-fields in the region of Ōta and Tatebayashi cities were left to the farmers' whim. Since dry crops were not taxed under the Ritsuryō system, most of the distal areas with light pumice fallout were converted to dry-fields. The Ritsuryō government not only lost income in situations such as this, it also contributed to its own decline by giving tax-free land grants to temples and nobles. This lowered its tax income in two ways, by signing over productive land to non-tax-paying units (*shōen*) and allowing farmers to escape to these tax-free havens from Ritsuryō-governed land. After approximately 30 years, with the decline of the Ritsuryō system and formation of new *shōen* run by members of the emerging warrior (*bushi*) class, the area around Ōta City came under the rule of the Fuchina-no-shō estate. In order to recover rice-growing lands that had been converted to *hatake* dry-fields after the Asama eruption, the rulers of Fuchina-no-shō embarked upon building a long canal, now called Onna-bori, across the landscape; however, their civil engineering was inaccurate and construction was abandoned. Since there was no water to feed new rice-paddies, the Fuchina-no-shō failed – but a neighbouring estate, the Nitta-no-shō, was successful in drawing water from the nearby Watarase River. The lands of Fuchina-no-shō were gradually acquired by Nitta-no-shō and other *shōen*, and they were resuscitated as paddy-fields, thus providing the rice-based income necessary for *shōen* operation.

Pre-modern Records of Pumice Clearance

After the Tenmei 3 (1783) eruption of Mt Asama, a lahar buried rice-fields under 50 cm of mud and rocks. Excavations at the Miyashiba-mae site, Isezaki City, Gunma revealed an extraordinary Edo-Period restoration procedure called *tenchi-gaeshi*, undertaken to "turn the earth over" within the known field boundaries (Noto et al. 2017). The rocks in the lahar made it difficult to reconstruct paddies on top of the lahar sediments, so the soil was renewed from underneath by digging successive parallel trenches down into the buried paddy soil and piling the sediments from digging one trench into an already dug and empty trench beside it. In this way, the top lahar mud was deposited into the trenches first, and the paddy soil from underneath, deposited last, became the new topsoil. This technique resembles that described above for the Kofun and Heian Periods but is totally different in intent: the former involved digging trenches to unearth previous topsoil for mounding on top of tephra to make new ridges, leaving the trenches to serve as the new furrows; the latter sought to bury tephra in newly-dug trenches, which when filled became the new ridges and the space between then became the new furrows.

All the paddy-fields revealed in the broadscale archaeological excavations at Miyashiba-mae were reconstructed in this manner, though the *tenchi-gaeshi* trenches within each field boundary were of different sizes and orientation. The patterning was due to the efforts of individual farmers who owned the land: it was their responsibility, as ordered by the regional daimyo administration, to rehabilitate the paddies to grow the rice for taxation. This reconstruction method was employed on lands held by the Tokugawa Bakufu government and so was applied to both 'government' and private land (Noto et al. 2017).

Excavations have also uncovered dry-fields which, being located in upland terrace areas, were not affected by the 1783 lahar but which received considerable pumice fallout (15 cm excavated thickness, probably 20–25 original depth). These dry-fields were reclaimed by digging the pumice into the existing soil. Various digging patterns (zig-zag, spirals) across the field extents are evident and again depended on individual farmer's inclinations. Land ownership maps for Kyōme-mura, Takasaki City, dating to Meiji 6 (1874) also clearly indicate that some farmers scraped pumice from their field surfaces and piled it up in field corners as *haikaki-yama*, 'mountains of raked tephra' (Noto 1989). There was also the option of removing the pumice from the field altogether and depositing it in another place. Thus, three options were available for reclaiming dry-fields: mixing tephra with the field soil; scraping it to one side within the field; or removing it from the field entirely. Which option prevailed depended on the land available, depth of the tephra, and incentives to work. In the Edo Period, since upland crops were often cash crops, and taxes were due in cash, it was in the farmers' best interests to bring the damaged fields back into productivity.

Summary of Restoration Activities

When settlements and fields were not entirely abandoned but efforts were made to reclaim fields and restore their productivity, technology was not necessarily the limiting factor. For even when restoration was technologically feasible, ideological and social/economic/political factors often guided or forestalled efforts.

In the Kofun Period at the Dōdō site, farmers were forced to reclaim paddy-fields and continue rice production by their overlords, as rice was the basis of their regional power. As much as possible, a local Kofun ruler tried to keep "his" farmers on the land, blocking their escape to an adjacent ruler's territory.

In the Ritsuryō Period (particularly Heian), the government was located much farther away than the proximity of previous local Kofun rulers. Moreover, many governors sent out from the centre (the Heian capital) were anxious to return to the capital after their tour of duty. Thus, if not interested in developing a localized power base, the governor did the minimum necessary to keep the central government inspectors happy and hasten both their returns to the capital. Thus, as seen at the sites around Maebashi and Takasaki Cities above, only the paddy-fields directly surrounding the provincial office were restored to productivity and shown to the inspector, while distant paddy-fields were allowed to be converted from growing rice to growing dry-field crops; those fields thus changed in terms of their land use categories from paddy-fields to dry-fields, with the latter requiring far less investment in capital and facilities (irrigation).

The rise of the *shōen* estates in the medieval period hastened the emergence of new local rulers. The *shōen* originally benefitted from tax-free status and provided a haven for farmers escaping the burden of Ritsuryō taxes on their land allocations. The *shōen* were run on their own abilities to produce rice within their territories. In order to open new land and create new rice fields, irrigation was necessary. In Gunma, the Onna-bori canal bears witness to such efforts by the new local rulers, unsuccessful though that endeavour was.

Summary of Farming Activities

A variety of historical texts – descriptions of the Imperial Gardens, tax registers, poetry, and Edo-Period agricultural treatises – inform us of farming activities and practices through time. Very few of these, however, deal with dry-field cropping and even less specifically with tephrogenic soils. Still, they provide a perspective on traditional agriculture in Japan that probably had its roots in late prehistoric times, as continental crops came to dominate the subsistence economy. These early texts can be contrasted with Meiji-Period innovations stimulated by German agricultural treatises; these Meiji innovations reveal what was lacking or insufficient in traditional methods – particularly in the realms of fertilizers and crop rotation systems.

There are still debates and disagreements among archaeologists about how far back in time to take traditional farming methods, and there is still a dearth of data that would answer these questions. For prehistory, it is still unclear what fertilizers were used, whether permanent dry-fields were intentionally left fallow, and if swidden was widely practiced. All these are logical for the time period, but we need firm evidence to understand exactly when, how, where, and why these practices came into being.

Excavations in Gunma and elsewhere (cf. Chapter 12) are providing essential information on the structures of prehistoric garden plots (*une-unema*), while ridge-and-furrow ploughed fields are often uncovered archaeologically (cf. Figure 5: upper left; also Chapter 12: Figure 9). The differences between these two field systems need further research into exactly what crops were grown in each, seasonally and year-by-year. It is fair to say that if swidden was not widely practiced, then tephrogenic upland soils were not brought into cultivation until terracing of rice fields began in the 12th century – or until commercial fertilizers came into wide use from the Edo Period. The native wisdom is that *kurobokudo* soils were historically avoided; it is now known that this was due to their acidity, their potential aluminium toxicity, and their lack of phosphorus.

Gunma was the first area where paddy-field remains were archaeologically excavated, at the Late-Yayoi Hidaka site, buried under Asama C (As-C) pumice of the late 3rd century. As elsewhere in the country, the paddies were constructed in the lowlands beside a stream, where water was easily available for irrigation. Subsequent excavations at the Dōdō sites, however, uncovered a structured Late-Yayoi field system in an upland position, fed with irrigation water drawn from a spring on nearby high ground. Thus major field divisions were maintained through the two Haruna tephra depositions in the Kofun Period, but the fields changed orientation and decreased in size. Water was drawn from the river instead of the spring, and later, water was pooled before distribution to the paddies.

TephroArchaeology has thus provided details of changes in agricultural activities through time in specific locations, inviting stratigraphic temporal comparisons. Such details of field recovery are generally absent in archaeological excavations unless sites have been repeatedly covered with tephra or floods, including lahars. We await more detailed plant analyses in future excavations to clarify the seasonal crops being grown in these different field systems and calculations of the substantial percentages of non-rice products relied on by pre-historic residents in these tephra-dominated landscapes.

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Figure & Table Sources

Figure 1 by GLB
Figure 2 Google Earth with Mapicons Maps Icons Collection https://mapicons.mapsmarker.com. Logo available at [https://mapicons.mapsmarker.com/wp-content/uploads/2011/03/miclogo-88x31.gif] CC 3.0 BY-SA
Figure 3 photos by GLB, 2008
Figure 4 line drawing after Takasaki-chō Kyōi 2018: fig. 14, modified by GLB; photos by GLB
Figure 5 after Komochi-mura Kyōi 1990: fig. 5, modified by GLB
Figure 6 after Noto & Sugiyama 2002: fig. 3, modified by GLB
Figure 7 after Ichimura & Yamato 1984: fig. 19, modified by GLB
Figure 8 after Fujiwara 1987: V-22, modified by GLB
Figure 9 photo by T. Soda, Oct. 2018
Figure 10 after Noto 2017: fig. 3-6, modified by GLB according to Noto's annotations
Figure 11 after GARF 2013: 7, modified by GLB
Figure 12 after GARF 1998: fig. 242, modified by GLB

Table 1 compiled from Yamada et al. 1985

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CHAPTER 15

Tephroarchaeology: Past, Present, and Future

Torill Christine Lindstrøm *

"Every end is a new beginning"
(proverb)

Tephroarchaeology has an interesting past, an outstanding present, and a challenging future. This book contains a collection of eminent chapters concerning tephroarchaeology. In this last chapter, before giving my own contribution, I aspire to give a short summing up some of the characteristics of the preceding chapters, their common cores, and their diversity.

Reflections

The topics in this volume range from a focus on important historical, theoretical and methodological considerations in the chapters by Soda (Ch. 2), Kuwahata (Ch. 3), Maruyama (Ch. 8), Horaguchi (Ch. 9), and Sakaguchi (Ch. 11); and instructive case studies by Oetelaar (Ch. 4), Fitzhugh, Funk and Bourgeois (Ch. 5), Murakami (Ch. 6), Pratt (Ch. 7), Maruyama (Ch. 8), Sugiyama (Ch. 10), Kuwahata (Ch. 12), and Noto and Barnes (Ch. 14); to minute details regarding volcanoes, volcanic activities, volcanic geology and the processes of transformations of tephra, lahar, pumice, ash and other volcanic aspects by Barnes (Chs 1, 13, Appendices A–D) and Machida and Arai (Appendix E). All these topics are essential for understanding the impacts of volcanoes and volcanic disasters from an archaeological perspective, and in particular the human adaptations to these impacts. Several authors conclude by stressing the importance, and simply the necessity, of interdisciplinary perspectives and research in tephroarchaeology. And indeed, the chapters in this book represent, and present, inputs from the following disciplines other than archaeology itself: natural history, human history, physics, chemistry, volcanology, seismology, genetics (DNA-analysis), osteology, botany, agricultural science, and psychology.

The Japanese archaeologist HAMADA Kōsaku saw Pompeii in 1918-1919, and was deeply impressed and inspired by it. The experience highly influenced his work. Although this volume focuses on tephro-archaeology in the North Pacific, the history of the field is deeply embedded in and influenced by studies and knowledge from volcanic events in other parts of the world. Comparisons between various cases are necessary to fully understand the individual cases.

Particularly in Japan, but also in other North Pacific regions, tephroarchaeology has a long history. As the chapters in this book show, all tephroarchaeological research obviously shares a traditional dependency on, and connection to, the 'hard' natural sciences (volcanology, seismology, geology, physics, chemistry and others). Yet, as general archaeology has developed and moved forward in the last decades, its connections to and uses of the 'soft' social and humanistic sciences (history, religious studies, literature studies, anthropology, ethnography, sociology and psychology), along with multiple methodologies, have developed and increased. This development in general archaeology is also highly relevant for tephro-archaeology.

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Several of the chapters in this volume have demonstrated that the impact of volcanic outbreaks and the human adaptations to such disasters are dependent on multiple explanatory factors. First of all, the kind and extent of a volcanic outbreak, the geological characteristics of the volcano and its surroundings, the geochemical characteristics of the tephra, but also the climatic zone and the season of the year are essential explanatory factors. The majority of the chapters address these issues, in particular regarding human long-term adaptation and responses to volcanic disasters. In these chapters 'responses' and 'adaptations' are to a large extent operationalized as a subsequent return to the affected areas, and with agricultural restoration and re-cultivation as indicators of successful adaptation – in contrast to an abandonment of the areas. Most of the papers that focus on restoration and continuation of agricultural subsistence as adaptation thus tend to focus on long-term adaptation, less on the immediate adaptation.

Yet, the concept *adaptation* has many meanings. In biology, it is an evolutionary process making organisms fit to their environment. It is an almost mechanical process at the interface of genes and environments. Contrastingly in the social sciences, adaptation involves voluntary, intentional behaviours, and means: "dealing with a situation", "finding ways to cope with a situation", whether it is a social or political situation, or as here, a natural disaster. Obviously, long-term adaptation is extremely important in tephroarchaeology, but short-term adaptation – the immediate human responses to volcanic disasters – is also important. Both immediate and long-term adaptations are dependent on multiple factors. Whereas long-term adaptations tend to leave considerable archaeological evidence, the ephemeral, immediate, short-term adaptations can (at least sometimes) be traceable in archaeological sites and findings, as some of the chapters in this book have compellingly shown. Such findings actually represent some of the more fascinating and telling findings in archaeology. The skeletons and plaster-casts of human and animal bodies in Pompeii (Italy) are famous. But also in Japan, fascinating footprints of animals and skeletons of animals and people are found, as described by Horaguchi and by Sugiyama in this volume.

In addition to the prominent and complex natural science geophysical aspects of a volcanic event, several chapters in this book also point to circumstantial factors of a human nature that contribute to explain the impact of volcanic events. Pratt mentions the possibility of governmental strategies for obscuring or denying the fact that disasters had happened, or even could happen. Pratt also mentions the importance of the symbolic value of volcanoes, both with regard to national identity and as religious symbols, and of volcanos regarded as divinities in themselves. Sugiyama also suggests the importance of religion in dealing with volcanoes. He describes the excavation of a man dressed as a warrior who apparently had tried to stop the volcanic impact by some kind of religious act or ceremony. And finally, I explain how characteristics of societies (but also of individuals) can influence the immediate responses in adaptive, as well as maladaptive, ways. These circumstantial explanatory factors (governmental, religious, and socio-psychological) show that insights from the 'soft' social and humanistic sciences can also contribute to our more well-established 'hard' natural science ways of understanding human adaptation to volcanic disasters. The various chapters in this volume convincingly demonstrate this, although, as should be, the emphasis of this volume is on the natural science side.

My contribution here concerns the socio-psychological circumstantial factors: peoples' immediate responses and adaptations to volcanic outbreaks. I present an elaboration of some social organizational and psychological factors that influence these immediate responses. I also present, sketchily, four examples where these factors are applied, in order to illustrate the differences in the human adaptation strategies.

Human Adaptation to Volcanoes

Why Do Volcanic Eruptions Have Such Different Consequences?

It is amazing how many people live close to, or in the vicinity of, volcanoes. And not only people. Many volcanic areas, both above and beneath the sea, are the homes of numerous species, plants as well as animals, fish and birds. The reason is simple: volcanic areas often abound with resources – resources that have developed over millennia and that are constantly renewed. Many volcanoes also produce resources such as mineral waters and hot springs. And although volcanic materials usually take long to disintegrate, over time they can provide fertile soil (Cronin, Németh & Neall 2008), although not always (cf. Chapter 13). But volcanic soils below the volcanoes Vesuvius in Campanian Italy and Etna in Sicily have given wine-grapes and wines that were famous in antiquity – and still are.

So, resources abound around volcanoes, but the price for living near them is to live under constant hazards, threats, and risks, although often hypothetical and distant ones. The most frequently occurring impacts of volcanoes tend to be more damaging than catastrophic, and more limited than total (Cronin, Németh & Neall 2008). This can easily create an attitude of "It won't happen in my generation!" – but sometimes it does. So to live in proximity to volcanoes is a paradoxical situation.

People have adapted to volcanic and concurring seismic threats and coped with disasters of varying magnitude for millennia, but in different ways for various reasons. Volcanoes are different, their activities and eruptions are different, their tephras are different, the landscapes and climatic zones they are in are different, and the human cultures affected by them are different. Finally, people respond differently to volcanic eruptions, both as cultures and as individuals. My focus here is party on social factors, but mainly on the emotional-cognitive responses as well as behavioural responses to perception of both potential and factual threats and risks, and responses to calamities when things happen. I feel that these aspects have not been elaborated sufficiently within archaeology, therefore this paper has a psychological twist.

I will explore some characteristic responses and adaptations, with examples from Kamchatka, Iceland, Pompeii and Santorini. The two latter examples are solely archaeological. The eruptions will not be described, as they are well known and described in detail elsewhere. Instead, the focus here is on the following psychological factors: risk perception, psychological defence mechanisms, coping strategies, and diffusion of responsibility within societies with their particular characteristics.

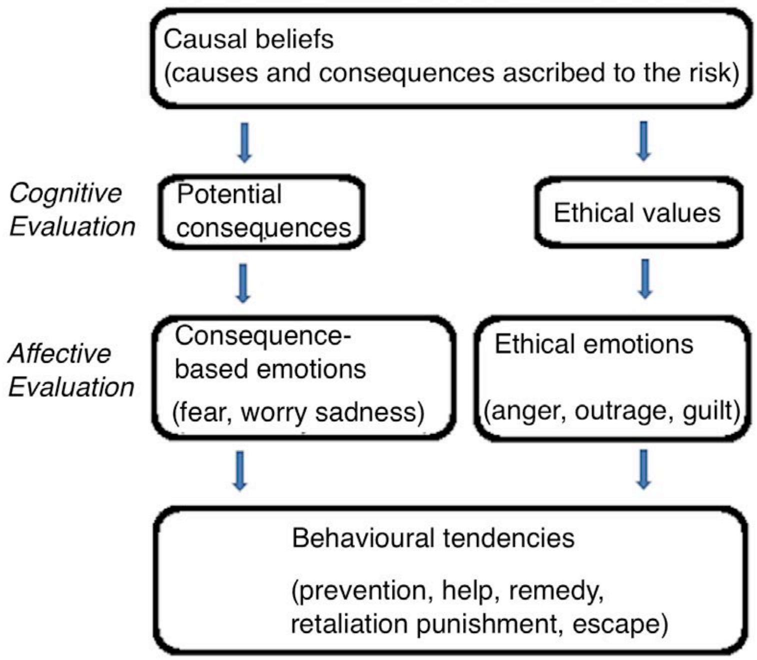
Risk perception

Signals and signs from volcanoes can be very ambiguous. What astonishes us is when people in prehistoric as well as present times have ignored signals of increasing volcanic activities. Psychological factors within individuals, as well as between them, may have played important roles – in addition to external factors of social as well as geological and geographic character.

Two bases for emotional evaluations in risk perception in relation to environmental risks have been identified in a number of investigations (Bassarak, Pfister & Böhm, 2015; Böhm & Pfister 2001, 2005; Pfister & Böhm, 2012) (Table 1). Unfortunately, this research is not focused on volcanic or seismic events and was conducted on modern humans. Yet it might still shed some light on how ancient people may have reacted to and responded to dramatic events, such as volcanic eruptions, in their natural environment.

Peoples' *causal beliefs* regarding risks or calamities, and the consequences ascribed to these, are essential to the cognitive evaluation of a situation. Dangers are believed to be either natural or man-made. Regarding volcanic events, beliefs – such as that supernatural forces (God, gods, divine powers) may cause eruptions – can also be part of the causal beliefs regarding environmental risks. Böhm and Pfister (2001, 2005) claim that if a risk is perceived as 'man-made' (caused by people), ethical values tend to be activated, and ethical emotional responses are more salient. I would here add that beliefs – that people have in some way enraged supernatural/divine powers (by sin, lack of service or sacrifice, etc.) and thereby provoked these powers – would elicit similar responses, putting both humans and divine powers as parts in a chain of causes and likewise of perceived risks.

TABLE 1 COGNITIONS, EMOTIONS AND BEHAVIOURS DERIVING FROM CAUSAL BELIEFS REGARDING RISK



According to Böhm & Pfister (2001, 2005), people tend to regard potential *consequences* as being more serious if humans and their property are endangered than when nature and other species are endangered. Regarding *ethical values*, questions about morality and responsibility are activated if people feel that humans in some way have caused the danger, either by themselves or, as I would add, indirectly by provoking supernatural powers that in turn could create calamities and disasters.

Relations between emotions and behaviours

These two evaluations – of consequences and ethical responsibilities – in turn lead to two basically different categories of emotions: consequence-based emotions (fear, anxiety, panic, worry, sadness, grief, desperation); and ethically-based emotions (anger, outrage, guilt, remorse). The former, consequence-based emotions, tend to lead to behaviours such as: attempts at prevention of damage; rescuing, helping, saving people, animals and objects; mending and restoration of property; and sharing. The ethical emotions can lead to blaming, revenge, retaliation, punishment – even self-punishment if the calamity was believed to be caused by one's own acts or failure to act (Table 2). Although these two categories of emotions are different, they may co-exist in the same persons, or in groups of persons, and oscillate over time (as emotions tend to do). They are neither mutually exclusive nor permanent. The important message here is that different beliefs regarding causality connect to different classes of emotions, and they trigger different behaviours. And conversely, different behaviours in the face of risks and calamities can be said to point back to different emotions and different cognitive evaluations of the risks – at least to some degree, considering that there is always considerable variability in human cognition and behaviour. Note that in the following table, both sets of emotions can be present simultaneously and oscillate. Therefore, both sets of behaviours may occur.

TABLE 2 RELATIONS BETWEEN EMOTIONS AND BEHAVIOURS

EMOTIONS:		
CONSEQUENCE-BASED EMOTIONS:	VERSUS:	ETHICS-BASED EMOTIONS:
(fear, panic, worry, sadness, grief…)		(anger, guilt…)
↓		↓
BEHAVIOURS:		
RATIONAL BEHAVIOURS:	*VERSUS:*	*IRRATIONAL BEHAVIOURS:*
(prevent danger, evaculate, help oneself and others)		(blame, retaliation, punishment of self, own group, others)

In a sense, one could claim (and complain) that this model takes for granted a certain self-determination in people, agency and a freedom and choice of action. However, we know that that is relative. Yet, it seems reasonable to assume that consequence-based emotions will lead to more rational and constructive action-oriented behaviours than the ethically-based emotions – also when volcanic eruptions are concerned. But a necessary condition for risk perception is that the risk(s) and threat(s) actually are perceived. Unfortunately, that is not always so.

A serious problem is: What can disturb and prevent people from performing rational, adaptive behaviours? There are, of course, many external, contextual restraints that put limitations on human agency confronted with volcanic eruptions – such as geographical, physical, cultural, and social restraints – and these will be commented upon. But the focus here is primarily on internal, psychological restraints of various kinds. As *psychological factors that can disturb and prevent adaptive behaviours,* I suggest: defence mechanisms, non-adaptive coping strategies, and diffusion of responsibility. As *promoting factors,* I suggest: coping strategies.

What May Disturb and Prevent Versus Promote Rational Behaviours in Reactions to Volcanoes?

Defence

When facing real or imagined dangers, people often respond with psychological defence mechanisms. The defence mechanisms, first elaborated by Anna Freud (1993 [1936]), are listed differently by various authors, but commonly recognized are: denial, displacement, intellectualization, projection, rationalization, reaction formation, sublimation, suppression, regression, and repression. Defence mechanisms imply that negative things, such as signs of danger, are not perceived realistically, and therefore not responded to in adequate and adaptive ways (Table 3).

Sometimes people may have stayed rather close to volcanoes and delayed evacuating during eruptions if some or several of these defence mechanisms were at work: denial, intellectualization, reaction formation, repression or suppression (see Figure 3). What they all have in common is an irrational denial and reformulation of potential threats, instead of doing something to avoid or escape them. People tend to "defend" themselves against feeling fear by saying to themselves, and to others, that there is no acute, imminent danger. For instance: “There is always smoke from the volcano and now it is just a little more”, or: “The shaking in the ground is just a subterranean god moving”. And they could ignore that birds and animals fled and focus instead on everyday issues and chores. The signs of danger would be ignored.

TABLE 3 DEFENCE MECHANISMS IN REACTION TO VOLCANOES

• DENIAL	Deny that there may be dangers
• INTELLECTUALIZATION	Explain away danger-signs “intellectually”
• RATIONALIZATION	Explain away danger-signs “rationally”
• REACTION FORMATION	Define the volcano as benevolent
• REPRESSION	Push thoughts of danger out of mind
• SUPPRESSION	Similar as repression, but consciously

Coping

Coping strategies are defined as the opposite of defence mechanisms – as adaptive and positive. As defence mechanisms imply a distortion of reality and therefore hamper adequate action, coping strategies, contrastingly, usually lead to adequate adaptive action. Coping strategies are rational, based on reasonably correct perception of and interpretation of stimuli in the environment; and the ensuing behaviours are consciously chosen and willed (Folkman & Lazarus 1984, Lazarus 1999; Ursin & Eriksen 2010; Ursin & Hytten 1992). Coping strategies are commonly classified as: problem-focused, emotion-focused, and avoidance-focused (Table 4). Yet, defence mechanisms may intricately interfere with good coping strategies and problem-solving. And some problem-solving strategies, although recognized as adaptive and functional in the particular culture, must be classified as magic and wishful thinking, being ineffective and actually disturbing adequate action. An example is to perform human sacrifice in order to stop a volcanic eruption or earthquakes, as apparently was done in Crete (Musgrave, Neave & Prag et al. 1994), or self-sacrifice as seen in Japan (Chapter 10). But even then, one could say that the signs of imminent danger were at least perceived and recognized, and some action taken – although magical and ineffective.

TABLE 4 CLASSES OF COPING STRATEGIES IN RESPONSE TO VOLCANOES

AVOIDANCE-FOCUSED COPING:		
	Non-adaptive:	postpone taking action, delay
		defence mechanisms (deny danger)
	Adaptive:	get away, evacuate
EMOTION-FOCUSED COPING:		
	Non-adaptive:	dampen emotions caused by perception of danger
	Adaptive:	emotional recognition & control, altruism
PROBLEM-FOCUSED COPING		
	Non-adaptive:	magic “problem-solving” (sacrifice)
	Adaptive:	adequate evacuation
		helping, co-operative behaviours
		realistic return- / migration-behaviours

Diffusion of Responsibility

In addition, there is the well-documented socio-psychological phenomenon of diffusion of responsibility (Darley & Latané 1968; Leary & Forsyth 1987), also called "the bystander effect". This phenomenon also represents a serious hindrance to adequate, adaptive action. Diffusion of responsibility means that people are less likely to take problem-solving coping action when others are present, assuming that the others are either responsible for taking action, or already have done so. The other persons' lack of action may even be interpreted as a safety-signal. Particularly in hierarchical social structures, societies and contexts, people tend to wait for orders by their superiors or leaders. And they might even risk punishment for taking "private initiative" - for instance to evacuate. So people tend to think: "When nobody else flees, why should I?" And in particular: "Why should I leave my valuables and my animals, so that those who remain may steal them?" Or: "I cannot leave my old parents, and they are not very mobile." And: "Let us wait until the king/chieftain/priest/boss/patron/superior/political-leaders/who-ever-is-in-charge tells us to evacuate". Such considerations might be rational, but not always.

Adding External Factors, and Summing up Factors Influencing Adaptation

As mentioned above, my focus here is on what I call 'internal factors', that is: psychological factors. But there are of course also external factors, from geological aspects to cultural ones, that profoundly influence how people respond to volcanic eruptions (Table 5). These external aspects have been thoroughly elaborated upon by others (Cashman & Giordano 2008; Cronin, Németh & Neall 2008; Németh & Cronin 2009; Harris 2015 [2000]; Pendea, Harmsen & Keeler et al. 2016; Sakellarakis & Sapouna-Sakellaraki 1981; Sheets & Grayson 1979; Tweed 2012), by the authors in this volume, and many more.

TABLE 5 FACTORS THAT INFLUENCE ADAPTATION TO VOLCANIC ERUPTIONS

INTERNAL, PERSONAL, INDIVIDUAL FACTORS:		
		defence mechanisms
		dysfunctional coping
		diffusion of responsibility
	Contrasting with:	
		realistic and functional coping
EXTERNAL CULTURAL, COLLECTIVE FACTORS:		
		sedentary living and local subsistence
		social restraints (loyalty, slavery, hierarchical society, belief systems)
		individualism
	Contrasting with:	
		nomadic, or more mobile life and subsistence
		fewer social restraints, more egalitarian society
		collectivism
EXTERNAL, GEOGRAPHICAL AND CLIMATIC FACTORS:		
		limited space, nowhere to go (islands, densely populated areas)
	Contrasting with:	
		available land to escape to and move to

Some authors have actually discussed the combination of internal and external factors, but then with the 'internal' factors being anthropological rather than psychological ones (Cashman & Giordano 2008). Here, I will draw attention to some selected keywords regarding external, cultural, and collective factors, such as:

• Life-style: sedentary living and local subsistence versus nomadic or more mobile life and subsistence.

• Social conditions: social restraints (caused by: loyalty, slavery, gender roles, belief systems and hierarchical social structures) versus fewer social restraints and a more egalitarian society; and individualism versus collectivism.

• And then there are external, population factors and geographical and climatic factors, such as: limited space, nowhere to go (islands, densely populated areas, conflicts with neighbouring groups or peoples) versus available land and friends to evacuate to and perhaps even move to.

There are also other aspects about human culture that can influence how people take action when facing a volcanic eruption. People with strong community ties and little chance of getting help from their government or leaders have been reported to show more resilience to volcanic eruptions than those who were less connected to each other (Sheets & Grayson 1979; Cronin, Németh & Neall 2008; Németh & Cronin 2009; and Chapter 8 herein). People in cultures with permanent residences tend to be more reluctant to leave their home, property, and valuable objects than people who live in nomadic or semi-nomadic cultures. Nomadic peoples are used to moving and transporting their belongings. The former are also more likely to return or try to return to their former areas, even though their habitat has proven to be insecure – particularly if their subsistence is dependent on those areas, if their culture defines valuable private ownership to land, and if there is a large population pressure on land – all factors that nomads are less restrained by. Cultures attributed to be more 'complex' and 'advanced' than nomadic cultures tend to suffer more damage both on a personal and a cultural level during and after a volcanic eruption. Now, given these premises, we shall have a quick look at four examples. The last two are archaeological cases and will be more elaborated.

Examples

Kamchatka, Russia

The Kamchatka Peninsula has ca. 160 volcanoes (e.g. Figure 1), of which 29 are regarded as active. Earthquakes and tsunamis are also frequent. Kamchatka has mainly a sub-arctic climate, and the areas are vast. Kamchatka was possibly first populated after the last glacial period 9000–10,000 years ago but may have been populated earlier. The populations are small, with many people living nomadic or semi-nomadic life-styles. Volcanic eruptions, although frequent, seem not to have had large-scale impacts on these cultures, as the populations can relatively easily migrate and re-locate themselves in new areas. What is surprising, however, is that even after nature has restored itself in

FIGURE 1 KORYAKSKY VOLCANO ABOVE PETROPAVLOVSK-KAMCHATSKY, RUSSIA

the affected areas, after plants and animals have returned and were firmly re-established in the affected areas, the human populations continue to shun those areas for 500 years or more before they return.

The relatively independent tribes with relatively flat social organizations, having large areas to move to, apparently have no 'reason' to use defence mechanisms to deny dangers, and therefore may be more likely to perceive risks adequately and to use adaptive coping strategies and take action: evacuate when danger arises and avoid the affected areas afterwards. By living in small groups, an action-laming diffusion of responsibility is less likely to happen.

We may conclude that the peoples in Kamchatka seem to have rational risk-perception, show little or no psychological defence, little or no diffusion of responsibility, and use adaptive coping mechanisms.

Iceland

FIGURE 2 EYJAFJALLAJÖKULL ERUPTION, ICELAND

Iceland also has many volcanoes, but compared with Kamchatka, there are fewer active ones in relation to area of land. Also, the population is small and the areas vast, and most of Iceland is unsuitable for agriculture. The landscape and soil is volcanic, and Iceland lies further north than Kamchatka and has a subpolar oceanic climate. Iceland was first populated in the 9th century AD. Farms are spread out, hay is the major crop, animal husbandry prevails, and livestock (mainly sheep and horses) graze outdoors all year round. Fisheries are also a major source of subsistence. Because of the small population and the graze-land farming and fishing subsistence pattern, relocation has been a relatively easily available coping strategy for populations affected by volcanic outbreaks.

Iceland has always been a democracy, with a population having close ties and helping networks among farms and communities despite the often long distances between them. Also, the flexibility in society and subsistence gives little 'reason' for psychological defence mechanisms, providing more potential for adequate risk perception and adaptive coping strategies. As groups are small and everybody knows their neighbours, a laming diffusion of responsibility is less likely, and helping behaviours are more likely.

As recently as 2010, the large eruption of Eyjafjallajökull occurred (Figure 2; Gudmundsson & Pedersen 2010). All the people and most of the farm animals in the potentially dangerous areas were evacuated, aided by the country's authorities and their neighbours. The eruption left thick layers of ash on farmers' fields and injured the lungs of farm animals; but paradoxically, a few years later in 2013 it was reported that the ash had functioned as a fertilizer in the fields, implying that the volcanic outbreak had been beneficial for the farms, and thus for people, in the long run.

We may conclude that the people in Iceland seem to have rational risk-perception, little or no psychological defence, little or no diffusion of responsibility, and they use adaptive coping strategies.

Mt. Vesuvius, Italy

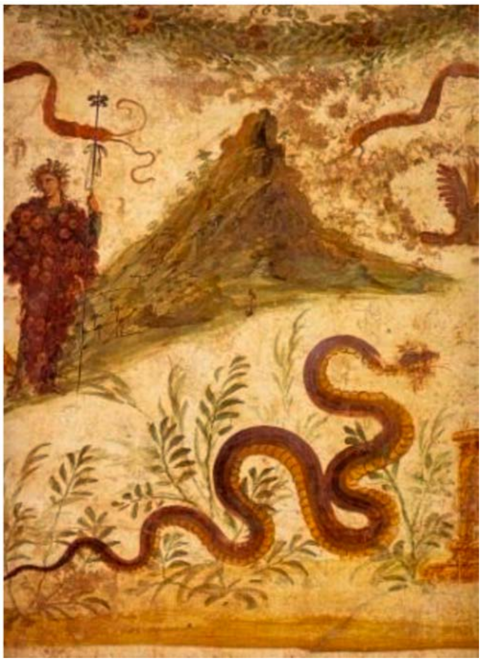


FIGURE 3 THE ANCIENT PAINTING OF VESUVIUS WITH BACCHUS

Fresco discovered in Pompeii, now in Museo Archeologico Nazionale, Naples

Vesuvius is famous for its catastrophic large Plinian eruption in AD 79 (Figures 3, 4). It destroyed large areas in Campania, where the cities Pompeii and Herculaneum are the best-known of the many destroyed locations (Jones 2007). Thousands died despite previous 'warnings', i.e. major earthquakes in 62 and 64 AD. The reaction to them was to rebuild and repair damaged buildings, not to abandon the area. And, in the days just before the eruption began, people could observe birds and animals leaving, and they experienced several minor earthquakes, yet these 'warnings' were also generally ignored. Vesuvius' eruption lasted for approximately two days; but already within 25 hours, most of the affected areas were completely destroyed. The development was fast, yet there must have been some time to escape.

A woman, Rectina, observed certain changes of Vesuvius and sent a messenger to her friend, the Roman author, Gaius Plinius Secundus (Pliny the Elder 2006), asking for help to evacuate. He had time enough to set sail with galleys and a cutter and attempted (not very successfully though) to rescue people. The events are described by Gaius Plinius Caecilius Secundus (see Moser, Gilman & Pliny 2007). In the beginning, pumice and ash started to rain. Many responded to this by seeking shelter inside houses. One may wonder why so few evacuated.

Regarding the minor 'warning' earthquakes, Pliny the Younger wrote that they "were not particularly alarming because they are frequent in Campania" (Moser, Gilman & Pliny 2007, VI:16, 20). So, despite that small earthquakes started on August 20th (79 AD) and increased over the following four days, most peoples' response was to ignore them. A likely explanation is that they used the psychological defence mechanisms of rationalization: "they are of the ordinary sort, nothing to worry about", and idyllization: "they are just tiny tremors", and repression: of the fact that the earthquakes grew larger, and denial: of the danger. As a consequence, most people did not take adequate adaptive coping actions in time.

FIGURE 4 MT VESUVIUS, NAPOLI, ITALY IN MODERN TIMES

The variuous contributing external, societal and geographical reasons could have been the following: There were few places to evacuate to because the area was, then as now, densely populated and densely farmed.

The fact that small earthquakes were regarded as "normal" may have made it easier to "defend away" and "explain away" warning signals. And paradoxically, even to have correct risk-perception and to engage in adaptive coping action (evacuating) could also imply risks: the society was strongly hierarchical, with strict rules and punishments for anything that could be interpreted as a mass-movement or public upheaval. Slaves, approximately 30% of the population, could be severely punished for running away. For the rich, leaving their homes could give slaves, poor people, and thieves opportunities for stealing.

So, both psychological defence mechanisms against perceiving the signs of danger, and a diffusion of responsibility (waiting to see what the others would do, and waiting for "official signals"), may have been at work. And finally, as the rain of pumice increased and other volcanic events took place, evacuating became impossible. Some tried to escape by boats, but big waves (due to earthquake-elicited tsunamis) were an additional danger. Those who had sought shelter in houses instead of fleeing could not get out because pumice blocked the doors. They might have guessed, but not known, that they would be stuck there. Many of those who finally tried to flee, fled too late.

We may conclude that the people living near Vesuvius seem to have had irrational risk-perception, much psychological defence, great diffusion of responsibility, and ensuing maladaptive coping strategies.

Santorini/Thera, Greece

The whole island of Santorini/ Thera is a volcano. Its enormous eruption in 1613 or 1628 BC (±7 years), called the Minoan eruption, lasted for some 48–64 hours, devastating the whole island and affecting large parts of the world (Figure 5; McCoy & Heiken 2000). However, compared to the Vesuvius eruption ca. 1700 years later, the Minoan Bronze Age population of Santorini coped much better. They must have perceived the risk early and did not use psychological defence mechanisms to "explain it away". They evacuated. One might say that they had more time to evacuate because they were 'warned' by a thin layer of pumice that had spread from the volcano about two months in advance of the big eruption, and there had been minor earthquakes. But the point is, they did respond to these 'warnings' in active adaptive coping ways. They even responded early enough to have time to put their larger belongings, such as big jars, in places where they might be safe (clearly hoping that they would return), and time enough to take their animals and lighter valuables with them. Just as there have been many smaller eruptions in later years at Santorini/Thera, there may also have been minor eruptions before 1613 BC. So the population might have "gotten used to" them; and they might have ignored the signs of a threat, and used psychological defence mechanisms against recognizing the 'warning' of the pumice fall. But they did not. The

FIGURE 5 THE REMAINS OF THE MINOAN ERUPTION, SANTORINI/THERA, HELLAS, GREECE

Santorinian/Theran population perceived the risk adequately and responded with good coping strategies. The archaeological evidence points in the direction of an almost total population evacuation, with only a few exceptions (eccentric 'squatters' as they are called in some reports) (Doumas 1983). Why was their reaction, adaptation and coping so different from that of the Roman/Italic population 1700 years later?

Several factors can contribute to that answer. I believe this large evacuation may have been made possible by the fact that Santorini/Thera had one of the largest and best (perhaps *the* largest and *the* best) fleet of trade-vessels in the Mediterranean of the times. Due to their vast trading economy and subsistence pattern, they had contacts and friends overseas in many places around the Mediterranean. In other words, they had places to escape to and migrate to. This background made psychological defences against adequately perceiving the threat and risks less likely, and adequate coping more likely to take place. As far as we know, the social structure was relatively flat, with no clear indicators of a strong leadership or hierarchical societal organization (Doumas 1983). This social situation made it more likely that people took initiative themselves and may have been less influenced by diffusion of responsibility. Yet, they might have had formal or informal leaders, whom they trusted and who urged the inhabitants to a collective evacuation. But that we will never know.

We may conclude that the people of Santorini/Thera seemed to have had rational risk-perception, little or no psychological defences, little or no diffusion of responsibility, and adaptive coping strategies.

Conclusion

The impact of a volcanic eruption is not determined by the geological, geothermal and seismological aspects alone. When it comes to human adaptation to volcanoes, that is also dependent on other factors. By the four presented examples, I hope to have, if not demonstrated, at least suggested how psychological factors (risk-perceptions, diffusion of responsibility, emotional reactions, psychological defence-mechanisms, and psychological coping mechanisms), both on individual and collective levels, can interact with external societal factors (living conditions, subsistence practices, population density, social restraints, type of government, religion, and individualistic versus collectivistic cultural characteristics), and also that both psychological and societal factors can have intricate interconnections with the external geographical/geological/volcanological/climatic factors (location, available space versus little available space, season, type of volcano, type and magnitude of event etc.). These complex interconnections are at work in human adaptation to volcanic eruptions, and they contribute to explaining why volcanic eruptions can have vastly different consequences.

Final Words

Although archaeology often is defined as "the study of material culture", it is a simple fact that all 'material culture' was once produced and used by living people. Thus, there are reciprocal inter-connections between the material cultural remains and the actual lived lives of the people who produced and used them. Therefore, a wide spectrum of perspectives and information-sources are needed for proper analytic understanding of volcanic events. Historical texts can give eye-witness accounts. History and sociology can give information about the societies that were afflicted, their organization and power-structures, and how these directed peoples' responses. Anthropology and religion can give information on peoples' values and religious beliefs regarding volcanoes, and how these influenced their habits and behaviours. Psychology can give information on typical human threat perception, reactions and characteristic choices in dangerous situations. Together, all these factors contribute to our understanding of how people have responded and adapted to volcanic disasters, the extent of their impact, and the adaptiveness of peoples' efforts.

All the chapters in this volume point to factors that determine the volcanic events and impact peoples' adaptation to volcanic outbreaks. Together they contribute to building up a comprehensive picture of the determining factors. The chapters also provide an overview of both former and recent findings in tephro-archaeology in general, and of TephroArchaeolgy in the North Pacific in particular. Although tephro-archaeology already has a solid foundation in inter-disciplinarity and the contributions are multi-disciplinary in themselves, several of the authors underline the necessity of further inter-disciplinarity in theories and research, and the need for holistic approaches in this field.

Last but not least, the more knowledge we have about past volcanic disasters, the better we can predict events and prevent disastrous consequences. Therefore, tephroarchaeology, a rapidly developing sub-discipline within archaeology, produces knowledge that is relevant not only for the past but also for the present and the future.

Figure & Table Sources

Figure 1 by Vfp15 (English Wikipedia ([1])) CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/), via Wikimedia Commons; [https://commons.wikimedia.org/wiki/File%3APetropavlovsk_Kamcatskij_Volcan_Koriacky_in_background.jpg]
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Table 1 redrawn from Böhm & Pfister 2001: figure 1, with permission
Tables 2–5 modelled by author

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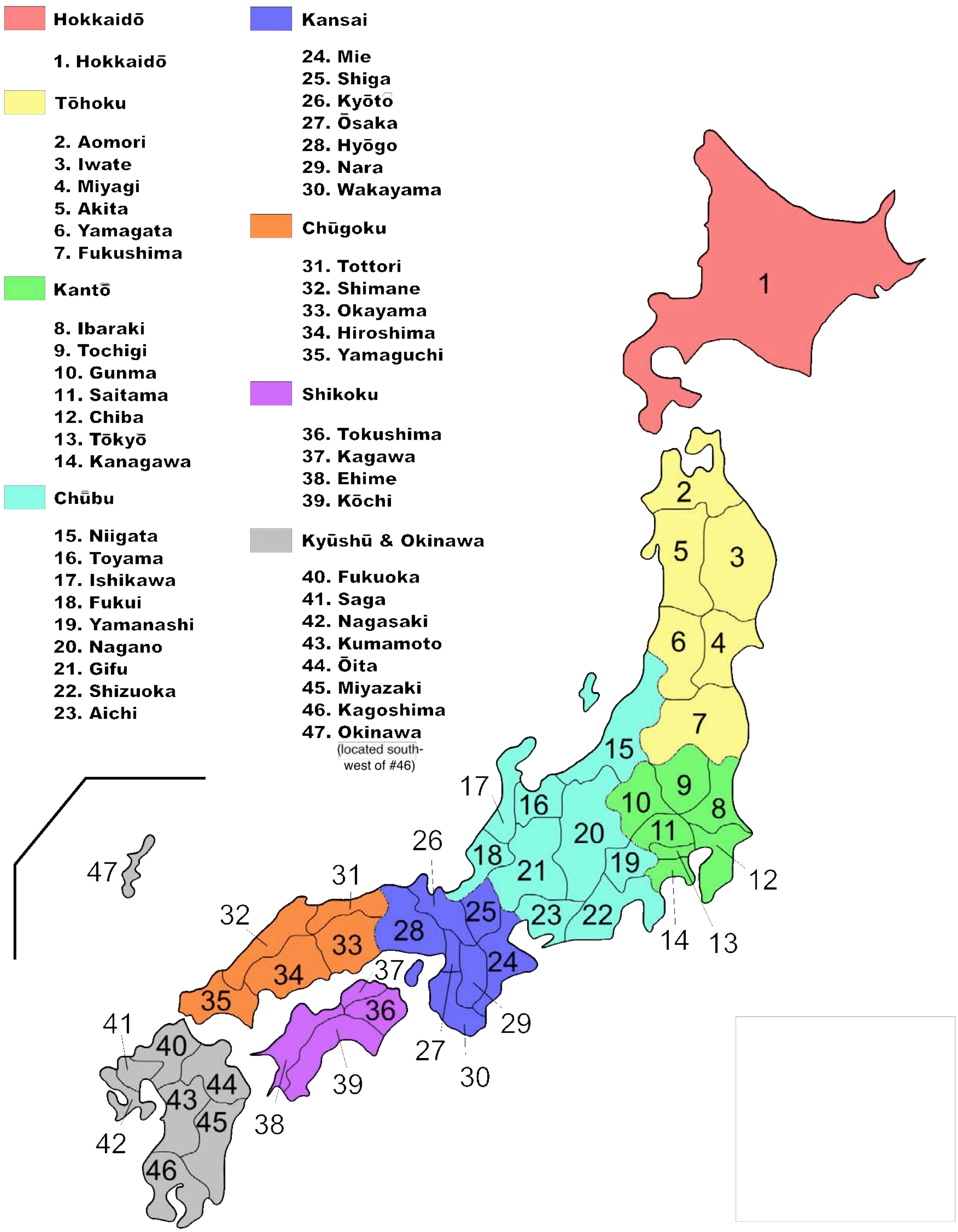
APPENDICES A–E Contents

Appendix Figures

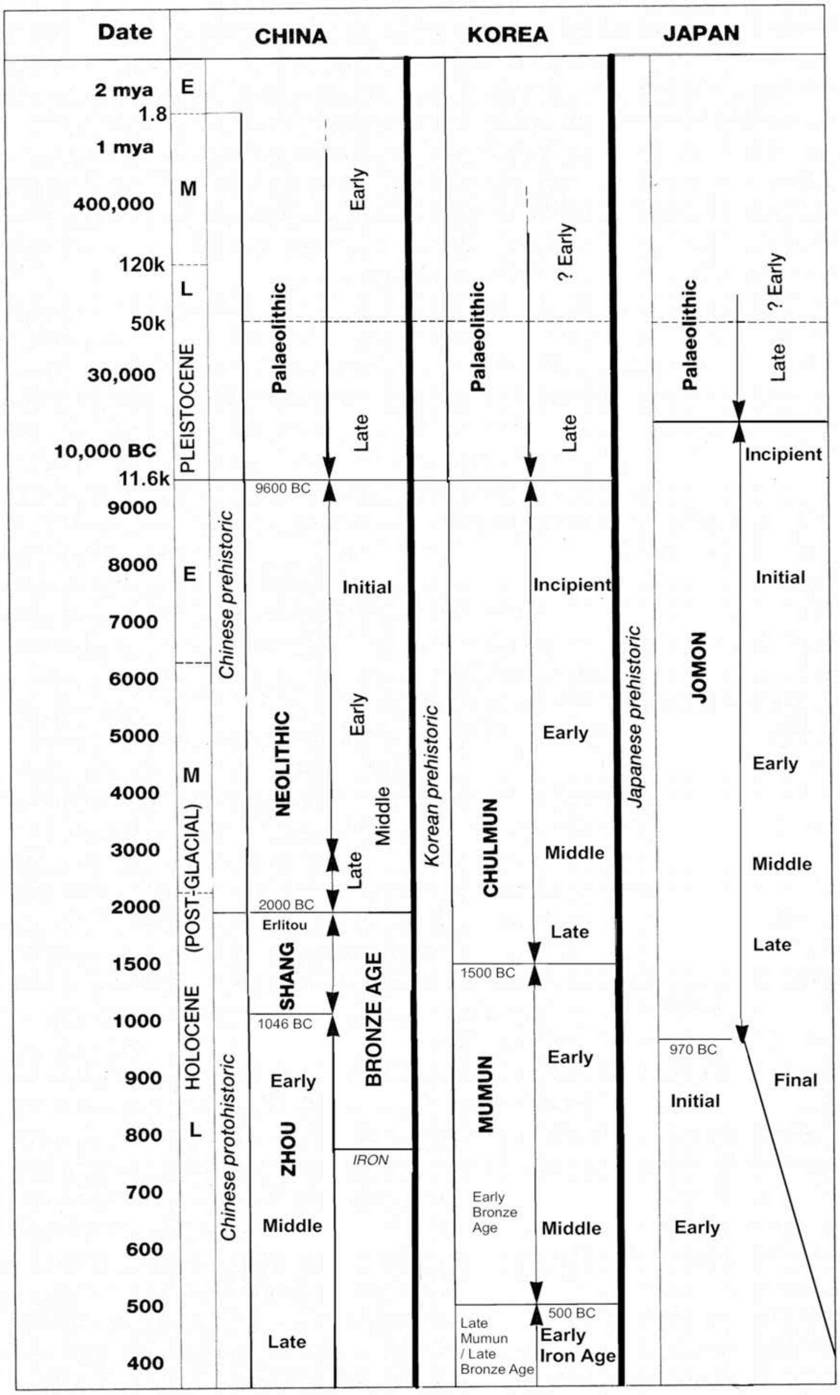
Appendix Tables

APPENDIX A: Map and Chronological Charts

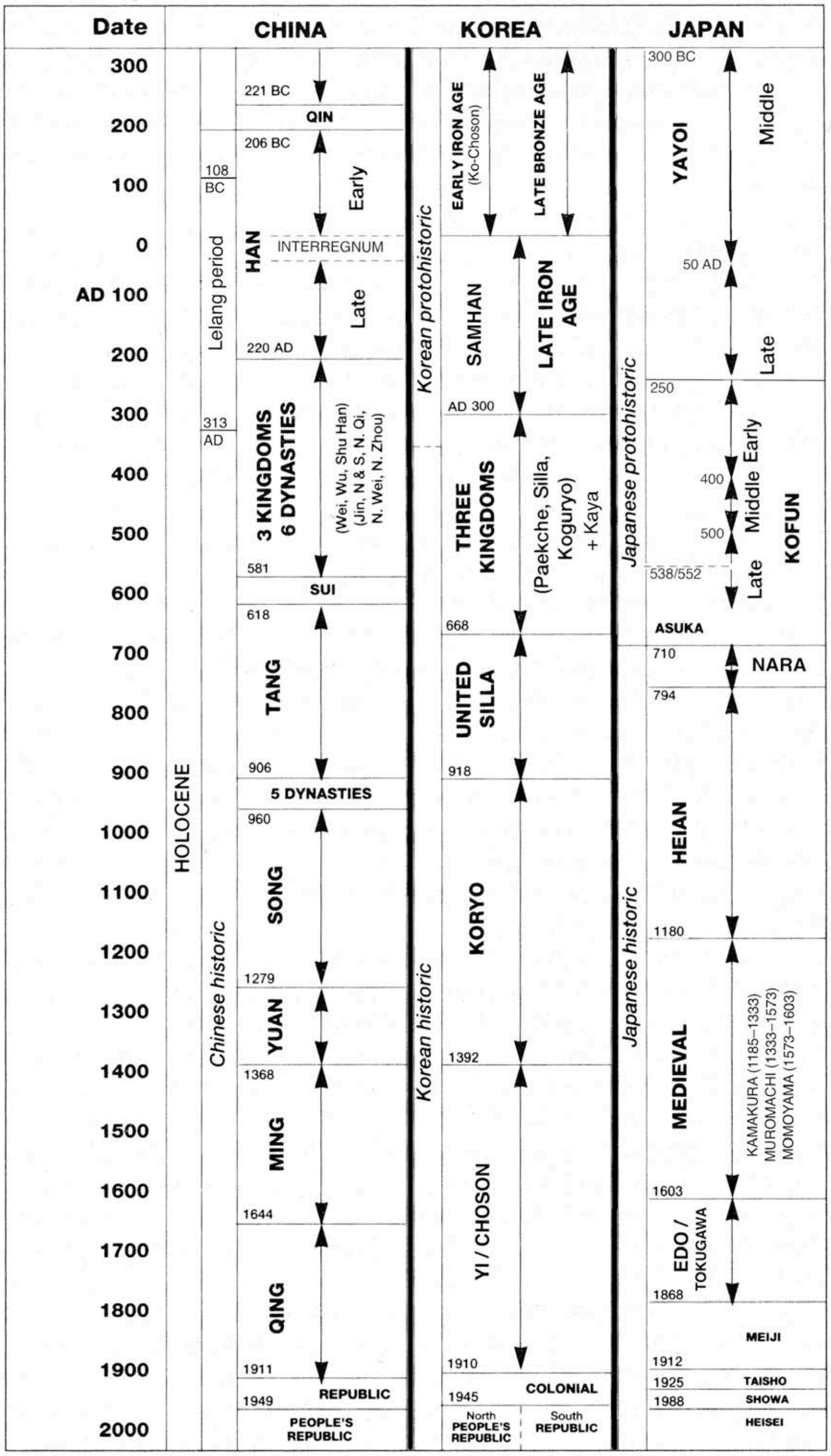
A-1. Map of Japanese Islands, Prefectures, and Districts



Appendix A.2 Chronological Charts for East Asia



EARLY PERIODS



LATE PERIODS

A-3. Japanese Archaeological Periodizations

TABLE A-3a. JŌMON PERIOD DIVISIONS

Dates of Jōmon phases based on calibrated AMS ^{14}C dates: the phase dates below derive from more than 2000 AMS ^{14}C datings throughout the archipelago. The name of the period derives from the ceramics used: 'cord-marking' (*jōmon*) was a prominent motif. Note that Incipient Jōmon began in the Pleistocene, but this scheme does not include any early finds of pottery before 15 kya (13,350 BC); these are assigned to the Palaeolithic.

Jōmon subsistence was based on hunting, gathering, and fishing, and some horticulture. Northwestern and northeastern Japan are distinguished by the early arrival of rice agriculture in the west, leading into the Yayoi Period after 970 BC, and by the time lag of rice technology diffusion through Honshu by the end of Middle Yayoi. Jōmon lifeways survived in Hokkaido through the Yayoi and Kofun Periods but were sidelined by dry-field agriculture and Satsumon pottery with the arrival of dry-field farmers from northern Honshu after ca. 600 AD.

Jomon phase	calibrated dates BP	calibrated dates BC
Incipient	15,000–12,500	13,350–10,550
Initial (Earliest)	12,500–7000	10,550–5050
Early	7000–5470	5050–3520
Middle	5470–4420	3520–2470
Late	4420–3200	2470–1250
Final (Latest)	3200–2920	1250–970 (SW Japan)
	3200–2350	1250–400 (NE Japan)
Epi- (Zoku-) Jomon		340 BC–700 AD (Hokkaido)

TABLE A-3b. YAYOI–KOFUN PERIOD DIVISIONS

Yayoi		Kofun	
Initial (Earliest)	1000–800 BC	Early	250–400 AD
Early	800–450 BC	Middle	400–500 AD
Middle	450 BC–50 AD	Late	500–710 AD
Late	50–250 AD	(Asuka)	552–710 AD

Note that the southwestern Yayoi were dependent on the newly imported wet-rice technology and used bronze tools and weapons. During the Early Yayoi, the northeast followed Epi-Jōmon lifeways, but agriculture was gradually introduced through the Middle Yayoi Period. Dry-field crops were more important to the northeastern Yayoi, who also survived generally without bronze. During the Kofun Period, the northeastern farmer-hunters were known to the Yamato Court as *emishi*, and many became accomplished horse-riders who harried expansionist troops during the Nara and early Heian Periods. Others migrated into Hokkaido after 600 AD and established the Satsumon culture.

Appendix B: Volcanic Geology

B-1. Elements

98.5% of the rocks of the Earth's crust are made up of only eight elements (Table B-1: section 1), which are the basic constituents of magma. Oxygen and silicon are the most abundant, and when combined, they form silicon dioxide (SiO_2), commonly called silica, the basis of all silicate rocks formed from magma.

- O and Si are non-metal elements belonging to Groups 16 and 14 in the Periodic Table respectively, though Si is sometimes referred to as a 'metalloid'.
- Al is a metal of Group 13 and Fe is a transition metal of Group 8.
- Mg belongs to the alkaline earth metals (Group 2)
- Ca, Na, K are alkali metals (Group 1).

The elements are often distinguished based on their densities, with lighter elements (L) <5 g/cm^3 and heavier elements (H) >5 g/cm^3, though this distinction may vary according to author.

B-2. Minerals

The main elements of the Earth's crust combine to form minerals: the six most common are called the rock-forming minerals (Table B-1: section 3 characterizing igneous rocks [MEMPR 2017]). Since there are approximately 5300 known mineral species (and thousands more varieties),[1] these six rock-forming minerals comprise only the first stages of rock formation from magma, with other minerals forming through other inorganic, metamorphic, or biological processes. Most of the rock-forming minerals are based on silica and therefore called 'silicates', derived from magma. The other major rock groups are sedimentary and metamorphic; they have their own common mineral types (see Davidson n.d.) such as the 'carbonates' ($CaCO_3$, $MgCO_3$), which form calcium or magnesium limestones. Metamorphic minerals form as existing rocks under specific pressure/temperature conditions or from fluid interaction with existing rocks (metasomatism).

Of the six rock-forming minerals, quartz is the oxide of silicon (silica SiO_2); it may occur in different forms: as quartz crystals formed of silica tetrahedrons (see illustration in Table B-2) or non-crystalline (amorphous) glass. Quartz crystals grow in slow-cooling igneous rocks (granite) and in pegmatite formations. Volcanic glass is encountered in high-silica lava flows (forming obsidian) where the silica has not had the chance to crystalize. Quartz is the primary constituent of tephra, though other mineral crystals and country rock fragments with different chemical constitutions may also be present in tephra. Moreover, the glassy component itself usually includes elements other than silicon (see Chapter 13); these are helpful in characterizing the tephra (see Appendix E) and contribute to soil formation.

The other rock-forming minerals are silicates: that is, silica (SiO_2) combines with other elements to form more complex minerals, as indicated by their chemical compositions in Table 1 (section 3). Minerals, like elements, are also divided into light and heavy – the latter with a density (specific gravity s.g.) $\geq$2.8–2.9 g/cm^3; their weights determine their differential distribution across the landscape during tephra fallout. Heavy mineral crystals occurring in tephra are useful for their characterization (Appendix E-5). The special category of mineral tephras have high ratios of mineral crystals to glassy fragments.

[1] Figures vary in the literature from 3000 to 5300, depending on the age of the publication; new minerals are constantly being discovered. The International Mineralogical Association (IMA) recommends mineral names and approves validity; their list numbers 5413 minerals as of November 2018 (IMA-CNMNC 2018).

TABLE B-1 ELEMENTS AND MINERALS DISCUSSED IN THE TEXT

1. Major elements of Earth's crust	Abbrev	Avg. % in magmas, tot 98.5%	4. Density	**2. Other elements cont.**	Abbrev	**3. Rock-forming minerals:** ***minerals* / MINERAL FAMILIES** their classifications (f,m,im) & their abbreviations	Chemical composition Specific gravity (s.g.)
oxygen (L, Periodic Table group 16)	O	46.6	1.429 g/l*	hydrogen	H	IN IGNEOUS ROCKS	
silicon (L, 14)	Si	27.7	2.33 g/ cm³	manganese	Mn	*quartz* (f) Q	SiO_2 s.g. 2.6–2.7 (L)
aluminium (L, 13)	Al	8.1	2.7 g/cm³	phosphorus	P	FELDSPARS:	s.g. 2.6–2.7 (L)
iron (H,8)	Fe	5.0	7.874 g/cm³	titanium	Ti	*orthoclase* (f) or K-feldspar, K-spar, potassium feldspar, kf	$KAlSi_3O_8$ s.g. 2.6 (L)
calcium (L, 2)	Ca (ai)	3.6	1.55 g/cm³	carbon	C	*plagioclase* (f) pl	$NaAlSi_3O_8$ –$CaAl_2Si_2O_8$ s.g. 2.62–2.75 (L)
sodium (L, 1)	Na (ai)	2.8	0.968 g/cm³	oxygen	O	PYROXENES: *augite* (m)	$(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$ s.g. 3.2–3.6 (H)
potassium (L, 1)	K (ai)	2.6	0.856 g/cm³	nitrogen	N	*hypersthene* (m)	$(Mg,Fe)SiO_3$, s.g. 3.4–3.9
magnesium (L, 2)	Mg (ae)	2.1	1.738 g/cm³	copper	Cu	AMPHIBOLES: am hornblende series (im) ho	$Ca_2(Mg,Fe)_4Al[AlSi_7O_{22}](OH)_2$ s.g. 2.9–3.2 (H)
2. Other elements						MICAS:	s.g. 2.8–3.0
chlorine	Cl			sulfur	S	*biotite* (m) bi	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$ s.g. 2.7–3.4 (~H)
molybdenium	Mo			zinc	Zn	*muscovite* (f)	$KAl_2AlSi_3O_{10}(OH)_2$ s.g. 2.8–2.9 (~H)
iodine	Io			barium	B	OLIVINES (m) ol	$(Mg,Fe)_2SiO_4$ s.p. 3.3–4.4 (H)

Key: * Density given for O at 0° Celsius
section 1. numbers = Group in Periodic Table; L = light element, H = heavy element (the designations vary in the literature); ai = alkali metals, ae = alkaline earth metals
section 3. m = mafic, f = felsic, im = intermediate; L = light mineral, H = heavy mineral (the designations vary in the literature)

B-3. Magma Types

Magma is basically molten rock from which minerals crystallize in order over time. A magma body may also be mixed, with different sources supplying magmas of different chemical compositions. These compositions are defined by their silica contents (Figure B-1)[2]. Table B-1 (section 1, column 3) lists averaged percentages of the main elements comprising magma. These compositions are presented as oxides (combined with oxygen) in Figure B-1 for different magmas categorized by silica content. The designations 'mafic, intermediate, and felsic' rocks correspond to silica ranges from 45 to 75% in content. Greater than 75% silica forms glass.

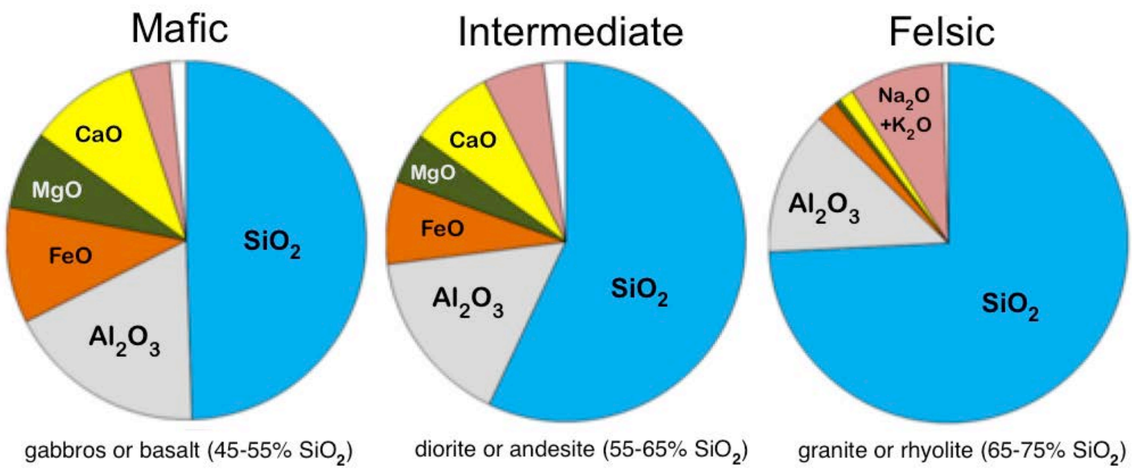
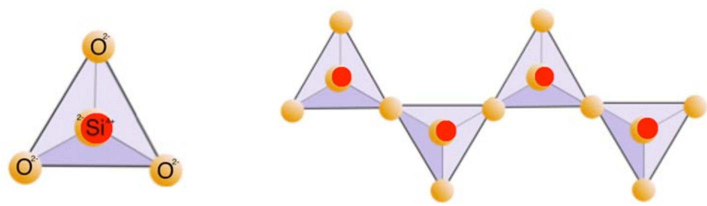


FIGURE B-1 MAGMA COMPOSITION ACCORDING TO SILICA CONTENT

TABLE B-2 CLASSIFICATION OF IGNEOUS ROCKS BY SILICA (SiO_2) CONTENT AND GRAIN SIZE

Grain size	Rock type				Context
	felsic	intermediate	mafic	ultramafic (mantle)	
Fine < 0.25 mm	Rhyolite	Andesite	Basalt		Extrusive (volcanic)
Medium 0.25–2 mm	Microgranite	Microdiorite	Dolerite		Intrusive (plutonic)
Coarse > 2 mm	Granite	Diorite	Gabbro	/Peridotite	Intrusive (plutonic/mantle)
wt.% SiO_2	75%	65%	55%	45%	
Silica content	<--------------increasing--- - - - - - - - - - decreasing--- - - - - - - >				



[2] Read Panchuck 2017 for free at https://physicalgeology.pressbooks.com/ (required attribution for figure).

The silicate minerals form via linkages between silica tetrahedra (Table B-2 illustration); a silicon atom has a positive charge (4+), while oxygen atoms have a negative charge (2-). Thus, one silicon atom can link to four oxygen atoms and balance its electric charge; however, each oxygen atom is still negatively charged (1-) and therefore is wont to link to other ions including other oxygen atoms of other silicon tetrahedra. The latter thus form chains of different shapes; clays (Table B-3), discussed in Chapter 13, typically have a layered structure as illustrated in Chapter 1: Figure 7.

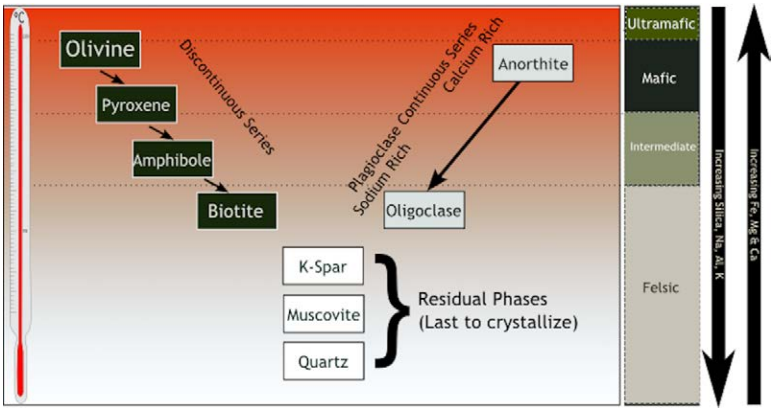


FIGURE B-2 BOWEN'S REACTION SERIES OF MINERAL FORMATION IN MAGMA

Crystallization of minerals in a magma occurs in a specific order through time and as temperature decreases, essentially from the mafic to felsic minerals according to the Bowen Reaction Series (Figure B-2) (Schieber n.d.). The type of resulting minerals (Figure B-3) depends on the elemental composition of the magma as seen in Figure A.

Figures B-2 & B-3 require the attribution: Read Panchuck 2017 for free at https: //physicalgeology.pressbooks.com/

The minerals combine into rocks that are classified by their silica content; each category (felsic, intermediate, mafic, ultramafic) has its characteristic mineral composition (Table B-2). The types of rocks listed in Table B-2 and Figure B-3 can occur as either *extrusive* (aka volcanic; extruded onto the Earth's surface) or *intrusive* (aka plutonic; crystalize in chambers within the Earth's crust). In addition to these basic igneous categories, there are many varieties of volcanic rocks that are formed under specific conditions.

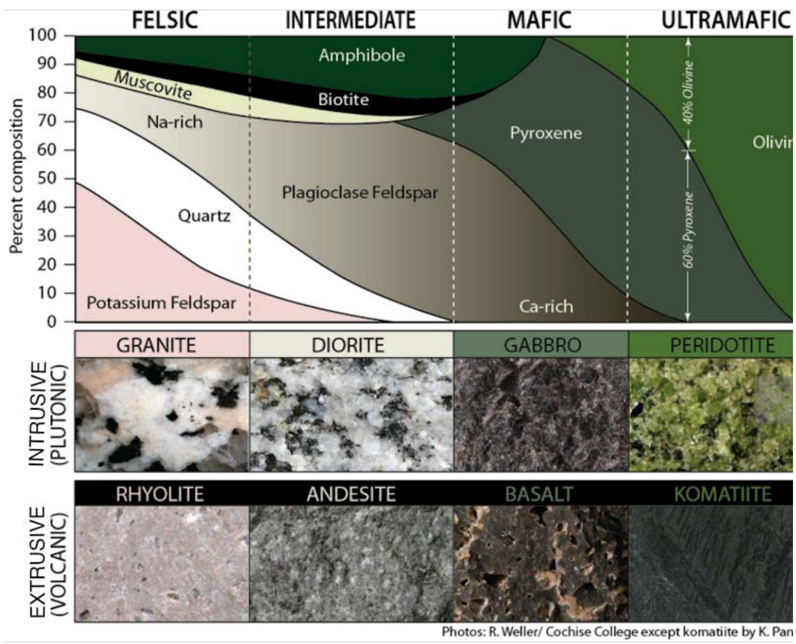


FIGURE B-3 MINERAL COMPOSITIONS OF ROCKS FROM ULTRAMAFIC TO FELSIC

Alkaline volcanism is mentioned in Chapter 7; its products are distinguished through containing alkali metals (potassium K, sodium Na), that are usually absent in other volcanic rocks. Comendite is a type of felsic rock that is peralkaline in composition, defined as having a higher ratio of alkalis than aluminium Al (K+Na>Al). It is often extruded with pantellerite, which is also a peralkaline felsic rock but has more iron Fe and even less Al than comendite. Trachyte is the intermediate (rather than felsic) product of alkaline volcanism. It is comprised mainly of K-feldspar (orthoclase) but generally no quartz. Two further terms trachyandesite and trachybasalt indicate compositions between trachyte (of alkaline composition) and andesite / basalt (of non-alkaline) composition.

TABLE B-3 CLAY GROUPS AND THEIR CHARACTERISTICS *

Clay group	Sub-group	Species	Structure	Shape	Chemical formula
Kaolin-Serpentine					
	Kaolin	Kaolinite	1:1	platy	$H_2Al_2Si_2O_8$ H_2O or $Al_2Si_2O_5(OH)_4$ or $Al_2H_4O_9Si_2$
	Kaolin	Halloysite	1:1	platy, tubular, or spheroidal	$Al_2Si_2O_5(OH)_4$ -$2H_2O$ (interlayer water of varying quantities)
Smectite				spongy, honeycomb	
	Di.smectite	**M**ontmor-illonite**	2:1	flakes	$(Na,Ca)_{0.33}(Al,Mg)_2$ $(Si_4O_{10})(OH)_2 \cdot nH_2O$ interlayer Na^+, Ca^{2+}, K+, Mg^{2+}
	(Tri.smectite)	Saponite	2:1	ribbon-shaped +isometric particles	$Ca_{0.1}Na_{0.1}Mg_{2.25}Fe^{2+}_{0.75}Si_3AlO_{10}(OH)_2{\bullet}4(H_2O)$
(Vermiculite)					
Mica	Mica	Illite	2:1	lath or hexagonal	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$
		Biotite	2:1	lamellae	$K(Mg,Fe)_3(AlSi_3O_{10})(F,OH)_2$
(Chlorite)					
Amorphous					
		Allophane	gel; colloid	hollow nano-spherules	$(Al_2O_3)(SiO_2)_{1.3\text{-}2}$ 2.5-$3H_2O$
	(proto-)	Imogolite	gel; colloid	nano-tubes	$Al_2SiO_3(OH)_4$

NB Vermiculite and chlorite not dealt with in this volume; see Eberl (1984).
* The literature on clay types is convoluted and often contradictory; a simplified scheme is adopted here.
** also called bentonite (Slaughter & Early 1965).

Magmas also contain significant elements that do not not form into crystals but combine to form gases: particularly, carbon + oxygen→carbon dioxide (CO_2); hydrogen + sulphur→hydrogen sulphide (H_2S), and hydrogen + oxygen→water vapour (H_2O). When emitted through volcanic eruptions, CO_2 becomes a major greenhouse gas, while H_2S converts to sulfuric acid (H_2SO_4) upon contact with the atmosphere, becoming an aerosol. Greenhouse gases contribute to climate warming, while aerosols tend to cool the Earth by reflecting the sun's rays. Both are processes that follow volcanic eruptions and are becoming important topics in TephroArchaeology as described in Chapter 1. Hydrogen in molecular form comprises 75% of the visible universe and 75% of the sun by weight but is insignificant in rock formation; nevertheless, H is a very important element because of its combination with O to form water H_2O, which is the main agent for rock weathering as discussed in Chapters 1 and 13.

Magmas contain gas in dissolved form; however, as magmas rise through volcanic systems, they decompress and the gases exsolve to be extruded into the atmosphere. Low-silica magmas are less viscous than high-silica magmas, and gases escape more easily from the former. Thus, the relative silica and gas contents of a magma determine its explosivity: mafic magmas flow more easily and degas simultaneously, as in Hawaiian-style eruptions. When a high-silica magma contains much gas, the low viscosity levels do not allow the gas to be released gradually, and the exsolving gas leads to explosive eruptions producing much tephra, as in Plinian and Ultra-Plinian eruptions (see Chapter 1 for more detailed discussion of tephra).

Magma generation occurs essentially in four tectonic settings (Figure B-4): mid-ocean ridges (constructive plate boundaries), producing basalt to form oceanic plates; hot spots fed directly from the mantle, also producing basaltic magma as in the Hawaiian Island chain; continental rifting, producing bimodal basaltic and rhyoitic volcanic products; and volcanism associated with subduction zone (destructive plate boundaries), which may produce any mafic to felsic magma but is most often intermediate to felsic in composition. The processes of magma generation in a subduction zone setting are discussed below.

B-4. Subduction Processes

The North Pacific region dealt with in this volume is part of what is commonly called the Pacific Rim of Fire. The Pacific Ocean floor is composed of tectonic plates of basaltic composition (oceanic plates). Because oceanic plates are composed of heavy, mafic minerals, they are heavier than continental plates, which are generally felsic in composition and comprised of the light minerals: quartz and feldspars. Continental plates thus have more buoyancy, so that in subduction, the heavier oceanic plate is drawn down, or subducted, underneath the continental plate. As an oceanic slab is subducted, it dehydrates, losing its water vapour to the mantle wedge above it (Figure B-4, using Japan as an example). The fluids lower the melting temperature of mantle rock, forming magma which then rises to collect in magma chambers and eventually be extruded through volcanic vents. Earthquakes often accompany magma movement and extrusion; these are very shallowly located compared to the earthquakes caused by subduction occurring along the Wadati-Benioff Zone.

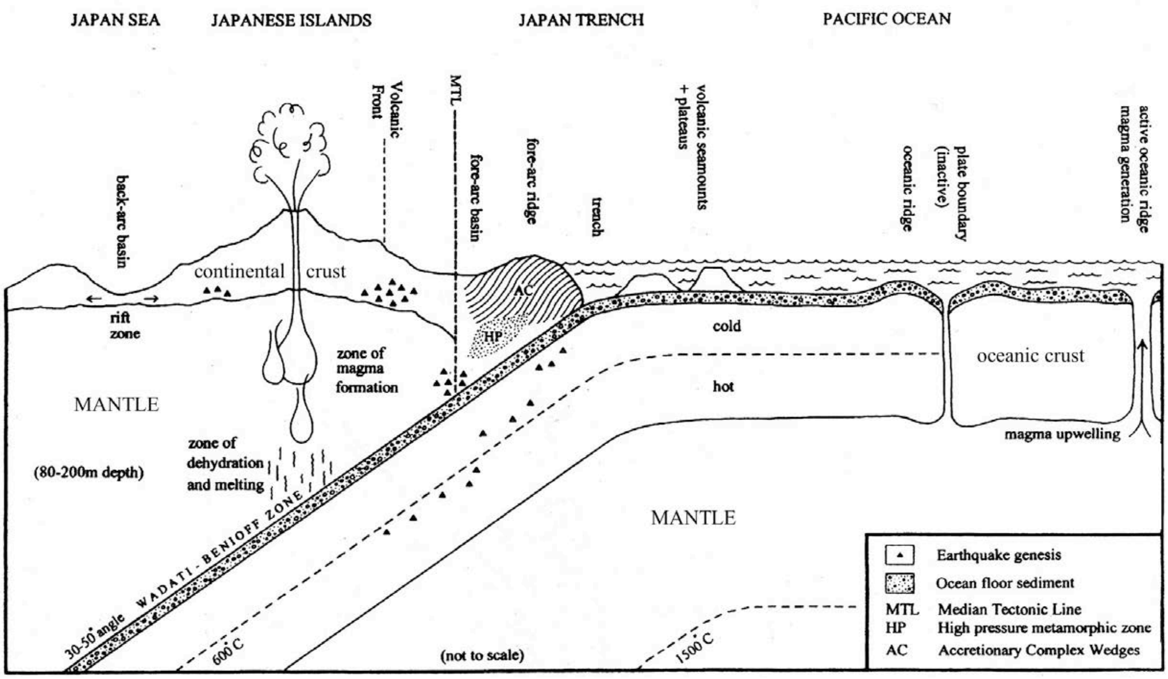


FIGURE B-4 SUBDUCTION ZONE SETTING OF MAGMA PRODUCTION AND VOLCANO FORMATION

Appendix C: Tectonic Setting of North Pacific Volcanoes

C-1. Subduction Zones of the North Pacific

The Pacific Ocean is mainly floored by the Pacific Plate, which is being created from the west side of the East Pacific Rise (a 'mid' ocean ridge) in the southeast (Figure C-1) and is moving northwestwards at ca. 7–11 cm/year. It is confined by the North American Plate to the north and east, and by the Eurasian Plate to the west. There are several other smaller plates and plate sections in the area: the large continental plates are often divided into smaller areas: the Bering, Okhotsk, and Amur Plates. Cocos and Nazca are oceanic plates created by the East Pacific Rise on its eastern flank, while the Philippine and Caroline Plates exist in the southwest Pacific. Of particular interest here are the Juan de Fuca and Gorda Plates in the Pacific northeast. These are remnants of a large oceanic plate, the Farallon (or Kula in Japanese) Plate which previously occupied the Pacific Basin and now is almost entirely subducted under the North American continent.

The Pacific Basin is bordered by two kinds of active borders: subduction zones and transform faults (jagged and long-dashed lines respectively in Figure C-1). Subduction zones are caused by the orthogonal or oblique meeting of oceanic and continental slabs, while transform faults occur where these slabs pass by each other in strike-slip fashion. These active borders are what cause the enormous amount of earthquake and volcanic activity around the Pacific Rim – in great contrast to the Atlantic Basin which has passive margins (i.e. continental and oceanic crust are continuously connected). Since there is no subduction around the Atlantic Basin, creation of magma by the mid-Atlantic ridge to form the Atlantic oceanic plates is pushing apart the Eurasian and North American plates on that side of the globe, and their movement outwards must be compensated by subduction in the Pacific Basin on the opposite side of the globe; this is in addition to accounting for the creation of new ocean floor by the East Pacific Rise.

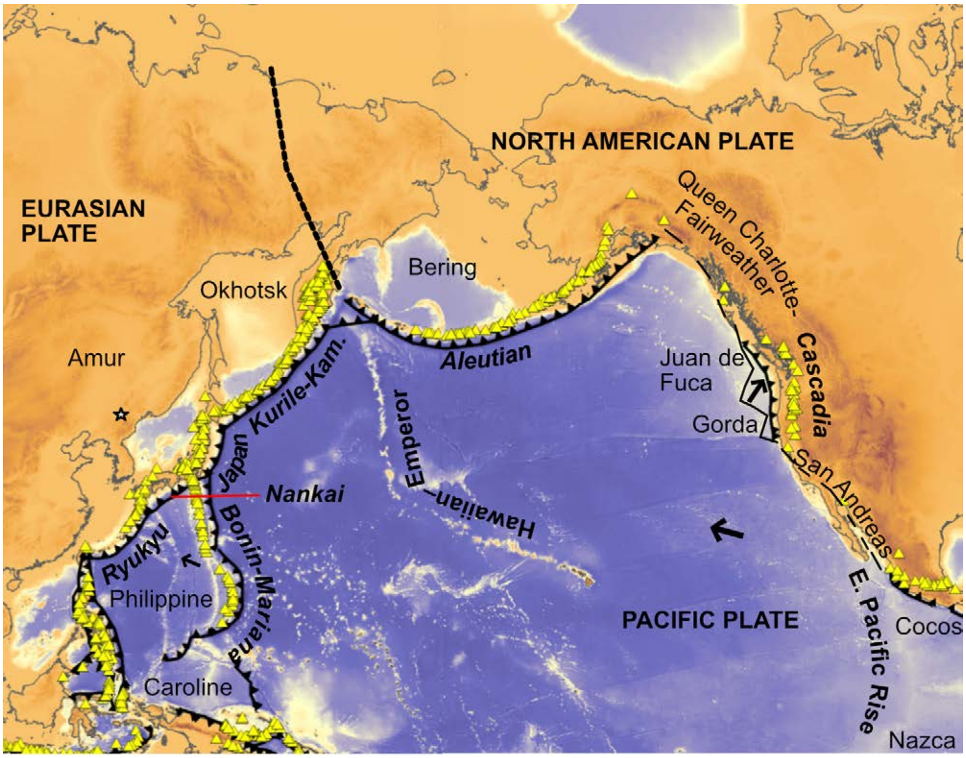


FIGURE C-1 PLATE STRUCTURE AND SUBDUCTION ZONES OF THE PACIFIC RIM

The North Pacific has two main transform fault zones, the Queen Charlotte-Fairweather Fault Zone running from eastern Alaska down the Canadian coast to meet the Juan de Fuca Plate, and the San Andreas Fault starting from the Gorda Plate, running onto land south of San Francisco and thence into the Gulf of California to meet the East Pacific Rise. The western end of the Aleutian arc is not (yet) a transform fault zone, but the Pacific Plate is passing almost parallel to the islands, which accounts for few volcanoes in that region – Buldir Island hosting the last volcano until meeting Kamchatka (see Chapter 5: Figure 1, top).

The main subduction zones of the North Pacific are named by their trenches or troughs, from east to west: Cascadia Trench in northwest North America, the Aleutian Trench along northern Alaska, the Kuril Trench from Kamchatka to Hokkaido in the northwest, the Japan Trench where the Pacific Plate meets northern Honshu, the Nankai Trough where the Philippine meets southwestern Japan, the Ryukyu Trough where the Philippine Plate is being subducted under the Ryūkyū Islands, and finally the Bonin-Mariana Trench where the Pacific Plate is being drawn under another oceanic plate, the Philippine Plate, causing the creation of the volcanic Izu and Ogasawara Island chains. All the subduction zones are lined with volcanoes (yellow triangles in Figure C-1).

Subduction zone volcanoes form in chains, the mean distance worldwide being 287±161 km landward from the subduction trench (DCO Project 2016) and 65–130 km above the subducting ocean slab (England et al. 2004). In Japan, volcanic fronts usually form between 100 and 200 km from the trench. The type of magma and/or tephra extruded from subduction zone volcanoes is typically andesitic to rhyolitic in composition, and the style is typically Sub-Plinian to Ultra-Plinian. Basaltic products are not unknown, but these are more characteristic of hot spot volcanoes such as those that comprise the Hawaiian–Emperor Seamount Chain.

The Kuril Trench is where the Pacific Plate is subducting under the Okhotsk plate (a microplate belonging to the North American plate). The trench extends ca. 2900 km from the mid-Kamchatka Peninsula to northeastern Hokkaido and is responsible for the formation of volcanoes on land in the southern Kamchatka peninsula and the volcanic island arc of the Kuril (Chishima) Islands (cf. Eichelberger et al. 2007. The volcanoes on land form three successive volcanic chains, indicating the displacement of the volcanic front due to trench jump and growth of the continental edge towards the east over time (Avdeiko et al. 2007). Chapter 5 discusses the prehistoric occupation of the Russian Kuril Islands, while the Koryaksky volcano is featured in Chapter 15: Figure 1. A stratovolcano towering over Petropavlovsk City, the administrative centre of Kamchatka territory (*krai*), its eruption history is known only from ca. 5500 BC, with its last eruption in 2009 (GVP 2013e).

Although the Pacific Plate is currently subducting under the eastern part of the Aleutian arc in a northwest direction, the western Aleutian Islands, the islands of the volcanic arc began forming between 50 and 55 mya via subduction of the Kula Plate underneath the North American Plate. The volcanoes of the island arc continue on land in the Alaska Peninsula where some of the most devastating eruptions are known (Chapter 5). Seismic results indicate an unusual composition of the volcanic arc, having a higher mafic content than usually seen in continental crust (Holbrook et al. 1999).

C-2. Cascadia Subduction Zone

The Cascadia subduction zone reaches from Vancouver Island to northern California between the two transform fault systems named above. Volcanic activity is caused by the continuing subduction of the Juan de Fuca and Gorda Plates in a northeastern direction. The results form the Cascade Mountain Range (Figure C-2), stretching from British Columbia through Washington and Oregon into northern California.

Two of the volcanoes are discussed herein: Mt St Helens and Crater Lake (USGS 2017; Brantley & 2005; Klimasaukas et al. 2002). Both these volcanoes are listed as having a "very high threat potential for further activity, but they are currently in a 'typical background, non-eruptive state'" (USGS 2018: unpg.).

Crater Lake, 6 km in diameter, resides in the caldera of an obliterated collection of volcanoes known as Mount Mazama, ca. 20 km in diameter judging from USNPS 2017. Volcanic activity began around 420,000 years ago, culminating in the cataclysmic Mazama Ash eruption 7700 years ago, forming a crater 8 km in diameter. Activity continued on and off for the next 750 years, and the last eruption was 4800 years ago. Mazama Ash still exists as a centimeters-thick layer within floodplain alluvium as far north as Edmonton, Alberta (Figure C-2) (see Chapter 4).

Mount St Helens was a young cone-shaped stratovolcano until it blew out its side in 1980. Forming from 250,000 years ago, it has erupted 44 times in the Holocene. Activity resumed in 2004–2008 (GVP 2013d).

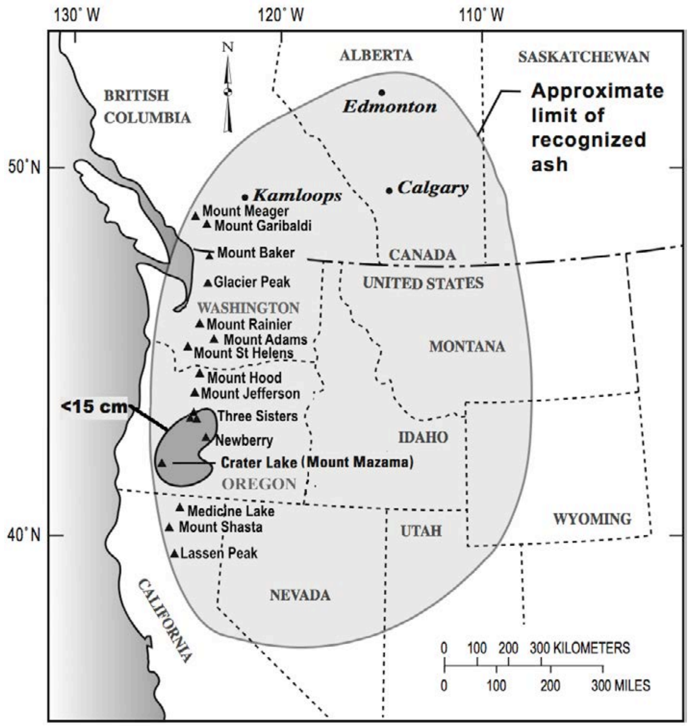


FIGURE C-2 DISTRIBUTION OF MAZAMA ASH >0.6 CM ERUPTED 77 KYA

C-3. Japan's Subduction Zones

The modern country of Japan is subjected to subduction activities in four discrete segments, marked by the Japan Trench, the Izu-Bonin Trench, the Nankai Trough and the Ryūkyū Trough. The first two consume the Pacific Plate, while the latter two consume the Philippine Plate. Because these oceanic plates themselves have very different angles and rates of subduction, the volcanics that occur from them vary in size, scale, and composition. For the main Japanese Islands, there are two main volcanic fronts recognized for these different subduction zones (Figure C-3: F1 and F2). These give rise to volcanoes with different chemical compositions from east to west (F2: zones 1-3, F1: zones 2-4) (Barnes 2008).

The volcanoes of mainland Japan fall into several zones; for example in Tōhoku, the Nasu zone takes in the three eastern volcanic chains (zones 1–3 of Alkaline and Sub-Alkaline rocks), while the western chain (zone 4 Alkaline rocks) comprises the Chōkai zone. Central Honshu (Figure C-3, circled) entails several volcanoes discussed below, but beyond is the Fuji Volcanic Zone which stretches from the Izu Islands across Honshu to the Japan Sea. The structure of western Japan essentially follows the strike direction of the Median Tectonic Line (MTL in Figure 4) from north Kyushu to the Kantō region around Tokyo. Kyushu Island, however, is also orthogonally split northeast to southwest by the Kirishima Volcanic Zone (Figure C-3: F1, zone 2) with extensional widening in the southern half. English descriptions of all 110 active volcanoes in Japan can be found in the National Catalogue (JMA 2013). Only a tiny portion of the information in the JMA website, the National Catalogue, and in Machida and Arai's *Atlas of Tephra* is provided below.

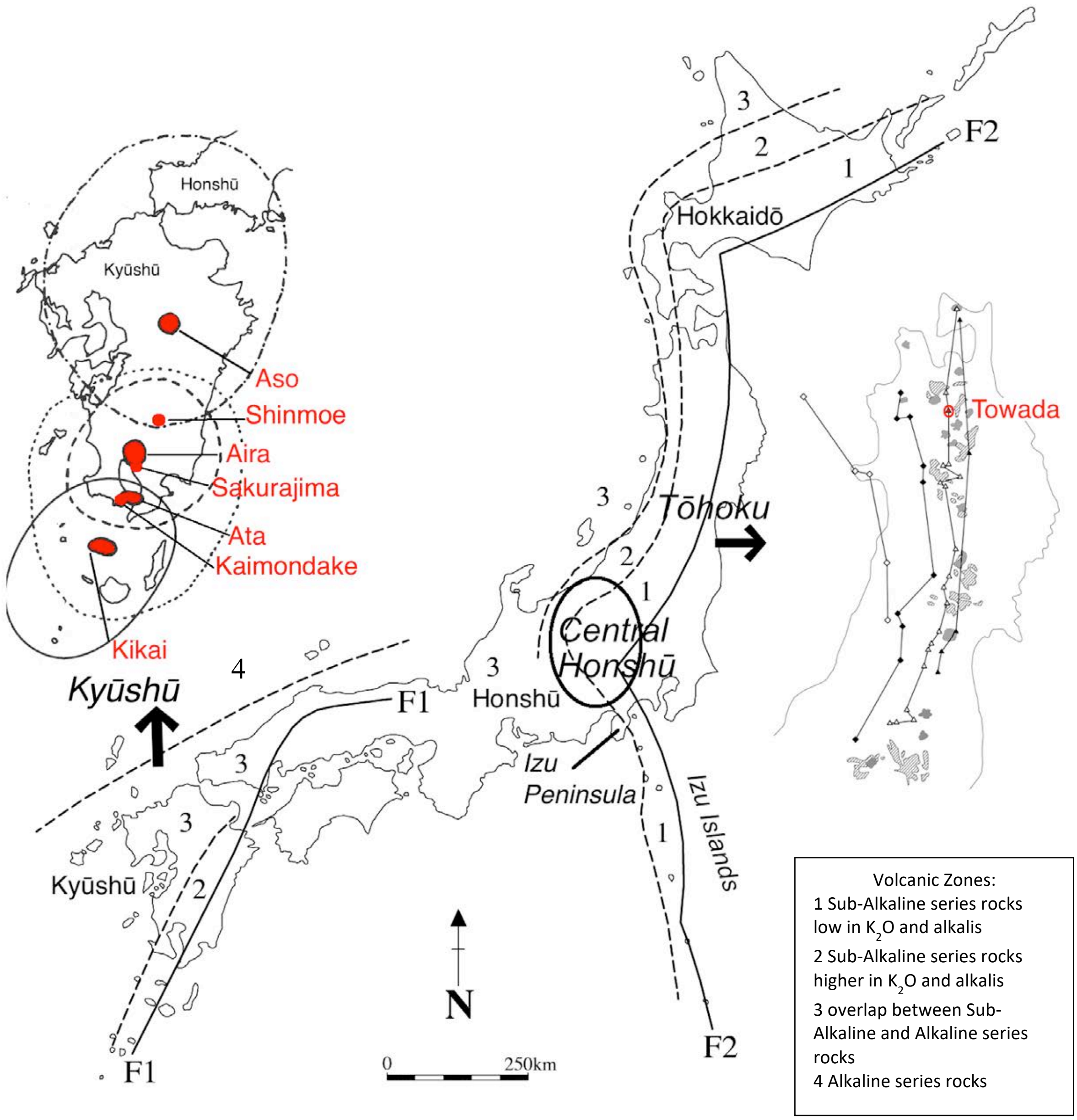


FIGURE C-3 VOLCANIC FRONTS (F1, F2) OF THE JAPANESE MAINLAND WITH TŌHOKU AND KYUSHU INSETS
Caldera volcanoes in Kyushu are encircled in black

C-4. Tōhoku Region

Volcanic activity of the Pliocene era (ca. 6–3 mya) is evidenced by lavas in the Tōhoku region (Figure C-3: inset solid grey), and that of the Early Pleistocene is evidenced by pyroclastics (Figure C-3: hatched areas). Quaternary volcanism began around 700,000 years ago, with Quaternary volcanoes arrayed in four chains (Figure C-3: Tōhoku inset), organized into two volcanic zones: three chains in the Nasu zone on the east and one chain in the Chōkai zone on the west (Gates & Ritchie 2006: 127).

FIGURE C-4 LAKE TOWADA, NORTHERN HONSHU, JAPAN

Towada volcano, discussed in Chapters 6 and 8, is sited in one of the Tōhoku chains. Towada is actually the name of the crater lake (Figure C-4) filling an 11-km dm caldera. The original size of the Towada volcano that erupted to form this crater is not known, but the crater is the same diameter as all of Mt St Helens. The eruptive history of this spot goes back 200,000 years, varying over time between basaltic and rhyolitic products (data from JMA n.d.). Successive eruptions in 55, 36 and 15 kya built the current large caldera. Between 15 and 12 kya, lava flows and eruptions continued in the southern part of the caldera. As many as eight explosive eruptions occurred thereafter until 915 AD, its last known eruption. These eruptions formed the 3-km diameter Nakanoumi crater, whose rim remnants comprise peninsulae within Lake Towada (one can be seen in the upper right of Figure C-4). In the upper left can be seen the dacite lava dome (Ogurayama) which grew on the Nakanoumi rim following an eruption in 7600 kya. The most recent phreatomagmatic eruption of VEI 5 in 915 AD from within Nakanoumi crater produced pumice and volcanic ash, pyroclastic flows and surge that – because of the water in the crater lake – immediately became a lahar that flowed out to the Japan Sea. An interesting legend remains about the lahar (see Chapter 6: Column).

C-5. Central Honshu Region

Several volcanoes important to Chapters 9 through 11 belong to the Jōshin'etsu Kōgen highlands of Nagano-Gunma-Niigata Prefectures. Further south are those that belong to the Fuji group.

• Akagiyama is a huge composite volcano 25 km in diameter; eruptions between 70–50 kya formed a caldera 3 x 4 km in size in which several post-caldera dacite cones developed. Between 45 and 40 kya, much pumice was erupted; most activity ceased by 24 kya, but a historical eruption was documented in 1251.

• Mt Haruna, a slightly smaller composite volcano 20 km in diameter, has formed two small caldera, the present one 2 x 3 km in size hosting a dacite cone. The eruption history is known only for the last 10,000 years. Eruptions have occurred from several other vents, the most recent being the Futatsudake vent, marked now by a lava dome. It was responsible for the catastrophic eruptions of VEI 4 and then VEI 5 in the 6th century discussed in Chapters 9, 10, and 11. The Ikaho Hot Springs resort in Shibukawa City is fed from Futatsudake, but there is no current volcanic activity.

• Mt Ontake in Nagano Prefecture (mapped in Chapter 2: Figure 1) is a basaltic~dacite composite stratovolcano which last erupted in 2014. Its formation began before 110 kya; a second stage lasted from 110–80 kya with eruptions from 8 different volcanic vents beginning with rhyolite-dacite tephra-fall, pyroclastic flows and lava dome formation. From 20 kya, there have been phreatic eruptions (JMA 2012).

C-6. Fuji Volcanic Zone

• The Mt Fuji that we see is a relatively young stratovolcano, 40–50 km in diameter, but three predecessor volcanic structures reside underneath (data from Yoshimoto et al. 2010; see their fig. 10). Fuji overlaps with another early volcano, Ashitake erupting 400–100 kya, to the south. The earliest in the Fuji sequence are pre-Komitake volcanic materials dating to 270–160 kya; then Mt Komitake itself erupted between 160 and 100 kya in the same location. Old Fuji shifted locations slightly to form a new stratovolcano between 100–10 kya, and the Mt Fuji seen today formed on top of it from 10,000 years ago to the present. Volcanic rocks from Fuji are basaltic, which is very unusual for an island arc complex. Since 8540 uncal. bc, Fuji has erupted 57 times (GVP 2013f), recently averaging every 300 years. Its last eruption was in 1707 and is therefore about due. The Disaster Hazard Map (Figure C-5) compiled by the Mt. Fuji Volcano Disaster Management Conference indicates that in a future eruption, Tokyo and the Chiba Peninsula will be covered by less than 10 cm of ash.

• Mt Hakone is a stratovolcano with two calderas, the larger being 10 x 11 km in diameter, formed during eruptions at 180 kya and 60–49 kya; 2900 years ago a lava dome was produced, accompanied by a pyroclastic flow (Volcano Discovery n.d.). Hakone has erupted eight documented times in the Holocene, the latest eruption being in 2015 (GVP 2013g).

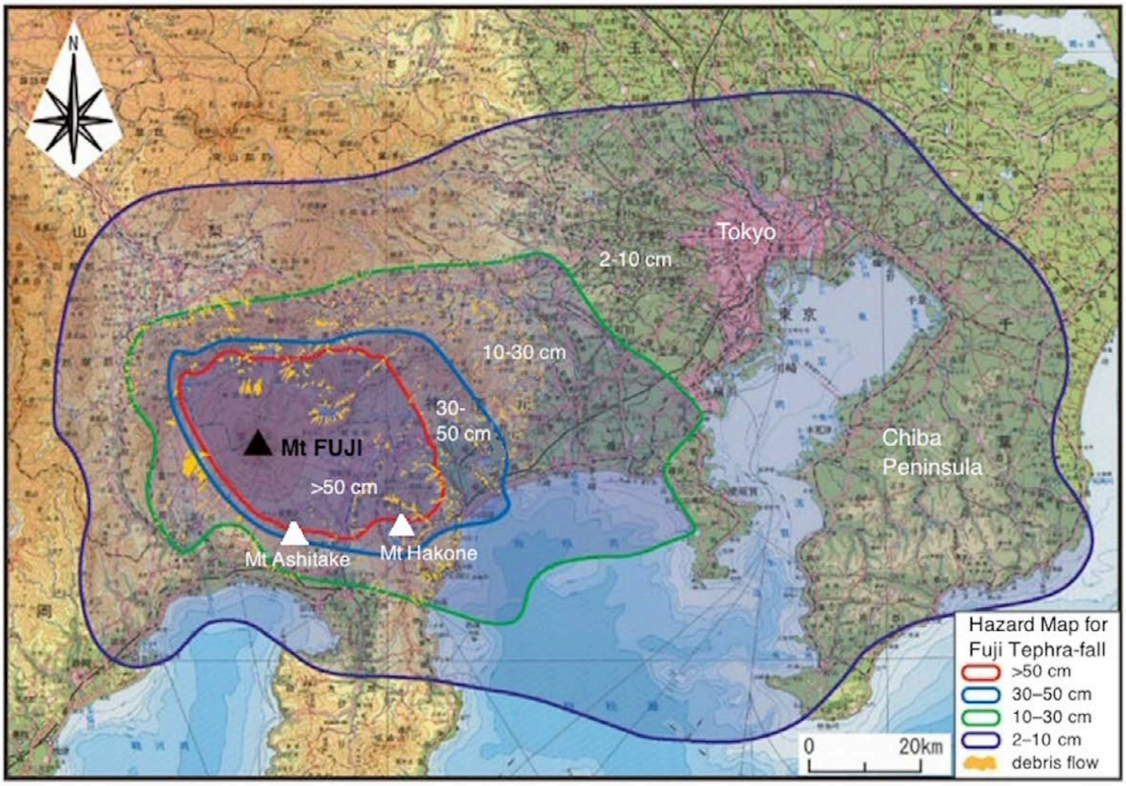


FIGURE C-5 HAZARD MAP FOR PROSPECTIVE ERUPTION OF MT FUJI

C-7. Kyushu Volcanoes

The Kyushu volcanoes are shown in Figure C-3: Kyushu inset.

• Mt Aso is a large caldera volcano in north-central Kyushu. From ca. 300 kya there have been four super-eruptions, the latest and greatest of which at 87 kya (Aoki 2008) laid Aso-4 tephra over all of Japan, except the northern tip of Hokkaido, at depths greater than 15 cm and buried northern Kyushu in pyroclastic flows (Machida & Arai 1992: 66-68). The resulting caldera measures 18 x 25 km, with several post-caldera lava cones in the centre; one continues to be active today – the Nakadake cone, which has eight "craterlet" vents within its main crater (Hoshizumi & Miyabuchi 2012). There are 185 known eruptions confirmed for the Holocene (GVP 2013a).

• Aira Caldera forms the upper part of Kagoshima Bay in southern Kyushu (cf. Chapter 2: Figure 5); a large eruption is known from 90 kya, then several between 50 to 30 kya when the eruption of AT tephra occurred (Machida 2002: fig. 1b). 500 km^3 of tephra were spread over all of Japan to half-way through Hokkaido (Machida & Arai 1992: fig. 2.1-6; Tatsumi et al. 2018). It has been quiescent since then, but a volcano developed on its rim: Sakurajima.

• Sakurajima (Sakura Island) sits on the southern edge of the Aira Caldera (see Chapter 2: Figure 5); it is a composite stratovolcano comprised of two separate volcanoes, Kitadake and Minamidake, as well as hosting several parasitic volcanoes (Iguchi & Nakada 2012). Periods of activity are known for Kitadake (26–24 kya, 13–5 kya), then activity shifted to Minamidake leading to four Plinian eruptions during historical times. The 1914 eruption extruded sufficient lava to connect Sakura Island to the Ōsumi Peninsula and left the Shōwa crater on the flank of Minamidake. The summit crater of Minamidake has been active since 1955, and activity recently resumed at the Shōwa Crater in 2008.

• Shinmoe is one of the Kirishima Volcanoes; a stratovolcano with a small crater, it has erupted 84 known times during the Holocene (GVP 2013b), with the 2011 event equaling the 1717 eruption size (Aizawa et al. 2014).

• Ata Caldera lies under the lower part of Kagoshima Bay (Chapter 2: Figure 1). Between 125–115 kya, it erupted several times, with more low-level activity between 60–50 kya, with its last eruption ca. 8 kya (Machida 2002: fig. 1b). The most significant Ata tephra was erupted between 110–90 kya; tephra fallout extended from the southern Ryūkyūs to the Kantō, but Miyazaki and Kagoshima Prefectures were subjected to widespread pyroclastic flows (Machida & Arai 1992: fig. 2.1-14). Between 4 kya and 894 AD, there were four eruptions from Kaimondake.

• Kaimondake is a parasitic volcano of the Ata Caldera at the tip of the Satsuma Peninsula; it laid Km(gr) tephra across Japan in the Late Jōmon, Middle Yayoi, Kofun, and Heian Periods. The archaeological remains of the 894 event were well researched by Shimoyama and colleagues at the Hashimure-gawa site (e.g. Shimoyama 2002).

• Kikai Caldera resides under the sea off the southwestern tip of Kyushu Island. Three super-eruptions are known: at 140, 95 and 7.3 kya, resulting in a double caldera (19 x 24 and 15 x 17 km) and one dome formation. Tatsumi et al. (2018) propose that both calderas were formed by the 7.3 kya eruption and that the dome is a post-eruption dome from that incident. The 7.3 kya eruption tephra is known as Akahoya tephra (K-ah); if both calderas were responsible, their combined eruption extruded 140 km^3 of tephra. Kikai Akahoya eruption disrupted all life in the western Japanese Islands during the Jōmon Period (Kuwahata 2016).

C-8. Eastern China Mainland

This region is anomalous but not unrelated to the northwest Pacific subduction zones. Its volcanoes are unusual in that they occur *within* the Eurasian continental plate; such intra-plate volcanoes are commonly fed by hot spots (e.g. Hawaii), but in this case, it is thought that magma formation is due to the presence of a stagnant portion of the Pacific Ocean slab sitting near the mantle/core boundary at 500 km depth (Zhang et al. 2014). Changbai (Paektu) and the volcanoes forming Cheju and Ulleung Islands off the southwest and southeast coasts respectively of the Korean Peninsula are thought to belong to this regime.

Ma et al. (2016: 26.1) report that "partial melting due to dehydration of the deep stagnant Pacific slab is one of the most favorite explanations of the Changbai mountain volcano origin". Seismic tomography has clearly outlined the existance of the stagnant Pacific slab underlying the eastern China Mainland (Zhao, Isozaki & Maruyama 2017; see their marvelous illustrations), and the authors conclude that the regional "intraplate volcanism is caused by hot and wet upwelling in the BMW [big mantle wedge] associated with corner flows in the BMW and deep slab dehydration as well" (Ibid.: 358, my annotation).

Changbai, as Mt Paektu, is discussed by Pratt in Chapter 7. It is a complex volcanic structure sitting on the boundary between modern China and North Korea (Figure C-1: star; data from Singer et al. 2014). It is one of several intra-plate volcanoes on the China Mainland, and is currently located about 1300 km from the Japan Trench subduction zone (GVP 2013c). Its genesis might be related to tectonic extension with the opening of the Japan Sea (Zhang et al. 2014; cf. Barnes 2008). Small amounts of Miocene basaltic lava in the Changbai volcanic field preceded widespread basaltic eruptions in the Early Pleistocene to form a shield volcano extending over ca. 90 x 120+ km; within this area are around 40 volcanoes or vents (Ma et al. 2016: fig. 1). The geochemistry of the Early Pleistocene basalts is determined to be similar to Kamchatka basalts from the "deep subduction zone" (Ma et al. 2016).

A more recent parasitic stratovolcano of alkaline composition sits over the shield volcano; smaller in extent, it still measures ca. 30 km in diameter. Lavas and tuffs of intermediate composition trachyte are known from 600 kya and 88 kya. The Qixiangzhan lava flow is dated by Singer et al. (2014: 2800) to 17 kya. They describe that lava as a comendite 'clastogenic' flow; this flow was covered by silicic ash-fall units dating to 4.2±0.4 kya and 1.2±0.2 kya (±2σ). The Qixiangzhan 'Period' as conceived by Pan et al. 2013 (discussed in Chapter 7) obviously applies to the tephra fallout at 4.2±0.4 kya, not the earlier lava flow. The tephra at 1.2 kya derived from the "Millennium eruption" and is dated to 946 AD (see Chapter 7). Singer et al. propose that the eruptions following the Late Glacial Maximum might have been stimulated by melting of local glaciers; another of their propositions is that the Tianchi crater lake formed in the volcanic vent of the Millennium eruption.

Appendix D: Volcanic Soils Geochemisty

This section provides supplementary materials as background for Chapter 13 on tephrogenic soils.

D-1. Physical Properties

In general, tephrogenic soils are valued for their friable texture due to their small grain size, low bulk density, good water retention, and good drainage. These latter two seem contradictory, but water retention is especially good in pumice-derived soils because the pumice grains are able to hold water film in their vesicles. Such pumice soils in Japan are called *miso-tsuchi* ('coarse soybean-paste earth'), having both the colour and consistency of brown miso, a fermented soybean cooking ingredient. Being too porous can lead to rainwater leaching out soluble metals, while being too saturated can lead to water-logging and stickiness. One problem with water supply is posed by the presence of the non-crystalline clays allophane and imogolite. Their own chemical structures bind water (H_2O) or hydroxyl (OH^-) molecules, making the moisture unavailable to crops. One method of mitigation is to dehydrate the colloids by drying out the soil (e.g. by covering it over), which then increases natural water available to plants (Shoji et al. 1993: 236); colloids once dehydrated cannot be rehydrated (Neall 2006).

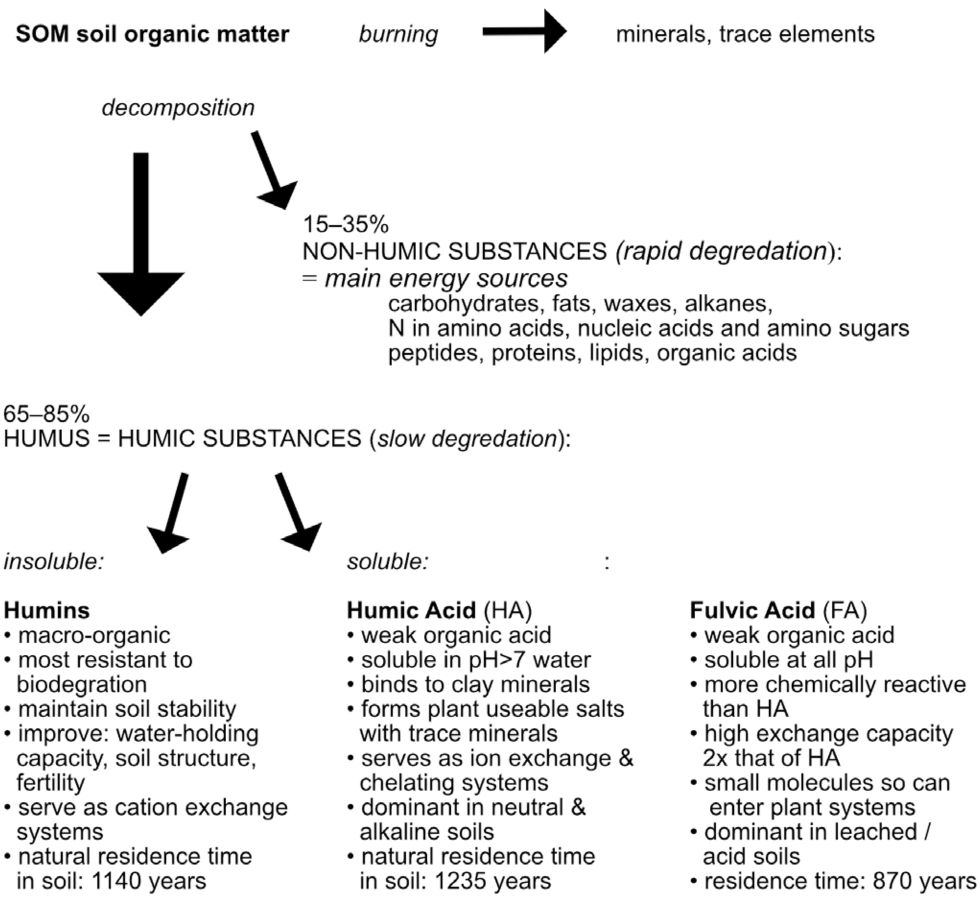
Friable texture depends on good water balance and the lack of large rock particles. When fine-grained tephrogenic soil is deep enough, long-rooted crops are well-suited for cropping, e.g. Japanese radish (*daikon*, ca. 30–35 cm in length) or edible burdock (*gobō*, 45–50 cm in length). This rootability depends on the absence of large stones or cemented layers; unweathered glass shards, however, can prevent earthworm habitation (Neall 2006).

D-2. Humus, Humic and Fulvic Acids

Soil scientists make a distinction between soil organic matter (SOM) and humus (Pettit n.d.); SOM is the sum total of plant and animal matter added to soils naturally or artificially; this includes living micro-organisms and animals that live in the soil. Most soils contain less than 2% SOM, though to be fertile, a soil should have >2.8% SOM (Pettit n.d.). Humus is the decomposed organic matter that has lost all its cellular structure. It makes up about 65–75% of SOM, while the remainder is comprised of various carbohydrates, fats, waxes, alkanes, peptides, amino acids, proteins, lipids, and organic acids – things that Pettit helpfully describes as having chemical formulae, whereas there is no chemical formula for humus. A gardening rule of thumb is that humus should comprise between 5% and 10% of soils for good fertility (Bond 2017). In Chapter 13: Table 2, we saw that andosols can vary widely in their humus content: 3–11% for allophanic and 4–22% for non-allophanic andosols. Both, nevertheless, are indicative of good fertility and are far above the average SOM contents of soils.

Humus can be further broken down into three components (Table D-1): insoluble humins, and the soluble acids humic acid (HA) and fulvic acid (FA). Humins in particular give andosols many of their unique characteristics, such as increased water capacity, soil stability and increased soil structure, and increased fertility.

TABLE D-1 HUMIC SUBSTANCES, THEIR RELATIONSHIPS AND CHARACTERISTICS



The high humic content in andosols is due to humus stabilization, accomplished through the formation of Al-humus complexes or attachment to colloidal clays and ferrihydrite, a mineral ($5Fe_2O_3 \cdot 9H_2O$); in addition, humus can be physically protected within soil micro-aggregates, or chemically protected by the lack of P or absence of Al toxicity, both of which affect the micro-organisms that biodegrade organic matter (Ugolini & Dahlgren 2002). Under humid conditions and soil pH <5, humus is much more likely to form complexes with Al, making the aluminium unavailable for allophane formation (Shoji et al. 1993: 145). This is the anti-allophane effect referred to above.

Humic and fulvic acids comprise two of the three groups of humic substances that result from the decay of organic matter; these are soluble in water of different pH values, while the third humic group, humin, is insoluble. The acids are of interest here in soil formation.[3]

• Humic acids (Table D-2) are structurally diverse and complicated, consisting of carbon chains and rings. Their activities in soils include 1) binding with clay minerals to form stable organic clay 'complexes', 2) binding other organic chemicals in their molecular lattices, and 3) chelation: binding with inorganic elements in a manner utilizable by plants. Chelated elements are generally the micronutrients Fe^{2+}, Cu^{2+}, Zn^{2+}, Ca^{2+}, Mn^{2+} and Mg^{2+} (names of elements listed in Table B-1). Note these are all metals with a valence of $2^{+,}$ while Al has a valence of 3^{+}, forming a more complicated chelate not only with humic acid but with other organic acids as well (see below under Al toxicity).

Four types of humic acid have been identified in Japanese tephra-derived soils: A, B, P, and RP (see Shoji et al. 1993: fig. 6.10), with A-type humic acid being the most highly 'humified' and forming the dominant type in melanic andosols, while P-type are more common in fulvic andosols. A-type humic acid forms organic complexes with Al and Fe.

• Fulvic acids (Table D-2) are similarly structured of carbon chains and rings, but they are more chemically active than humic acids (because of their more numerous hydroxyl COH and carboxyl COOH groups).

Once the hydroxyl and carboxyl groups have expelled their hydrogen, then COO- and CO- are available to bind with free metal cations of 2+ valence, forming humate salts; thus HA and FA serve to preserve metals in the soil (Pettit n.d.) (FA not to be confused with Hr-FA tephra).

TABLE D-2 COMPARISON OF HUMIC AND FULVIC ACIDS

	HUMIC ACIDS (HA)	FULVIC ACIDS (FA)
formula	C+H+O	$C_{135}H_{182}O_{95}N_5S_2$
pK1 value	4–8	
	charge density	
solubility	soluble in water of alkaline pH and precipitated at pH<2	soluble in water of all pH values
	fewer COOH and COH groups ∴ less active than fulvic acids	more COOH and COH groups ∴ more active than humic acids
		relatively low molecular mass
		more acidic than humic acid
		forms strong complexes with Fe^{3+}, Al^{3+}, and Cu^{2+}

D-3. Andosol Nutrients

As we have seen above, andosol chemistry is first determined by the type of magma deposited as tephra. Basaltic and andesitic tephras are noted for their productivity in Java and Japan. The general fertility of tephra-derived soils is likely due to a continued high weathering rate of glassy materials which furnishes plant nutrients such as K and P (Shoji et al. 1993: 210). Plants need macronutrients (N, P, K), secondary

[3] Information mainly from Pettit n.d. unless otherwise stated.

nutrients (Ca, Mg, S), and micronutrients (B, Cu, Fe, Cl, Mn, Mo, Zn). Depending on their magma chemistry, volcanic products can contain all these except N, but they also contain significant amounts of Al, Na, and Io which can be toxic.

Nitrogen N

It was noted above that pioneer andolizers have the ability to fix nitrogen for their own use; however, once dead plant (and animal) matter is added back into the soil, it forms a pool of organic N. The organic compounds containing N are mostly complex proteins from rotting organic matter (non-humic substances in Table D-1) and are not accessible to plant growth until this *organic* N has been converted into inorganic forms by soil microbes as part of the 'nitrogen cycle' (PASSEL n.d.-a). Through a complicated set of chemical reactions, the proteins are broken down by micro-organisms to produce ammonium NH_4^+ in a process termed 'mineralization'. In a second multi-stage process, 'nitrification', micro-organisms convert organic N to nitrate NO_3^-. Both of these forms of *inorganic* N, nitrate and ammonium, are useful to plants. Inorganic N production processes occur best at pH levels around 7; greater or lesser pH causes a decline in inorganic N production, as does lack of oxygen or moisture for micro-organism metabolism (PASSEL n.d.-a).

Nitrate moves freely in soil solutions, thus being immediately available to plants; but it is also therefore susceptible to leaching. Nitrate leaching is exacerbated in acid soils, and high precipitation rates will carry nitrates down into the subsoil where is it unavailable to plant roots. Japan has a humid temperate climate with precipitation of 725–2474 mm/yr, the same as the northwestern United States, though less than Indonesia (975–4974 mm/yr), but more than New Zealand (975–1474 mm/yr) and much more than the Mediterranean region (475–974 mm/yr). One reason for extensive leaching in andosols is that they have very little positive charge in their A horizons for the nitrate anion to combine with; thus, nitrate can move downwards in the soil profile as fast as 10 cm per 100 mm of rainfall (Shoji et al. 1993: 177).

Ammonium, on the other hand, reacts with clays and organic matter in exchangeable or non-exchangeable forms. NH_4^+ attach to clay mineral surfaces and to humic particles as exchangeable ions, and these can be released through ion exchange for plant use (Nielsen 1972). However, the ions can also be adsorbed into pores in the clay mineral crystal lattices, becoming fixed and non-exchangeable. Ammonium competes with K for these from aqueous solutions (ECIFM n.d.; Alshameri et al. 2018; FAO n.d.). The efficiency of moving ammonium from the soil solution into clay relates to clay type and soil pH: experiments on six clay types showed an increase in removal between 2 to 6 pH, peaking between 6–7 pH, and declining thereafter; however, the maximum removal figures ranged from ca. 18% to 90% between halloysite and vermiculite (Alshameri et al. 2018: fig. 3). Another study documented a 91% uptake of ammonium by montmorillonite, non-crystalline clays 45–54%, and only 10% by hallyosite (Bajwa 2008). Thus, andosols with significant amounts of non-crystalline clays will adsorb (fix) significant amounts of ammonium, making it inaccessible for plant use.

Phosphorus P

In contrast to nitrogen, "phosphorus is not the limiting nutrient element in revegetation of tephra-covered lands" (Shoji et al. 1993: 218). On volcanic soils, inorganic phosphate (P_i) is provided mainly by the phosphate-containing apatite minerals (calcium phosphates), more common in felsic than mafic tephras; apatites $Ca_5(PO_4)_3(F,Cl,OH)$ dissolve relatively rapidly in acid solutions, becoming immediately available for plant growth (Ibid.: 217). In some tephras, P_i supply is constant: in the regosolic soils of Mt Usu, P levels after 25 years were "almost comparable with that of the fresh ash" (Shoji & Takahashi 2002: 114). Plants also supply phosphorus in an organic form (P_{org}) produced by the decay of biological matter; this form of P_{org} is held in organic compounds and is only useable after its conversion (mineralization) to P_i by micro-organisms.

P_i circulates freely in the soil solution where it is taken up by plants as $H_2PO_4^-$ and $HPO_4^=$ (PASSEL n.d.-b); Under strongly acidic conditions, non-ionic phosphoric acid H_3PO^4 dominates; as the conditions move towards basic conditions, hydrogen atoms are dissociated to form H_2PO^{4-} then H_2PO^{4-} and finally the phosphate anion PO_4^{3-} in strongly basic conditions. The uptake of P is best between soil pH of 6.5–7; below pH 6.5 it tends to be fixed by Fe, Al, and Mn, and above pH 7 it fixes mainly with Ca (PASSEL n.d.-b). P that is removed from the soil by fixation or plant uptake needs resupply by transferring P_i from the 'Active Pool' in the soil if albitite sources are unavailable. The Active Pool holds organic and inorganic P in solid compounds which must be broken down into P_i. P_{org} is bound with humic and fulvic acids, and it can be stabilized in Fe/Al-humus complexes in acid soils or with Ca and Mg in neutral or alkaline soils (Makarov & Malysheva 2006). P_i also associates with these humus acids using Al and Fe as metal bridges (Bedrock et al. 1997); Tan (2008: 432) explains that 'aluminum bridging' helps the storage of phosphates and preserves humic molecules in Indonesian andosols. P_i can react directly with iron and aluminium; some of these reactions are reversible, but P_i is only released under certain biological or chemical conditions, so they are not a good source of P nutrient. Irreversible insoluble chelation reactions of P with Fe and Al are considered part of the 'Fixed Pool' where P is virtually unavailable for plant use. This pool also contains P_{org} that is resistant to mineralization (Pagliari et al. 2017). A separate problem is phosphate fixing due to coatings of hydrous Fe or Al oxide developing on phosphates adhering to mineral surfaces (Anon. 2017).

The high content of Fe and Al complexes in andosols is responsible for the sorption of phosphate (Table D-3); as tephra weathering increases, these active elements combine with phosphate to form insoluble compounds and lead to P deficiency for growing crops (Shoji et al. 1993:171). One of the criteria for andic soils is seen in Chapter 13: Table 1 is a high P retention of ≥85%; however, this retention rate depends on Al+½Fe % content. Acid, non-allophanic soils bind twice as much P with 5 times tighter bonds. P-sorption increases with temperature rise, so it is a greater problem in summer and sub/tropical climates (see Shoji et al. 1993: ch. 6.5.3 for details).

TABLE D-3 COMPARISON OF P-SORPTION BETWEEN ANDOSOLS

	Non-allophanic andosols	**Allophanic andosols**
P retention % at Al+½Fe %	P=48% at Al+½Fe=0.4%	P=38% at Al+½Fe=0.5%
max P=85% at Al+½Fe %	at Al+½Fe=1%	at Al+½Fe=2%

Potassium K

Potassium is supplied naturally in tephras from the weathering of volcanic glass (Shoji et al. 1993: 222-224); rhyolite tephras contain higher levels than basaltic tephra, and K content also varies between calc-alkaline and alkali tephras. K variability is one of the difficult parameters to address in andosol fertility. In non-allophanic andosols of humid climates, the weathering of non-coloured glass provides K for the formation of 2:1 layer clays (see Appendix B: Table B-3), the allophane in allophanic andosols does not preferentially retain K. Both sequester K in humic matter.

Soil pH

Soil acidicity or alkalinity is simply measured by pH on a scale from 0 to 14, reflecting the amount of hydrogen ions H^+ in the soil solution. The neutral value is pH 7.0, and most vegetable crops grow in the pH range from 4.5 to 8. Volcanic ash deposits may start out with high pH due to the presence of the several alkali and alkaline base metals in felsic magma products, but these can be leached out quickly by exposure to moisture, and the weathering of volcanic glass as discussed above releases base metals through time.

Changes in soil pH may occur over time due to several processes: leaching out of nitrates as well as base metals, dissolution of aluminium compounds, and the neutralization of humic and fulvic acids. For example, when Al^{3+} combines with water, it produces aluminium hydroxide and a H+ as a by-product: $Al^{3+} + H_2O \rightleftarrows AlOH^{2+}(aq) + H^+$; and the dissociation of hydrogen from the carboxyl (COOH) and hydroxyl (OH) groups on the surfaces of humic and fulvic acids occurs in the reactions $COOH \rightarrow COO^- + H^+$ and $COH \rightarrow CO^- + H^+$ (Pettit n.d.). Non-allophanic andosols are more acidic than allophanic andosols (Chapter 13: Table 2). In general andosols have a pH less than 7.0 (neutral) (Shoji et al. 1993: 165).

Al Toxicity & Tolerance

Most studies mention free Al^{3+} as the specific agent of aluminium toxicity in soils, since free Al^{3+} reacts with the cell walls and membranes of plant roots, restricting their growth (CCMA 2013). Aluminium becomes a problem when soil acidifies. As pH drops below 6.2 into acidic soil conditions, Al becomes increasingly soluble (Yokel 2002), dissolving from its bound forms and entering into the soil solution as free Al^{3+}, for example as in the reversible reaction we saw above: $AlOH^{2+}(aq) + H+ \rightleftarrows Al^{3+} + H_2O$.

Al toxicity of soils can be tested by extracting it from soil solutions using potassium chloride (KCl). KCl extractable Al in amounts of 5–11 cmolc/kg can be toxic to plant roots (Shoji & Takahashi 2002);[4] Dadamouny (2015) gives the amounts of 0.5 ppm (parts per million) as troublesome and 1.0 ppm as toxic. Since non-allophanic andosols are generally more acidic than allophanic andosols, the former are more at risk of Al toxicity (Shoji et al. 1993: 232-233).

Methods to mitigate Al toxicity are:

1) adding carbonates: adding lime (calcium carbonate, $CaCO_3$) so that it forms aluminium carbonate $Al_2(CO_3)_3$ (dawsonite), or adding gypsum (calcium sulfate, $CaSO_4$) so that the dissolved Ca pushes Al deeper into the subsoil (Davidson 2014); or

2) adding organic matter (green manuring) to the topsoil to form the salts Al fulvate and Al humate (Blamey 1999).[5] Either liming or green manuring inactivates aluminium by removing it from the soil solution through chelation so that it cannot further attack plant roots.

Appendices A–D Figure & Table Sources

Figure A-1 map by TheOtherJesse [Public domain], via Wikimedia Commons, modified by GLB [https://commons.wikimedia.org/wiki/File:Regions_and_Prefectures_of_Japan.svg]

Figure B-1 magma composition: from Panchuk 2017: fig. 7.8, font replaced for readability; distributed via CC-by-4.0 International License [https://creativecommons.org/licenses/by-nd/4.0/deed.en_GB]

Figure in Table B-2 read Panchuck 2017 [https://physicalgeology.pressbooks.com/] (required attribution for free use of figure)

Figure B-2 Bowen Reaction Series, By Colivine (Own work) [CC0=Public Domain], via Wikimedia Commons [https://commons.wikimedia.org/wiki/File%3ABowen's_Reaction_Series.png]

[4] cmolc = centimoles of charge: a unit for calculating exchange capacity for soils.

[5] Pettit (n.d.) uses 'humate' to include salts of both humic and fulvic acids; salts are merely electrically neutral compounds of a base and an acid.

Figure B-3 magma minerals from Panchuk 2017: fig. 7.11, some font replaced for readability; distributed via CC-by-4.0 International License [https://creativecommons.org/licenses/by-nd/4.0/deed.en_GB] and rock photos by special permission of Roger Weller
Figure B-4 modified from Barnes 2003: fig. 4
Figure C-1 modified from DCO Project 2016: fig. 1
Figure C-2 modified from Driedger et al. 2014: 428
Figure C-3 modified from Barnes 2008: figs. 6, 13
Figure C-4 by Soica2001 (Own work) [Public domain], via Wikimedia Commons [https://commons.wikimedia.org/wiki/File%3ALake_Towada_from_Ohanabe_2008.jpg]
Figure C-5 by 富士山防災協議会 (the Mt.Fuji Volcano Disaster Management Conference); Miya.m added the URL and the information to the Map and uploaded under the permission of the Cabinet Office of the Japanese Government; CC-BY-2.5, via Wikimedia Commons [https://commons.wikimedia.org/wiki/File%3APredicative_map_of_Mt.Fuji_volcanic-ash-fall.jpg]

Tables A-2, A-3 from Barnes 2015: tables 1.5, 1.7
Table B-1 compiled from http://www.indiana.edu/~geol105/1425chap5.htm; http://periodictable.com/Elements/001/index.html; www.people.carleton.edu/~cdavidso/Geo110/CommonMinerals.pdf; http://homepage.usask.ca/~mjr347/prog/geoe118/geoe118.sgtable.html
Table B-2 after Palmer & Easterbrook 1999: pl. 6.12; percentages updated from Panchuk 2017, and tetrahedron illustration modified from Panchuk 2017: fig. 2.13 (arrows deleted, silicon atoms added, charges added) distributed via CC-by-4.0 International License [https://creativecommons.org/licenses/by-nd/4.0/deed.en_GB]
Table B-3 compiled from Velde & Meunier (2008), Bauluz (2015); formulae mainly from PubChem n.d.
Table D-1 compiled from Pettit n.d.
Table D-2 compiled from Shoji et al 1993; Pettit n.d.
Table D-3 based on Shoji et al. 1993: fig. 6.21

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Appendix E: History of Tephra Identification Methods

by MACHIDA Hiroshi * & ARAI Fusao **

This appendix describes the methods by which various tephras have been identified in Japan, discriminating between eruptions and phases of eruptions of one volcano or between tephras of different volcanoes. It was published in Japanese as Chapter 3 in the Atlas of Tephra in and around Japan *by MACHIDA Hiroshi and ARAI Fusao (1992, revised in 2003, 2011); an update to the first edition was published in English (Machida 1999). Examples are drawn from tephra found in Japan and adjacent seas but include the Korea Peninsula tephras from Mt Paektu (Changbaishan) on the present-day border between China and North Korea, and the Ulleung-do volcano off the Korean Peninsula to the east.*

Despite recent advances allowing chemical analyses of single glass flakes and specific phenocrysts of tephra to provide suspected correlations of widespread tephra, multiple strands of data are still necessary for tephra identification. Herein are described the multiple steps to be taken both in the field and in the laboratory for thorough and convincing identifications as originally presented by the authors. The Atlas of Tephra *has been the standard reference for all tephra research in Japan for the last quarter-century, and it is currently undergoing thorough revision and updating. (ed. & translator, GLB)*

E-1. Discrimination of Primary Tephra Layers

It is well known that tephra is a collective term of Greek origin for all pyroclastic materials. It is a product of explosive volcanic eruptions including subaerial, submarine and subglacial eruptions. Large explosive eruptions produce tephra which is spread by blast and wind, thereby tephra occurs extensively, forming conspicuous layers within a very short time.

As transportation and deposition of tephra is of many types, we must be careful about whether or not each is of primary explosive volcanic origin. Strata comprised of coarse-grained porous tephra such as pumice and scoria, if created by air fallout, can easily be distinguished from sand and gravel deposited by wind or water. However, in the following situations, when it is not clear whether the tephra is a primary deposit or not, careful examination is necessary: 1) when sandy–silty deposits are sandwiched by lacustrine strata; 2) when pyroclastic flow deposits (pryroclastic density current, PDC) cover a large area or when pumice fallout covers a region in which tephra occurs abundantly in sediments in lower river drainages. In both these situations, it is first necessary to examine the grains by handlens or microscope to see if they are tephra grains, to determine if they have been rounded by erosion, and to assess how much other material is mixed in with the tephra.

In the first case (1) above, a crucial point is to separate tephra grains of low porosity from other sand grains. In southern Kantō, among the peaty sediments in the valleys of the eastern terraces, numbers of scoria layers from Holocene Mt Fuji eruptions are often found. At first glance, these look like sand layers of common occurrence, but upon close examination, they are seen to consist of angular cinder-like grains riddled with pores forming a tephra stratum.

On the other hand, even when found to be pumice or scoria or even lithic fragments, the second situation (2) above may obtain: that they form a secondary deposit. In such strata, cross-lamination may be recognizable and there may be an abundance of rounded, eroded grains. In particular, these should be understood as reworked tephra strata laid by water if mineral grains are identified coming from various tephra layers in the background.

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E-2. Fundamentals in Identifying Tephra Layers

In order to correlate and identify tephras, the following two aspects must be elucidated: 1) whether they match in terms of eruption date and source volcano, and 2) among their characteristics as eruption products, what points are similar. Tephra goes through several processes in a very short time: eruption, transport, and deposition. After eruption, weathering and reworking often occur; their characteristics as sedimentary deposits combine that information plus their basic nature as extrusions from their parent magma. Consequently, identifying tephra involves collecting as much data as possible on these two aspects before comprehensively judging them. The major steps in tephra identification are given in Table E-1. Among these, the stratigraphic methods are those which pursue layers incorporating tephra; a sharp eye is needed in the field examination. Conversely, methods for describing the rock materials aim to reveal aspects of the volcanic rocks; in order to elucidate all the special characteristics of tephra useful for their identification, various experimental techniques are undertaken from the point of view of material science. Both are needed for a successful result. Below we will concentrate on how we can investigate the special characteristics of tephra as material deriving from its parent magma and how these contribute to tephra identification.

TABLE E-1 ANALYSES LEADING TO TEPHRA IDENTIFICATION

Stratigraphic methods (mainly in the field):

- Temporal and stratigraphic relationships of tephra stratum
  - Stratigraphic position
  - Dating by available radiometric means
  - Dating by micro-fossils
  - Dating by cultural relationships
- Documentation of tephra stratum characteristics
  - Stratum thickness
  - Grain size
  - Colour
  - Fall unit
  - Materials of similar or different composition
  - Degree of weathering

Petrographic characteristics (mainly in the laboratory):

- Rock level
  - Bubble form; crystal/glass ratio
  - Mineral composition (percentages of different minerals; heavy/light mineral ratio)
  - Chemical composition (whole rock [bulk], determined by XRF; wet chemical analysis)
- Mineral level
  - Form (crystal habit; in case of volcanic glass, details of its shape type, colour, microcrystalline, or crystallite)
  - Refractive index (of e.g. volcanic glass, pyroxenes, amphiboles, feldspars)
  - State of magnetization (for strongly magnetized minerals, the Curie point, etc.)
  - Chemical composition (major and trace element percentages for volcanic glass and phenocrysts using EPMA, XRF, AA, ICP, INAA [see below])
  - Other (e.g. lattice constant values of specific minerals; isotopic values of strontium Sr in volcanic glass)

E-3. Field Examination

Detailed descriptive analyses of tephra in the laboratory and dating analyses begin from observing the nature of tephra in the field. Within a radius of several tens of kilometres from a volcano of Holocene or late Pleistocene in age, it is often the case – once we have become accustomed to the procedures – that we can just examine tephra outcrop after outcrop and easily estimate the sources and stratigraphic relation between tephra layers. The criteria for judgement in those situations are the characteristics of the tephra layers themselves: grain size, thickness, bedding, the basic material composition and the proportion of similar or different materials, and the change of colour due to composition, weathering, etc. In addition, the relationship of a tephra stratum to other tephra layers (especially to key tephra layers) and to the marine or fluvial formations are important sources of information. When one volcano erupts repeatedly at high frequency and many layers of extruded tephra stack up, their material composition and rock attributes are extremely similar – as will be discussed below – and it is often impossible to discriminate individual layers on the basis of those attributes alone. However, even in this situation, they can be distinguished in the field examining each individual layer by naked eye; thus, exceptional attention to detail is necessary. Despite rock type being very similar, the amount and grain size of the extruded material at the time of eruption, the height of the eruption column, the direction and speed of the wind, or the extent of weathering all endow each tephra layer with an individual nature.

In temperate, humid and tectonically active areas like Japan, the Holocene and late Pleistocene tephrochronology relates more closely to landscape development and archaeology than do those of Middle to Early Pleistocene history. Therefore, Holocene and late Pleistocene tephras have been described in more detail (as presented in Part II of the *Atlas of Tephra*). The phase that divides the Middle and Late Pleistocene is the last interglacial period: marine isotope stage 5e/6, ca.126 kya.

Field observations made by researchers throughout Japan, and particularly in those areas hosting many volcanoes, have provided useful descriptions of multitudes of tephra layers, confirmation of their stratigraphic sequences, and chronologies. However, it is a fact that there are limitations in detailed field examination when comparing tephras long-distance or tephras that have accumulated in unusual environments. To maximize the extraction of tephra's many special characteristics regardless of deposit on land or in sea requires identifying where and when minute particles, crypto-tephra, were created. For this, petrographic descriptions of tephras are indispensable.

E-4. Composition of Tephra

Although tephra essentially derives from magma, it is composed of more than just the 'essential materials' (*honshitsubutsu)* of that magma. In addition, it contains 'accessory material' (*ruishitsubutsu)* deriving from the preceding or old products of the volcano, and 'accidental material' (*ishitsubutsu)* from the country rock surrounding the volcanic plumbing. The proportions of these in any one tephra vary by eruption size and style and how far distant from the source the tephra is transported. The major product of large Plinian eruptions is comprised primarily of essential materials. Moreover, any accessory and accidental materials that Plinian tephra carries are rather heavy, and they tend to be deposited near the source; distal tephras, therefore, have little of these additional materials and are comprised almost entirely of essential materials, i.e. volcanic glass. Tephras emanating from relatively small eruptions or steam eruptions contain very little essential material and much of both accessory and accidental materials. Post-deposition, during the development of soils, tephras commonly become contaminated by regional materials unrelated to the source volcano. If these materials are not volcanic in and of themselves, it is easy to discriminate them from source volcano tephra by eye; but if they consist of old tephra materials, then it becomes troublesome.

Consequently, in order to conduct tephra identification, the characteristics of the essential materials need to be known via a reference sample of the source tephra described in detail. The best prospect is to collect a sample of tephra at the type locality near the volcano. The volcanic glass and mineral crystals comprising pumice and/or volcanic ash correspond respectively to the magma and the already crystallized minerals existing just prior to the eruption. The matrix of large pyroclastic flow deposit is comprised mainly of fragmented magma forming volcanic glass shards, and the proportion of additional and accidental materials is generally very small. Distal co-ignimbrite ash is also composed of such volcanic glass. On the other hand, in the case of thin distal tephras, it must be kept in mind that materials are often incorporated in considerable proportions after deposition, and these circumstances must be acknowledged with their interpretation.

In regions close to the source volcano, there are occasions when exceptional minerals have been identified among the accidentals: for example, cordierite, garnets, and epidote crystals. These are important clues for tephra identification and collation, representing the bedrock surrounding the magma chamber.

E-5. Identification of Tephra on the Basis of the Rock Level or Bulk Level

Rocks are made of minerals and minerals are made of elements. In this section we will look at the mineral assemblages that make up volcanic rocks, with individual mineral analyses discussed in the next section. Out of the more than 2,300 types of minerals, there are six *groups* that are the most common 'rock-forming minerals': olivine, quartz, feldspar, mica, pyroxene, and amphibole (cf. Appendix B: Table B-1); these are particularly useful in identifying igneous rocks (MEMPR 2017). Each group except quartz consists of a variety of different minerals, some common, some rare. Tephra may be considered an 'unconsolidated rock' for characterization purposes.

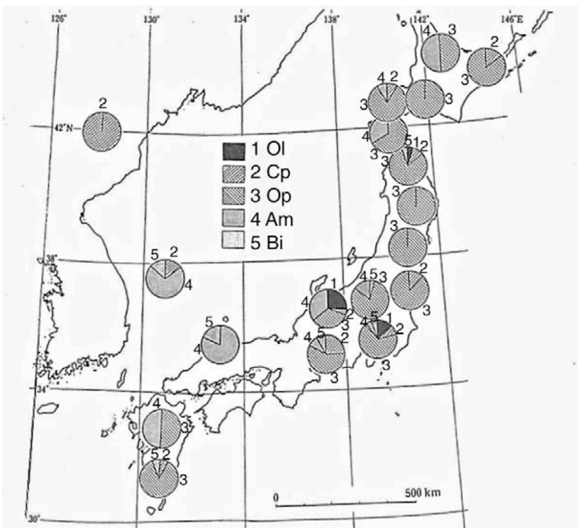

FIGURE E-1 MINERAL ASSEMBLAGE FREQUENCIES IN LATE QUATERNARY TEPHRAS OF THE JAPANESE ISLANDS AND THEIR SURROUNDINGS

Mafic assemblages:

1) ol + cpx + opx	Ol-type: ol ≥ cpx (opx)
2) cpx + opx + ol	Cp-type: cpx ≥ opx (ol)
3) opx + cpx + ol	Op-type: opx ≥ cpx (ol, ho)

Assemblages dominated by hydrous minerals:

4) am + ho + opx + cpx	Am-type: ho ≥ opx (cpx, bi)
5) bi + am + opx	Bi-type: bi ≥ ho (opx)

See abbreviation explanations in Table E-2

Mineral Assemblages in Tephra

The most common rock-forming minerals that occur in Late Quaternary tephra of the Japanese Islands are given in Table E-2. Note that the amphibole *group* in this table includes one of the group's most common mineral series: hornblende.

The components of tephra that have been long-documented are the heavy minerals listed in Table E-2; certain combinations of these, called 'mineral assemblages', are very important characteristics of proximal tephra composition (Kantō Loam Research Group 1965). Five assemblages are most common in Japan (Figure E-1); these are given below by abbreviation with the mineral/groups in their order of abundance on the left; these are then classified into types by their main mineral on the right. Figure E-1 illustrates their geographical distributions by type. Of these, the third assemblage, the opx-type, is most prominent. It should be noted that regional tephras may or may not be all of one type, though usually one is dominant.

In the case of an island arc like Japan, tephra extruded from volcanoes near the volcanic front usually contains many mafic crystals of olivine, orthopyroxene, and clinopyroxene. Farther away from the volcanic front, hydrous minerals such as amphibole and biotite are increasingly present.

For this reason, when tephra containing the hydrous mineral types intrudes into regions where mafic minerals are predominant, the intruders become key strata. A good example is in the southern Kantō region around Tokyo, where the Kantō Loam is overwhelmingly comprised of mafic tephra from such basaltic and andesitic volcanoes as Mt Fuji and Mt Hakone. Strata that yield biotite and amphibole/hornblende are important indicators for the intrusion of distal Ontake 1 tephra (On-Pm1) (Kobayashi et al. 1968) in this area.

TABLE E-2 COMMON MINERAL GROUPS OCCURRING IN LATE QUATERNARY TEPHRAS IN JAPAN

English	**Abbreviation**	**Japanese**	**Pronunciation**
olivine *group*	ol	カンラン石	*kanran-seki*
clinopyroxene (monoclinic pyroxenes) *sub-group* of the *pyroxene group*	cpx	単斜輝石	*tansha-kiseki*
orthopyroxene (rhombic pyroxenes) *sub-group* of the *pyroxene group*	opx	斜方輝石	*shahō-kiseki*
amphibole *group*	am	角閃石	*kakusenseki*
hornblende *series*	ho	普通角閃石 （ホルンブレンド）	*kakusenseki* *(horunburendo)*
feldspar *group*			
K-feldspar (orthoclase, alkali feldspar)	af	アルカリ長石	*arukari-chōseki*
plagioclase	pl	斜長石	*shachōseki*
biotite of the *mica group*	bi	黒雲母	*kuro-unmo*

However, there are many tephras of the same mineral compositions that are difficult to distinguish from each other. It had been attempted to differentiate them on the basis of relative proportions of heavy minerals or the mineral crystal/glass fraction proportions, but problems abound. Individual mineral crystals (phenocrysts) can fall out of the eruption cloud at various distances according to their weight; or the weathering can act to winnow the crystals. Together with variations in the methods used to produce the proportional results, large differences can occur in measuring tephra composition. Thus, it is imperative to develop a standard for tephra identification in which the results are not subject to the effects of deposition distance from the vent, or subject to influence of the wind and depositional regime, but which can characterize a given tephra wherever it is found.

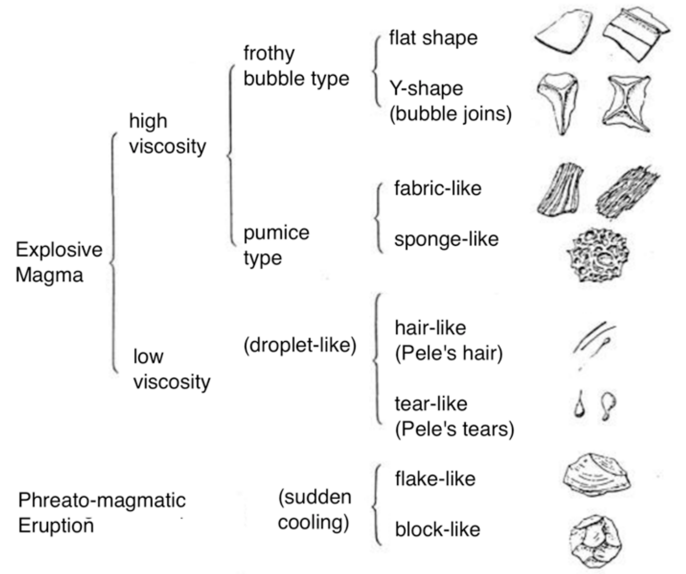

FIGURE E-2 CLASSIFICATION OF TEPHRAS ACCORDING TO ERUPTION STYLE

It is only the magma at eruption time and its volcanic glass and mineral content that can be used to characterize a tephra. In order to characterize these 'essential materials', it is necessary to examine individual crystals of the minerals to the level of their molecules and atoms, and to investigate the form (Figure E-2) and composition of the volcanic glass fragments. This is the basis for widespread tephra identification.

Mineral-level Identification of Tephra

The characteristics of the colours and shapes of volcanic glass observable with a handlens or an optical microscope are not only useful for describing tephras, but they are also important for estimating magma viscosity and eruption style. Heiken and Wohletz (1985) demonstrated the variety in volcanic glass fragments by electron microscope and explained them according to eruption style. There are several proposals for classifying volcanic glass fragments (Yoshikawa 1976; Wohletz 1983; Furusawa 1990), but we will use the one illustrated in Figure E-2 as the standard for our discussion. Its division is based on the difference between several kinds of eruption styles (cf. Chapter 1: Figure 9).

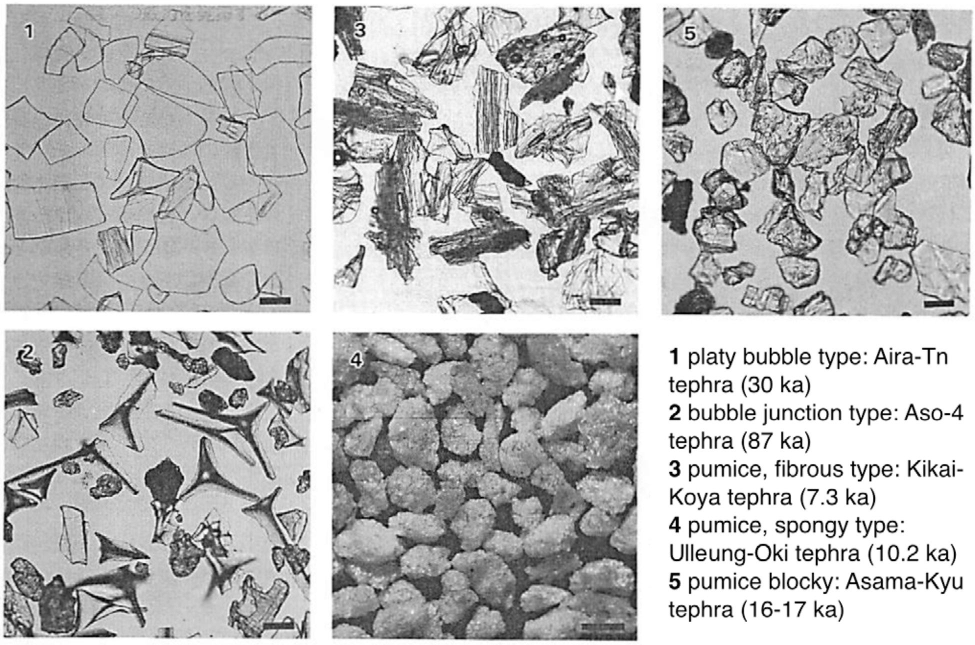

FIGURE E-3 MICROPHOTOGRAPHS SHOWING REPRESENTATIVE TYPES OF VOLCANIC GLASS
bars indicate scales of 0.1 mm for photos 1–3, 5 and 1 mm for photo 4

Large-scale eruptions produce mainly bubble or bubble-wall fragment types and pumice-type fibrous or sponge-like grains (Figure E-3). As the name of the first type suggests, they are the wall fragments of large soap-like bubbles which burst. Such bubble fragments have always been recognized to be curved, but observations of many almost flat glass fragments speak of very large diameter bubbles. These could not have formed by magma exploding deep in the ground under high pressure but indicate that the bubbles formed near the surface. Such volcanic glass fragments are commonly seen in large pyroclastic flow deposits and in their accompanying volcanic ash (co-ignimbrite ash) fallout deposits, attesting to the formation processes of large pyroclastic flows. On the other hand, pumice-type volcanic glass forms in the neck of the magma chamber and volcanic vent and is shot out like particles from a gun barrel. This type of Plinian eruption mainly produces pumice fallout (Plinian tephra) (cf. Chapters 9–11). The pumice-type glass created in large Plinian eruptions is very porous, so in distal fine-grained tephras it is well represented among bubble-type glass.

In slightly weathered volcanic glass deposits, fragments with Y-shaped or X-shaped ridges can be seen; these are areas of thicker glass where bubbles were joined together. The thinner glass walls of the bubbles have already weathered away and only the joins are left. Moreover, the glass thickness varies directly with the viscosity of the magma: high-viscosity magmas typically produce thicker glass fragments than do low-viscosity magmas. Glass colour also indicates magma chemistry and is an attribute that varies among tephra deposits. Generally, there is a tendency for the glass to be darker as the iron component increases and the silica component decreases. Thick, coloured volcanic glass weathers more easily than transparent, thin glass. The reason there are few places where old, distal, mafic-tending tephras can be sampled is because their glass and mineral fractions are easily weathered. If the tephras are of andesitic or basaltic composition, typically having low silica content, then the volcanic glass fraction quickly weathers to clay and only the more persistent mineral fraction remains (quartz, iron-rich minerals, orthopyroxenes, amphiboles, feldspars, etc.). In such cases, these mineral varieties become useful indicators in the rock-type descriptions.

The rate of weathering is dependent on temperature and water content, thus the same tephra in Kyushu (south) and Hokkaido (north) will weather at different rates. A good example is the Aso 4 tephra (Aso-4) which erupted around 87,000 years ago. It spread from Aso caldera in central Kyushu to Hokkaido; climatic conditions varied, but from Kyushu to central Honshu the tephra has generally weathered to clay, whereas in northern Japan it is well preserved.

In any case, in order to identify tephra by its volcanic glass and mineral assemblage, the following procedures are necessary:

- Document the individual characteristics of each tephra layer
- Present those characteristics quantitatively at as high resolution as possible
- Process the sample as efficiently and quickly as possible, otherwise it will not be utilizable

Recent advances in analytical technology have made the above procedures routine, but new problems have arisen. Below we will introduce a few further characterization methods.

E-6. Refractive Index (RI) of Volcanic Glass and Mineral Crystals

Assessing the refractive index (RI) of volcanic glass and phenocrysts is one physical method that informs on chemical components and structures at the atomic level. The RI of a material is calculated as $n = c/v$, where ‘c’ represents the speed of light in a vacuum, and ‘v’ represents the phase velocity of light in a medium. The reference value is $n = 1$, based on the speed of light in a vacuum; most RI of common materials have ‘n’ values greater than 1, as seen in Figure E-3.

Figure E-4 illustrates relationships in the refractive indices, colour and chemical compositions of minerals and volcanic glass that make up tephra. The thickened lines indicate the range of RI indices of minerals found in Japanese Quaternary tephras. In previous studies, many researchers have measured and described the refractive index as a primary method for characterizing tephra (Yoshikawa 1976; Arai 1972; Arai & Machida 1980; Arai et al. 1986; Miyachi 1987). Orthopyroxenes and amphibole crystals have especially been targeted for RI analysis as they are easily measured and occur ubiquitously.

After deposition, volcanic glass shard surfaces gradually absorb water over time. This hydration process raises the RI of volcanic glass high above their RI when they were erupted or first deposited. After several thousand years, depending on the environmental conditions, hydration of fine glass shards is virtually complete; thus, their RI stabilizes. However, younger volcanic glasses are in the process of absorbing water; hydrated and non-hydrated areas co-exist in the same shard. Because their RI is spread over a wide range, it is difficult to use them as a standard for identification. In such cases, the volcanic glass shards can be heated to evaporate the water, and measurements can be taken on the dry samples for the tephra identification (Nakamura et al. 2002).

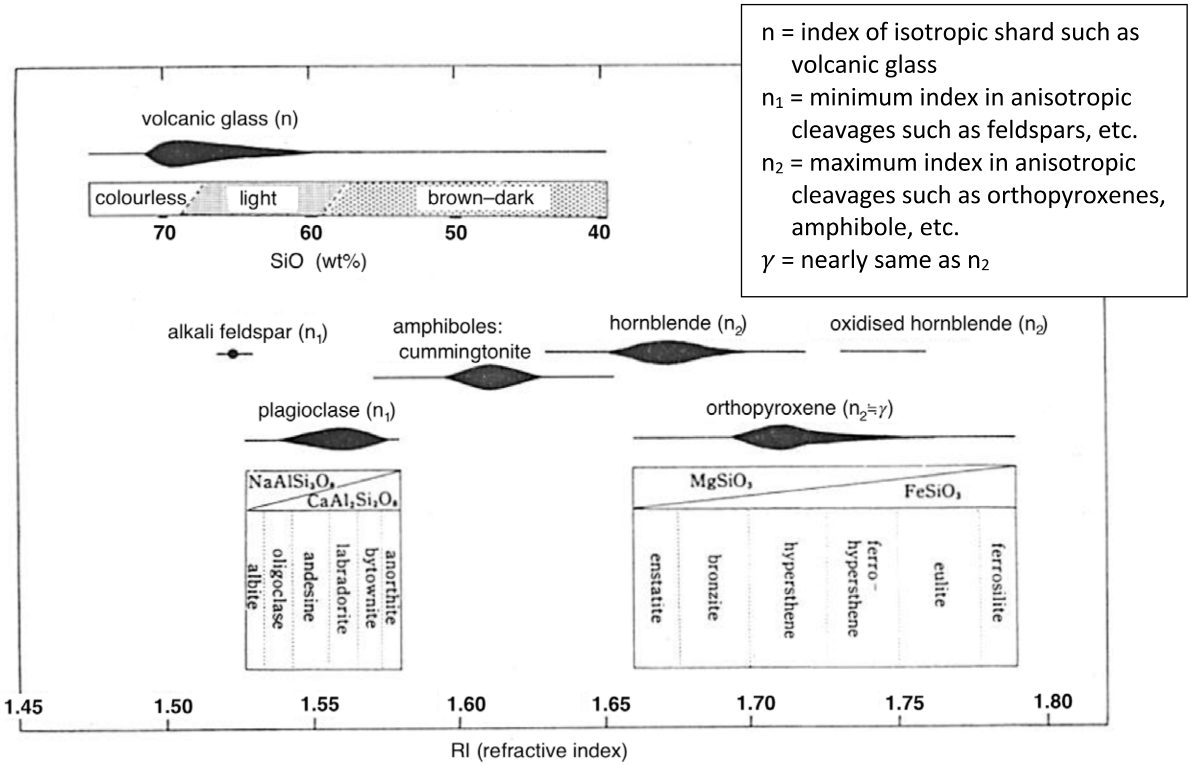

FIGURE E-4 COMPARISON OF STANDARD MINERAL REFRACTIVE INDICES (BOXES) WITH RI OF MINERALS IN JAPANESE QUATERNARY TEPHRAS (THICKENED LINES)

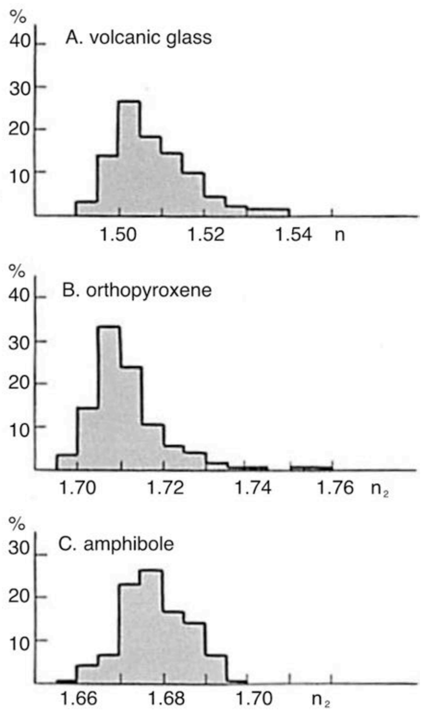

FIGURE E-5 REFRACTIVE INDICES (RI) OF SELECT MINERALS IN JAPANESE QUATERNARY TEPHRA

Figure E-5 illustrates the frequency distribution of RI ranges for Late Quaternary representative tephras found across the Japanese Islands. The tephras with low frequent RI ranges are most easily used for identification. In fact, a combination of two or three mineral indices can limit the number of tephra possibilities and increase the accuracy of identification. In our analyses, we aim for as accurate measurements as possible, with RI numbers running to three or four digits. Careless or inadvertent results would have a large margin of error of ±0.005; not only is that useless for tephra identification, it hinders investigation. It is always necessary to give the margin of error in measurements, and our methods give the following: ±0.0002 for the immersion liquid, and ±0.001 for the microscope speculum; thus, the total range of margin of error for RI measurements is ±0.001–0.002.

There are two main methods for measuring Refractive Index: the liquid immersion method and the thermal heating method (Arai 1993; Danhara et al. 1992). Using both increases the efficiency, but if one is to choose, the former is better for measuring minerals that have optical anisotropy, while the latter is better for measuring the RI of individual glass fragments. Anisotropic materials have structures whose components are organized in different directions, which means that impinging light will be bent in those directions. Isotropic materials have uniform structural directionality which blocks the passage of light through them.

Characterization by Refractive Index requires only a tiny sample. Measurements of high accuracy can be made quickly if only pure, true ‘essential materials’ are targeted. This method also has the benefit of being economical compared to the latest instruments, to be discussed below. However, at most, RI is only one characteristic of tephra. When we previously identified regional tephras from various parts of Japan using only their refractive indices, mistakes were made. Of course, in comparing tephras and their identities, not only RI but a number of aspects must be double-checked (Table E-1) in order to arrive at an overall result; in retrospect, too much emphasis was put on the significance of the refractive index. Most widespread tephras in Japan have been identified according to the important indicators of volcanic glass and the RI of one or two mineral types. But in the case of distal tephras, crystalline minerals are sparse, and in many cases the tephras have been identified on the basis of their volcanic glass contents alone, reducing the certainty of the results. Therefore, additional information such as chemical composition is necessary.

E-7. Chemical Composition of Mineral Crystals and Volcanic Glass

Recently, electronic analytical instruments of high accuracy have been developed and applied in the field of tephra identification. Those that have led to refined results in tephra research are:

- EPMA (Electron Probe X-ray Micro Analysis) is used to identify eight to ten major elements (Smith & Westgate 1969; Furuta et al. 1986; Aramaki & Ui 1976). The EPMA instrument combines an electron microscope with a precision X-ray machine. It works by irradiating a polished surface with a narrow electron beam and measuring the reflected X-ray wavelength and intensity that characterize the elements in a microscopically small area of the polished surface several to 20 microns in diameter and thickness per one shard. Very little sample material is required. Consequently, it is advantageous for the quantitative analysis of special materials such as volcanic glass in the tephra mixture while examining the material under the microscope without destroying it. There are differences among such machines, such as those using energy-dispersive (EDS) or wave-dispersive (WDS) approaches (Nishida 1983; Okumura 1993). EPMA methods have the advantage of being able to measure major elements, but they are unable to identify trace elements. Many kinds of trace elements, including REE (Rare Earth Elements), can be determined by other analysis such as XRF, AA, ICP, INAA, and LAICPMS.

  Some tephras are difficult to distinguish by their major element composition but can be separated by their trace elements. Such trace elements in volcanic glass are not only useful in tephra identification but are also important to estimating the source magma.

- XRF (X-ray Fluorescence Spectrometry) (Yamamoto et al. 1986)
- AA (Atomic Absorption Analysis) can identify 6 to 20 major and trace elements (Shōji et al. 1974)
- ICP (Inductively-Coupled Plasma) mass spectrometry can identify 6 to 20 major and trace elements; it requires absolutely purified test samples – this takes time and effort (Yoshikawa 1990)
- INAA (Instrumental Neutron Activation Analysis) can measure 12 to 24 trace elements; it requires absolutely purified volcanic glass – this takes time and effort (Borchardt et al. 1971; Fukuoka 1991, 1993)
- LAICPMS (Laser Ablation Inductivity-Coupled Plasma Mass Spectrometry) has lately been applied to tephra, measuring the trace element composition in any one volcanic glass shard rapidly and with great

accuracy. It is an especially effective tool for use in identifying tephra when only thin, tiny amounts in cores taken in distal regions are available (Kimura 2001). Recently, a set of analyses has been able to provide as much as fifty elements in and around Japan.

Many researchers are focussing on lake, ocean floor and high latitude ice cores which are far distant from the source volcano; thus, identifying tephra in sediment and ice cores relies on extremely small (<10μ dm.) flakes of volcanic glass.

- In addition to the above, strontium isotope analysis (Kurasawa et al. 1984), composition analysis of ferromagnetic minerals (Shōji et al. 1974), Mössbauer spectra (Daniels et al. 1985), and lattice constants of mineral crystals (Okada & Kosaka 1982), etc. are used in tephra identification. Especially, ferromagnetic minerals have higher resistance to weathering than other mineral crystals so that they remain relatively stable while the tephra weathers to clay – advantageous for being used as a material for tephra identification (Suzuki 2000).

By measuring the chemical composition of tephra components by these various methods, one can statistically obtain the degree of similarities as the first step in identification. Borchardt et al. (1971) presented the similarities and differences between many tephras as simple percentages, establishing metrics as a basic ingredient for tephra identification. This scheme has gone through various revisions and is widely used overseas. Discrimination by multivariate analysis is also conducted (Stokes et al. 1992).

E-8. Reflections

As observations mount up through employing various methods of tephra characterization, other problems manifest themselves. One is that depending on the tephra, components are not unimodal but may have bimodal or even polymodal characterization values. These very interesting cases may be due to the presence of several magmas with different natures which intermix during eruption, or they may derive from magmas of segmented composition. Of course, such cases cannot be characterized by a single averaged compositional value. Second, as more refractive index and chemical composition data are produced by numerous research facilities, it becomes necessary to mutually cross-check the values; differences in values arise according to the instrumentation and methods used. This problem cannot be ignored and requires that researchers communicate effectively concerning the standardization of measurement methods. Such standardization would be welcomed by the users to avoid unnecessary confusion, and it is imperative to obtain an international consensus (Froggatt 1992; Kuehn et al. 2011).

Despite various problems of detail, the precision of tephra identification can only improve as data relating to the descriptive features of rocks become perfected in quality and quantity. Here we have outlined characterization at the mineral level with the aim of tephra identification. However, this doesn't stop with tephra but extends to research in volcanological studies of magma generation and eruption. Already, with thorough measurements – taken on volcanic glass, major and trace elements in various minerals, and oxygen and strontium isotopes – the mechanisms of magma formation and eruption as well as the composition, depth and temperature variations of the magma chamber are being debated (Doe et al. 1982; Hildreth et al. 1984; Christiansen 1984; Gardner et al. 1991).

Appendix E Figure & Table Sources

All taken directly from the *Atlas of Tephra*, copyrighted by Machida & Arai, with the permission of H. Machida; modified by GLB for publication in English.

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Glossary and Character Index by Chapter

showing Japanese & Korean (Kor.) terms

	used in Chapter/Appendix:
akatsuchi 赤土 lit. ‘red earth’ = volcanogenic loam	13, 14
aki-no-enokoro-gusa 秋の犬ころ草 Japanese bristlegrass (*Setaria faberi*)	13
aki no nanakusa 秋の七草 lit. ‘seven grasses of autumn’	13
ando 暗土 lit. ‘dark earth’	1, 13
awa 粟 foxtail millet (*Setaria italica*)	14
azuki / adzuki 小豆, 荅 azuki beans (*Vigna angularis*)	14
buna 山毛欅, 橅, 椈, 柏, 橿 Japanese beech / Siebold’s beech (*Fagus crenata*)	13, 14
bushi 武士 warrior class	14
chō 町 a unit of land measurement = .992 of 1 hectare (ha. = 100 x 100 m)	12
daikon 大根 white radish (*Raphanus sativus var. longipinnatus*)	13, 14, App. D-1
dandan-batake 段々畑 stepped dry-fields	14
doronoki 泥の木 Japanese poplar (*Populus maximowiczii*)	13
emishi 蝦夷 people living beyond the jurisdiction of the Ritsuryō state	6, 8
enkihōwa-do 塩基飽和度 base saturation	13
enoki エノキ属 Chinese hackberry (Celtis)	10
fukkō 復興 restoration	9
fukkyū 復旧 recovery	9
geta 下駄 wooden sandals	14
gobō 牛蒡, 牛旁, 悪実 burdock (*Arctium lappa* L.)	13, 14, App. D-1
hagi 萩 Japanese clover / bush clover (Lespedeza ssp.)	13
haikaki-yama 灰掻き山 ‘mountains of raked tephra’	14
haizetsu 廃絶 abandonment	9
hatake 畑, 畠 dry-fields	13, 14
hie 稗 Japanese millet / barnyard millet (*Echinochloa utilis = E. esculenta*)	13, 14
hi-ire 火入れ ‘setting fire’	14
honshitsubutsu 本質物 essential materials	App. D-4
hŭkch’ang (Kor.) 黒倉 “black granary”	7
imo 芋 yam = 薩摩芋 *satsuma-imo* (*Ipomoea batatas*)	14
imogo 芋子 a type of clay colloid in soil, lit. ‘potato child’	1
ine 稲 rice (*Oryza sativa*)	14
iriai-chi 入会地 common use areas	14
ishitsubutsu 異質物 accidental materials	App. D-4
isunoki 蚊母樹, 柞 winter hazel (*Distylium racemosum*)	3
iwana 岩魚 charr, member of the Salmonidae	6
iyachi 嫌地 despised land	14
jishin kōkogaku 地震考古学 earthquake archaeology	1
jōbata 常畑 permanent dry-fields 14	
jōri 条理 gridded land-divisioning system from China	9, 12, 14
kabanoki 樺の木 Japanese white birch (*Betula platyphylla* var. japonica)	13
kabe 壁 wall	Preface
kanden 乾田 dry-paddies	14
kazanbai kōkogaku 火山灰考古学 tephroarchaeology, lit. ‘volcanic ash archaeology’	1, 2

kazanbaido 火山灰土 lit. 'volcanic ash earth'	2, 14
kibi 黍 common millet (*Panicum miliaceum*)	14
kihada キハダ Amur corktree (*Phellodendron amurense* Ruprecht)	10
kōkansei shio 交換性塩 exchangeable base / salt	13
kōko-kazangaku 考古火山学 archaeovolcanology	2
konara 小楢 evergreen oak (*Quercus serrata* Thurnb.)	10
kunugi-bushi クヌギ節 sawtooth oak (*Quercus* sect. *Cerris*)	10
komochi magatama 子持勾玉 large 'piggy-back' curved bead	10
konyaku 蒟蒻 devil's tongue / snake palm (*Amorphophallus konjac*)	14
kōya 荒野 rough meadows	13
kuri クリ chestnut (*Castanea crenata* Sieb. et Zucc.)	10, 14
kurobokudo 黒ボク土 andosols, black 'fluffy' soils; Gunma dialect *kuronoppo*	1, 13, 14
kuroboku-dosō 黒ボク土層 black 'fluffy soil' stratum	13
kurotsuchi 黒土 lit. 'black earth' = topsoil	13, 14
kyōshitsuden 強湿田 wetland paddies (cf. *shitsuden*)	14
mochi 餅 glutinous rice-cakes	14
medaka メダケ属 monopodial bamboo (Plioblastus)	3, 10, 14
mehi-shiba メヒシバ (*Digitaria adscendens* Henr.)	13
miso-tsuchi 味噌土 grainy soil deriving from pumice	1, App. D-1
mizunara 水楢 an evergreen oak (*Quercus crispula* Blume)	14
mugi 麦 wheat (*komugi*) OR barley (*ōmugi*)	14
momi モミ属 fir (Abies)	10
naedoko 苗どこ seedling bed 11	
nanushi 名主 manager, headman	14
nezasa 根笹 dwarf bamboo (Pleioblastus ssp.)	3, 9, 13
no-ine 野稲 dry rice	14
nōsho 農書 Edo-period agricultural treatises	14
okabo, see *rikutō*	–
onoe yanagi Sakhalin willow (*Salix sachalinensis = S. sachalinensis F. Schmidt*)	13
p'al sŏngdang (Kor.) 八 聖堂 the Shrine of Eight Worthies in Koryō-period Korea	7
p'ungsu (Kor.) 風水 Chinese geomancy, *feng shui*	7
rikutō or *okabo* 陸稲 dry-rice	14
rōnō 老農 Edo-period agricultural experts	14
ruishitsubutsu 類質物 accessory materials	App. D-4
ryūsui kyakudo 流水客土 guest soil in irrigation water	14
saikaihatsu 再開発 re-development	9
sakutori (冊?) サク取り cutting furrows	14
sansin (Kor.) 山神 mountain spirts	7
sasa 笹, 篠, 筱, 筿 bamboo grass (Bambusoideae, Sasa spp.)	13, 14
sato-imo 里芋 taro (*Colocasia esculenta* (L.) Schott)	14
satoyama 里山 village hill (commons)	13, 14
satsuma-imo 薩摩芋 sweet potato *(Ipomoea batatas*)	13
senbei 煎餅 savoury rice biscuits	14
shinki kaihatsu 新規開発 new development	9
shirakaba 白樺 Japanese beech (*Betula platyphylla* var. japonica)	13
shirasu 白砂 white pumice, lit. 'white sand'	1, 6
shiroza 白藜 lamb's quarters / white goosefoot (*Chenopodium album*)	9

shiso 紫蘇 beefsteak plants (*Perilla frutescens* var. *crispa*) 13, 14
shitsuden 湿田 wet-paddies (cf. *kyōshitsuden)* 14
shōen 荘園 untaxed medieval private estates 14
sō 層 layer, stratum 13
soba 蕎麦 buckwheat (*Fagopyrum esculentum*) 13
sugi スギ科 Japanese cedar (*Cryptomeria japonica*) 10
sohō nōgyō 粗放農業 extensive agriculture 14
suiden 水田 paddy fields 13
suiden shikō 水田志向 preference for rice 14
suitō 水稲 wet-rice 14
susuki 芒, 薄 Japanese pampas grass / Chinese silver grass / eulalia (*Miscanthus sinensis*) 3, 9, 10, 13, 14
taegan (Kor.) 大幹 a mountain range 7
taihi 堆肥 compost 14
tanada 棚田 terraced or stepped paddy fields, lit. 'shelf paddies' 2, 14
tanpopo タンポポ亜科 dandelion subfamily (Cichorioideae) 10
tenchi-gaeshi 天地返し 'turn the earth over' 14
tera 寺 temple 6
tochinoki トチノキ属 horse chestnut (Aesculus) 10
tsunami kōkogaku 津波考古学 tsunami archaeology 1
ŭich'ang (Kor.) (Ch. *yichang*) 義倉 'charitable granary' 7
une 畝 ridge 12, 14
unekae 畝換え, 畝替え 'remaking the ridges' 14
unema 畝間 furrow 12, 14
uruchi 粳 steamed rice 14
ushigusa ウシクサ族 *blue stem grass (*Andropogoneae) 10
wakakusa 若草 lit. 'young grass' 13
yabukōji 藪柑子 coralberry (*Ardisia japonica*) 13
yaki-harai 焼き払い cleaning by controlled burning 14
yakihata 焼畑 swidden fields / slash-and-burn agriculture 14
yakihata nōkō 焼畑農耕 swidden agriculture 14
yamakaji 山火事 forest fire 14
yasechi 痩地 infertile soils 13
yashabushi 夜叉五倍子 Japanese green alder (*Alnus firma*) 9

See also mineral names in App. E: Table E-2.

Index I: Archaeological Sites

mentioned in Chapter (:Figure)[1]

[1] Most but not all sites/locations appearing in Figures are discussed in the chapter text. See Appendix A.1 for prefecture locations in Japan.

Index II: Volcanoes and Related Geological Terms

mentioned in Appendix (App) or Chapter (:Figure)[1]

[1] Most but not all sites/locations appearing in figures are discussed in the chapter text. See pp. 275-6 for Appendix figure & table page numbers.

[2] On Iturup Island, disputed with Russia.