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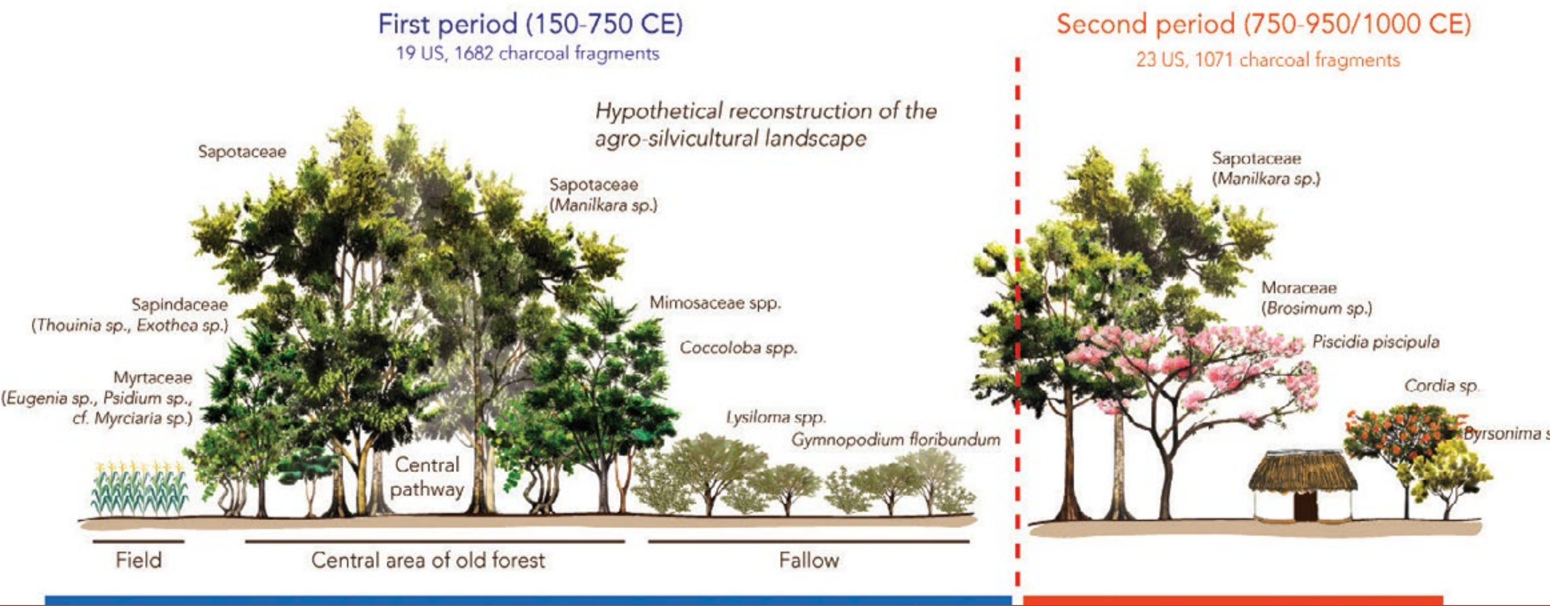
Different Times?
Archaeological and Environmental Data from Intra-Site and Off-Site Sequences

Edited by

Zoï Tsirtsoni, Catherine Kuzucuoğlu,
Philippe Nondédéo and Olivier Weller



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Cover: Firewood and woodland management at Naachtun (Guatemala), based on charcoal analysis, by Lydie Dussol.

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FOREWORD TO THE XVIII UISPP CONGRESS PROCEEDINGS

UISPP has a long history, originating in 1865 in the International Congress of Prehistoric Anthropology and Archaeology (CIAAP). This organisation ran until 1931 when UISPP was founded in Bern. In 1955, UISPP became a member of the International Council of Philosophy and Human Sciences, a non-governmental organisation within UNESCO.

UISPP has a structure of more than thirty scientific commissions which form a very representative network of worldwide specialists in prehistory and protohistory. The commissions cover all archaeological specialisms: historiography; archaeological methods and theory; material culture by period (Palaeolithic, Neolithic, Bronze Age, Iron Age) and by continents (Europe, Asia, Africa, Pacific, America); palaeoenvironment and palaeoclimatology; archaeology in specific environments (mountain, desert, steppe, tropical); archaeometry; art and culture; technology and economy; biological anthropology; funerary archaeology; archaeology and society.

The UISPP XVIII World Congress of 2018 was hosted in Paris by the University Paris 1 Panthéon-Sorbonne with the strong support of all French institutions related to archaeology. It featured 122 sessions, and over 1800 papers were delivered by scientists from almost 60 countries and from all continents.

The proceedings published in this series, but also in issues of specialised scientific journals, will remain as the most important legacy of the congress.

L'UISPP a une longue histoire, à partir de 1865, avec le Congrès International d'Anthropologie et d'Archéologie Préhistorique (C.I.A.A.P.), jusqu'en 1931, date de la Fondation à Berne de l'UISPP. En 1955, l'UISPP est devenu membre du Conseil International de philosophie et de Sciences humaines, associée à l'UNESCO. L'UISPP repose sur plus de trente commissions scientifiques qui représentent un réseau représentatif des spécialistes mondiaux de la préhistoire et de la protohistoire, couvrant toutes les spécialités de l'archéologie : historiographie, théorie et méthodes de l'archéologie ; Culture matérielle par période (Paléolithique, néolithique, âge du bronze, âge du fer) et par continents (Europe, Asie, Afrique, Pacifique, Amérique), paléoenvironnement et paléoclimatologie ; Archéologie dans des environnements spécifiques (montagne, désert, steppes, zone tropicale), archéométrie ; Art et culture ; Technologie et économie ; anthropologie biologique ; archéologie funéraire ; archéologie et sociétés.

Le XVIII° Congrès mondial de l'UISPP en 2018, accueilli à Paris en France par l'université Paris 1 Panthéon-Sorbonne et avec le soutien de toutes les institutions françaises liées à l'archéologie, comportait 122 sessions, plus de 1800 communications de scientifiques venus de près de 60 pays et de tous les continents.

Les actes du congrès, édités par l'UISPP comme dans des numéros spéciaux de revues scientifiques spécialisées, constitueront un des résultats les plus importants du Congrès.

Marta Arzarello

Secretary-General / Secrétaire général UISPP

Contents

List of Figures and Tables

S. Granai *et al.*: The role of the duration and recurrence of settlements in our perception of human impact on the environment: an example from Northern France

L. Lemer *et al.*: Dynamiques environnementales et impact de l'anthropisation au Néolithique dans le vallon du Vey à Cairon (Calvados, Normandie) : apports des analyses à haute résolution sur une nouvelle séquence pollinique hors-site

C. Kuzucuoğlu *et al.*: Geoarchaeological and chronological reconstruction of the Aşıklı PPN site spatial development (Central Anatolia, Turkey)

M. Pomadère *et al.*: Times of historical developments and environmental changes in the Minoan town of Malia, Crete: an intra and off-site geoarcheological approach

V. Villa *et al.*: Environmental change and population responses in the Sechura Desert during the late Holocene

Ph. Nondédéo *et al.*: Archaeological and paleoenvironmental reconstructions in the tropical Maya area: the case of Naachtun (Guatemala)

L. Dussol: Tracing the hidden history of the Maya forests through anthracological sequences

Introduction

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The present volume brings together some of the papers presented in a session organized in the 18th World Congress of the UISPP, under the title 'Different Times? Archaeological and Environmental Data from Intra-Site and Off-Site Sequences'.

A common characteristic of these papers, besides their theme broadly speaking, is their connexion with the activities of the Working Group 'Environmental and Social changes in the Past' (*Changements environnementaux et sociétés dans le passé*), animated in the frame of the Cluster of Excellence 'Dynamite' (*Territorial and Spatial Dynamics*) of the University Paris 1-Panthéon-Sorbonne. This Cluster of Excellence, funded by the French State (ANR-11-LABX-0046, *Programme d'Investissements d'Avenir*), was created in 2012 as part of a public policy aiming at favouring interaction between researchers and disciplines that do not usually work together –or not enough. 'DynamiTe' (http://labex-dynamite.com/fr/) was conceived as a consortium of laboratories representing different disciplines –geography mainly, but also anthropology, history, sociology, archaeology– susceptible to investigate issues around the key-concept of Territory, in the present, past and future. The Group 'Environmental and Social changes in the Past' focuses on evidenced landscape changes that affected human societies and the perception of these changes by the same societies. Its members are mostly archaeologists and physical geographers, many of them being further specialized in analytical techniques deriving from natural sciences (zoology, paleobotany, palynology, geology, sedimentology, malacology, anthracology). This small community –ca. 65 active members at the time of the Congress– handles and/or produces every day substantial quantities of data in relation with past events in the four corners of the earth (see also Giligny and Tsirtsoni 2015). And like most of their colleagues around the world, they give particular attention to the recording of time scales and interpretation of time records.

Time is indeed an essential parameter to be taken into account in any research dealing with the past, since all our hypotheses lay on that. If the reading of time is not right, if an event that we place at a time A happened actually at a time B, several years, decades or centuries after the presumed time A, all the narratives that we may build are wrong. Anyone who ever read a detective novel is aware of how important this factor is for the solution of the mystery and the arrest of the guilty! The gravity of the mistake becomes bigger as we pile up narratives or we try to combine evidence in order to *explain* things. Thus, if we presume causality between an environmental change and a societal event, either positive (e.g. emergence of a new way of living) or negative (e.g. shrinkage or abandonment of a settlement or settlements in a region), we have to make sure at least that the environmental change took place before or roughly simultaneously with the societal event itself. Of course this is still not a proof of causality, but it is a minimum prerequisite, the first step of the demonstration (see Coombes and Barber 2005; Maher *et al.* 2011; van der Plicht *et al.* 2011; Middleton 2012; Bonsall *et al.* 2015; Kuzucuoğlu and Tsirtsoni 2015; Contreras 2017; Beach *et al.* in press). If the chronology of events is reversed, the whole scenario collapses.

Attention is needed when we talk about environmental change. In many works, even recent ones, there is confusion between 'environmental changes' and 'climate changes' or 'climatic events'. These are not synonyms though, and the difference between the two is a difference of scale, spatial and temporal. Climate changes do not have the same impact everywhere, nor synchronously, especially if we talk in terms of human time. This fact is usually dissimulated behind the long time scales used by paleoclimatologists. Even those that are described as 'global' do not affect equally the various parts of the globe, and although the main symptoms are the same (e.g. a substantial cooling or warming of the atmosphere over an entire hemisphere), the local impacts can be of varying intensity and even of different nature (Curtis *et al.* 1996; Miller-Rosen 1997; Wilkinson 1997; Andrews *et al.* 2000; Gill Richardson 2000; Allen 2003; Haug *et al.* 2003; Calaway 2005; Kuzucuoğlu 2009; Berger *et al.* 2016; Oster *et al.* 2019). Societies, on the other hand, do not respond to climate changes in general, but to changes in their immediate environment or in more distant environments on which they depend (e.g. for pastures or agriculture, for raw materials or, in more developed societies, for trade purposes).

Environmental changes can also be induced by geological phenomena, e.g. earthquakes or volcano eruptions, which have a priori nothing to do with climate –although some of them can actually have an impact on climate (Sicre *et al.* 2011; Cooper and Sheets 2012; Dunning and Houston 2011). In this case, the time scale of the geological event is rather short (even if repeated eruptive episodes can sometimes stretch over several decades), but the distances at which its effects will be visible can vary considerably and not necessarily in a straightforward way.

And of course, environmental changes can also be provoked by human action. Small-scale actions may include intensive farming or forest exploitation in a limited area, deviation of small watercourses, etc. But the same actions developed over larger or more critical areas (from an ecological point of view) can have heavier impacts (Redman *et al.* 2004; Aimers 2007; Kuzucuoğlu 2007, 2009; Fleury *et al.* 2014).

Whatever its origin, some time passes before people actually *feel* the impact of a given change on their natural or economic environment, and even more time passes before they *react* to this impact, first by adapting (whatever mechanisms this implies: see Wossink 2009 with previous bibliography, and also Smyth *et al.* 2017), then eventually by moving to some other place.

Therefore, when we discuss regional phenomena and try to correlate behaviours here and there (e.g. massive abandonments of settlements as a response, presumably, to environmental changes generated by climate changes), we have to: first, make sure that we record time correctly at each individual spot, and second, consider properly the timespan needed to move from one spot to the other taking into account the distances, the nature of changes seen in the environment, and also the nature of the behaviour presumably involved (e.g. interruption of agricultural practices favouring reforestation, water control etc., or conversely, turn to husbandry favouring erosion).

What is true for regions is also true for sites. The same events recorded in a primary archaeological context (e.g. a house destruction layer, or an undisturbed grave) and in a secondary depositional context (e.g. a fill, a colluvium, or a secondary burial), do not have the same historical meaning, and do not provide the same information in terms of temporal framing. Before making any correlation, we have then to make sure that the sedimentary/deposition processes are understood correctly and that the time delay between the two points (primary-secondary) is taken into account. The interpretation procedures –and the risks– are the same also for contexts far from settlements. An undisturbed silt deposit and a reworked colluvium, even if they provide the same dates, do not actually refer to the same 'events'; to say it crudely: they are not contemporaneous, and any narrative that would consider them as such would be false.

Last but not least, changes –environmental as well as social– are not always rapid or dramatic. Smooth changes also exist, which derive from long-duration processes and well-established practices. Correlations between phases of stability in the human and environmental record are also of interest for archaeologists and natural scientists, and are also subjected to the limitations described above.

The higher the resolution of the available data, the better we can examine the different combinations seen in the environmental and human record, and try to deduce meaningful patterns between the two (Lespez *et al.* 2016; and several papers in Carcaud and Arnaud-Fassetta 2014). Natural sciences –physics mainly– have made great progress in the past decades, providing us with dating methods capable to reach a previously unsuspected precision. To take only the example of radiocarbon, in the last fifty years raw measurements passed from an average precision of 150-250 years BP to a precision of 30-50 years BP; combined to the improvement of calibration method, this gives us today calendar dates spanning less than two centuries for the biggest part of Holocene (including those affected by 'plateaux', i.e. rapid variations in the calibration curve), reaching sometimes less than 80 years (see Evin and Oberlin 2005; Reimer *et al.* 2004; Reimer *et al.* 2009; Taylor and Bar-Yosef 2014). This is however not always sufficient for resolving chronological issues in periods where cultural change is too rapid and/or historical evidence contradictory (see Bietak and Czerny 2007; Manning 2006-2007), but one can hope that this will soon be the case.

But the resolution is not just a question of density or precision of measurements. It is also a question of reliability of the samples: phenomena like the so-called 'old-wood effect', the marine or freshwater 'reservoir effect', or the various suspected problems around the carbon content of burnt bones (Schiffer 1986; Facorellis *et al.* 1998; Bonsall *et al.* 2004; Van Strydonck 2016) or endocarps of wild fruits (Quade *et al*. 2014), can produce more-or-less significant deviations from the real age of dated samples. It is also, more importantly, a question of *adequacy* of the measured samples with the actual events that they are supposed to represent. A charcoal in a house destruction layer and another in a colluvium that reworked this same layer do not provide the same information in terms of temporal framing –and this, independent of the short- or long-lived character of the charred plant species. If the sample does not correspond to the layer we think it does, or if we misinterprete the nature of the dated deposit (primary, secondary, mixed), the physical quality of the sample and the precision of the date will be of little use in interpreting things (see Ashmore 1999; Demoule *et al.* 2009: 211; Tsirtsoni 2016: 41). Being aware of the discrepancies generated by such contextual differences is essential for our understanding of the succession or amplitude of past events (see case studies in Berger *et al.* 2014; Borić *et al.* 2015). This is why we prefer here to speak of 'time reading' rather than 'time measurement': making inferences about past chronologies is not a mechanistic juxtaposition of numbers but the outcome of a complex analysis, quantitative as well as qualitative.

Our Group defends also the necessity of a closer dialogue between specialists that would overcome the separation between intra-site and off-site records, the former being considered as the 'ground' of archaeologists, the latter as that of geomorphologists and natural scientists. Although convenient in practical terms and justified to a certain point by differences in the theoretical backgrounds and skills, this separation minimizes the interaction between the two spaces –whose definitions are in themselves far from evident– over the short, middle and long terms, and neglects the similarities in the approaches or the methodological tools used here and there (Dincauze 1987; Demoule *et al.* 2009: 174-175). Ultimately, comparisons between intra-site (i.e. basically anthropogenic) sequences and neighbouring off-site (i.e. basically environmental) sequences must to take into account, in addition to distance distortion, the effects of time delay observed, or estimated, in the recording of mutual impacts. Only then can we propose a common narrative, a convincing joint reconstruction of past events. The papers gathered here exemplify the difficulties met in this exercise and propose some 'good practices' to follow.

The papers are presented in a rough geographical movement from metropolitan France to the Eastern Mediterranean –Old World first–, then to the Americas –New World. Incidentally, the movement is also chronological, although not in a perfect order, going from the early protohistoric contexts (Neolithic and Bronze Age, 9th to 2nd mill. BC) to the late Historic ones (1st and 2nd millennium AD). This movement in time and space shows without ambiguity that: a) the methodological problems are essentially the same everywhere; b) similarities are sometimes dissimulated by changes in the vocabulary and the academic traditions.

The contribution of Granai *et al.* points to the crucial issue of our understanding of human presence in a given area, depending on the precise nature of the sites studied and the intensity and overall duration of occupation. The main proxy used here consists of terrestrial and freshwater molluscs. The paper confronts results of analyses from one Neolithic site in Northern France (Passel 'Le Vivier') with the picture retrieved from previous analysis of data on coeval sites over a radius of c. 100 km, observing some differences that seem troubling at first sight given the geographical proximity and the similarities in the landscape originally surrounding the sites. The explanation may be lying in the nature of this particular site (an enclosure), which, although more monumental in aspect than the others, is ultimately less marked by human activities, as it was occupied only for a short period and involved little or no cultivation of the fields around. The key for all comparisons –between the built 'intra-site' space and the more or less natural 'close off-site' sequence, as well as between Passel and the other sites in the area– is, of course, chronology, based on a series of high-precision AMS dates from shell and charcoal fragments. The dates are few and not always consistent with their stratigraphic position. For this reason, the authors search for additional support in correlations with malacological assemblages collected in other features, and in logical arguments about the stratification of material over the entire sequence. This shows how important it is to consider evidence not only from the particular 'slice of time' that interests us more, but also from the years/centuries before and after, in order to evaluate things correctly.

The contribution of Lemer *et al*. also concerns comparisons between individual sites and regional patterns in Northern France, related to the Neolithic. The authors aim to precise the interactions between environmental changes recorded by palynological studies and development of agricultural practices in the Plain of Caen (Normandy). Based on the results of a new high-resolution palynological study in the Vey valley at Cairon, close to a Neolithic settlement, they highlight environmental dynamics in the area and propose detailed correlations between anthropogenic indicators and the three occupation phases of the archaeological site (c. 4400-3500 BC). Although the paper presents only the pollen proxy, this case study demonstrates the importance of high-resolution analyses and accurate chronological framework for the understanding of environmental evolutions.

With the paper by Kuzucuoğlu *et al.* we change environment completely. This is again about Neolithic, but of much earlier date and in very different topographical and climatic conditions. The discussion here is about one of the earliest sedentary settlements of the Near East, established in a river valley on the Central Anatolian plateau and prospering continuously for almost 1000 years. The authors first present separately the evidence from intra-site (archaeological) and from close and more distant off-site (geomorphological) investigation. Confronting their respective results, they propose a joint scenario for the conditions under which the first inhabitants settled at this spot and progressively expanded in a changing environment. Besides being highly pedagogical, this kind of presentation allows measuring: a) the difficulties met by each discipline in 'reading' the various lines of evidence, including time (e.g. inversions or inconsistencies of ^{14}C dates), b) the importance of a thorough, multi-parameter analysis in each field of research (architecture, fauna, etc. for archaeology; diverse sediment analyses for geomorphology), and c) the benefits obtained from a close and long-term collaboration. For space and time are indeed quality parameters also in the present: inter-disciplinary research is still, unfortunately, too often understood as different specialists working separately from each other and/or over short periods only –physical geographers and natural scientists being more or less considered as temporary 'service providers' for the pluri-annual archaeological projects. The same is true for radiocarbon scientists and specialists of other dating methods, who, although constantly solicited, are rarely implicated in the selection of samples and the reasoning behind the requested measurements. The results of such a cooperation are limited in accuracy and ambition despite the precision of individual data. By contrast, a truly integrated approach requires proximity of the different specialists in the field (i.e. working together, scrutinizing together the same features, sections, records, etc.) and time for maturation of ideas and interaction. In the case of Aşıklı Höyük the results are convincing: the inhabitants benefited from the specific site location as much and as long as possible, and departed when the local conditions –and not the climate– made their maintenance there less interesting from a socio-economic perspective.

The paper by Pomadère *et al.* about the area around the Bronze Age palace and town of Malia, in Crete, is a good example of the limitations imposed to ambitious joint archaeological-environmental projects by the paucity or ambiguity of data themselves. The authors are confident that this situation may change with the processing of additional lines of evidence (i.e. proxies that are not yet thoroughly exploited). It appears then, once again, that good interdisciplinary research needs time… Until reaching final results, the authors make a number of interesting hypotheses about human activities in the area, in connection –or not– with changes in the local environment (e.g. expansion/shrinkage of the nearby coastal marsh) but also in connection with major regional phenomena, like the eruption of the Santorini volcano. The confrontation of the local chronological data, obtained from both intra-site excavations and off-site cores, with the complex and largely contradictory evidence about the date of the eruption itself, is an opportunity to discuss a series of crucial methodological issues.

The next three papers take us to the other side of the Atlantic Ocean: first at the coastal desert of Peru, with a contribution by Villa *et al.* about two neighbouring micro-regions whose evolution is tracked over the last two millennia; then in Guatemala, with papers by Nondédéo *et al.* and by Dussol, who discuss, on different time and space scales as well as from different perspectives, the connection of the Maya city of Naachtun with its surrounding environment.

The region investigated by Villa *et al.* in South America is very different from all other areas presented in the volume. It concerns a hyper-arid desert on the north Peruvian coast. The authors are conscious of the importance, for the human societies in the past, of possible climatic variations during the Holocene (and especially the early Holocene), that may have caused occurrences of (i) environmental conditions less constrained by humidity depletion than the present one, and (ii) extreme rainfall linked to the El Niño Southern Oscillation (ENSO) events. In this context, the authors compare intra-site data from two sites of contrasted dimensions and time lengths of occupation: (1) a fishermen site occupied for c. 300 years during the 5th to 8th centuries AD, and (2) a mound occupied more-or-less continuously for more than 1000 years, from the 5th to the 15th century AD. In parallel, off-site data are provided by sedimentary archives studied in coastal humid environments (*playas* and intra-dune wetlands). Results allow the authors to evidence:

- the succession of contrasting climatic phases during the last two millennia, with the identification, in particular, of two humid phases separated by a more arid one at the onset of the 8th century AD.
- the variety of responses of populations who adapted their subsistence economies to the substantial environmental fluctuations, before and after the 8th century AD. It is indeed evidenced that, in the coastal area facing the sea along the Sechura desert, the first centuries

> of our era saw short-term opportunistic occupations focusing on the exploitation of temporary marine and wetland resources. On the wider scale of the regional territory between the coast and its hinterland, populations could address a higher variety of resources. This richness allowed permanent occupation and adaptation, even when the resources changed over time. This trend continued until the installation of hyper-aridity during the second half of the 15th century AD (i.e. a date known in the northern hemisphere as the end of the 'Medieval Optimum').

The following paper, by Nondédéo *et al.*, confronts two sequences: a cultural one (intra-site), recording also the archaeo-environmental context of a very large Maya city (Naachtun) mainly occupied during the Classic period, and a palaeoenvironmental sequence composed of several cores and observations made on a much wider scale around (off-site), in a forest and wetland context. The confrontation of these sequences leads to a quite new image on different time scales: a 'short' scale (c. 800 years) during the construction and main lifetime of the Maya city; a long scale, during a few millennia preceding the building of the Maya city. The results show also the interest of working on different space scales: the scale of the city vs. that of resource exploitation in closer or more distant 'natural environments'. In particular, off-site palaeoenvironmental investigations evidence a very early occupation of the area by human societies practicing agriculture on a wide scale around the city (which is not yet born), thus adding new light and time depth to the history of Naachtun. This evidence of human presence before the Classic times was unknown until now in the area, and confirms similar results obtained in other Maya sites. The authors underline however that, while intra-site archaeological chronology is well constrained, off-site chronology of palaeoenvironmental records does not provide a similar resolution, mainly because of a lack of control on the origin of the dated material and on possible time-lags produced by sedimentation processes.

Finally, the paper by Dussol concentrates on the different perceptions of human presence in a given area with respect to the nature of the investigated sites and to the material used for analysis. The question –and to a larger degree, the results– recall strongly those exposed in the paper by Granai *et al.* (*supra*). The environmental proxy used here is different (charcoal) and the comparisons are not between the big city of Naachtun and the broader region, but between the setting around Naachtun before, during and after the city itself. The overall conclusion is however the same: not all activities are equally visible in all types of sites, and it is not necessarily the most monumental among the latter (i.e. the most visible archaeologically) that provide the most accurate or the most reliable evidence about demography on the long-term. The last point is a useful reminder to all those who try to map out past demographical trends over vast geographical zones and chronological periods by compiling and modeling the available radiocarbon data. 'Available' is indeed not synonym of 'representative'; much more efforts like those exposed here are needed to equilibrate the relation between past realities and archaeological record.

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The role of the duration and recurrence of settlements in our perception of human impact on the environment: an example from Northern France

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Abstract

Based on the synthesis of Holocene malacological data collected at fifteen sites in the large floodplains of the Seine basin, three major environmental stages separated by two transitional phases had been previously reconstructed. The results indicated that anthropogenic disturbance was the key factor in the openness of the Holocene landscape. This long-term environmental impact of human societies highlighted the continuous use of these lowlands even if the archaeological remains were often minimal. The malacological analysis recently carried out at Passel 'Le Vivier' called into question this regional pattern. The analysis performed on a natural sequence located in the vicinity of a Neolithic causewayed enclosure revealed a dense forest habitat during and after the Neolithic occupation. The construction of the enclosure and its occupation had only a slight impact on the surrounding environment. These results question the parameters influencing our perception of human impact, particularly the duration and recurrence of settlements.

Key-words: palaeoenvironment, malacology, Holocene, Northern France, human impact

Résumé

La synthèse des données malacologiques holocènes de quinze gisements localisés dans les grandes plaines alluviales du bassin de la Seine a permis d'identifier la succession de trois grandes phases environnementales séparées par deux épisodes de transition. Une tendance à l'ouverture des paysages dont les sociétés humaines sont la cause principale a été observée. Cette empreinte environnementale aux conséquences perceptibles dans la longue durée témoigne d'une fréquentation continue des espaces alluviaux par les sociétés humaines alors même que les vestiges archéologiques y sont souvent ténus. L'étude récemment menée à Passel questionne ce modèle. L'analyse conduite à proximité directe d'une enceinte néolithique a mis en évidence le développement d'une forêt profonde pendant et après l'occupation. La construction de l'édifice et son occupation ne semblent pas avoir affecté l'environnement dans la durée. Cette étude illustre comment notre perception de l'impact humain peut être influencée par différents facteurs, en particulier la durée et la répétition des occupations.

Mots-clés : paléoenvironnement, malacologie, Holocène, nord de la France, impact anthropique

1. Introduction

In the Paris basin, the development of research on valley bottoms over the past twenty years has led to the investigation of numerous sedimentary and palaeobiological (mainly palynological) archives. Based on these studies, it was possible to reconstruct the main stages of the Holocene geomorphological and palaeoenvironmental developments in this region (Pastre *et al.* 2001 and 2014). Recently, the picture has been enriched with malacological data offering a finer spatial resolution than pollen. The malacological approach allowed reconstructing the vegetation cover in environments poorly suited for pollen conservation, particularly near human settlements (Granai 2014). Molluscs have thus been a valuable source for assessing land use (Granai and Limondin-Lozouet 2014). The comparison of the malacological data of about fifteen series of the Seine basin floodplain has highlighted a regional environmental trajectory characterized by two phases of environmental transition (Granai and Limondin-Lozouet 2018). A first transitional phase marked by the shift from forest environments to fragmented landscapes was observed between 4600 and 3500 cal. BC. During the second transitional phase, which covered the period between 1600 and 800 cal. BC, a significant expansion of grassland was observed.

After having studied the temporality and possible causes of this second transitional phase that broadly covers the Middle and Late Bronze Age periods (Granai and Limondin-Lozouet, 2015), we propose now to explore those of the first transitional phase, whose extent corresponds to the Middle Neolithic in northern France. Previous malacological studies carried out in this region had mainly focused on natural sequences (Limondin-Lozouet *et al.* 2013) and on archaeological sites that were almost continuously occupied between the Middle Neolithic period and the Early Bronze Age (Granai and Limondin-Lozouet 2014). They highlighted a long-term human impact on landscapes, suggesting a constant use of lowlands for various activities, although archaeological remains were sometimes tenuous and consisting only of scattered artefacts (Granai and Limondin-Lozouet 2014).

Here we analyse a new molluscan succession recovered in northern France, at Passel 'Le Vivier' (Oise), where a causewayed enclosure from the Middle Neolithic period has been brought to light. We reconstruct the palaeoenvironmental developments observed before, during and after the Neolithic occupation and compare this new succession with those found on contemporaneous archaeological and natural sites. We aim to highlight how the duration and recurrence of sites can influence our perception of human impact on the environment.

2. Material and methods

2.1. Site setting and malacological sampling

The archaeological site of Passel 'Le Vivier' is located in the Oise Valley (Figure 1A), at 40 m a.s.l., at the confluence of the Oise and Divette rivers and at the foothills of the Mont-Renaud, a sandy tertiary hill that rises to 85 m a.s.l.. A causewayed enclosure from the Middle Neolithic period ('Chasséen septentrional' culture), formed by three concentric ditches and a palisade that surround a total surface area of around 4 hectares, was built on this spot (Figure 1B). A palaeochannel of the Soyer, a tributary stream of the Divette, was found north of the enclosure. The conservation of 249 bases of posts from the palisade provided a dendrochronological dating for the felling of trees that covers a very short period, between 3895 and 3891 cal. BC. The AMS radiocarbon dates obtained from charcoals found in the ditches range from 4259 to 3631 cal. BC. This difference between the oldest dendrochronological and radiocarbon ages should certainly be explained by the dated material, integrating the sapwood in the case of posts and more related to heartwood for some of the charcoals.

Malacological analysis was carried out in a natural sequence located on the northern periphery of the enclosure and in two sections of ditches (Figure 1B). Within the natural sequence, the malacocoenoses have developped in situ and thus reflects the local environment (Evans 1972). Within the ditches, additional anthropogenic inputs are possible, particularly if material such as branches and leaves has been used to cover the bottom or edges of the feature, as assumed in the Mesolithic pits of Champagne (Granai and Achard-Corompt 2017).

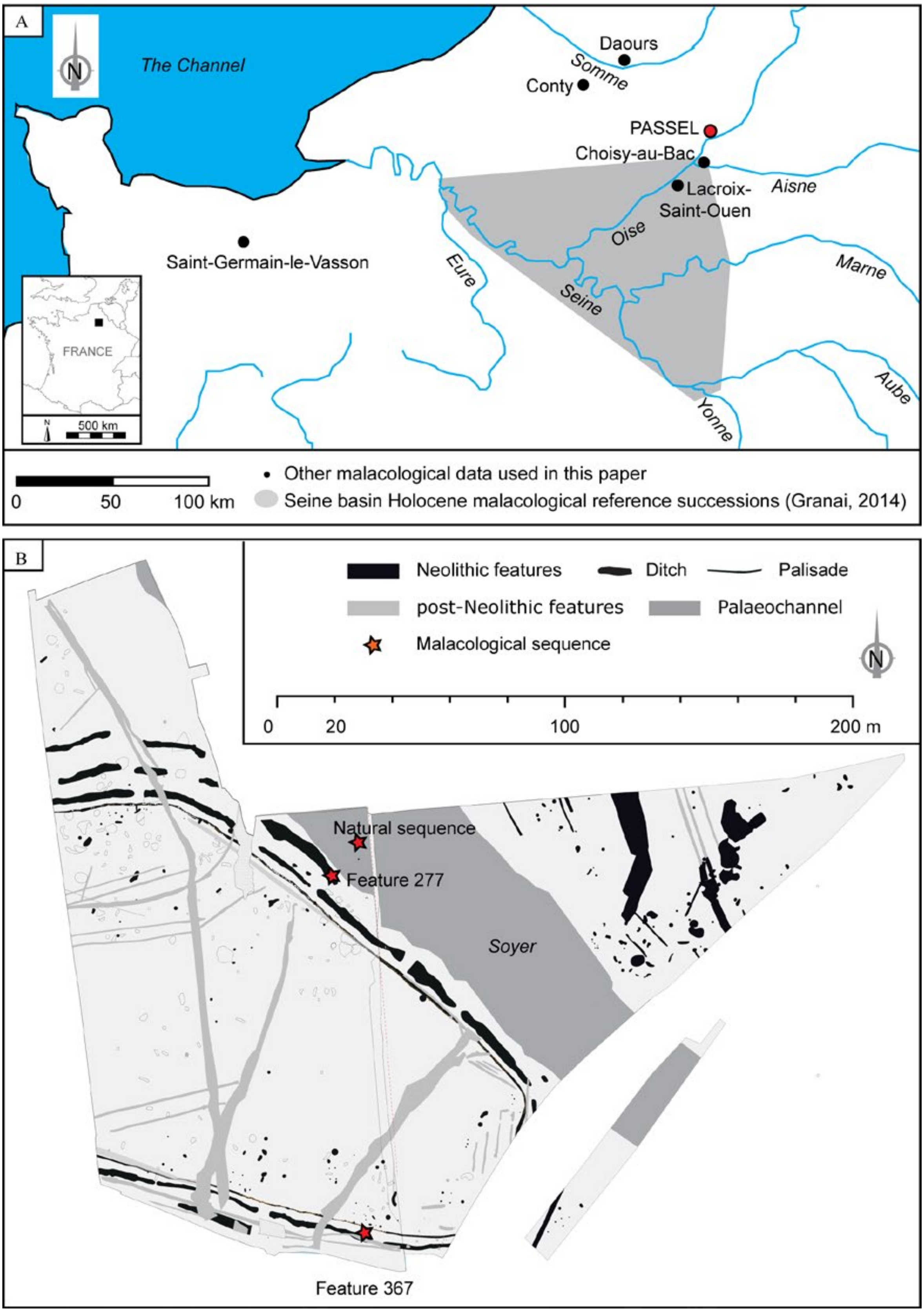

Figure 1. Location of Passel 'Le Vivier' and the main surrounding malacological series included in this study (A). Map of the ditches and palisade of the enclosure with the position of paleochannels and malacological sequences (B).

15 samples were taken from the natural sequence, in which ten sedimentary units grouped into five main sedimentation phases were observed (Figure 2). The base of the cross-section consisted of bluish sands (Unit 10). These sands were covered by organic-rich clays comprising a peat layer (Units 9 to 6). An alternation of tufa and silts was then observed (Units 5 to 3b) and covered by sandy units (Units 3a and 2). The sequence ended with clayey silts (Unit 1). Six radiocarbon dates were performed on charcoal and shells directly extracted from this profile (Table 1). Some inconsistencies were noticed in dates obtained from shells in Units 5 and 3b. The arguments raising them are presented in the discussion below.

Feature 277, which was located about 10 meters south of the natural sequence (Figure 1B), was filled with a black clayey silt rich in charcoal and organic debris (Figure 3A). The two base samples of the ditch were taken in a 5 cm sampling pattern (samples bottom/55 cm and 55 cm/50 cm). The next samples were then taken in a 10 cm sampling pattern. The sample 30 cm/20 cm consisted of a transition horizon with oxidized beige grey silt that covered the ditch. Feature 367, which is a section of the first (inner) row of ditches of the enclosure in the southeastern part of the settlement, was dug in sand and filled with sand (Figure 3B).

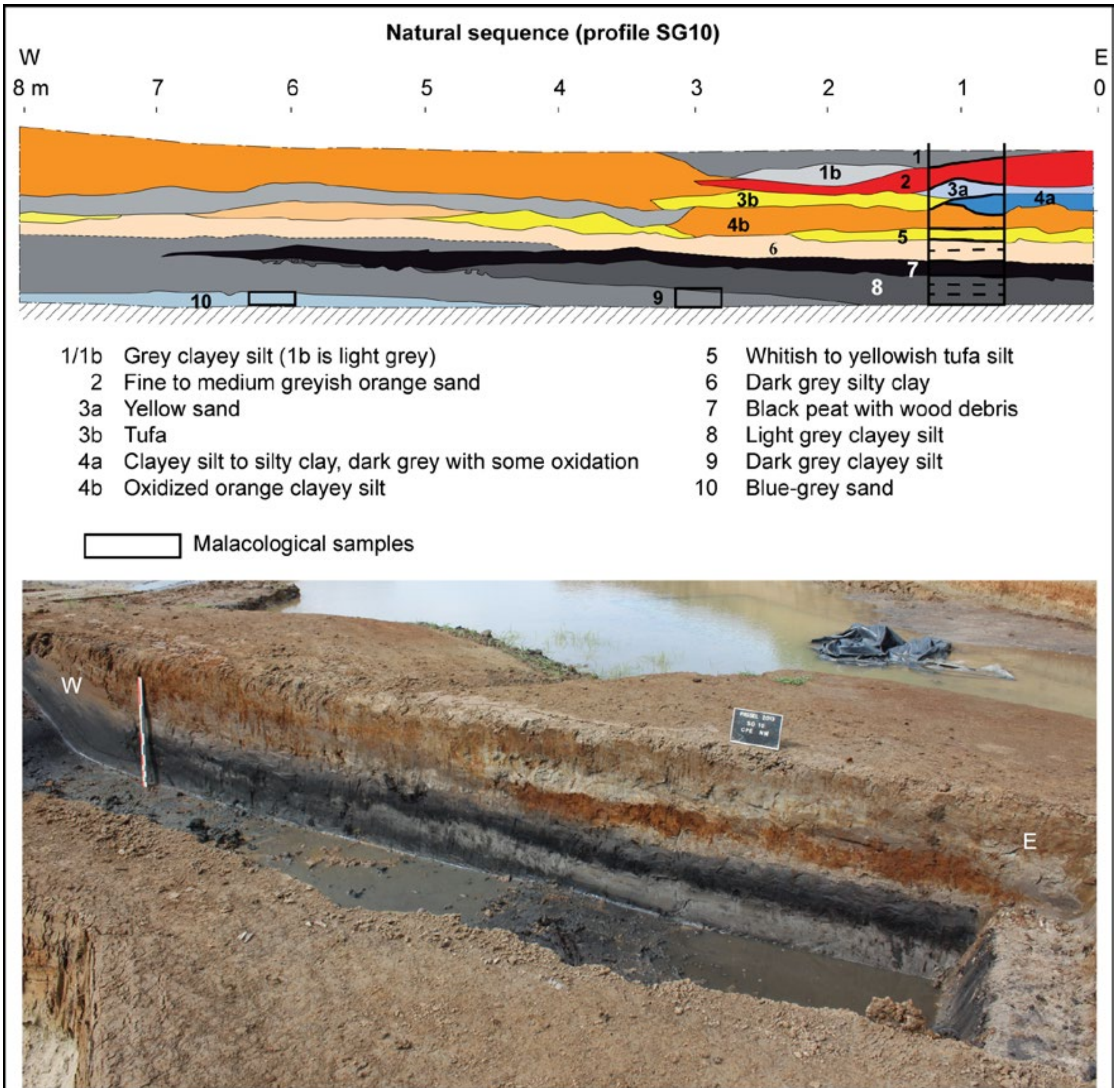

Figure 2. Stratigraphic profile of the natural sequence with position of the malacological samples.

Lab. Code	Unit	Material	Age (BP)	Standard deviation	Calibrated age (cal. BC)	Calibrated age (cal. BP)
DeA-12482	9	charcoal	8958	34	8274-7976	10223-9925
DeA-12459	9	shell (*Discus rotundatus*)	8852	35	8208-7823	10157-9772
DeA-12460	8 (top)	shell (*Discus rotundatus*)	8698	35	7811-7597	9760-9546
DeA-12484	5	charcoal	5206	27	4046-3965	5995-5914
DeA-12461	5	shell (*Discus rotundatus*)	6341	30	5461-5224	7410-7173
DeA-12486	3b	charcoal	3523	24	1926-1766	3875-3715
DeA-12462	3b	shell (*Discus rotundatus*)	4370	25	3084-2911	5033-4860

Table 1. Radiocarbon dates and their calibration. Calibration was performed with the IntCal13 curve (Reimer *et al.* 2013).

Figure 3. Illustrative pictures of features 277 (A) and 367 (B) showing variations in the colour of their infilling.

The malacological analysis involved samples of 8 to 10 litres of sediments that were screened with water over a 500-micron mesh. The screen refusals were then examined under a binocular microscope. For some samples from the natural sequence, the high shell abundance observed at the macroscopic scale motivated their fractionation in order to reduce the time spent in binocular sorting. The screen refusals of these samples were laid out flat to ensure a good mixture of their different granulometric components, and then separated into quarters as described in Evans (1972). A report on the amount of sediment sorted for each sample is given, as well as a projection of the number of specimens if all screen refusals were sorted (Table 2). The threshold for the representativeness of a fossil malacological assemblage has been estimated by Evans (1972) to encompass between 150 and 200 individuals. At Passel, samples that have been partially sorted show abundances well beyond this threshold. For other samples that have been fully sorted, this threshold was not reached, thus preventing any statistical analysis.

2.2. Species determination and molluscan analysis

After sorting, species determination was based on several reference works (Horsák *et al.* 2013; Kerney and Cameron 2015; Welter-Schultes 2012). Some taxa have presented problems of determination, which are listed below.

Two taxa could only be identified at family level (Unionidae and Hydrobiidae). Some taxa were listed with a genus name followed by the mention ‘sp.’. These taxa, such as *Cepaea* and *Radix*, were represented by incomplete shells that did not contain all the relevant criteria for species determination. For some *Vertigo*, the mention ‘dextral’ or ‘senestral’ was added, according to the direction of their whorl. In the case of *Pisidium*, the determination at the species rank has proved too complex to be carried out in the scope of this study, except for the species *Pisidium amnicum*. Slugs were a special case. Behind this vernacular name were concerned two families of molluscs, Limacidae and Milacidae. All slugs were here aggregated into a unique set. *Cecilioides acicula* was

Ecology	Species / Sedimentary units	10	9	8(b)	8(m)	8(t)	7	6(b)	6(t)	US5	4b	4a	3b	3a	2	1
Shade-demanding species	*Acanthinula aculeata*			6	2	5	1		4	6	4		11			
	Acicula fusca												23	6		
	Aegopinella nitidula		101	132	122	163	8		23	126	34	9	372	166	12	
	Aegopinella pura					1			4	11	8		22	6	1	
	Carychium tridentatum	5	145	329	195	178	11		62	430	198	20	429	156	19	3
	Cepaea sp.	1	1	1	4	2	1		2	22	1	1	67	18	3	1
	Clausilia bidentata	1	9	16	22	37	5		3	81	8	1	77	13	3	
	Clausilia dubia												1			
	Cochlodina laminata									3			2			
	Discus rotundatus	5	94	86	109	90	8		45	305	133	17	581	206	15	1
	Discus ruderatus			8	2	1			3	3			3	5		
	Helicodonta obvoluta									5			10			
	Macrogastra rolphii									2	1		25	7		
	Macrogastra ventricosa												3			
	Merdigera obscura			1					1	2			1			
	Monachoides incarnatus												1			
	Pomatias elegans									2	1		26	8	1	
	Sphyradium doliolum												17			
	Vertigo alpestris		4	3									3	2		
	Vertigo pusilla	1	18	25	39	56			1	1						
	Vitrea crystallina		5	7	40	43	1		8	28	22	1	44	14		
Mesophile species	*Cochlicopa lubrica*	2	56	142	74	82			18	70	34	7	56	35	9	
	Helicigona lapicida								1	7	1		4	5	1	
	Slugs		7	11	4	18	2		11	103	18	18	101	111	23	
	Nesovitrea hammonis		35	98	45	41	1		1	11	9	1	26	3		
	Oxychilus cellarius									12	4	1	70	27		
	Punctum pygmaeum	1	14	34	36	30	2		1	17	16		10	3		
	Trochulus hispidus	2	29	110	40	10			6	25	16	5	93	59	7	
	Vallonia costata	3	23	83	16	10			3	13	64	11	18	11	5	
	Vitrea contracta		2	5	3	1				6			10	2		
	Vitrina pellucida			3		2				2	1		3	5		
Open-ground species	*Chondrula tridens*												1			
	Monacha sp.													4		
	Succinella oblonga												3			
	Vallonia excentrica													10		
	Vallonia pulchella		1	56	8	11	3			48	76	15	14	32	9	3
	Vertigo pygmaea	3		5	4					12	31	5	22	17	3	
Marshland species	*Carychium minimum*	4	145	417	439	941	40		30	77	102	16	72	30		
	Columella edentula		1													
	Cochlicopa nitens			4							6		5			
	Euconulus alderi		3	14	13	14	1			2	2	2	6	6		
	Oxyloma elegans		12		8	27			4	29	22	2	51	42	9	
	Pupilla alpicola									1			10	1		
	Vertigo angustior			3	13	56	4			3	1		2	1		1
	Vertigo antivertigo		9	38	32	37	2			5	4		3			
	Vertigo moulinsiana		4	2	3	7								1		
	Vertigo substriata					11	2									
	Zonitoides nitidus		57	100	93	64	2		4	12	7	3	2	6		

Table 2. List of species and number of specimens recovered in the natural sequence.

Ecology	Species / Sedimentary units	10	9	8(b)	8(m)	8(t)	7	6(b)	6(t)	US5	4b	4a	3b	3a	2	1
Freshwater species	*Anisus* sp.					1				1	1			1		
	Bithynia sp.		1							1						
	Galba truncatula		38	34	27	45				13	16	4	8	2		
	Hippeutis complanatus										1					
	Hydrobiidae										2		2			
	Physa fontinalis					3				1						1
	Pisidium sp.	9	285	434	328	545	53		19	46	27	5	89	111	40	3
	Pisidium amnicum													12		
	Radix sp.		48	105	76	67	6		7	40	44	2	25	20	5	
	Unionidae									1			1			
	Valvata cristata		5	7	40	222	22		3	4	1		1			
Total sorted		37	1152	2319	1837	2821	175		264	1589	916	146	2426	1164	165	13
Estimation for 10 litres		37	4608	37104	29392	45136	175	0	265	6356	1832	146	9704	1164	165	13
Number of terrestrial species		11	23	28	25	27	17	0	21	34	28	18	42	33	15	5
Cecilioides acicula														2	2	4

Table 2. Continued.

not considered in this analysis since living specimens of this species have been observed up to 2 m below the current soil depth (Evans 1972).

Due to their small size, their slow dispersal and their short life, most species have distinctive environmental requirements (Welter-Schultes 2012). Malacologists working on Quaternary fauna have defined systems for classifying species according to their ecological preferences (Sparks 1961; Ložek 1964; Puisségur 1976). In the Seine basin floodplains, the ratio between shade-demanding, mesophile, marshland, open-ground and freshwater species referred to changes in two environmental variables that are of particular importance to molluscs: moisture and vegetation cover density (Granai 2014). In this study, the same ecological classification was used. The distribution of individuals among these four main ecological groups of terrestrial malacofaunas was carried out through stacked bar graph. In addition to this approach of the main environmental components reflected by the ecological distribution of individuals, a presence/absence diagram allows comparison between the species composition of the assemblages from several sites.

3. Results

3.1. Natural sequence

Only very few shells were found in the blue-grey sand (Unit 10).

In the grey clayey silts (Units 9 and 8), interpreted as bank deposits, malacological assemblages with comparable ecological (Figure 4) and specific (Figure 5) compositions but with contrasting abundances have been found (Table 2). With respect to diversity, the samples from Units 9 and 8 ranged from 23 to 28 terrestrial species and at least 4 to 6 aquatic species. In all 4 samples, the percentage of freshwater molluscs ranged from 20 to 30% and the *Pisidium* was the predominant taxon. Terrestrial molluscs accounted for about 70-80% of the assemblages. The most abundant species was *Carychium minimum*, inhabiting marshland. It was accompanied by a diverse range of terrestrial species, in which open environment species accounted for a negligible proportion while shade-demanding species accounted for more than 20% of the assemblages.

There were only 175 shells in the sample from the peaty Unit 7. The ecological (Figure 4) and specific (Figure 5) compositions of the malacological assemblage of this sample were comparable to those found in Unit 8. Then, the sample from the base of the clayey Unit 6 was sterile. In the

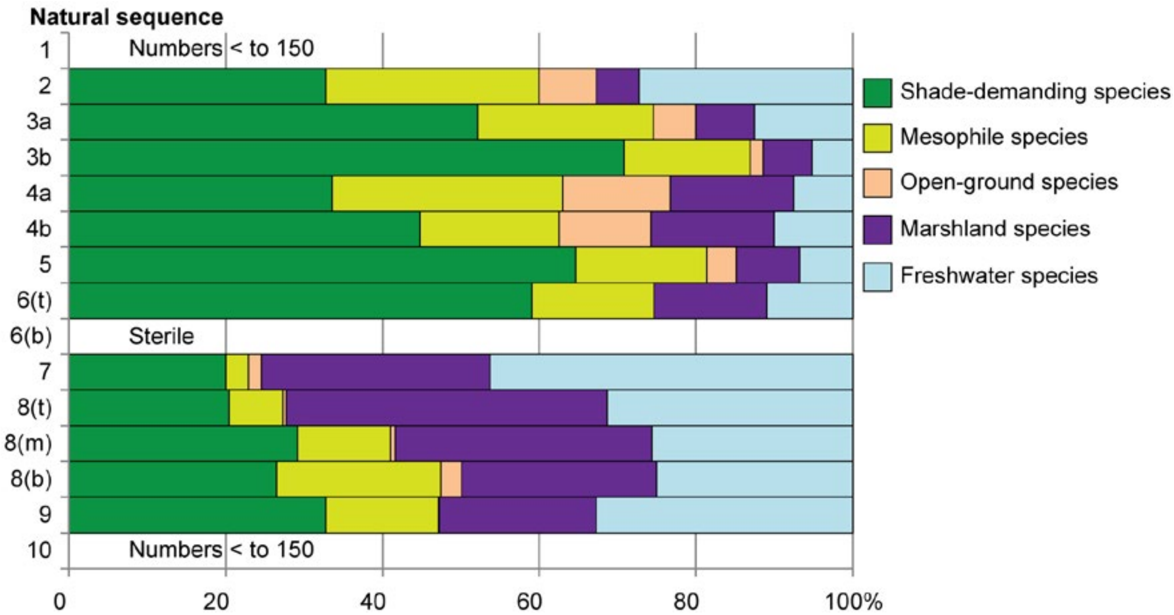

Figure 4. Ecological distribution of the molluscan specimens recovered within the natural sequence. Percentages were calculated based on the total number of individuals (terrestrial and freshwater molluscs) in each sample. (b): bottom; (m): middle; (t): top.

sample at the top of Unit 6, 264 individuals were comparable in their composition to the sample from the next Unit. This is why we believe that most or all of the molluscs recovered from Units 7 and 6 may have resulted from contamination from neighbouring units.

In the sample from the tufa silt of Unit 5, an abundant assemblage comprised 34 terrestrial species and at least 8 aquatic species (Table 2). Freshwater molluscs represented less than 10% of the total assemblage (Figure 4). Mesophile, marshland and open environment species were of minor proportions in comparison to shade-demanding molluscs, which represented 70% of the terrestrial assemblage. The predominant species in this ecological group were *Carychium tridentatum*, *Discus rotundatus* and *Aegopinella nitidula* (Figure 5). In addition, five new shade-demanding species appeared in this sample: *Helicodonta obvoluta*, *Cochlodina laminata*, *Macrogastra rolphii*, *Oxychillus cellarius* and *Pomatias elegans*.

In samples related to the silty Unit 4, an exponential decline in shells was observed (Table 2). The diversity of terrestrial species dropped from 34 species in Unit 5 to 28 and then 18 in Unit 4. The percentage of freshwater molluscs was as low as in the Unit 5 (Figure 4). In the terrestrial assemblage, a decline in shade-demanding species was observed in favour of mesophilic, marshland and open environment molluscs, with a particular emphasis on *Carychium minimum*, *Vallonia costata*, *Vallonia pulchella* and *Vertigo pygmaea* (Figure 5).

In the tufa of Unit 3b, the number of specimens increased (Table 2). In addition, there was an increase in diversity, as 42 terrestrial species were identified. This was the richest sample of the sequence. The percentage of freshwater molluscs was lower than 5% (Figure 4). Shade-demanding species were the majority: they accounted for 78% of the terrestrial assemblage. Within this group, the predominant species were the same as those already mentioned for Unit 5, i.e. *Carychium tridentatum*, *Discus rotundatus* and *Aegopinella nitidula*. Five new species appeared: *Sphyradium doliolum*, *Monachoides incarnatus*, *Clausilia dubia*, *Macrogastra ventricosa* and *Acicula fusca* (Figure 5).

In the sands of Unit 3a, the number of individuals and the diversity decreased in comparison to Unit 3b but the assemblage still appeared abundant and diverse (Table 2). Despite the disappearance of several taxa, especially within the group of shade-demanding species, the structure of the

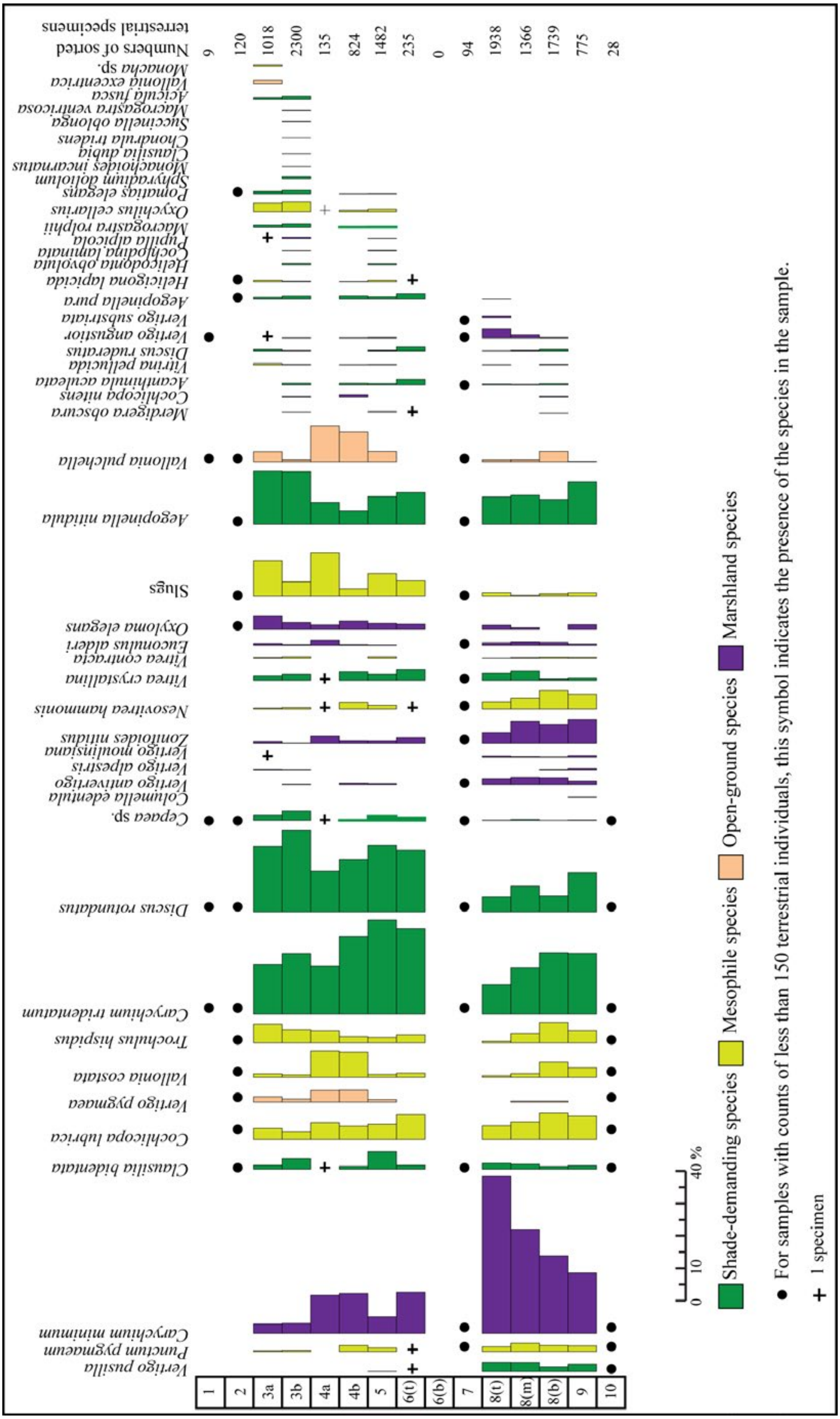

Figure 5. Histograms showing the percentages of terrestrial species in each sample. The percentages were calculated on the basis of the total number of terrestrial individuals in each sample. (b): bottom; (m): middle; (t): top.

assemblage remained comparable to that described for Unit 3b in its major ecological and specific components.

In the two samples of the top of the sequence, from the sands of Unit 2 and the clayey silts of Unit 1, the number of specimens decreased drastically (Table 2). In these samples, there was an increase in freshwater molluscs.

3.2. Ditches

26 terrestrial species and at least 6 aquatic species were listed in the four samples from the black clayey silt from feature 277 (Table 3) whereas the beige grey silt was sterile. The malacological assemblages of the four fossiliferous samples were broadly comparable in their ecological and specific composition (Figure 6), which suggested the existence of stable environmental conditions while the ditch was being filled. Actually, the constant presence of molluscs without significant variations in diversity and abundance supports the hypothesis of a natural filling of the ditch with sedimentary material and snails from the immediate environment. The hypothesis of the addition

Ecology	Species / Samples name	55/bottom	55/50	50/40	40/30	10/0
Shade-demanding species	*Acanthinula aculeata*	6	2	2		
	Aegopinella nitidula	46	34	42	21	
	Carychium tridentatum	60	32	34	17	
	Cepaea sp.	3	1	3	1	
	Clausilia bidentata	5	2	2	4	
	Discus rotundatus	93	69	58	36	
	Discus ruderatus		2		2	
	Helicodonta obvoluta	1	4	1		
	Macrogastr rolphii		1	3	1	
	Vertigo pusilla	1				
	Vitrea crystallina	8	7	9	3	
Mesophile species	*Cochlicopa lubrica*	14	13	12	6	
	Helicigona lapicida	2	1	3	1	
	Slugs	29	28	37	36	29
	Nesovitrea hammonis	14	3	5	4	
	Oxychilus cellarius		4	7	5	
	Punctum pygmaeum	1	1			
	Trochulus hispidus	8	2	5		
	Vallonia costata		1	1	1	
	Vertigo dextral			2		
	Vitrina pellucida		3			
Marshland species	*Carychium minimum*	32	5	12		
	Euconulusalderi	2	1	1	1	
	Oxyloma elegans	8	6	6	11	
	Pupilla alpicola		1			
	Zonitoides nitidus	7	4	12	6	
Freshwater species	*Anisus* sp.	5	5	2	2	
	Physa fontinalis		1			
	Pisidium sp.	109	65	97	20	
	Radix sp.	8	6	6	3	
	Unionidae	1				
	Valvata cristata		1	1	1	
Total sorted		463	305	363	182	29
Estimation for 10 litres		463	610	726	364	29
Number of terrestrial species		19	24	21	17	1

Table 3. List of species and number of specimens recovered in feature 277.

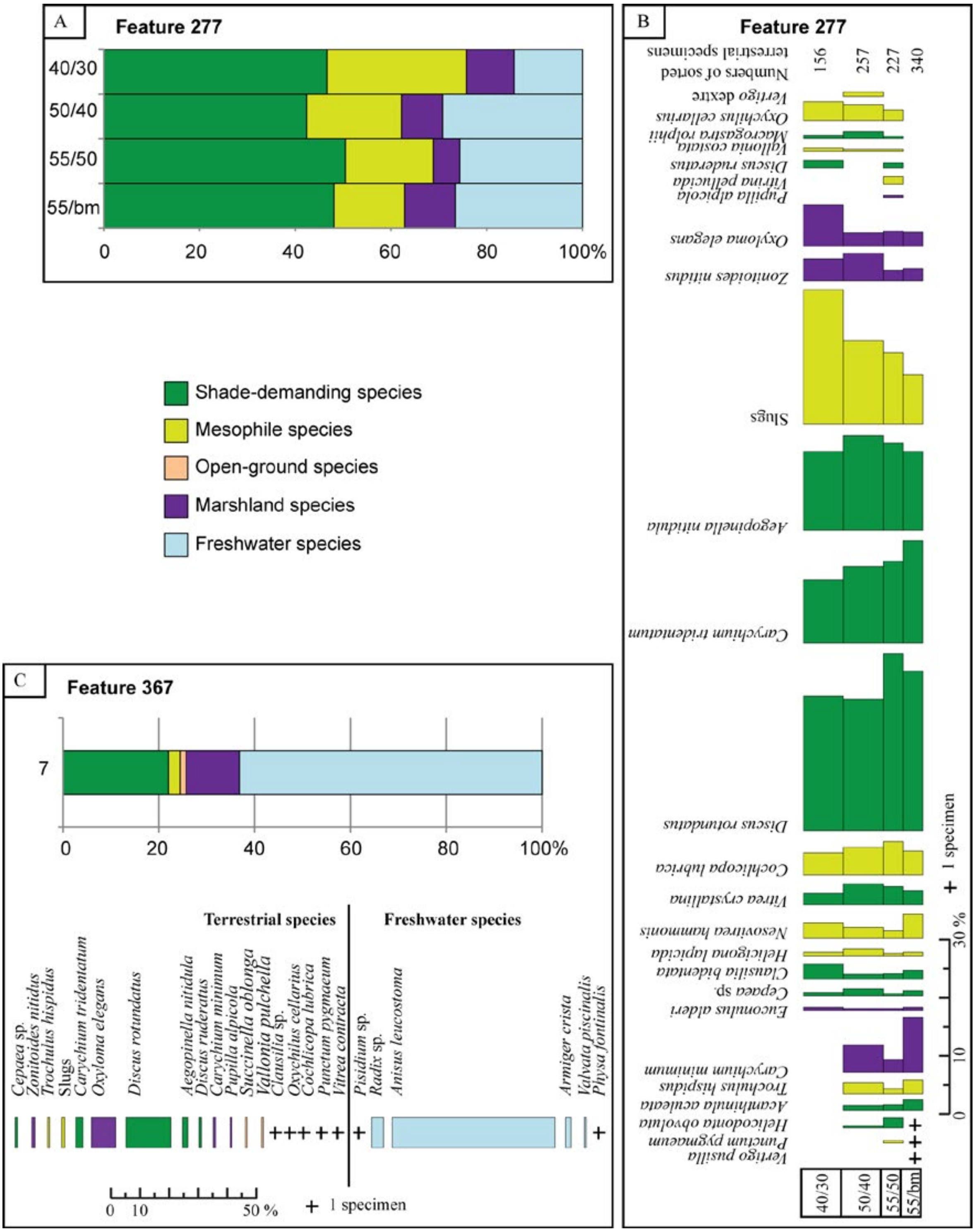

Figure 6. Ecological distribution of the molluscan specimens in feature 277 (A). Histograms showing the percentages of terrestrial species in each sample in feature 277 (B). Ecological distribution and histograms showing the percentages of both terrestrial and freshwater species in sample 7 from feature 367 (C).

of branches and leaves to the bottom and edges of the ditch, which would have been responsible for the presence of shade-demanding molluscs, seems unlikely in comparison with the malacological assemblages of Mesolithic pits in Champagne where mollusc counts are highly variable in pits concerned by this type of input depending on the position of the malacological samples within pits (Granai and Achard-Corompt 2017). In the feature 277, about 80% of all collected molluscs were from terrestrial fauna; shade-demanding species were the majority and open-ground species were

Ecology	Species / Samples name	6	7	8
Shade-demanding species	*Aegopinella nitidula*		6	
	Carychium tridentatum	4	8	
	Cepaea sp.	1	3	
	Clausilia sp.		1	
	Cochlodina laminata	1		
	Discus rotundatus	8	50	
	Discus ruderatus		3	
	Macrogastra sp.	1		
Mesophile species	*Cochlicopa lubrica*		1	
	Limaces	2	3	
	Oxychilus cellarius		1	
	Punctum pygmaeum		1	
	Trochulus hispidus	2	2	
	Vertigo senestral	1		
	Vitrea contracta		1	
Open-ground species	*Succinella oblonga*		2	
	Vallonia pulchella		2	
Marshland species	*Carychium minimum*		3	
	Oxyloma elegans	3	27	
	Pupilla alpicola		2	
	Zonitoides nitidus	1	4	
Freshwater species	*Anisus leucostoma*	2	181	
	Armiger crista		6	
	Physa fontinalis		1	
	Pisidium sp.	1	1	1
	Radix sp.	7	13	
	Valvata piscinalis		2	
Total		34	324	1
Number of terrestrial species		13	24	1

Table 4. List of species and number of specimens recovered in feature 367.

absent. The four most common taxa were *Discus rotundatus*, *Carychium tridentatum*, *Aegopinella nitidula* and slugs.

The malacological samples from feature 367 showed highly variable malacological assemblages (Table 4). Sample 6, from the lowest part of the filling, contained a very small number of specimens but was quite diverse. Sample 7 was then more diverse and much more abundant. Finally, sample 8 was almost sterile (only one individual). In sample 7, the only sample providing statistically exploitable assemblages, freshwater species were the majority, particularly the species *Anisus leucostoma* (Figure 6).

4. Discussion

4.1. Palaeoenvironmental developments before the enclosure was built

The scarcity of molluscs within Unit 10 of the natural sequence is indicative of unfavourable conditions for the development or conservation of molluscs. A rapid and strong flooding event, suggested by the sandy component of this unit, could explain this phenomenon. Dissolution of shells in acidic sands could also be invoked, as well as a glacial climate unfavourable to the establishment of vegetation and molluscs.

Samples from Units 9 and 8 provided abundant and diversified malacological assemblages. The freshwater composition of the assemblages points to the existence of a permanent stream in the neighbouring channel. The composition of terrestrial assemblages, which are dominated by marshland and shade-demanding species, allows for a wet and shaded riverbank environment to be reconstructed. The outstanding frequencies of molluscs in Unit 8 could result from the accumulation of drift shells from the surrounding area along the riverbank. The significant proportions of forest species in Units 9 and 8 are clear evidence of a Holocene age, which was confirmed by three AMS radiocarbon dates giving ages between 8300 and 7600 cal. BC (Table 1), i.e. from the second half of the Early Holocene *sensu* Walker *et al.* (2012). This chronological attribution is consistent with regional malacological evidence from this period. Indeed, malacological assemblages from the first half of the Early Holocene are usually characterized by mesophile and marshland species and only contain a small proportion of shade-demanding molluscs, whereas during the second part of the Early Holocene, the diversity of forest species increases and the proportions of molluscs of this ecological group can exceed 25% of the assemblages (Limondin-Lozouet 2011), such as observed in Units 9 and 8. In addition, in northwestern Europe, the appearance and development of *Discus rotundatus* are of biostratigraphical significance. At Saint-Germain-le-Vasson, in Calvados, *D. rotundatus* appeared around 9000 BP (Limondin-Lozouet and Preece 2004) and at Conty, in the Somme, around 8800 BP (Limondin-Lozouet 2012), which is consistent with the ages around 8900 BP from Unit 9.

In Units 7 and 6, the virtual disappearance of shells is not taken to reflect a complete destruction of the vegetation but more likely to result from the chemical characteristics of the soil. Such taphonomic issues are widely encountered in oligotrophic peatlands, poor in nutrients and deficient in calcium ions, which are unfavourable both to the development and conservation of shells (Limondin-Lozouet and Moine 2014). This certainly explains the poor molluscs' content of the peaty Unit 7. In the clayey Unit 6, the soil was likely to be asphyxiated, considering the highly hydromorphic character of this layer. The development of peat and hydromorphic clay is indicative of marshland since these sedimentary units reflect quiet and stable flows in the channel. Their development occurred between the end of the Early Holocene and the beginning of the Middle Holocene, which are characterized by the deposition of organic sediments in many valley bottoms in northern France, as observed in the Somme, Mue and Marne rivers (Antoine *et al.* 2003; Lespez *et al.* 2008; Le Jeune *et al.* 2012). In floodplains, soils developed under biostasic conditions and archaeological remains from various phases of the Mesolithic and Neolithic periods are often found in the same stratigraphic units (Granai and Limondin-Lozouet 2014). For instance, at Neuilly-sur-Marne 'La Haute Ile', archaeological remains dating from the Middle Mesolithic to the Early Neolithic were found in a 10 centimetres thick layer of black clay (Le Jeune *et al.* 2012).

4.2. Palaeoenvironment of the Neolithic settlement

In Unit 5, the proportions of shade-demanding species and their rich diversity are indicative of a dense forest environment. Two inconsistent dates were obtained from charcoal and shells in this unit (Table 1). A topographic correlation between Unit 5 of the natural sequence and the digging surface of ditch 277 was observed in the field, which was further reinforced through the observation of tufa fragments in the ditch section. Based on this, the date on charcoal derived from Unit 5 is considered as more correct than that derived from shells, since it gave an age consistent with the Neolithic occupation at about 4000 cal. BC. In addition, the presence of *Helicodonta obvoluta*, *Macrogastra rolphii*, *Oxychillus cellarius* and *Pupilla alpicola* in feature 277 provides a biostratigraphic connection with Unit 5 of the natural sequence since: 1) these species were missing from lower sedimentary units, and 2) new species appeared in upper units. This biostratigraphic correlation is also based on the filling of the ditch section in the southern part of the enclosure (feature 367), where the species *Macrogastra rolphii*, *Oxychillus cellarius* and *Pupilla alpicola* were found (Figure 6). In the filling of features 277 and 367, the presence of freshwater molluscs suggests flooding phases during the occupation of the site, especially in its southern part (feature 367), where a fauna dominated by *Anisus leucostoma*, a species characteristic of temporary standing waterbody (Welter-Schultes 2012), was recovered.

The malacological assemblages from the ditches and from Unit 5 of the natural sequence reflect a phase of expansion of shade-demanding species. The Neolithic enclosure therefore appears to be surrounded by a forest environment providing a dense shade, at least in the eastern part of the site. These malacological assemblages are poorly consistent with those recovered within archaeological settlements dating from the same period in the Seine basin. At Choisy-au-Bac 'La Confluence', located fifteen kilometres downstream (Figure 1), shade-demanding species only accounted for about 20% of an assemblage dominated by open-ground and marshland species (Figure 7) in a layer with Neolithic remains from the same period as Passel and a date on charcoal at 5120 ± 40 BP, i.e. between 3991 and 3797 cal. BC (Granai 2014). This difference in the structure of the vegetation cover is also reflected in the species lists, which significantly differs between the two sites. The malacological assemblage of Choisy-au-Bac is characteristic of what is observed on a larger scale in the Seine basin. Indeed, in this area, malacological assemblages from layers with Middle Neolithic remains are often characterized by moist environments in the process of openness (Granai and Limondin-Lozouet 2014 and 2018). On the other hand, at Daours, in the Somme, about sixty kilometres northwest of Passel (Figure 1), a tufa sequence yielded a malacological succession covering the entire Middle Neolithic period, in a natural context devoid of any archaeological evidence dating from this period (Limondin-Lozouet *et al.* 2013). The ecological distribution of molluscs and the list of species observed at Daours are highly comparable to those found at Passel (Figure 7). The comparable results obtained at Passel and Daours suggest a low human impact on the general structure of the vegetation cover when the enclosure was occupied. The presence of dense forest cover might seem surprising in view of the monumental nature of the enclosure, which would suggest that the building should be seen from afar. Actually, it is likely that very few trees had been collected in the direct vicinity of the enclosure. Indeed, according to pollen analyses, alder was the main taxon around the enclosure and the oaks used to build the palisade were certainly found further away. In addition, the clearings are hardly or not at all noticeable even in the oak pollen curve. Although a locally strong human impact is assumed, since a taxon was targeted for the construction of the palisade, it was likely of short duration. This suggests what can be seen in the pollen diagrams of the villages of the linear pottery culture in Central Europe, where there is hardly any noticeable human impact on the environment despite the presence of dozens of houses. Actually, fields are thought of as being burned and then cultivated for a short period of time (about a decade) before being abandoned and recolonized by forests (Bogucki 1988; Bogaard 2004). At Passel, the typochronology of artefacts and the radiocarbon dates strongly suggest a short period of use of the enclosure. By contrast, on sites such as Choisy-au-Bac, with more tenuous archaeological evidence consisting of scattered artefacts, longer periods of occupation extending to the recent phases of the Neolithic period are generally reconstructed (Granai 2014). Such sites were certainly used repeatedly over a long period for specialized activities focused on wetland exploitation.

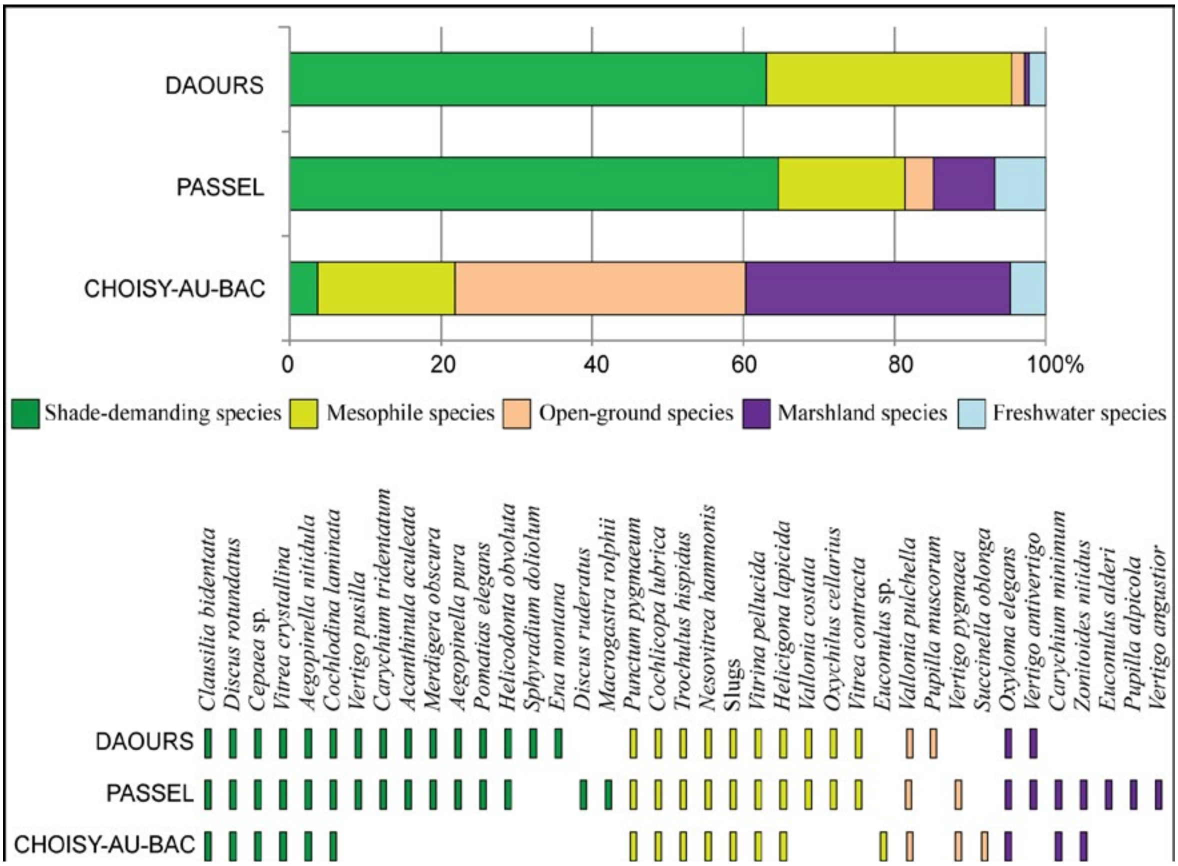

Figure 7. Comparison of the molluscan assemblage from Unit 5 of the natural sequence at Passel with the molluscan assemblage from samples 123, 122 and 121 (profile 51) at Choisy-au-Bac 'La Confluence' (Granai 2014) and from the natural sequence from Daours (Limondin-Lozouet *et al.* 2013): ecological distribution of the molluscan specimens (top) and list of terrestrial species (bottom).

4.3. Palaeoenvironmental developments after the enclosure was abandoned

In Unit 4, an episode of environmental stress whose origin may be related to a change in soil moisture content was observed in the malacological succession. Indeed, the sedimentary characteristics of Units 4b and 4a (oxidation, coloration) were likely the result of hydromorphic conditions where a possible anoxia could have disrupted vegetation and malacofauna developments.

By contrast, the tufa of Unit 3b, which had the richest set of terrestrial species of the whole sequence, provided optimal conditions for the development and conservation of molluscs. The specific and ecological composition of the sample extracted from this unit enabled the reconstruction of a forest environment with a soil under deep shade. Two inconsistent AMS radiocarbon dates were obtained in this unit. One, on shells, gave an age of 4370 ± 25 BP, whereas the other, on charcoal, gave an age of 3523 ± 24 BP; their calibrated values fall respectively in the beginning of the 3rd and the first quarter of the 2nd millennium BC (Table 1). Without other dating arguments, especially from archaeological evidence, the precise age of this deposit could not be determined. In the pollen analyses carried out on the site, a phase of extensive landscape openness was recorded during the Late Bronze Age, i.e. between 1300 and 800 cal. BC. It can therefore be assumed that the forest optimum phase observed in Unit 3b was older and was likely comprised between the end of the Middle Neolithic and the end of the Middle Bronze Age, i.e. between 3500 and 1300 cal. BC.

The reconstruction of a forest optimum phase at such a late stage has rarely been reported in northern France and, on a wider scale, in northwestern Europe. Such environmental developments have been observed in areas with little impact from human societies, particularly in mountainous areas of Central Europe, such as in the Carpathians in Poland (Alexandrowicz 2009; Alexandrowicz and Gołas-Siarzewska 2013) and Slovakia (Juřičková *et al.* 2018) and in the Sudetes in the Czech Republic (Juřičková *et al.* 2014). In contrast, in northern France, with extensive flat lowlands, an environmental trajectory towards increasingly open landscapes has been widely observed

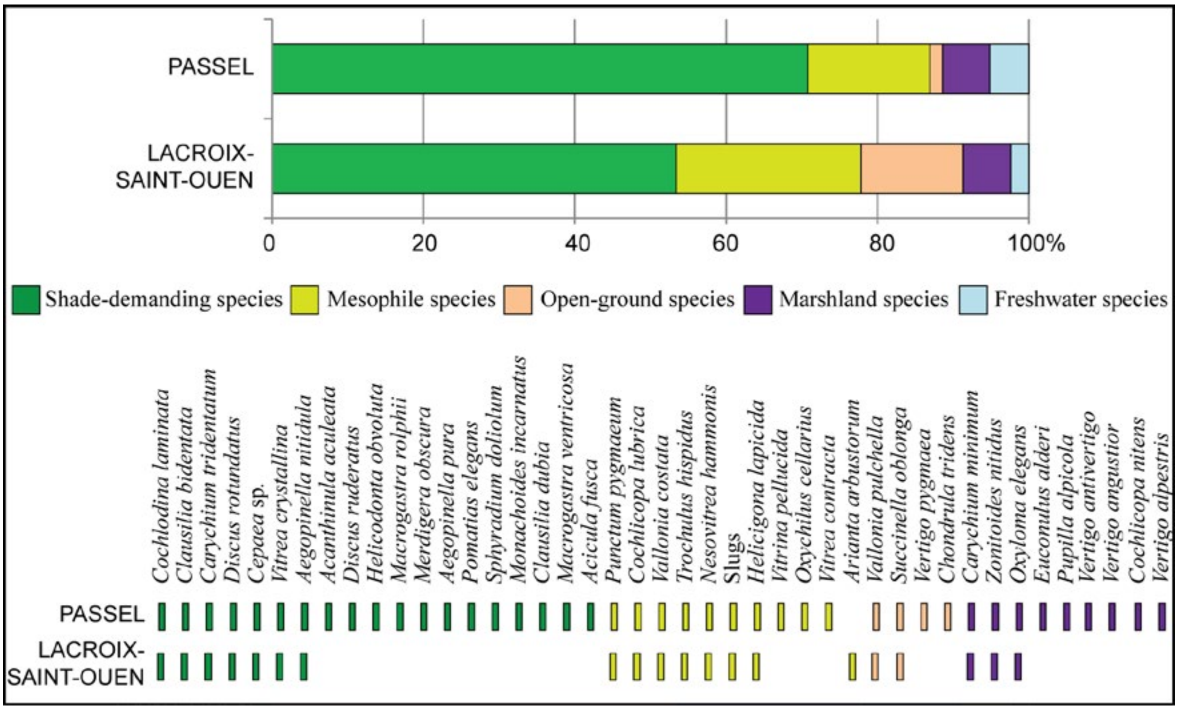

Figure 8. Comparison of the molluscan assemblage from Unit 3b of the natural sequence at Passel with the molluscan assemblage from sample 4 (profile North) at Lacroix-Saint-Ouen 'Station d'épuration' (Granai 2014): ecological distribution of the molluscan specimens (top) and list of terrestrial species (bottom).

(Granai and Limondin-Lozouet 2018). At 25 km southwest of Passel, at Lacroix-Saint-Ouen 'Station d'épuration' (Granai 2014), in a layer with Early Bronze Age remains, and in which a date on shells gave an age of 3866 ± 35 BP (DeA-15454, unpublished), i.e. between 2465 and 2209 cal. BC, in accordance with archaeological evidence, a malacological assemblage dominated by shade-demanding molluscs has been recovered (Figure 8). However, the species list of this ecological group was very short at Lacroix-Saint-Ouen compared to Passel's. The most demanding species in terms of shade were absent, reflecting a semi-forested environment, while a dense forest cover was reconstructed at Passel. Impoverishment of malacological biodiversity and fragmentation of forest cover were observed at Lacroix-Saint-Ouen, while there was a continuity of archaeological occupations between the Late Neolithic and the Early Bronze Age (Granai 2014). In comparison, at Passel, no archaeological remains were found for the period between the Middle Neolithic and the Late Bronze. The impoverishment of shade-demanding mollusc diversity and populations in Lacroix-Saint-Ouen was probably the result of a continuous process due to the recurrence of human settlements in the area. On the other hand, the long-term abandonment of Passel favoured a new phase of expansion of forest fauna. This pattern of environmental development is reminiscent of what observed for instance in the Iron Age hillfort of Vladař,in Czech Republic, where a full regeneration of forest environments is observed after the site has been abandoned, despite extensive clearing during the period of occupation (Pokorný *et al.* 2006).

The decrease in abundance and diversity of malacological assemblages at the top of the sequence finally suggests an episode of environmental stress and/or poor preservation that can be broadly attributed to the Late Holocene without further detail.

Conclusion

The malacological analysis from Passel provided a paleoenvironmental succession covering the Early and Middle Holocene and, to a lesser extent, the Late Holocene. After the development of a forested and moist environment during the first half of the Holocene, the enclosure was built in a thick forest environment and human activities were found to have little impact on this environment. An even denser forest developed after the abandonment of the site. Such environmental succession has little in common with the other malacological series studied in the Oise Valley, in particular with the Choisy-au-Bac and Lacroix-Saint-Ouen sites, which were occupied during the same periods. On a broader scale, while the other Holocene series studied in alluvial contexts in northern France are characterized by a progressive expansion of grasslands, Passel stands out for the persistence of forest environments. Actually, Passel has greater connections with European natural sites located far from any human impact. This case study illustrates how our perception of the human impact in a same valley can depend, site by site, on the duration and recurrence of human settlements.

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Dynamiques environnementales et impact de l'anthropisation au Néolithique dans le vallon du Vey à Cairon (Calvados, Normandie) : apports des analyses à haute résolution sur une nouvelle séquence pollinique hors-site

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Résumé

Dans la Plaine de Caen, les études paléoenvironnementales interdisciplinaires montrent un problème de divergence de représentativité spatiale et temporelle dans la corrélation des données hors-sites et intra-sites du Néolithique. Pour appréhender finement les interactions entre changements environnementaux et développement des pratiques agricoles, de nouvelles recherches ont débuté en 2016. Elles sont basées sur l'analyse à haute résolution de séquences sédimentaires hors-sites. Dans cet article la présentation d'une étude pollinique réalisée dans le vallon du Vey à Cairon montre l'intérêt de cette méthode pour appréhender avec une chronologie fine les dynamiques environnementales au Néolithique. La résolution temporelle de nos données met en évidence des évolutions du milieu qui n'avaient pas pu être décelées sur une ancienne séquence pollinique issue du même secteur. Elle nous permet aussi de corréler l'évolution des indices d'anthropisation avec les différentes phases d'occupation du site archéologique du Néolithique moyen de Cairon.

Mots clés : Anthropisation, Néolithique, Palynologie, Analyse à haute résolution, Normandie

Abstract

Environmental dynamics and anthropogenic impact during Neolithic period in the Vey valley at Cairon (Calvados, Normandy): contribution of high-resolution analyses on a new off-site pollen sequence

Interdisciplinary palaeoenvironmental studies in the Plain of Caen show a problem of spatial and temporal representativeness divergence in the correlation of Neolithic off-sites and intra-sites data. To understand precisely interactions between environmental changes and development of agricultural practices, new research began in 2016. They are based on high-resolution analyses on off-sites sedimentary sequences. In this article we present results of a palynological study carried out in the Vey valley in Cairon. It demonstrates the interest of the method to understand with a precise chronology environmental evolutions during the Neolithic. Our data temporal resolution highlights environmental dynamics that could not be detected on a former pollen sequence from the same area. Furthermore it allows correlation between evolution of anthropogenic indicators and the different occupation phases of the archaeological site of the Middle Neolithic of Cairon.

Key words: Anthropization, Neolithic, Palynology, high-resolution analysis, Normandy

Introduction

En Normandie, les archives sédimentaires issues des dépôts holocènes sont particulièrement importantes dans les fonds de vallées secondaires et les marais tourbeux (Lespez *et al.* 2012a). Cela a favorisé le développement des études sur les dynamiques paléoenvironnementales dès les années 1960 (Clet-Pellerin et Verron 2004; Elhaï 1963). Elles ont permis d'appréhender l'histoire globale de la formation du relief et des paysages végétaux à l'échelle régionale. Au cours des années 2000, les recherches se sont concentrées sur les interactions nature/sociétés, en se focalisant sur des petits hydrosystèmes mieux adaptés à l'étude des communautés rurales (Lemer *et al.* 2018 ; Lespez 2012). Les études de plus en plus centrées sur l'impact des activités humaines ont souligné la nécessité d'adopter une démarche pluridisciplinaire, qui intègre les données paléoenvironnementales hors-sites et intra-sites, pour mieux comprendre les dynamiques paysagères dans leur ensemble. Or, depuis les années 1980, la Plaine de Caen a été le siège de très nombreuses découvertes de sites archéologiques liées au développement de l'urbanisation. Dans le cadre de fouilles programmées, la plupart des sites ont fait l'objet d'analyses paléoenvironnementales multiples. Ces données ont été complétées par des recherches géoarchéologiques sur les pédo-sédiments des plateaux, suite à la création en 2007 d'un Programme Collectif de Recherche qui avait pour objectif de faire le lien entre les données paléoenvironnementales hors-sites et intra-sites très abondantes dans ce secteur (Germain-Vallée et Lespez 2011, 2016, 2018; Lespez *et al.* 2012b).

Malgré l'importance des recherches menées jusqu'à présent, l'influence de l'arrivée des premiers agriculteurs sur le paysage est encore mal définie dans la Plaine de Caen. Les données paléoenvironnementales intra-sites montrent que le développement des activités agropastorales au Néolithique influe localement sur le paysage végétal. Pourtant, les enregistrements polliniques hors-sites qui témoignent des pratiques agricoles sont rares, et ceux qui existent apportent peu d'informations. L'emprise spatiale des défrichements liés au développement de l'agriculture, mais aussi à la construction des grands monuments funéraires au cours du Néolithique moyen n'a pas encore pu être précisément définie. Enfin, les conséquences environnementales des courtes fluctuations climatiques survenues pendant cette période ne sont presque pas documentées. Pour pallier ces lacunes, des recherches fondées sur l'analyse à haute résolution de nouvelles séquences hors-sites ont débuté en 2016. Dans le cadre de ces recherches, les résultats polliniques que nous avons obtenu sur une nouvelle séquence à Cairon doivent nous permettre de souligner l'intérêt de cette méthode pour appréhender avec une chronologie fine les interactions entre changements environnementaux et développement des pratiques agricoles à partir du Néolithique.

1. Données paléoenvironnementales hors-sites et intra-sites sur le Néolithique dans la Plaine de Caen

Les enregistrements polliniques hors-sites

Les premiers agriculteurs du Néolithique s'installent sur les plateaux de la Plaine de Caen dans un environnement très forestier, dominé par le chêne et le noisetier qu'accompagnent l'orme et le tilleul. Dans les fonds de vallées, la sédimentation organique qui se met en place démontre la généralisation des espaces fluvio-palustres en lien avec le haut niveau des nappes d'eau souterraines. Les cours d'eau peu actifs se divisent alors en de multiples chenaux sinuant au sein d'une végétation dominée par les herbacées hygrophiles et les Cypéracées, et longés par une ripisylve plus ou moins dense (Clet-Pellerin *et al.* 1977; Lespez *et al.* 2005; Lespez *et al.* 2008 ; Lespez, 2012). La sédimentation organique qui se dépose dans une majorité des fonds de vallées au cours de cette période a fourni des enregistrements polliniques précieux. Ces données sont quasiment les seules à apporter des informations sur l'influence des populations néolithiques. Pourtant elles sont très ténues. En effet, comme dans le reste du Bassin Parisien entre le Néolithique ancien et le Néolithique moyen, l'impact des pratiques agricoles sur la végétation semble restreint et très dépendant de la densité de peuplement (Leroyer 2003; Leroyer 2006; Leroyer et Allenet 2006). Dans notre secteur d'étude, pour le Néolithique ancien, aucun indice d'anthropisation n'a été observé sur les séquences tourbeuses étudiées. Elles sont trop éloignées des sites archéologiques connus qui, pour cette période, sont localisés sur les plateaux dans la Plaine de Caen (Figure 1).

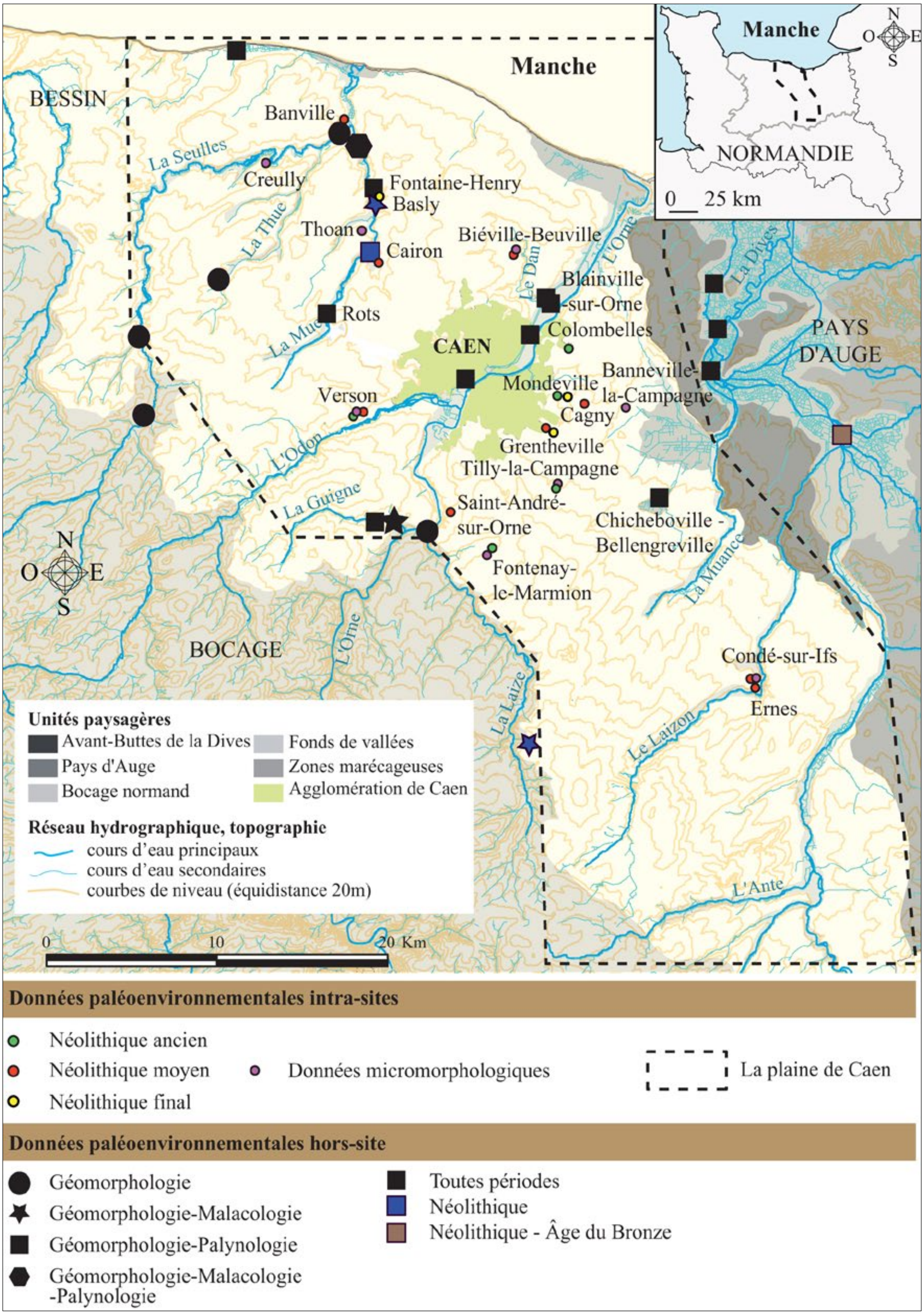

Figure 1. Les données paléoenvironnementales hors-sites et intra-sites disponibles pour le Néolithique (modifiée de Lespez et Germain-Vallée 2011).

En revanche, pour le Néolithique moyen, trois séquences (Cairon, Rots et Blainville-sur-Orne) qui se situent à proximité immédiate d'occupations fournissent des enregistrements polliniques qui témoignent de l'influence des activités agricoles (Lepsez *et al.* 2005; Barbier-Pain non publié). Les diagrammes montrent principalement une diminution des pollens d'arbres au profit des pollens de prairies, de rudérales et des spores de fougères. Ces données attestent d'une ouverture du couvert forestier par défrichement de clairières. En revanche, très peu d'indices témoignent du développement des cultures céréalières. Seules les séquences de Rots et Blainville-sur-Orne fournissent quelques rares occurrences de pollens de plantes cultivées. Ces indices d'anthropisation ténus ont généralement été associés aux occupations proches. Pourtant le manque de datations sur ces séquences polliniques ne permet pas de les corréler précisément aux données archéologiques. Entre la fin du Néolithique moyen et le début du Néolithique récent l'ensemble des données polliniques indiquent l'essor de l'aulne qui vient coloniser les fonds de vallées. Cet essor survient également dans les marais de Chicheboville-Bellengreville dans un secteur éloigné des occupations anciennes connues (Clet-Pellerin non publié, données brutes de comptage disponibles sur European Pollen Database). Les pollens de céréales sont absents des diagrammes pour le Néolithique récent et final, mais des marqueurs d'anthropisation sont pourtant toujours présents. A Fontaine-Henry, ces marqueurs ont été corrélés à l'occupation du site de l'éperon barré de Basly daté du Néolithique final (Lespez *et al.* 2005). Mais à Blainville-sur-Orne, ils ne correspondent à aucune occupation proche et contemporaine de cette période. L'enregistrement de ces indices d'anthropisation, malgré le filtre lié au développement de l'aulne, pourrait témoigner d'une empreinte plus forte et plus durable des populations de la fin du Néolithique sur le paysage.

Les enregistrements polliniques de la Plaine de Caen ne fournissent, en outre, presque aucune information sur l'influence environnementale des courtes fluctuations climatiques survenues durant le Néolithique (Mayewski *et al.* 2004). En Europe de l'Ouest, elles sont la plupart du temps marquées par des périodes plus froides et humides, et favorisent un hydrodynamisme plus important. La séquence pollinique de Chicheboville-Bellengreville est la seule à montrer des variations de la végétation qui peuvent témoigner de ces fluctuations. Dans ce diagramme, l'essor des pollens de Cypéracées parallèlement à une diminution des pollens du noisetier illustrent l'extension de la zone humide, et témoignent de cinq périodes de haut niveau de la nappe durant le Néolithique (Lespez 2012).

Les données paléoenvironnementales intra-sites

Les données paléoenvironnementales intra-sites dans la Plaine de Caen, en plus d'être nombreuses, fournissent des informations sur toutes les périodes du Néolithique (Figure 1). Elles proviennent principalement des sites de Colombelles (Billard *et al.* 2014), Mondeville, Grentheville (Chancerel *et al.* 2006), Tilly-la-Campagne (Charraud *et al.* 2016), Fontenay-le-Marmion (Giraud *et al.* 2012), Verson (Germain-Vallée *et al.* 2014), Cairon (Ghesquière and Marcigny 2011), Condé-sur-Ifs, Ernes (Dron *et al.* 2016) et Cagny (Giraud *et al.* 2015). En dehors des sites d'Ernes et de Condé-sur-Ifs, l'ensemble des occupations connues est situé sur les plateaux limoneux dans la partie nord de la Plaine de Caen. Les données archéobotaniques et archéozoologiques témoignent du développement des activités agropastorales aux alentours des sites dès le Néolithique ancien. Les lots carpologiques présentent des restes de céréales et de légumineuses cultivées, et les ossements d'animaux domestiques indiquent la présence de cheptels dominés par les bovins, et suivis à part quasi égale par les porcs et les caprinés. Malgré leur fertilité relative, la texture légère des sols limoneux était compatible aux techniques agricoles des Néolithiques et a pu favoriser l'installation des premiers agriculteurs. Les luvisols de la Plaine de Caen témoignent de la stabilité des paysages végétaux tout au long du Mésolithique. En revanche, les recherches géoarchéologiques conduites sur les plateaux apportent la preuve de premières phases érosives au Néolithique ancien à Fontenay-le-Marmion et au Néolithique final à Banneville-la-Campagne (Béguier *et al.* 2011 ; Germain-Vallée et Lespez 2011). L'exploitation des espaces défrichés est alors probablement temporaire car elle est toujours suivie d'une recolonisation durable par la végétation forestière attestée par la résilience des luvisols. Les clairières sont abandonnées après quelques générations, et l'influence des pratiques agricoles sur le couvert forestier des plateaux est encore restreinte (Lespez 2012 ; Germain-Vallée et Lespez 2016, 2018). Le maintien de ce couvert protecteur empêche l'arrivée des particules limoneuses arrachées aux sols cultivés dans les fonds de vallées qui ne présentent aucune trace de sédimentation détritique contemporaine du Néolithique (Lespez 2008, 2012 ; Germain-Vallée et Lespez 2011a).

Si les données archéobotaniques et archéozoologiques confirment que la forêt est encore bien présente durant l'ensemble du Néolithique, le développement de l'agriculture a probablement entraîné l'apparition d'un paysage en mosaïque autour de certains sites, les espaces forestiers encore parfois très denses sont entrecoupés de prairies, de cultures et de friches. Au Néolithique moyen et final, l'impact des pratiques humaines semble même s'intensifier autour des habitats. L'augmentation des espèces héliophiles dans les lots anthracologiques des sites de Cairon, Condé-sur-Ifs et Ernes suggère l'essor des écosystèmes de fourrés post-forestiers, de landes ou de friches. La présence des restes osseux du cheval à Cairon implique aussi l'existence d'étendues ouvertes. Ces changements peuvent attester d'une multiplication des clairières cultivées ou abandonnées, de l'influence croissante du pâturage, mais également d'un essor de la pression démographique sur le paysage végétal au cours de ces périodes. En effet, les données archéologiques suggèrent que la construction des monuments collectifs funéraires et des grandes enceintes au Néolithique moyen II traduit le passage à un seuil démographique plus important (Ghesquière *et al.* 2014).

2. Une nouvelle étude paléoenvironnementale dans le fond de vallée de Cairon

La divergence d'échelle de représentativité entre les données hors-sites et intra-sites dans la Plaine de Caen

L'ensemble des données paléoenvironnementales témoigne du maintien d'un couvert forestier important à l'échelle régionale durant une majeure partie du Néolithique. Cela a probablement limité l'enregistrement des pratiques agropastorales dans les archives sédimentaires de fonds de vallées. Les données intra-sites nombreuses ont permis d'établir une première hypothèse d'évolution du paysage sous l'influence des pratiques humaines. Mais la représentativité spatiale et temporelle de ces données est restreinte par rapport à celle des enregistrements hors-sites. Jusqu'à présent, les analyses polliniques ont été réalisées avec une résolution temporelle relativement large et sur des séquences sédimentaires parfois mal calées chronologiquement. Elles ne permettent donc pas d'appréhender des dynamiques environnementales liées à des occupations qui ne couvrent parfois qu'une ou deux générations d'individus ou à des courtes évolutions du climat. Dans le cadre des recherches interdisciplinaires menées dans la Plaine de Caen, cette divergence d'échelle de représentativité entre les données hors-sites et intra-sites a rendu problématique la corrélation des différentes informations.

Pourquoi une nouvelle étude dans le fond de vallée de Cairon ?

Cairon se situe dans le vallon du Vey, un petit affluent de la Mue, et fait partie des secteurs déjà étudiés il y a une dizaine d'années (Lespez *et al.* 2005, 2008). Des analyses polliniques ont été réalisées sur une séquence organique (que nous appellerons Cairon 2005) qui couvre une majeure partie du Néolithique et qui se situe à environ 250 mètres d'un site archéologique (Figure 2) sur lequel trois phases d'occupations distinctes ont été mises au jour (Ghesquière and Marcigny 2011). La première (c. 4400 cal. BC) est marquée par les restes d'un espace de dalles dressées et d'un foyer interprétés par les archéologues comme les vestiges d'une aire cultuelle. La deuxième (c. 4200-4000 cal. BC) correspond à un habitat domestique fossilisé dans un « vieux sol » qui a fourni des restes archéobotaniques et archéolozoologiques qui ont pu être étudiés. Enfin, la dernière phase correspond à la construction d'un monument funéraire de type cairn vers 3900 cal. BC qui sera

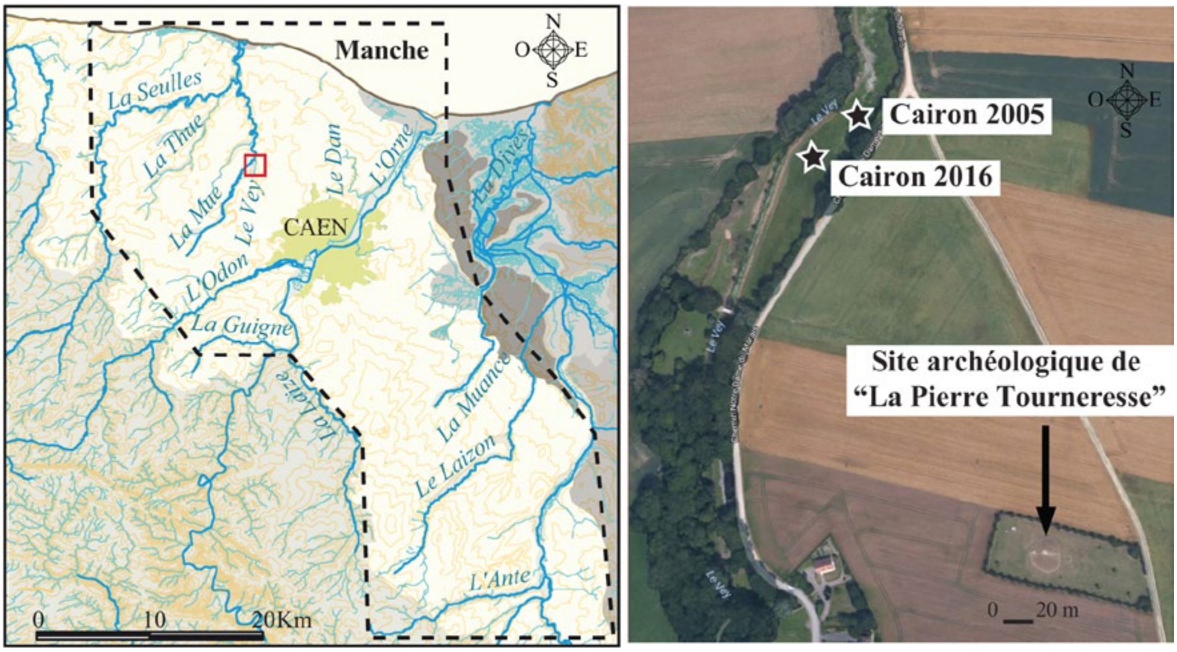

Figure 2. Localisation du secteur d'étude, des carottages et du site archéologique de Cairon (carte modifiée de Lespez et Germain-Vallée 2011 ; photographie aérienne Google Maps-2018).

fréquenté jusqu'à la fin du Néolithique moyen II (c. 3500 cal. BC). Nous avons donc choisi de reprendre les recherches dans ce secteur qui offre des conditions particulièrement favorables pour étudier les dynamiques d'anthropisation au Néolithique. Des analyses polliniques à haute résolution couplées à des datations radiocarbone ont été effectuées sur une séquence organique issue d'un nouveau carottage (Cairon 2016) réalisé au carottier à percussion sur la même parcelle qu'en 2005 (Figure 2). La comparaison des nouvelles et des anciennes données polliniques nous permettra de souligner les apports de ce type d'étude pour appréhender avec une chronologie fine les évolutions environnementales et le développement des pratiques agricoles avant, pendant et après l'occupation du site de Cairon.

3. Méthodes de la recherche

Datations et chronologie

La chronologie de Cairon 2016 est basée sur 5 datations radiocarbone (AMS) au lieu de 4 sur la séquence de Cairon 2005. Ces datations ont été calibrées (Table 1) avec le logiciel OxCal 4.3 (Bronk Ramsey and Lee, 2013), avec la courbe de calibration IntCal 13 atmospheric curve (Reimer *et al.*, 2013). Deux modèles d'âge (Figure 3) ont été réalisés avec une interpolation linéaire sur Clam-R (Blaauw, 2010) et nous ont permis d'attribuer un âge aux limites des zones polliniques des deux séquences pour faciliter la comparaison des données.

Code laboratoire	Profondeur (cm)	Matériel	Age 14C (1σ)	Dates calibrées (2σ) BC/AD	Dates calibrées (2σ) BP
Beta-449779	53,5 – 54	Tourbe	4650 ± 30 BP	3515 – 3360 BC	5465 – 5310 BP
Beta-449781	73,5 – 74	Tourbe	5150 ± 40 BP	4040 – 3810 BC	5990 – 5760 BP
Poz-94959	130 – 131	Tourbe	6230 ± 40 BP	5181 – 5061 BC	7131 – 7011 BP
Beta-451268	161,5 – 162	Tourbe	6390 ± 30 BP	5470 – 5310 BC	7420 – 7260 BP
Poz-94958	189 – 189,5	Limons organique	6940 ± 35 BP	5899 – 5733 BC	7849 – 7683 BP

Table 1. Calibration des datations AMS du carottage Cairon 2016.

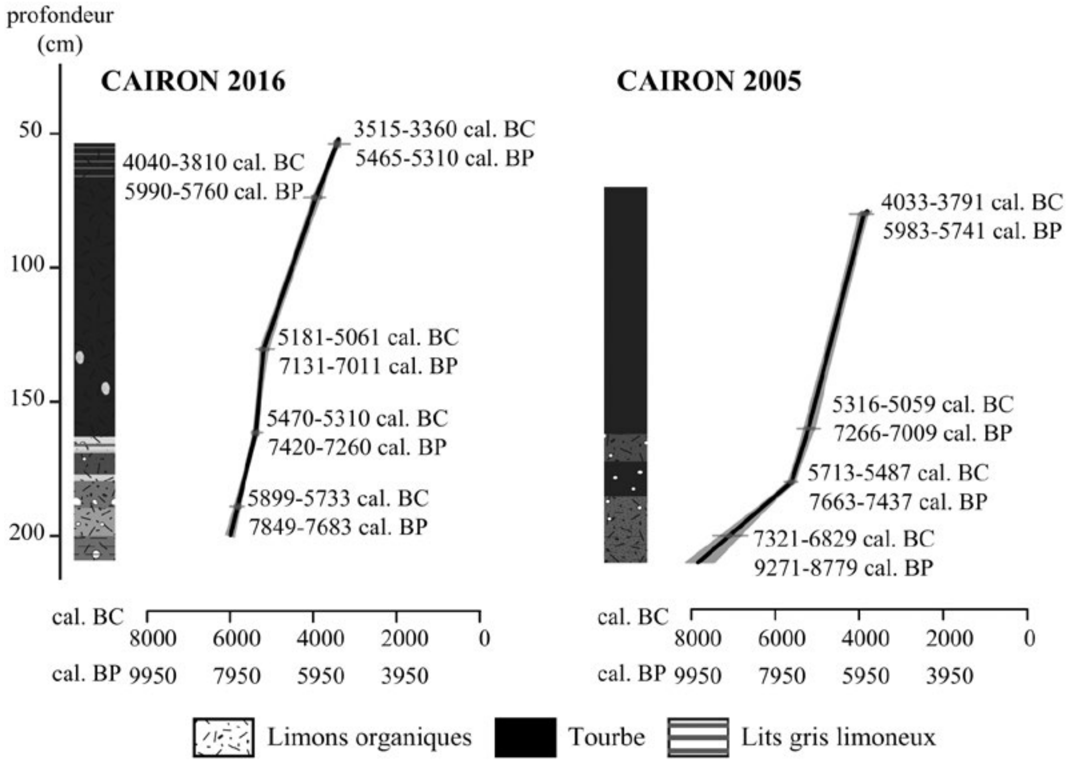

Figure 3. Modèles d'âge réalisés sur Clam-R (Blaauw 2010) avec une interpolation linéaire des séquences organiques de Cairon 2005 et 2016.

Analyses polliniques

Des analyses polliniques ont été réalisées sur 39 échantillons prélevés sur la séquence organique de 141 cm de Cairon 2016. Les lames polliniques ont été préparées à partir d'un protocole adapté des ouvrages de Moore, Webb, et Collinson (1991) et Faegri et Iversen (1989). Pour chaque échantillon, les comptages ont été poussés à un minimum de 300 grains de pollens identifiés avec au moins 20 taxons différents. Sur 4 échantillons qui présentaient une faible diversité taxonomique, les comptages se sont arrêtés à 18 ou 19 taxons différents (à 102,5, 104,5, 109 et 117 cm). Le nombre de grains de pollens comptés et identifiés pour une lame varie entre 305 et 584, pour une diversité taxonomique qui va de 18 à 28 taxons. Par contre, sur le carottage de Cairon 2005, les analyses polliniques ne concernent que 26 échantillons prélevés sur les 123 cm de séquence organique. Le nombre de grains de pollens comptés et identifiés sur une lame varie entre 103 et 185, pour une diversité taxonomique qui va de 9 à 14 taxons. Pour pouvoir comparer les données polliniques des deux séquences, le diagramme de Cairon 2005 a été refait à partir des données brutes de comptage obtenues sur European Pollen Database. Pour les deux diagrammes réalisés avec le logiciel Psimpoll 4.27 (Bennett 2009), les pourcentages de taxons arboréens (AP) et herbacés (NAP) ont été calculés à partir de la somme de base AP + NAP. Les pourcentages de Ptéridophytes, de grains indéterminés et de grains indéterminables ont été calculés à partir de la somme de AP + NAP + Ptéridophytes + indéterminés + indéterminables.

4. Résultats et apports des nouvelles analyses polliniques

La séquence pollinique Cairon 2016 couvre une période équivalente à celle de la séquence Cairon 2005, allant du Mésolithique récent au Néolithique récent (Figure 3). En revanche, la résolution temporelle et les seuils de comptages des nouvelles analyses nous permettent d'identifier des évolutions plus subtiles et rapides de la végétation, ainsi que des marqueurs d'anthropisation corrélables aux phases d'occupations du site archéologique (Figure 4).

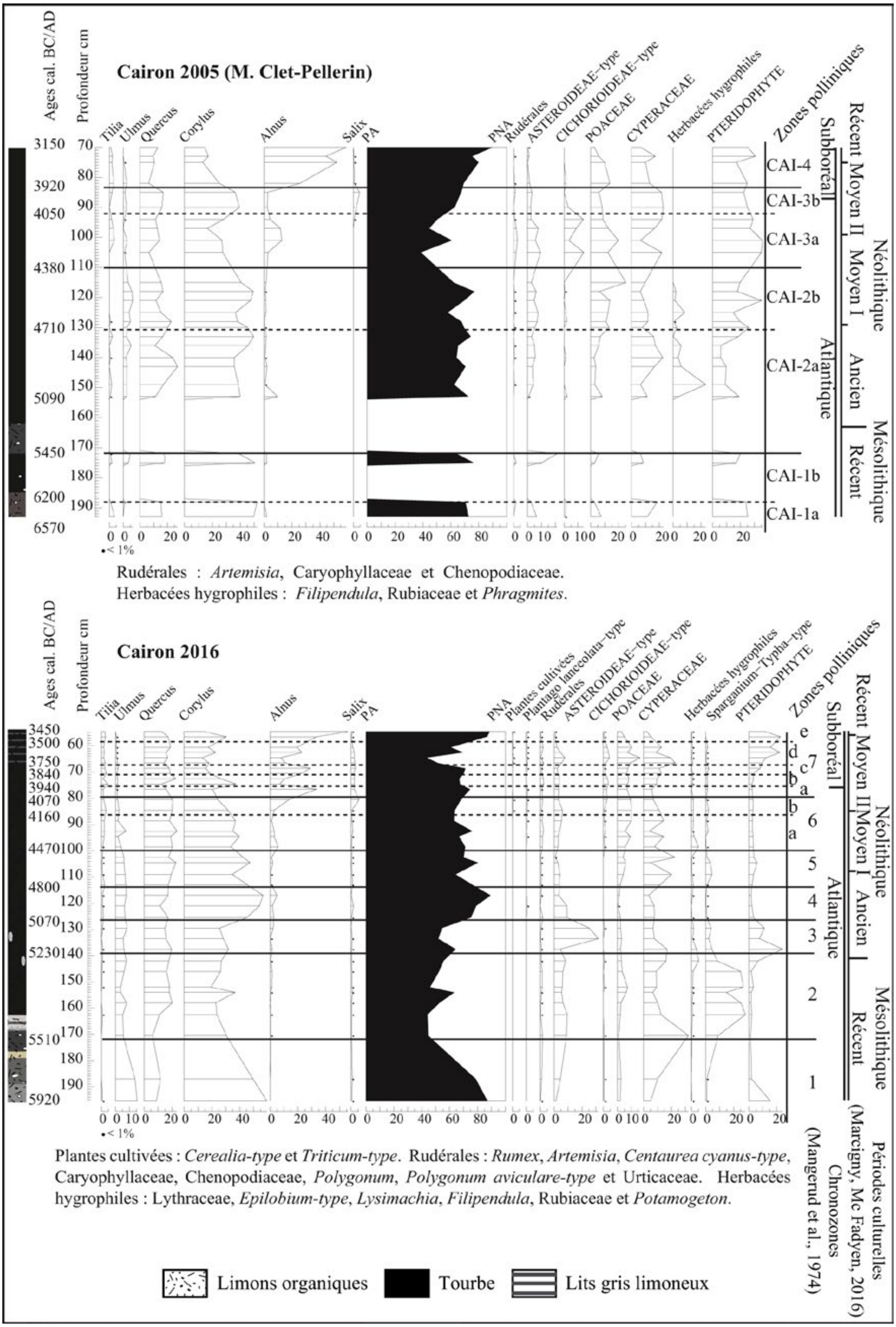

Figure 4. Diagrammes polliniques simplifiés des séquences organiques de Cairon 2005 et 2006.

Zone pollinique 1 : Mésolithique récent (c. 5920-5510 cal. BC)

Comme sur le diagramme de Cairon 2005, les pourcentages de pollens arboréens sont élevés (aux alentours de 80%) et attestent de l'existence d'un couvert forestier dense dominé par le noisetier, puis le chêne et l'orme. Dans le fond de vallée ouvert et marécageux, une zone humide à Cypéracées bordée de prairies se développe.

Zone pollinique 2 : fin du Mésolithique récent et début du Néolithique ancien (c. 5510-5230 cal. BC)

Les taux de pollens arboréens diminuent autour des 50% principalement à cause de la baisse de *Corylus*. Les pourcentages de Cypéracées décroissent également alors que ceux des aquatiques (principalement *Sparganium*-t.) augmentent beaucoup. Ces évolutions illustrent l'extension de la zone humide en fond de vallée qui témoigne du haut niveau de la nappe localement. Cette période correspond principalement à un hiatus pollinique dans le diagramme de Cairon 2005 dans lequel les pollens de *Sparganium*-t. sont absents sur l'ensemble de la séquence.

Zones polliniques 3 et 4 : Néolithique ancien (c. 5230-5070 cal. BC et c. 5070-4800 cal. BC)

Dans la zone pollinique 3 les taux d'aquatiques diminuent alors que ceux des Ptéridophytes et des Asteroideae augmentent. Dans la zone pollinique 4, les taux d'aquatiques continuent à diminuer alors que ceux de *Corylus*, *Alnus* et *Salix* augmentent. La zone humide se rétracte ce qui témoigne d'un abaissement du niveau de la nappe. Ses abords sont colonisés par les herbacées de prairies et les fougères, puis dans un deuxième temps par la végétation arbustive pionnière. Sur le diagramme de Cairon 2005 cette période correspond à l'apparition et l'essor des pollens de *Phragmites* (qui n'ont pas été distingués lors des comptages de Cairon 2016) et à l'augmentation des taux de Cypéracées. Ces données ont au contraire été interprétées comme des indices d'extension de la zone humide (Lespez *et al.* 2005).

Zone pollinique 5 : fin du Néolithique ancien et début du Néolithique moyen I (c. 4800-4470 cal. BC)

Les taux de pollens arboréens diminuent légèrement (autour de 70%) à cause de la baisse des pourcentages de *Alnus* et *Corylus*, alors que ceux des Cypéracées augmentent beaucoup et ceux des aquatiques légèrement (principalement *Sparganium*-t. qui atteint 5%). L'essor des herbacées hygrophiles témoigne d'une extension de la zone humide dans laquelle les zones d'eau libres où poussent les plantes aquatiques sont moins présentes en comparaison de ce qui a été observé dans la zone pollinique 2. Ces évolutions de la végétation attestent d'une hausse du niveau de la nappe moins importante ou équivalente à la précédente, car il se peut également que l'exhaussement de la tourbière depuis le début du Néolithique ait influé sur l'évolution du milieu. Sur la séquence de Cairon 2005, cette période correspond à un essor des pourcentages de Ptéridophytes, Poacées et *Corylus*, interprété comme des indices d'assèchement du milieu (Lespez *et al.* 2005).

Zone pollinique 6 : Néolithique moyen I et début du Néolithique moyen II (c. 4470-4079 cal. BC)

Les pourcentages de Cypéracées diminuent légèrement, ceux des aquatiques beaucoup et ceux de *Alnus* augmentent un peu. Les taux de rudérales et de Poacées augmentent, alors que la courbe des Cichorioideae devient continue. Ces dynamiques témoignent d'une nouvelle évolution de l'environnement du fond de vallée vers des conditions plus sèches et de l'essor des prairies. Dans la sous zone pollinique 6a les taux de *Corylus* diminuent légèrement, et des occurrences de *Plantago lanceolata* apparaissent. Ces indices d'anthropisation qui suggèrent le développement de l'élevage aux alentours du fond de vallée sont corrélables à la phase d'occupation cultuelle du site de Cairon datée du Néolithique Moyen I (c. 4400 cal. BC). Dans la sous zone pollinique 6b les premières occurrences de céréales apparaissent et les pourcentages de *Corylus* diminuent de manière plus prononcée. En plus de l'élevage, la céréaliculture est pratiquée aux abords du vallon au cours de cette période qui correspond à la phase d'occupation domestique du site de

Cairon datée à la limite entre le Néolithique Moyen I et II (c. 4200-4000 cal. BC). Les défrichements qui touchent principalement le noisetier entraînent une ouverture du couvert forestier un peu plus importante que lors de la période précédente. Comme sur la séquence de Cairon 2016, sur celle de Cairon 2005 les pourcentages de rudérales, Poacées et Cichorioideae augmentent, alors que ceux de *Corylus* diminuent. En revanche, aucun pollen de céréales et de *Plantago lanceolata* n'a été observé. Les pourcentages de Ptéridophytes sont beaucoup plus élevés et les taux de pollens arboréens nettement plus bas. Si des indices d'anthropisation pour cette période avaient déjà pu être observés, ils étaient plus ténus, et ne montraient pas d'évolution des pratiques agropastorales corrélables aux différentes phases d'occupation du site.

Zone pollinique 7 : Néolithique moyen II et début du Néolithique récent (c. 4079-3450 cal. BC)

Les pourcentages d'*Alnus* connaissent des variations importantes, avec une alternance d'augmentation et de diminutions brutales. Une aulnaie envahit le fond de vallée à la suite de l'abandon probable de l'habitat domestique de Cairon (c. 4000 cal. BC) et va connaître deux périodes de défrichements importants. Les premiers défrichements (sous zone pollinique 7b) se produisent autour de l'époque de la construction du monument funéraire de Cairon, vers 3900 cal. BC. Les rudérales, *Plantago lanceolata* et les herbacées de prairies sont toujours bien représentés dans le diagramme. Les sous zones polliniques 7d et 7e présentent des occurrences de pollens de céréales, et montrent un essor important des Ptéridophytes. La sous zone 7d montre une diminution des taux de pollens arboréens liée à la baisse importante de *Corylus* et *Alnus*, alors que ceux des herbacées augmentent. Les indicateurs polliniques d'anthropisation présents en continu attestent de la continuité des pratiques agricoles dans des secteurs relativement proches du fond de vallée. En revanche, les cultures céréalières ne sont attestées par les données polliniques que suite à la deuxième phase de défrichement de l'aulnaie (sous zone pollinique 7d) au cours de laquelle l'ouverture du couvert forestier est la plus importante. Cette période est aussi marquée par l'essor des fougères qui suggère la multiplication des espaces en friches (Lespez *et al.* 2005). L'ensemble de ces données peut témoigner de l'intensification des pratiques agricoles et de l'essor de l'emprise territoriale des populations du secteur au cours du Néolithique moyen II. Sur la séquence Cairon 2005, les taux d'*Alnus* augmentent aussi au cours du Néolithique moyen II, mais les phases de défrichement de l'aulnaie sont moins visibles et les indicateurs polliniques d'anthropisation très peu marqués.

4. Dynamiques environnementales et impact de l'anthropisation au Néolithique dans le vallon de Cairon

Des évolutions environnementales principalement liées au niveau de l'aquifère (c. 5920-4400 cal. BC)

Entre la fin du Mésolithique et le début du Néolithique, les dynamiques environnementales du vallon du Vey correspondent au schéma global d'évolution des fonds de vallées de la Plaine de Caen sous l'influence des grandes variations hydroclimatiques (Lespez 2012). En revanche, notre haute résolution d'analyse fait ressortir des dynamiques rapides de la végétation qui attestent de fluctuations du niveau de la nappe localement. La remontée de l'aquifère entraîne alors l'extension de la zone humide marécageuse au sein du fond de vallée aux dépens des prairies et des espaces forestiers. Ces deux périodes de haut niveau de la nappe sont en grande partie synchrones à des fluctuations hydroclimatiques rapides régionales (Lespez 2012 ; Macklin *et al.* 2010 ; Magny 2004) et /ou plus globales (Bond *et al.* 2001) (Figure 5).

Comme sur les autres séquences étudiées dans la Plaine de Caen, à Cairon les indices polliniques d'anthropisation sont quasiment absents du diagramme avant le Néolithique moyen. L'essor des conditions marécageuses au cours des périodes de haut niveau de la nappe n'a probablement pas favorisé l'occupation des terrains proches du fond de vallée. En revanche, entre ces deux périodes la zone humide se rétracte au profit des prairies, puis des espaces forestiers. Les conditions sont

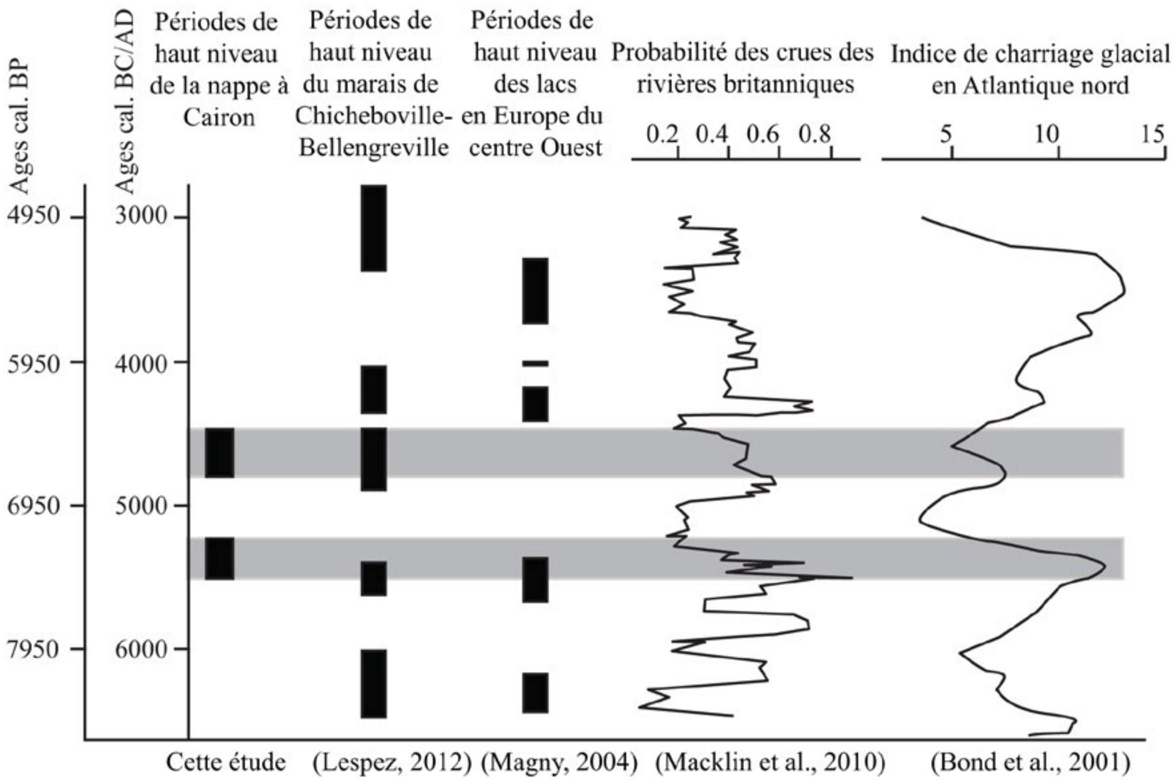

Figure 5. Comparaison des périodes de haut niveau de la nappe à Cairon avec d'autres enregistrements hydroclimatiques.

alors plus favorables à l'installation des populations. Cependant, les indices d'anthropisation dans le diagramme sont particulièrement ténus. Les dynamiques environnementales semblent donc principalement liées aux fluctuations du niveau de la nappe jusqu'à l'installation d'une première communauté d'agriculteurs à proximité immédiate du fond de vallée vers le milieu du Néolithique moyen I.

Le développement des activités agropastorales en lien avec les deux premières périodes d'occupation du site de Cairon (c. 4400-4000 cal. BC)

Les premiers indices archéologiques d'occupation du site de « la Pierre Tourneresse » datent du Néolithique moyen I, au cours d'une période marquée dans notre diagramme pollinique par une nouvelle rétractation de la zone humide. Les conditions environnementales sont alors plus favorables au développement des activités agricoles à proximité des espaces marécageux. Nos données polliniques enregistrent pour cette période un léger recul du couvert forestier local, et surtout l'apparition des marqueurs d'élevage. Elles fournissent les premiers indices de l'utilisation des terrains du vallon pour les activités pastorales. Les vestiges de l'occupation du site à cette période ont été interprétés comme les restes d'une aire cultuelle et n'apportent pas la preuve d'une exploitation permanente de notre secteur. Le bétail a par exemple pu être amené sur ces terrains seulement saisonnièrement. L'impact des pratiques agricoles semble encore très restreint, elles n'entraînent pas de défrichements massifs et étendus du couvert forestier.

A la transition entre le Néolithique moyen I et II, les vestiges de l'occupation domestique de Cairon montrent l'installation plus stable d'une communauté d'agriculteurs à proximité immédiate du fond de vallée. Les pollens de céréales qui apparaissent dans notre diagramme indiquent que la céréaliculture se développe localement suite à l'installation de cet habitat. Dans le diagramme pollinique, la baisse du taux du noisetier est plus marquée et témoigne d'une pression plus importante sur le couvert forestier. Le développement des cultures céréalières a pu entraîner l'ouverture de nouveaux espaces sur les secteurs proches des versants et du plateau, qui fournissent des sols *a priori* plus favorables aux cultures. Le poids important des espèces héliophiles (principalement du noisetier) dans les archives polliniques et archéobotaniques témoigne de l'existence d'écosystèmes ouverts et semi-ouverts de type lisières forestières, fourrés ou friches, qui ont pu se multiplier suite à l'installation d'une occupation plus pérenne dans le secteur. Si dans les lots anthracologiques le chêne est l'espèce dominante, certains charbons proviennent d'espaces forestiers denses et non touchés par les déboisements agricoles, situés probablement sur les plateaux. Dans le diagramme pollinique, la courbe du chêne est effectivement particulièrement stable, et ne montre pas de baisse significative suite au développement des activités agricoles. Les forêts claires dominées par le noisetier présentes localement étaient probablement plus faciles à défricher. Si l'aulne et le saule connaissent un petit essor dans les données polliniques durant cette période, ils montrent une faible représentation dans les lots anthracologiques, indiquant une exploitation limitée de la ripisylve par les populations (Marguerie in : Ghesquière and Marcigny 2011).

L'extension de l'emprise territoriale des populations du Néolithique moyen II (c. 4000-3450 cal. BC)

Suite à l'abandon de l'habitat domestique de Cairon, les données polliniques indiquent que le fond de vallée est envahi par l'aulne. L'essor très conséquent de l'aulne au cours de cette période est un phénomène qui semble commun à l'ensemble des fonds de vallée de la Plaine de Caen (Lespez *et al.* 2005; Clet-Pellerin non publié). Si cette période correspond en grande partie à la construction et à la fréquentation du cairn de Cairon, aucun habitat daté de la fin du Néolithique moyen et du début du Néolithique récent situé à proximité du vallon n'est connu actuellement. Comme dans la vallée du Dan à Blainville-sur-Orne, malgré le filtre de l'aulnaie et la liaison moins forte avec une occupation, les indices d'anthropisation sont toujours présents dans le diagramme. Ils attestent la continuité des activités agropastorales dans le secteur, qui semblent même s'intensifier vers 3800 cal. BC. L'ensemble des prospections archéologiques réalisées dans le secteur montre la présence de nombreux sites sur les plateaux alentours. Une partie de ces sites pourraient correspondre à des occupations du Néolithique. Une enceinte à fossé interrompu qui évoque les enceintes du Néolithique moyen II a notamment été repérée sur le versant, à un peu plus d'un kilomètre du fond de vallée (Ghesquière and Marcigny 2011). Les activités agropastorales pourraient ainsi être liées à une de ces occupations, ou à des occupations connues mais plus éloignées dans la vallée de la Mue, comme celle de Basly par exemple (Figure 1). Ces données suggèrent l'intégration du vallon de Cairon à un territoire agricole plus vaste. Elles témoignent d'une emprise territoriale plus forte des populations de cette période. Elles appuient l'hypothèse déjà émise grâce aux données archéologiques du passage à un nouveau seuil démographique au cours du Néolithique moyen. Le groupe d'individus probablement isolé qui occupait le versant du vallon pendant la première partie du Néolithique moyen n'a eu qu'une influence restreinte autour du site. En revanche par la suite, avec l'installation d'une communauté plus importante et organisée capable de construire le monument funéraire de Cairon, l'emprise territoriale s'étend et marque de façon plus durable et importante le paysage végétal.

Conclusion

La résolution temporelle des données obtenues sur la nouvelle séquence de Cairon a mis en évidence des dynamiques environnementales qui n'avaient pas pu être décelées précédemment. Jusqu'au milieu du Néolithique moyen I, l'enregistrement pollinique n'apporte pas d'informations précises de l'impact des populations d'agriculteurs qui s'installent dans la Plaine de Caen. L'évolution environnementale du vallon est principalement influencée par les variations du niveau de la nappe. Les dynamiques de la végétation locale illustrent deux courtes périodes d'augmentation du niveau de l'aquifère qui peuvent correspondre à deux fluctuations hydroclimatiques rapides, d'échelles régionales ou globales. Le calage chronologique précis de notre séquence nous permet de corréler l'évolution des indices d'anthropisation dans le diagramme pollinique avec les différentes phases d'occupation du site archéologique à partir du

Néolithique moyen I. Vers 4400 cal. BC, alors que l'environnement du fond de vallée évolue vers des conditions plus sèches, l'élevage dans le vallon a pu être pratiqué de façon discontinue ou saisonnière, en lien avec l'aire cultuelle de Cairon. En effet, c'est uniquement durant la période d'occupation domestique (c. 4200 cal. BC) que les marqueurs de cultures céréalières apparaissent dans le diagramme. Avec l'installation continue et durable d'un groupe d'individus la pression sur le couvert forestier autour du site s'accentue un peu, mais semble toujours très localisée. Après l'abandon de cet habitat, et malgré le développement d'une aulnaie dense dans le fond de vallée les marqueurs d'anthropisation sont présents en continu dans le diagramme. Au cours du Néolithique moyen II, suite au passage probable à un nouveau seuil démographique, l'emprise agricole et territoriale des populations semble s'intensifier et s'étendre. Les résultats de l'étude de cette séquence pollinique mettent en évidence l'intérêt de recherches basées sur des analyses à haute résolution temporelle pour appréhender finement les évolutions environnementales et les dynamiques d'anthropisation. C'est avec la même démarche méthodologique que des analyses des micro-restes non polliniques, du signal incendie, de susceptibilité magnétique et du rapport C/N ont été réalisées sur le carottage Cairon 2016. Ces données, en cours de publication, nous permettront d'affiner nos connaissances sur les évolutions du milieu et des pratiques agricoles afin d'appréhender plus clairement le rôle respectif des facteurs naturels et anthropiques dans les dynamiques environnementales de cette période.

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Geoarchaeological and chronological reconstruction of the Aşıklı PPN site spatial development (Central Anatolia, Turkey)

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Abstract

Aşıklı Höyük is a very important site in the study about the emergence of early sedentary societies in the Eastern Mediterranean. Located in Central Anatolia, it is one the oldest Neolithic sites of Turkey north of the Taurus. The occupation spans the whole development of the Pre-Pottery Neolithic (PPN) in Central Anatolia, from c. > 8350 to 7300 BC (> 10.3 to 9.25 ka cal BP). Excavated since 1989, the site is composed of five levels defined on the basis of their cultural characteristics, developments and trends, and ^{14}C dated. It is located in a flood valley environment that was influenced by Late Glacial deposits and showed environmental variability before, during and after the settling of PPN population. At that time, the wide Melendiz river valley was still filled by Late Glacial deposits. Today, this terrace is positioned 4 m above the present river bed. Although not seen in today's landscape of the valley because of active lateral erosion during the Holocene, the terrace is well preserved below colluvium east of the mound, where it forms a 'gutter' in which a series of cores, section studies and soundings have been performed between 2010 and 2015. These cores reveal an unexpected spatial growth of the site during Level 2 (the latest PPN level). The results of this palaeoenvironmental program, led in connection with the latest archaeological excavations on the site, produce a parallel chronology and show entangled relationships between the site's occupation and cultural development on the one hand, and the dynamics of its environment on the other hand, which modified the landforms and settlement remains in the surroundings of the site.

Key words: Aşıklı, Neolithic, Late Glacial, Early Holocene, Palaeoenvironments, Melendiz River setting

Résumé

Aşıklı Höyük en Anatolie centrale, est l'un des sites néolithiques les plus anciens à l'Ouest et au Nord du Taurus central. L'occupation du site couvre toutes les phases du Néolithique Pré-Céramique (Pre-Pottery Neolithic, PPN) d'Anatolie centrale, de > 8350 à 7300 BC (> 10.3 à 9.25 ka cal BP). Il est donc très important pour l'étude de l'émergence des premières sociétés sédentaires en Méditerranée orientale. Initiées en 1989, les fouilles ont mis au jour cinq phases culturelles définies par leurs caractères spécifiques et datées par le radiocarbone. L'étude géomorphologique du site et de ses environs met en évidence des relations étroites entre, d'une part la construction de la plaine d'inondation de la vallée de la rivière Melendiz où le site est situé, et d'autre part la variabilité hydro-environnementale de cette vallée pendant l'Holocène ancien lorsque le site archéologique se développait. Au début de l'occupation du site, la majeure partie de la vallée était remplie de sédiments tardiglaciaires. Aujourd'hui, ce remplissage forme une terrasse « cachée », quasiment invisible dans le paysage actuel, et dont la surface, fossilisée sous le site archéologique, se trouve à 4 m au-dessus du lit actif de la rivière. Presque partout dans la vallée, ce remplissage a donc disparu, érodé par incision et érosion latérale, sauf à l'est du tell. Dans cet espace légèrement déprimé en forme de gouttière dirigée vers le sud, plusieurs carottages et sondages archéologiques ont été réalisés entre 2010 et 2015. Ces séquences ont révélé une extension insoupçonnée de niveaux archéologiques datant plus particulièrement du « Niveau 2 » (dernière phase d'occupation PPN). En outre, les reconstructions paléoenvironnementales sous et autour du site, réalisées en étroite connexion avec les travaux archéologiques les plus récents, montrent comment (1) la formation du site et l'expansion de ses phases culturelles successives se sont inscrites chronologiquement et spatialement dans la dynamique morphologique de la vallée, et (2) la présence du site dans la vallée a interféré avec les facteurs géologiques et hydrodynamiques vis-à-vis de la préservation ou de la destruction de certains niveaux archéologiques à certaines époques et dans certains secteurs de la vallée.

Mots clefs : Aşıklı, Néolithique, Tardiglaciaire, Holocène Ancien, Paléo-environnement, Melendiz (vallée de)

1. Introduction

Among other challenges, pluridisciplinary investigations based on 'in-site' archaeological excavations and 'off-site' palaeoenvironmental research face important questions about how to manage chronological frames of distinct natures, obtained by distinct and differently scaled operations. These questions concern, for example, the natural context of the development of a site and the evolution of resources with respect to the evolution of habitat-type(s) and technology. While in-site sediments deliver anthropogenic data of various natures (architectural, cultural, environmental, sedimentary, technical, funerary, biologic, chemical, behavioral etc.), off-site research does not concern humans directly but aims at defining the physical, climatic and biologic (ecosystemic) context of the society's development. In parallel, when using regional climatic and palaeoenvironmental reconstructions from more or less distant off-site lake or marsh sequences, it is necessary to take into account the different geomorphological settings and hydrological dynamics which are specific at the site location.

The site chosen here for this discussion is the prehistoric site of Aşıklı Höyük in East Central Anatolia, Turkey. Here, the time resolution of the archaeological layers' accumulation ('höyük' is the Turkish word for tell, mound) is much better constrained than that of the palaeoenvironmental cores and sections, mainly because the archaeological chronology is not only based on ^{14}C dates on charcoals, seeds and plants (>200 ^{14}C dates until now), but also on very detailed references produced by stratigraphy and cultural successions (Özbaşaran *et al.* 2018a; 2018b). Continuous occupation lasted more than 1000 years, from c. 8350 BC to 7300 BC, i.e. from c. 10.3 to c. 9.3 ka cal BP (Esin and Harmankaya 1999; Gérard and Thissen 2002; Özbaşaran 2012a; Stiner *et al.* 2014; Özbaşaran *et al.* 2018b; Quade *et al.* 2018). Off-site sequences plunge deeper in time, evidencing several distinct environmental phases since the Last Glacial Maximum (LGM, c. 24.5-20 ka BP) until the end of the site occupation. They are documented by 16 ^{14}C dates previous to the foundation of the site, 10 ^{14}C dates from buried archaeological layers, and one ^{14}C date after its abandonment (Kuzucuoğlu *et al.* 2018).

2. State of the art

In Central Anatolia, Neolithic is divided in two phases: (1) the Pre-Pottery Neolithic (PPN), dating from c. 10.3 to 9.0 ka cal BP, and (2) Pottery Neolithic (PN), from c. 9.0 ka cal BP to 8.4 ka cal BP. Before PPN, only one Epipalaeolithic site has been excavated in Central Anatolia: Pınarbaşı-Karaman in the south of the Konya plain, c. 200 km to the southwest of Aşıklı (Baird 2012a). Regarding the early stage of PPN, Aşıklı Höyük (Özbaşaran *et al.* 2018a), Balıklı (Duru and Kayacan 2018) Pınarbaşı and Boncuklu (Baird 2012a; 2012b) are the only sites excavated so far, with the addition of an obsidian workshop in the Göllüdağ that covers the PPN to Early Chalcolithic periods (Balkan-Atlı *et al.* 2008). Other sites (Kayacan *et al.* 2019) and workshops (Binder *et al.* 2011) have been identified by surveys in Cappadocia, of which only sites younger than Aşıklı have been excavated, e.g. the PN/Chalcolithic sites of Pınarbaşı-Bor (Todd 1980; Silistreli 1984) and Tepecik-Çiftlik (Bıçakçı *et al.* 2012), Köşk Höyük (Öztan 2012) and Güvercinkayası (Gülçur 2012).

In other regions of Anatolia, Late PPN and PN sites occur as soon as 9.2 cal BP in the Konya plain (Çatalhöyük), since 9.0/8.8 ka cal BP in the Lake District west of Konya, in and around the Bor plain

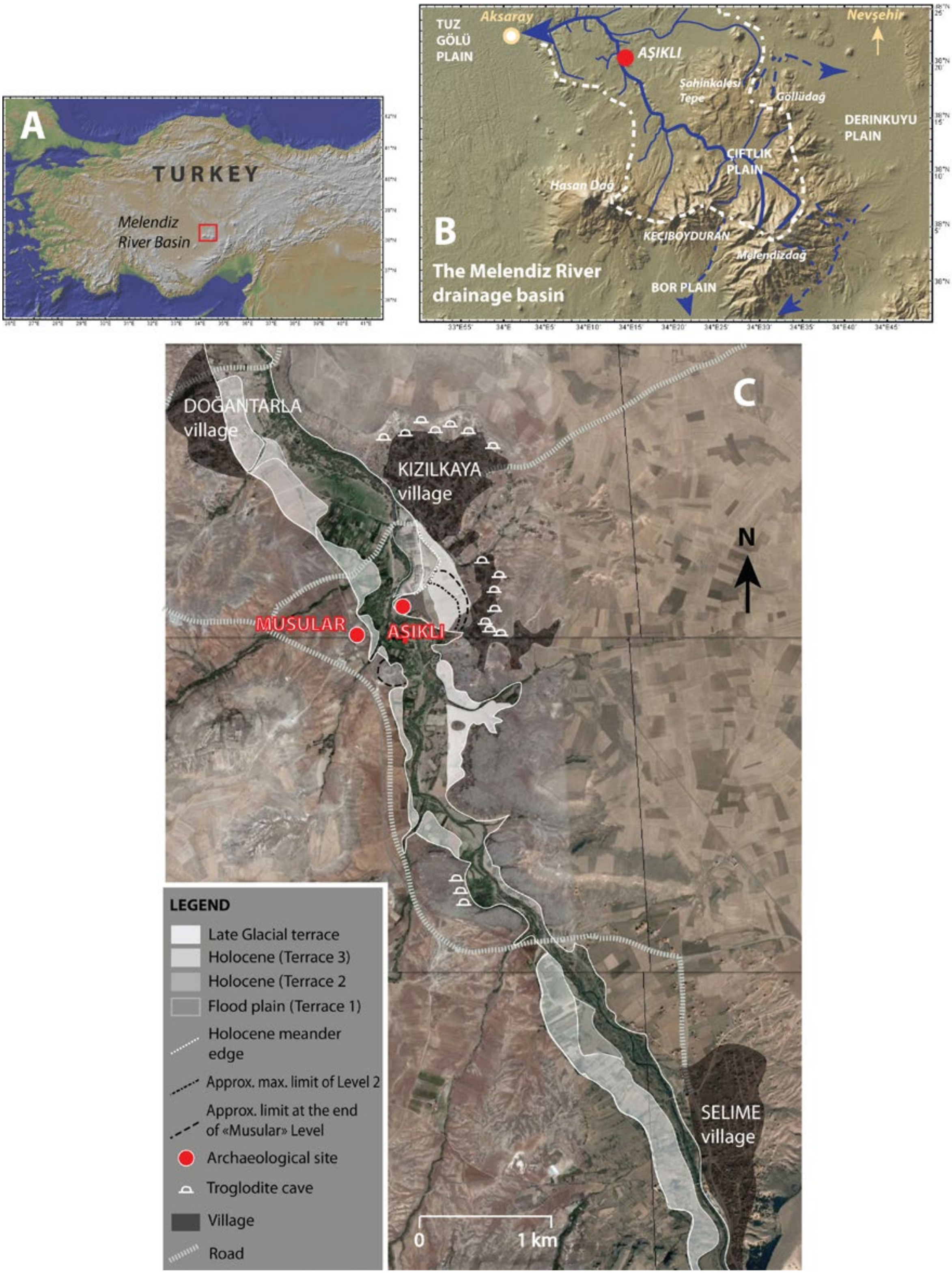

Figure 1. Aşıklı Höyük, located in the Melendiz river valley, between Selime and Doğantarla villages (western Cappadocia). Source: modified from Kuzucuoğlu *et al.* (2018). A) Location of Melendiz river basin in Turkey (background: GeoMapApp); B) The Melendiz River basin in western Cappadocia (background: Google Earth); C) Late Glacial and Holocene terraces in the Melendiz river valley between Selime and Doğantarla villages (background: Google Earth) (Design C. Kuzucuoğlu).

south of Cappadocia, in the Aegean (Ulucak, Çukuriçi and Uğurlu), in the Mediterranean (Öküzini, Yumuktepe), and since 8.5 cal BP in the Marmara region (Barçın Höyük, Hoca Çeşme, Yenikapı/Istanbul) (Düring 2011; Özdoğan *et al.* 2012a, b; Özdoğan *et al.* 2013; Kuzucuoğlu 2014). After 8.4 ka cal BP, Late Neolithic to Chalcolithic sites form a high variety of cultures developing in all regions of Anatolia with increasingly distinct cultural sets and regional 'identities'.

2.1. Aşıklı Höyük: general data

The Neolithic site of Aşıklı (Figure 1A) was first identified by Hittitologist Edmund Gordon when surveying the region, and later studied and described in more detail by the archaeologist Ian Todd (1980). Since 1989 it is excavated by teams led by the Istanbul University, first under the direction of Prof. Dr. Ufuk Esin (Esin and Harmankaya 1999), and since 2006 under the direction of Prof. Dr. Mihriban Özbaşaran (Özbaşaran *et al.* 2018a). The site rises c. 16 m on the right bank of the Melendiz river, dominating a set of three fluvial terraces whose surface lies at 2 to 5 m above today's active river bed (Kuzucuoğlu 2013) (Figure 2). In the archaeological accumulation, five occupation levels have been identified. The highest one (named 'Level 1') corresponds to an eroded, barely known occupation, whose age is uncertain and its stratigraphic relationship with underlying 'Level 2' not yet well-evidenced. The remaining four levels represent an uninterrupted sedentary occupation belonging to the PPN. The initial settlement (Level 5) is composed of semi-subterranean structures separated by open 'activity areas', while the latest phases of the PPN occupation at the site (Level 2) form a well-organized and highly populated village made of agglomerated adobe houses (Esin and Harmankaya 1999; Özbaşaran 2011, 2012a; Özbaşaran *et al.* 2018b).

2.2. Aşıklı Höyük: geographic context

Aşıklı Höyük is located in the famous landscapes developed within the Cappadocian Neogene ignimbritic plateaus that cover most of the area between Nevşehir and Aksaray cities (Figure 1A). At the location of the site, the Melendiz valley is 300-500 m wide. The river collects water from a W-E extending volcanic barrier corresponding to the southern Cappadocian highlands (Hasandağ, Keçiboyduran, Melendiz dağ) (Kuzucuoğlu 2013; Mouralis *et al.* 2019). When flowing at Aşıklı, the river heads northward in direction of the Tuz Gölü plain where it outflows in the today mostly dried, Pleistocene Tuz Gölü lake (Figure 1B). At the location of the PPN site, the valley is 75m incised in a succession of three ignimbrites (Le Pennec *et al.* 1994; Kuzucuoğlu *et al.* 2018): (1) at the base, the grey, unwelded Cemilköy ignimbrite (c. 24 m) outcrops on both banks of the river; it is irregularly? covered by (2) a c. 5 to 15 m thick outcrop of the Gördeleş ignimbrite, where many cave shelters are dug (see cave locations in Figure 1C), itself blanketed by (3) the extensive, very hard Kızılkaya red ignimbrite (5.5 to 5 Myrs old).

A few hundred meters north of Aşıklı Höyük, at Kızılkaya village (Figure 1C), the Kızılkaya ignimbrite that tops the Cappadocian plateau forms c. 45m high steep cliffs dominating all landscapes around. East and northwest of the valley, the same ignimbrite is irregularly? covered by a hard tuffite, while south of Doğantarla village a various lithology-rich coarse alluvium (older than the Cappadocian Mio-Pliocene volcanism?) outcrops with sections exhibiting a few meters thickness. As a result of this relief configuration, the general environment of the site is well-constrained by the limits of the valley (the vertical cliffs above), while variations in the thickness of the Kızılkaya ignimbrite allow widening of the valley at places due to the outcrops of either softer ignimbrite (eg. the Gördeles ignimbrite) or Mio-Pliocene alluvium. South of Aşıklı, a few small tributaries also outflow from lateral entrenchments (Figure 1C).

2.3. Early Holocene in Central Anatolia: geoarchaeology and palaeoenvironmental data

The word 'geoarchaeology' is composed of 'geo' (earth, in all its dimensions) and 'archaeology' (past human societies and cultures, in all their dimensions). The 'geo'-related sciences (when other than archaeology itself) are: physical geography, geomorphology, geology, sedimentology, hydrology, climatology, botany and soil sciences (with their biological content and geochemical characteristics), etc. Objectives and approaches differ between geoarchaeology within an archaeological site (i.e. in-site), and geoarchaeology around or in the close vicinity of an archaeological site (i.e. off-site). In the first case, objectives concern the study of environment-related proxies related to the human society itself within the site; in the second case, the objectives are closely related to the environmental context of the population's life and resources, with possible indication on the climatic context before, during and after the life-time of the site. Besides, palaeoenvironmental data (plant remains, micromorphological reconstructions etc.) are collected from other sites, which may have no direct relationship to the archaeological site under study, but provide regional environmental reconstructions connected with climatic records possibly related to global climatic forcing. In the region where Aşıklı Höyük is located, two high-resolution palaeoenvironmental reconstructions cover the Late Glacial (14.5 to c. 11.4 ka cal BP) and the Holocene (c. 11.4 ka cal BP to today): Eski Acıgöl near the Acıgöl village (Nevşehir Province: Roberts *et al.* 2001; Woldring and Cappers 2001; Woldring and Bottema 2003; Turner *et al.* 2008), and Nar Gölü on the northern slope of the Göllüdağ in the centre (Niğde Province: Dean *et al.* 2015). These sequences can be compared, not only to one another (Roberts *et al.* 2016), but also to other similar or different sequences through the region, the country and the Eastern Mediterranean (Woodbridge *et al.* 2019).

3. Methods

3.1. Archaeological operations and dating

The chronology of the occupational sequence at Aşıklı Höyük results from four series of field operations (Figure 2):

a) In-site excavations and archaeological soundings in the Aşıklı mound

From 1989 on, the höyük surface was cleaned of the eroded and scattered remains of 'Level 1'. Below Level 1, detailed extended excavation unearthed the very well preserved and widely distributed PPN layers of Level 2. Below Level 2, excavation reached 'Level 3', followed by 'Level 4', followed by 'Level 5', which is under excavation at present. In parallel, a deep sounding was made at the NW part of the höyük, in order to obtain a stratigraphic, cultural and chronological reference section for the whole occupation. In 2015, an archaeological sounding (named '15') was performed below the initial occupation layer (Level 5) at the bottom of the deep sounding. The wall-section of the latter completed the sediment record forming the substratum of the site and allowed the detailed study of the contact between the Level 5 structures and the soil below them.

In 2016 and 2018, archaeologists cleared over > 2 m the foot of the scarp caused by river erosion into the southern side of today's höyük. The resulting section exposes several meter long virgin sediments covered and truncated by both archaeological material and structures and non-archaeological deposits pertaining to Levels 5 (semi-dwelled, round structures) to 4 and 3.

b) In-site excavation at Musular

The site of Musular faces Aşıklı mound. This Late PPN site is installed over the bedrock forming the western side of the Melendiz river valley. It was excavated during the 2000's. Not a settlement properly speaking but an activity area, this site presents a rather small thickness over the surface of the Cemilköy ignimbrite and a small extent too (especially when compared with its 'twin' site across the river).

c) *Off-site soundings in terraces.*

In 1995, a core (named '95/3') was retrieved by a hydraulic, truck-mounted corer from a terrace surface at + 3.5/4 m above the river bed. In 1996, a trench (named '96') was excavated by archaeologists in the lowest terrace, from a surface at + 1.5 m above the present river bed.

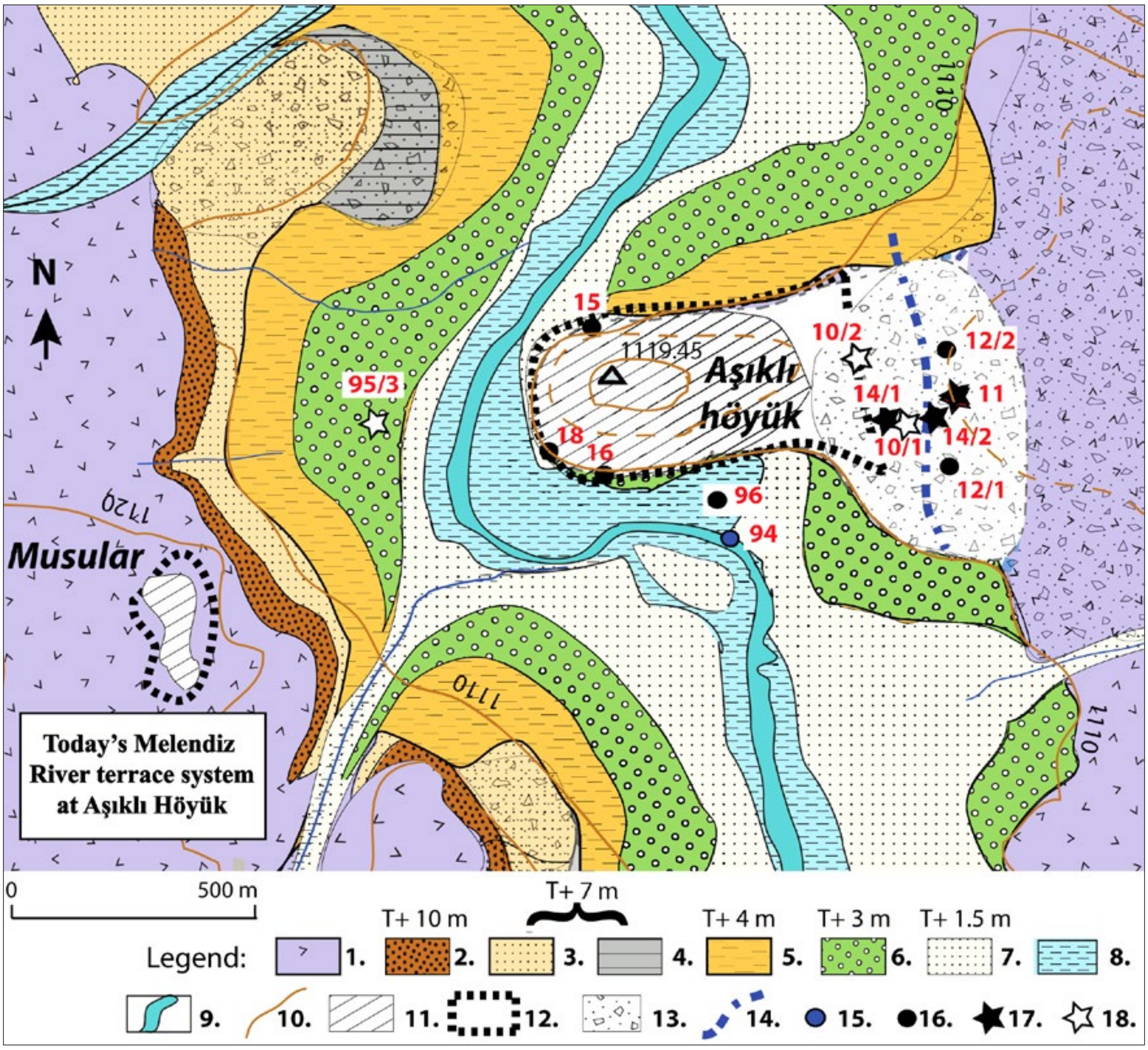

Figure 2. Fluvial terraces in the Aşıklı Höyük vicinity, with location of the sequences used for reconstructing the Late Glacial and Early Holocene environmental and archaeological contexts in the valley. Source: modified from Kuzucuoğlu *et al.* (2018). Captions: 1. Cemilköy ignimbrite (= rock basement); 2. +10 m terrace; 3. + 7 m terrace dating LGM; 4. + 5 to 4 m terrace dating Late Glacial; 5. + 4 m terrace dated Early to Mid-Holocene; 6. + 3 m Mid to Late Holocene terrace; 7. +2 m Late Holocene terrace; 8. + 1.5 m, major bed, regularly flooded; 9. Today's river channel; 10. Altitude contours (from 1:25.000 topographic map); 11. Excavated archaeological areas; 12. Apparent limits of archaeological sites on the surface; 13. Major colluvium fed by upper slopes; 14. Late Glacial erosion channel ('gutter') identified in the cores; 15. Section (named '94') evidenced by today's river bank erosion of Late Holocene terrace (+ 1.5 m) during 1994 spring flood , and exhibiting *in situ* archaeological layers pertaining to Aşıklı Höyuk Level 2; 16. Spots studied using archaeological sounding or trench; 17. Spots cored by hand with open gouges 18. Spots cored with a truck-mounted hydraulic corer (Author C. Kuzucuoğlu).

d) Off-site soundings in the sediment fill East of the mound

In 2012, two archaeological-type soundings (named '12/1' and '12/2) were excavated into the sediment fill of a N-S oriented, shallow and elongated depression (named 'gutter' in this article) separating the eastern slope of the mound and the ignimbrite cliff bordering the valley in the East. The altitude of the 'gutter' decreases slowly southward, from the höyük's easternmost shoulder toward a very small tributary to the Melendiz river that out-springs from below the southernmost houses of the Kızılkaya village.

All the archaeological operations described above have been accompanied by ^{14}C dating performed on burnt material, mainly wood charcoals (Özbaşaran 2012a; Quade *et al.* 2018) and hackberry shells (Quade *et al.* 2014)

3.2. Field works for the reconstruction of palaeoenvironments

3.2.1. Geomorphological reconstruction of river-related landform successions

First, a geomorphological field survey was performed around the höyük and along the valley, over a surface corresponding roughly to Figure 1C. This survey allowed identifying (1) the geological context and the limits of basement outcrops, and (2) the landforms in the area around the site (especially flat surfaces vs scarps), their constitutive sediment, soil, vegetation cover, and relative altitudes of topographic surfaces reported to the present active river bed level. Sections in sediment accumulations were inspected and recorded in detail. The data collected were grouped in a common data base allowing the drawing of topographic profiles and geological/lithological sections through the valley, as well as the mapping of the terrace system (Figure 2).

3.2.2. Exploring sequences with coring, archaeological soundings and natural section exposures

On the basis of the records collected during the field survey, a strategy for the study of underground sequences was elaborated. During and after coring or sounding, sediments characterization relied on observations concerning mainly the facies, colors, grain size, organic content such as rootlet presence, peat remains, charcoal pieces, reed stems and pressed leaves, oxidization and/or waterlogging traces, etc.

Truck-mounted hydraulic percussion cores

This type of coring has been used for preliminary exploration, aiming to reveal more precisely targeted sequences to be hand-cored in the following years. The truck-mounted cores were performed:

a) In 1995 in the low terraces occupying the main valley path, from the outflow of the river into the larger valley occupied today by the Mamasın dam lake (core 95/1), to the flooded area at the foot of the Kızılkaya village (core 95/2), and upstream again to the bank facing the eroded höyük (core 95/3) (cores 95/1 and 95/2 are not shown in Figure 2; see their location and related detailed results in Kuzucuoğlu 2013). These cores did not evidence any connections with the Neolithic settlement, except for an obsidian piece at the bottom sample of core 95/3, immediately above the ignimbrite rock basement (see below, Figure 5: 95/3).

b) In 2010 east of the höyük summit surface, at two locations positioned in the 'gutter':
   i- a core named '10/1', retrieved from a point in the axis of the 'gutter'. Sampling was done at the excavation house the very evening.
   ii- a core named '10/2', retrieved in the middle of the road next to the eastern limit of the site, at the highest point over the threshold dominating the gutter. For this core, sampling was performed on the field.

Hand-coring with open gauges

On the basis of the results from the truck-mounted percussion cores, several cores were performed in the later years, using 62 mm diameter and 50 cm long drives. With this material, sampling must occur in the field, between each drive-withdrawal. Three such cores, named '11', and '14/1' and '14/2', were performed in 2011 and 2014 in the same area as the 2010/1 one, as they all aimed at detailing the initial results from core '10/1' (see Figure 2).

Archaeological sections, and river natural sections

Sections have also been studied:

a) in the archaeological soundings '12/1', in the downstream part of the gutter east of the site, '12/2', in the terrace surface on the gutter threshold, '15' from below the earliest occupation layers, and '96' in the lowest river terrace (+ 1.5 m) to the South of the mound.

b) in the long archaeological cleaning performed in 2016 and 2018 (named '16' and '18' in Figure 2). This section cuts the bottom of the vertical cliff eroding the southern limit of the höyük above the two lowest river terraces. As said already (supra, § 3.1), this cleaning exposes the sedimentary succession prior to the earliest occupation layers, and some of the earliest occupation structures as well.

c) in a section cut by the river in the + 2.5 m terrace during the 1994 spring flood, which exposes in situ archaeological layers pertaining to the mound's Level 2. This point is named '94' in Figure 2.

3.2.3. Laboratory analyses

Physical, geochemical and carbon analyses have been performed at the Laboratory of Physical Laboratory in Meudon (France). Grain size analyses have been performed on sequences 10/1, 11, 12/2 and 15, using a LS230 Beckmann-Coulter Laser analyser. When necessary, sand fraction has been observed under the binocular. In addition, magnetic susceptibility, total C, organic C and C/N analyses have been performed at the LGP on samples from the 10/1 and 11 cores. Total C, organic C, and C/N results were collected with a CHNS Flash 2000 Thermoscientific analyzer. Magnetic susceptibility was measured by a Bartington MS2 apparatus.

3.2.4. Radiocarbon dating

An approximate total of 200 dates have been produced by radiocarbon measurements in organic material from archaeological layers since 1989 (Özbaşaran *et al.* 2018a). Recent studies have shown that dates from hackberry remains, numerous in Aşıklı's archaeological sediments, are often 'rejuvenated' due to fixing of environmental carbonates in the endocarps of hackberry fruits and seeds (Quade *et al.* 2014). Once this difficulty overcome with selection of validated samples, dates from charcoal and other plant remains have produced a rather well constrained chronology of the five cultural periods identified in Aşıklı höyük (Quade *et al.* 2018).

In the palaeoenvironmental programme, the aim of radiocarbon dating was to constrain the depositional timing of the sediment units identified and determine possible hiatuses in sequences. Dates have been performed on charcoals, associated either with archaeological layers or important fire events, as well as on reed leaf layers and small plant leaf remains picked from marshy and/or peaty sediment samples. 19 dates (SacA-x) were produced according to the protocols described in Dumoulin *et al.* (2017) and Moreau *et al.* (2013) at the LMC 14 with the Artemis accelerator mass spectrometer (AMS) at Saclay (France), and 7 dates (Poz-x) were produced at the Poznan Radiocarbon Laboratory (Poland). Palaeoenvironmental dating concentrated on five sequences:

- the 10/1 exploratory core operated with a trunk-mounted hydraulic percussion corer;
- the 12/1 and 12/2 detailed archaeological soundings;
- the 14/1 core retrieved with a hand corer at about the same location as 10/1;
- the archaeological sounding 15 below Level 5 at the northwest edge of the mound.

In Table 1, the calibration of these dates is performed using Calib 1.7 (Stuiver *et al.* 2018).

Depositional Environment	Ref. LAB	Core -Sample # ((depth in core	Sediment facies and/or Depositional environment	Dated material	Radio-carbon date					
					Raw BP date	(Calibrated BC (1 Σ			Mean (BC (1 Σ	Calib BP
						Max	Min	% confid		
After 7.9 ka cal BP										
Reworked Sediment	Poz-66034	ASI 14/1 150-153	'Above 'Musular	Charcoal	40 ± 6580	5586	5555	1	5530	**7480**
	SacA 23897/Gif-12637	ASI 10/1 150-153	'Above 'Musular	.Reworked m.o	60 ± 10030	9695	9443	0,888	9585	**11535**
	SacA 23898/Gif-12638	ASI 10/1 167-170	'Above 'Musular	.Reworked m.o	45 ± 9660	9231	9130	0,697	9135	**11085**
From 11.5 to 8 ka cal BP										
Archaeological Accumulation	SacA 30752	ASI 12/2 250-253	*'Musular-Type'*	Charcoal	60 ± 7510	6441	6353	0,789	6375	**8325**
			Musular-Type exists also in 12/1, separated by' orange silts from older archaeological layers below							
Colluvium			*Orange silts, slightly sandy (pumice). No apparent structure*							
Archaeological Accumulation	Poz-66035	ASI 14/1 175-177	Uppermost level	Charcoal	80 ± 8090	7184	7017	0,702	7065	**9015**
	SacA 30755	ASI 12/1B 335-345	Upper level of mid-archaeological site unit, indurated	Charcoal	35 ± 8265	7357	7282	0,529	7310	**9260**
	SacA32315	ASI 12/1B 390	Level associated with pebbles	Charcoal	40 ± 8430	7545	7484	1	7515	**9465**
	SacA 30754	ASI 12/1B 440-445	Above sterile level	Charcoal	35 ± 8440	7547	7494	1	7725	**9675**
	SacA 30756	ASI 12/1B 520	*(? Red layer (tephra*	Charcoal	35 ± 8470	7570	7526	1	7545	**9495**
	Poz-66190	ASI 14/1 2,5-2,53	Upper middle part	Charcoal	50 ± 8640	7681	7591	0,954	7650	**9600**
	Poz-66036	ASI 14/1 2,70-2,72	Level associated with pebbles	Charcoal	50 ± 8460	7576	7512	1	7535	**9485**
Tephra no 5	Poz-66120	ASI 14/1 2,80-2,83	*Indurated level*	Charcoal	50 ± 8840	7996	7825	0,626	7975	**9925**
Archaeological Layer	SacA 32313	ASI 10/1 260-262	*Below indurated level*	Charcoal	40 ± 8785	7940	7783	0,928	7853	**9803**
Soil			*Soil formation weathering the colluvium post- Late Glacial*							
Colluvium	Poz-66121	ASI 14/1 3,52-3,54	Orange silts,with clay, immediately below *in-site* tephra overlain by L2 level	Charcoal	50 ± 9640	9223	9121	0,544	9025	**10975**
	SacA 30753	ASI 12/2 310	(?) Orange silts, eroded below L2/Musular site	Charcoal	40 + 9965	9457	9320	0,826	9435	**11385**
Reworked alluvium	Poz-66123	ASI 14/1 4,25-4,28	Sandy silts + scarce gravels (reworked alluvial (material with orange matrix	Charcoal	60 ± 10020	9676	9437	0,865	9570	**11520**

Table 1. Off-site ^{14}C dates in cores and sections around Aşıklı Höyük, performed by Saclay/Artemis/LSCE (23) and Poznan (6) Laboratories. Calibration performed using Calib 7.1 (Stuiver *et al.* 2018). The colors point to archaeological layers (orange) and occupation phase attribution (blue). Bold italics in the last column indicate rejected dates due to suspicion of reworking. Source: modified from Kuzucuoğlu *et al.* (2018).

Depositional Environment	**Ref. LAB**	**Core -Sample #** ((depth in core	**Sediment facies and/or Depositional environment**	**Dated material**	**Radio-carbon date**					
					Raw BP date	(Calibrated BC (1 Σ			Mean (BC (1 Σ	Calib BP
						Max	Min	% confid		
From c. 15 to 12.0 ka cal BP										
Backswamps	SacA 30750	ASI 10/1 428-429	Charcoal forming thin layers in grey clay	Charcoal	45 ± 10215	10067	9874	1	9975	**11925**
	SacA 44148	ASI 15/6a 66-63	Black organic thin layers in grey clay	Charcoal	45 ± 10250	10142	9994	0,803	10045	**11995**
	SacA 23899/Gif-12639	ASI 10/1 467-468	Black organic layer in grey clay	Org. Matter	50 ± 10315	10233	10054	0,776	10182	**12132**
	SacA 23900/Gif-12640	ASI 10/1 488-490	Massive grey clay with oxydations and many (charcoal dust + black layers (pressed	Charcoal	50 ± 10025	9675	9443	0,927	9573	**11523**
	SacA 23901/Gif-12641	ASI 10/1 495-496	Massive grey clay with oxydations and many (charcoal dust + black layers (pressed	Charcoal	45 ± 10340	10288	10115	0,744	10243	**12193**
Colluvium		ASI 15/3b	*Reworked pumice*							
Tephra no 4	SacA 30751	ASI 10/1 507-509	*Pumice ash fall in backsamps*	Charcoal	45 ± 10700	10770	10627	1	10715	**12665**
	SacA 44149	ASI 15/3a 100-98	*Pumice ash fall in backsamps*	Charcoal	50 ± 10720	10763	10694	1	10724	**12674**
Lowering water table			*Light grey clay with sand (lowering water level in (marshes*							
Tephra no 3	SacA 23902/Gif-12642	ASI 10/1 518-520	Grey clay with organic thin layers (above tephra (no 2	Charcoal	45 ± 10525	10548	10473	0,63	10541	**12491**
Tephra no 2	SacA 23903/Gif-12643	ASI 10/1 524-526	*Tephra in situ*	Charcoal	45 ± 10850	10804	10753	1,00	10784	**12734**
Backswamps	SacA 44150	ASI 15/2 136-132	Black organic thin layers in grey clay	Charcoal	45 ± 10475	10592	10439	0,966	10486	**12436**
Compressed peat			Chocolate clay', massive'							
Soil	SacA 44151	ASI 15/1c 165-160	(Top of creamy clay (with soil processes	Plant remains	50 ± 11980	11910	11798	0,799	12881	**14831**
Backswamps & Erosion			Dark grey in the east of mound. Creamy clay (with orange silts (erosion input							
Backswamps	SacA 44152	ASI 15/1b 195-200	Creamy clay, massive with orange-colored mottles, overlaying thin tephra	Plant remains	60 ± 12920	13608	13355	1	13488	**15438**
Tephra no 1	SacA 23904/Gif-12644	ASI 10/1 533-535	*Pumice ash fall in backsamps (dark grey clay with (hard layers*	Plant remains	50 ± 12260	12296	12123	1	12221	**14171**
Backswamps			Dark grey clay, massive, with fainted black lines							

Table 1. Continued.

3.2.5. Facies variety and interpretation

Active fluviatile deposition is recorded in minor and major river beds (annual/seasonal occupation by running water in bed or overbank areas) and/or in association of exceptional high flooding. The classic succession during the formation of a terrace composed of such sediments through time starts with (a) bedload dominantly composed of pebbles, with some gravel layers, following with (b) decreasing river capacity recorded by deposits of rounded gravels in sandy matrix, and by well-washed sand layers (pure sand lenses). Typically, river-transported elements are rounded and mix all the lithologies of the bedrocks around and in the drainage basin of the river. The final stage of terrace formation is composed of overbank flood deposits in which the dominating grain-size is silts, often rich in organic matter eroded from the upstream terrace surfaces and slopes.

Marshy episodes in the plain are recorded by the deposition of a grey clay which may be massive or contain vegetation remains such as: (a) pressed reeds (leaves and stems) forming thin black horizontal layers, and/or (b) tiny vegetal particulates evenly distributed in the clay (gyttja-type). These deposits record landscapes of backswamps in a valley floor, dominated by sediment accumulated by slow currents characterizing low water discharge. Interstratified in the grey clay unit, a dark brown-black peat layer signals the end of the backswamp episode. This peat layer is typically encountered in other Late Glacial and Holocene sediment fill of plains in the region (eg. Bor, Ereğli), where it records the drying-off transformation of marshy clay.

Tephra and tephric layers are also encountered. They present typical white color when composed of fresh pumices. They are orange-colored when the pumices are weathered. Rarely containing lithics, they also present different grain size (coarse or thin to very thin). They have been identified in various contexts: in situ in grey clay, reworked in fluviatile context and colluvium (mostly), interstratified within archaeological accumulation.

Archaeological layers have occurred frequently in the sequences cored, sounded or incised (e.g. by the river). They were easily identified in cores because of a rich content in charcoal associated with abundant bone pieces and regularly present obsidian fragments, as well as by the 'leaf'-like structure of the sediments.

4. Results and discussion

4.1. In-site chronology and cultural records

Levels in Aşıklı are defined on the basis of differences/changes in architecture and cultural assets (Esin and Harmankaya 1999). They span over twelve meters of continuous anthropogenic deposits (Figures 3, 4) and represent an uninterrupted human occupation of more than 1000 years, recording all the PPN (Pre-Pottery-Neolithic) stages known west of the Taurus range in Anatolia. Through the site, ^{14}C dates show several stratigraphic reversals, due to charcoal in refuse possibly being older or younger than adjacent charcoal from habitat features (Quade *et al.* 2018). These reversals suggest reworking and mixing of sediments, as well as downhill slumping of material. In addition, considerable uncertainties of ~200 years in the radiocarbon dates (because of rapid variations in the concentration of ^{14}C in the atmosphere, producing flat areas on the calibration curve) have generated difficulties in constraining dates of intermediate boundaries/transition periods between levels. Despite these problems, the record of radiocarbon dates from archaeological contexts is generally robust.

At the base of the mound, Level 5 is characterized archaeologically by round, subterranean hut-like structures. It is dated older than 8.3 ka BC (older than 10.25 ka BP).

Developed in continuity above Level 5, Level 4 is characterized by semi-subterranean, oval-planned buildings made of sun-dried mud bricks ('kerpiç') and located around open-air activity areas. In

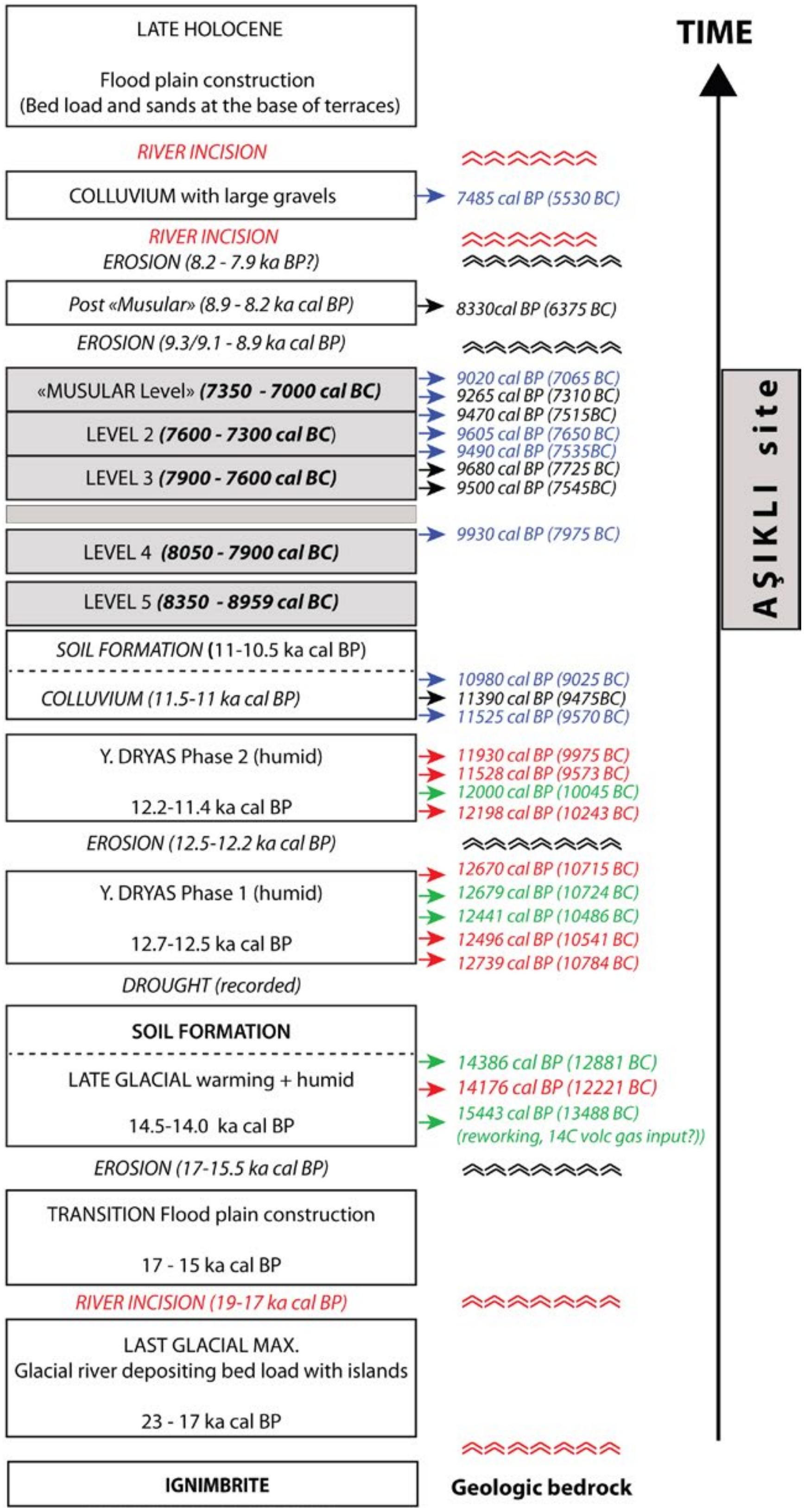

Figure 3. Composite stratigraphy and chronology of sedimentary units preserved below and around Aşıklı Höyük, enlightened by ^{14}C dates, and facies of all sequences studied in off-site cores and sections, and off-site archaeological soundings. Dates are calibrated BP, with calibrated BC in brackets. Source: simplified from Kuzucuoğlu (2013) and Kuzucuoğlu *et al.* (2018). Captions: - Black broken lines point to slope erosion and reworking phases; - Red broken lines point to river incision embedding two terraces (an old one vs a younger one); - Colors of dates are red for 10/1 (core), black for '12/1' (sounding) and '12/1' (core), blue for '14/1' (core), and green for '15' (sounding) (Author C. Kuzucuoğlu).

accordance to this evolution, this phase is named ECA (= 'Early Central Anatolian') Phase II. Dated by ^{14}C to 8350-8050 BC (i.e. 10.3-10.0 ka cal BP), it is roughly coeval with pre-Pottery Neolithic A in the Levant (Özbaşaran and Buitenhuis 2002; Thissen 2002).

Level 3 is characterized by semi-subterranean oval buildings similar to Level 4, but clustered, indicating changes in the use of space and the possibility of an increase in population. Abandoned buildings function as middens and activity areas. According to ^{14}C dates, this level dates from 8100-7740 BC (i.e. 10.0-9.7 ka cal BP).

Level 2 contains multiple construction phases (2A to 2J), with a notable shift in the plan of buildings, which become now rectangular. Dense spatial organization of agglomerated adobe houses structured with outer as well as inner spaces become dominant. In the meantime, large, communal midden areas develop. In addition to this evolution in architectural features, fauna evidences a 'proto-domestication' of sheep and goats (Buitenhuis 1997; Stiner *et al.* 2014). The total duration of this level covers the years between 7850-7550 BC (i.e. 9.8-9.5 ka cal BP). Its end, corresponding to phases A-C, comprises a wide gravel 'street' descending south along a palaeo-slope oriented southward in direction of the river at the time. The gravel street separates the Dwelling Area from the 'Special Purpose Buildings Area', excavated in the SW extremity of the investigated area and comprising a painted lime floored building, with specific inner architectural features (Özbaşaran 2012a).

Level 1 is the youngest archaeological level, with remains scattered and eroded at the summit of the höyük. The material collected is insufficient to define a cultural phase. Considering the youngest dates from the uppermost datable layers of the mound, the age of this level is estimated to c. 7500-7300 BC.

The last three phases of Level 2 (2A-C) and probably Level 1 are contemporaneous of the site 'Musular', which is positioned over the ignimbrite eroded roof overlooking the left bank of the Melendiz river valley (Özbaşaran 2012b). This satellite site exposed both installations and artefacts testifying for wild cattle hunting, butchery and skin processing activities together with rituals and feasting. Both PPN sites, namely Aşıklı and Musular, seem to be abandoned around 7300 BC. Musular site has been re-occupied at the end of Neolithic and beginning of Chalcolithic (the latter being dated 6th mill. BC) (Özbaşaran 2012b).

4.2. Off-site chronology and palaeoenvironmental records

4.2.1. The ^{14}C dating program

Like for the chronological frame established by in-site ^{14}C dates, the dating suite in the cores shows a few inversions (Table 1). The very low number of uncertain dates is also due to the relatively fewer number of radiocarbon dates in the cores when compared to the site. Out of a total of 29 dates, five are in an inversed position. Of these, three charcoals are associated with pumice-rich sand, suggesting that charcoals may have been oldered, aged during their life-time, by mantle sourced gas emitted during eruptions of the Hasan Dağ (Kuzucuoğlu *et al.* 1998; Schmitt *et al.* 2014), a dormant volcano located c. 30 km south of Aşıklı Höyük. One Another sample may have been affected by in-take of mineral carbon during evaporation hardening the sediment. The two last two 'inversed samples are from the top soil of the initial exploratory sequence extracted with a truck-mounted corer (core '10/1'); these much too old ages have no connection at all with the sequence.

4.2.2. Palaeoenvironmental records evidenced by the off-site/in-site stratigraphic and geomorphologic connections

Level 5.

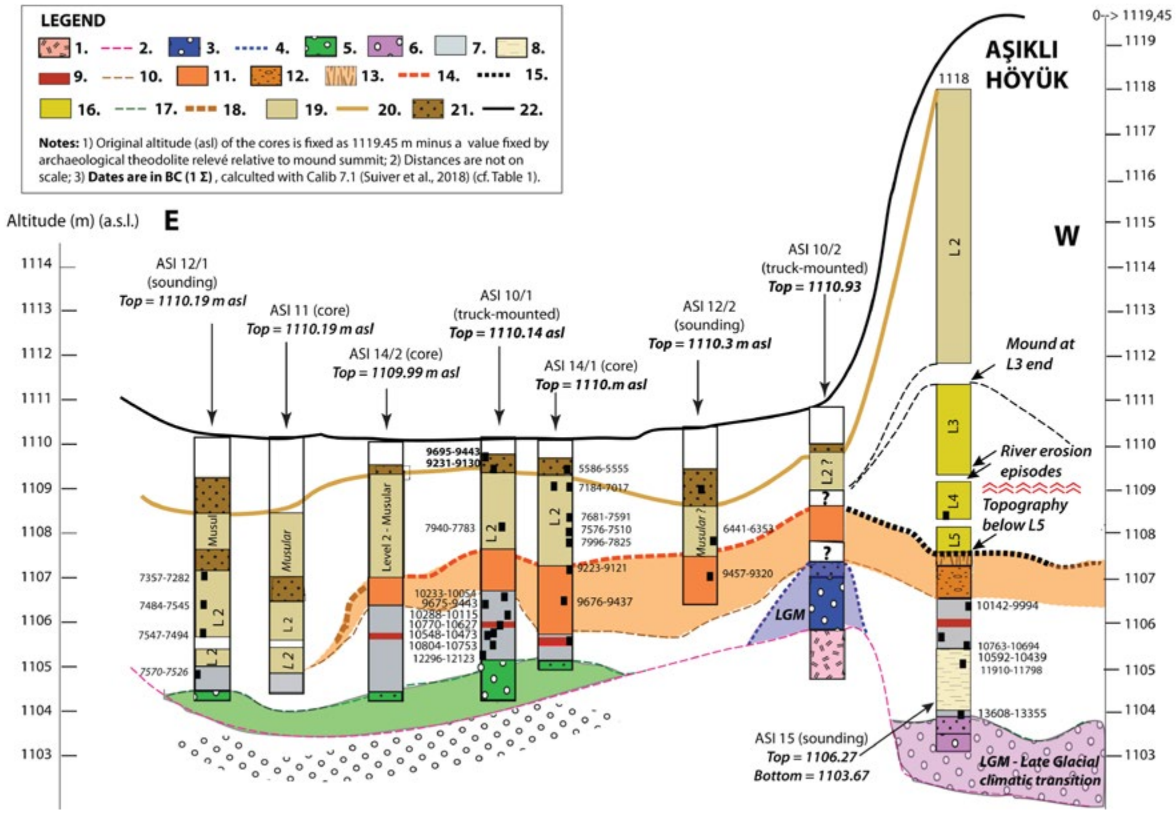

Figure 4. Aşıklı Höyük and its surroundings to the east: facies, stratigraphy, and chronology of sediment formations (Figure 4 continues west with Figure 5). Source: based and modified from Kuzucuoğlu (2013) and Kuzucuoğlu *et al.* (2018). Captions: 1. Cemilköy ignimbrite bedrock; 2. Tentative reconstruction of the erosion surface truncating the ignimbrite; 3. LGM-1 (Late Glacial Maximum-1) fluvial bedload and sand deposits; 4. Scarp of Late Pleistocene embedded terrace dominating the valley floor; 5. Fluvial bedload and sand deposits dating end LGM (Late Glacial Maximum-2); 6. Fluvial bedload and sand deposited during LGM/Late Glacial transition; 7. Grey clay, with levels enriched in pressed plant (reed) remains; 8. Dry peat rich in tiny plant remains; 9. Peat transformed in massive black peat; 10. Tentative reconstruction of the surface previous to 11.6-11.5 ka cal BP (9.6-9.0 cal BC) pumice-rich sand deposit; 11. Orange pumice-rich sand colluvium deposit; 12. Whitish pumice-rich colluvium; 13. Low intensity soil formation (soil structure; burrows); 14. Surface of the orange sand deposit east of the mound; 15. Surface of the orange sand deposit under first Level 5 habitat structures; 16. L5 to L3 archaeological accumulation layers; 17. Mound shape and topography before the extensive development of L2 settlement; 18. Erosion surface of a small valley incising the colluvium east of the oldest levels of the mound; 19. Accumulation of L2 to Musular-aged archaeological layers; 20. Erosion surface truncating the last archaeological occupation layers; 21. Latest colluvium layers, with soil features, blanketing eroded archaeological occupation layers; 22. Today's surface of the N-S elongated depression east of the mound (Author C. Kuzucuoğlu).

Structures of Level 5 (10.5-10.3 ka cal BP) are installed over a soil topping a > 6 m thick Last Glacial to Early Holocene terrace dated from the end of LGM to 10.5 ka cal BP (Figure 3; Table 1) (Kuzucuoğlu *et al.* 2018). This terrace, bottomed with sands and gravels terminating a river bedload deposit, lies directly over the ignimbrite bedrock (Figures 4, 6/A, 6/B).

Level 4 (8350-8050 BC; 10.3-10.0 ka BP).

No part of any cored sequence has been dated from this occupation phase. This may mean that there was less sediment dynamics than before and after, meaning also that the river activity had weakened, as well as the slope dynamics. Accordingly, Level 4 may have been a rather dry period, which was followed by a much contrasting geomorphological activity that accompanied the development of Level 3.

Level 3 (8100-7740 BC; 10.0-9.7 ka cal BP) and Level 2 (7850-7550 BC; 9.8-9.5 ka cal BP).

During Level 3, the river was eroding –most probably laterally– the Late Glacial-Early Holocene terraces still widely preserved in the valley (Figure 6/C). Meantime, discontinuities between the Early Holocene 'orange-colored colluvium' deposit (Figure 3) and the archaeological site covering it east of today's mound (Figure 4), record at least two episodes of vertical erosion in the vicinity of the site during its life-time: one around 7900 BC (see core '14/1' in Figure 4) and the other around 7500 BC (see sounding '12/1' in Figure 4).

During the transition period between Levels 3 and 2 or at the beginning of Level 2, a street paved with pebbles was constructed by the inhabitants, following a slope that recorded the river incision and/or the rise of the höyük (supra, § 4.1). The street was regularly raised all through Level 2. This phase corresponds also to the construction of special buildings characterizing Level 2. Further excavations are planned to precise the topographic and chronologic meanings of the 'paved road'.

Meanwhile, erosion re-activated also an old (eastern) branch of the Melendiz river, a memory of the LGM end when the river was flowing on both sides of an ignimbrite promontory still topped by LGM pebbles (Figure 6/A). The sequence illustrated by Figure 4 clearly shows (in spite of the non-respect of distances in the profile scale) that, at the transition time between Levels 3 and 2 (c. 7900 BC) the PPN settlement 'exploded' (Figures 4, 6D), invading the eastern Late Glacial terrace that had been preserved until then from river erosion and incision through the ignimbrite obstacle on the other side of the höyük (Figure 5). According to the results from the coring program performed along the topographic gutter east of the höyük, Level 2 developed over a wide surface, especially eastwards but also westwards (Figure 5) These records suggest a development of the site over most of the space available in the river valley, somehow 'pushing' the river westward, and making the life in the höyük a little bit crowdy and tight.

Finally, regarding the geomorphological evolution of the site and surroundings during the PPN period, one could say that there are –at the same location and one above the other– two successive mounds at Aşıklı, whose dimensions make them look like strangers to one another:

(1) a mound composed of Levels 5 to 3, growing only 3 to 4 m above the summit of the earliest Holocene landform (dated c. 9200 BC). This landform corresponds to the colluvium that had inundated the valley while the river was flowing west of the mound, already incising deeply the Late Glacial terrace down to the late LGM terrace (Figures 5, 6/A, 6/B);

(2) a 'very wide 'toupet' mound (9 m high west of the ignimbrite threshold where the road accessing the site is positioned today) that extended eastward to the ignimbrite valley limit (Figure 5), and in the south-north direction toward both the upstream and downstream parts of the river meander that had been growing wider and wider through time (Figures 6/C, 6/D)... The vast extent of the Level 2 at the time (Figure 6/D) has been revealed (1) by the natural section cut during river flood in winter 1994, that exhibited the vertical erosion of in situ Level 2 layers within the right bank overlooking today minor's bed (Figure 5), and (2) by the unexpected presence of archaeological layers pertaining to Level 2 in soundings and cores performed in the 'gutter' east of the site (Figure 4).

After the dispersal of the Neolithic population away from the höyük.

At or after the end of the höyük occupation by PPN populations, there has been two major episodes of incision-accumulation alternation that generated two recent set of terraces (Figures 3, 5):

- Terrace n° 3, possibly aged Mid-Holocene, reaches + 4 m above today's river bed and still fills most of the valley on the western bank of today's river. It is in this terrace that core 95/3 was extracted. The corer reached the ignimbrite bedrock at 4 m depth, and retrieved an obsidian

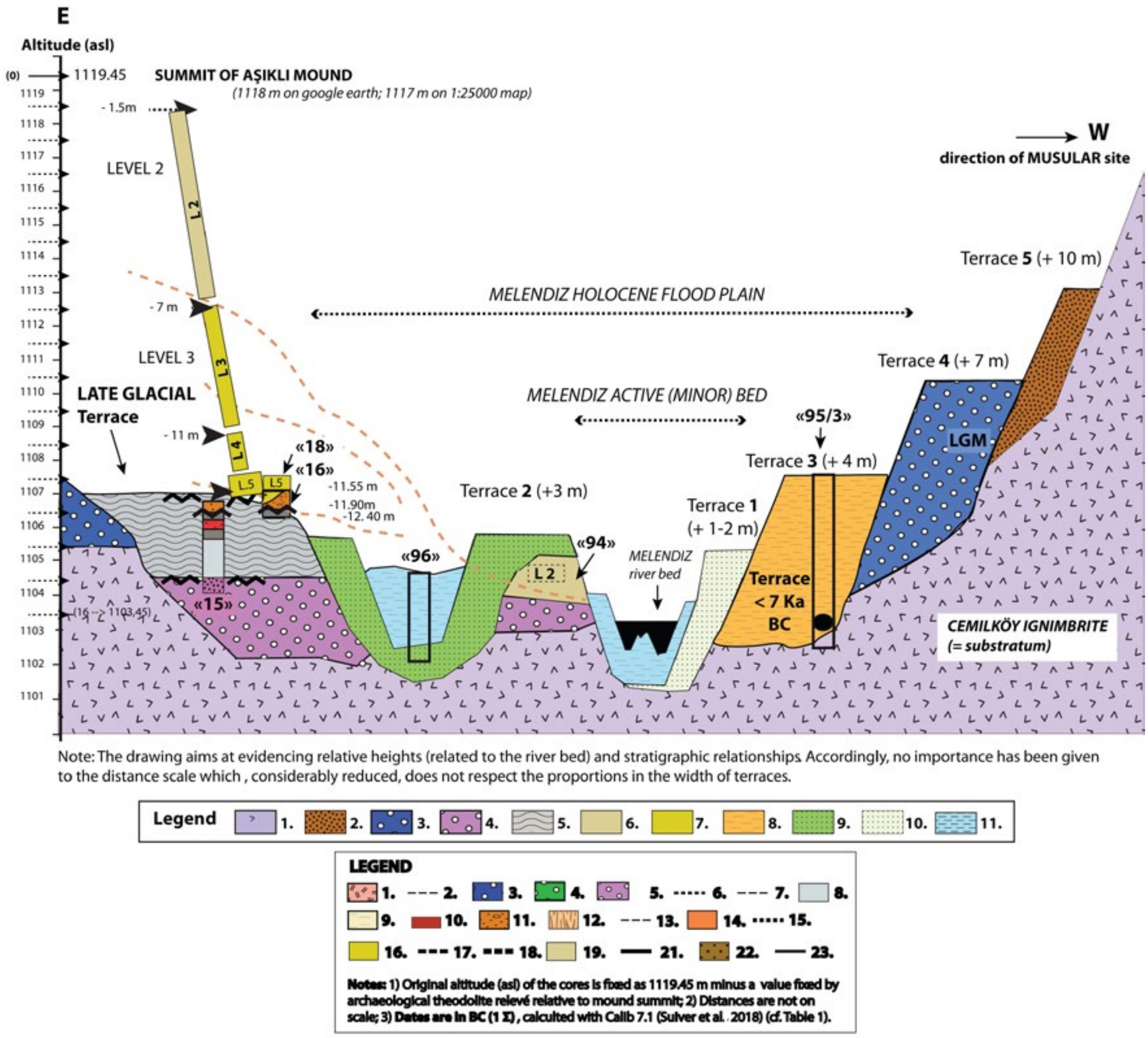

Figure 5. Sequences of Pleistocene to Holocene fluvial deposits west of Aşıklı Höyük (continues Figure 4 in direction of West). Source: based and modified from Kuzucuoğlu (2013) and Kuzucuoğlu *et al.* (2018). Captions: 1. Cemilköy ignimbrite bedrock; 2. Terrace + 10 m; 3. Last Glacial terrace (+ 7 m); 4. End LGM bedload; 5. Late Glacial terrace (+ 4 m); 6. Archaeological Levels 5 to 3; 7. Archaeological Level 2; 8. Approximate section profiles of the mound at the transitions between levels; 9. Mid-Holocene (?) terrace no 3 (+ 4 m); 10. Late Holocene terrace n° 2; 11. Late Holocene terrace n° 1; 12. Present minor (incising) bed of the river Melendiz. The black circle represents an obsidian piece retrieved from the lowest fluvial sediments in core '95/3' (Author C. Kuzucuoğlu).

piece toward the bottom of the sediment fill. This obsidian can only come from the höyük, which was then actively being eroded.

- Terraces n°2 and 1 (Figure 5) record two activity phases of the river flood plain construction:
  (a) a high magnitude incision, well recorded in the stratigraphic relationships between the lowest part of the scarp cutting the western and southern slopes of the höyük, followed by the sediment accumulation forming Terrace n° 2. The latter is positioned today at the right bank of the Melendiz river.
  (b) the incision of Terrace n° 2 was followed by the formation of Terrace n° 1 (+ 1.5 to + 2 m), which corresponds to today minor flood plain of the Melendiz river (Figures 2, 5).

The activity of today's Melendiz river within Terrace n° 1 provokes the erosion of Terrace n° 2 (e.g. along the meander banks, thus causing the sudden outcropping of Level 2 layers exceptionally preserved below Terrace n° 2.

With regard to their stratigraphic and geomorphologic positions, both Terraces n° 2 and n° 1 can be attributed to the Late Holocene, although no datable material has been found. Both incisions were triggered by two successive dynamic changes provoking first a river incision, followed by a terrace deposition. Such changes in dynamics may have occurred in response to: (1) climatic conditions; or (2) river profile (changes in altitudes of the head-ward part of the river or at its mouth), possibly triggered by tectonism; or (3) surface conditions (such as soil erodibility, vegetation cover) triggered either by climate or anthropogenic usages. These hypotheses need to be further investigated.

5. Conclusion

The results exposed above illustrate how two distinct scientific fields investigating the same space and time scales obtain not only complementary information useful to one another, but raise questions that would not have been otherwise asked or/and answered.

5.1. Regarding the emergence of sedentary life at the site

The oldest PPN (Pre-Pottery-Neolithic) level at Aşıklı Höyük (i.e. Level 5: 10500-10300 cal BP) was most probably occupied seasonally. Successive non-anthropogenic and anthropogenic layers

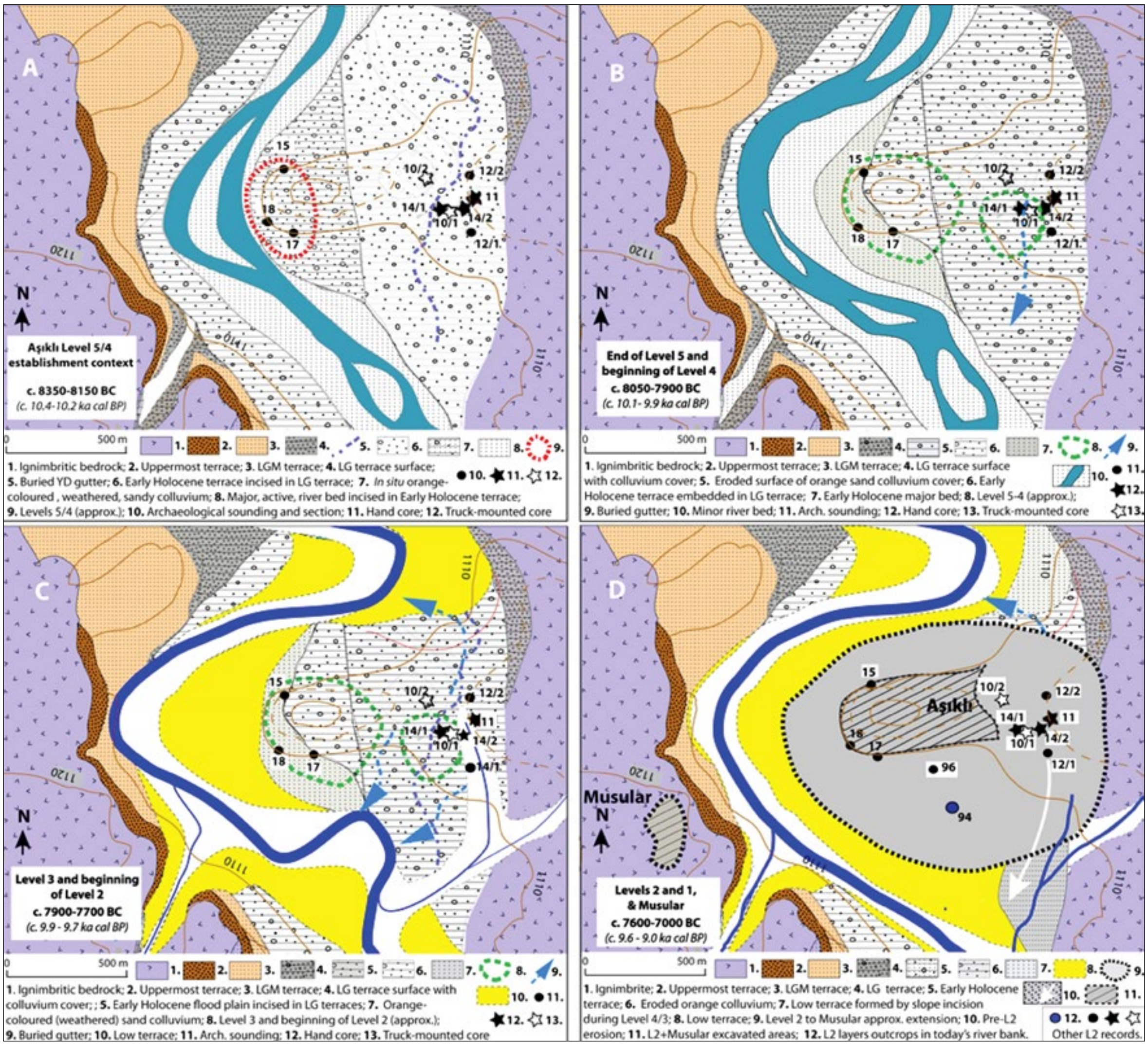

Figure 6. Four steps of the geomorphological dynamics of fluvial deposition/incision landforms in the river valley and vicinity of Aşıklı Höyük from Late Glacial Maximum to c. 7300 BC (Author C. Kuzucuoğlu).

(recorded in the deep sounding '15', as well as in the '18'-'16' section at the base of the höyük) represent outdoor activity areas, burned surfaces, fireplaces or layers with burned wood, Celtis (hackberry) remains etc., suggesting irregular intervals of settling. The fully sedentary life started during Level 4 (10,300-10,050 years ago). According to cores reaching the soil and sediment series over which the tell rose at the time, weakened activities of the river record a rather dry period which would have encouraged the inhabitants to this direction. This dry phase parallels noticeably the 10.3 ka cal BP 'event' in the Iceland and northern Atlantic cores, as well as other similar changes in activities in PPN settlements of southeastern Anatolia and northern Syria (Borrell *et al.* 2015; Flohr *et al.* 2016; Berger *et al.* 2016).

5.2. Regarding the dynamics of the settlement through time and space

At the end of Level 3 and beginning of Level 2 (i.e. c. 9.7 ka cal BP) archaeological data evidence a re-organization of the settlement layout. At Levels 4/3 transition, great changes occur in architectural plans (dominantly rectangular) and in use of space. New buildings start to be built over open spaces, suggesting an increase in population that could have led to an expansion in settlement. Increasing during Level 2, new groups of buildings and neighborhoods settled over remains of the Late Glacial Terrace surface in the valley. One of these extensions fossilizes a very deep river incision, which occurred during the first or second centuries of the 8th mill. BC, destroying parts of the Early Holocene mound. These dramatic events did not affect the success story and growth of the site. The settlement continued to expand over a dispersed pattern, well organized around the settlement core on top of the archaeological mound. This expansion suggests the successful increase of its population, based on the increasing domestication of animals and butchery activities at the site.

The parts of the valley concerned by this positive settlement dispersion were out of reach of the dangerous nature of the river. Both the renewed expansion and its geography in the valley have been discovered with the coring program performed East of the mound. These results suggest that, when the occupation in the main mound ceased ca. 7300 BC, the site was formed by (1) a settlement core, already forming this + 13 m high mound over the surface of the Late Glacial terrace remains, and (2) at least four satellites installed a few hundreds of meters from the core on both parts of the minor bed. Life and activities reconstructed from the archaeological remains of one of these latter sites (Musular) suggest that land use followed a similar expansion in the late Neolithic and Early Chalcolithic.

5.3. Regarding the end of the site occupation and of the Central Anatolian PPN

Aşıklı was abandoned approximately between 7300-7200 BC (ca 9.3-9.2 ka cal BP). No natural disaster, such as eruption, fire or an epidemic disease, was identified. No record of a change in the river dynamics that would have responded to the 9.2 ka cal BP climatic change was identified (Flohr *et al.* 2016; Berger *et al.* 2016). However, a significant change in socio-economy of the community and the pulling effects of fertile lands west of the volcanic region for agriculture and animal husbandry stand as charms for the community's new lifeway.

In conclusion, when the Aşıklı population moved to the plains surrounding the Cappadocian highlands, the triggering factor was not a climatic change, but (1) overpopulation vs physical constraints imposed by the geomorphological frame (a fixed width of the river valley and too few soils for agricultural development) and (2) the impasse generated by the location of the site with regard to these increasing practices. Indeed, economic and social development of Aşıklı community had been based during 1000 years on animal domestication practices and economy. At the end of PPN, it was time to add a new aim to domestication practices: that of the plants that could grow around sites.

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Times of historical developments and environmental changes in the Minoan town of Malia, Crete: an intra and off-site geoarcheological approach

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Abstract

The site of Malia, on the northwest coast of Crete is stimulating for geoarchaeological research. A Minoan palatial town developed during the Middle and Late Bronze Ages in an area that was occupied for a long time, and has been the subject of archaeological excavations for a century. A small wetland located near the sea and close to the archaeological site offers rich natural archives and new record. The latter can now be combined with archaeological data and allow to address some important questions on the history of the whole area. New excavations have improved our knowledge of the relative chronology at the site, but the duration of these successive phases, the causes and rates of change observed are difficult to precise and call for a dialogue with specialists of natural sciences. Can we link the major shifts identified in the material culture and history of the site with broader environmental changes, sudden or durable? This paper addresses the methodological problems for time reading and exemplify them by focusing on two important time lapses, the first occupation of the area (Neolithic and Early Bronze Age) on the first hand, and the Neopalatial phase on a second hand. For each example, we discuss the complexity to establish relationships between the off-site and intra-site events and shifts. We highlight, nevertheless, the growing evidence for an impact of the Santorini eruption on the landscape as well as on the Minoan town of Malia. The preliminary results show that the implementation of multidisciplinary researches and the combination of scales of study is productive to build new or more precise narratives for the history of a site.

Key words: Crete, Archaeology, Protohistory, Chronology, Geoarchaeology

Résumé

Le site de Malia, sur la côte nord-est de la Crète, constitue un terrain d'étude stimulant pour la géoarchéologie. L'agglomération et le palais de l'âge du Bronze sont explorés par les archéologues depuis un siècle, et sont bordés par un petit marais littoral qui offre de riches archives sédimentaires, récemment investiguées. La combinaison des données archéologiques et environnementales permet ainsi de reprendre les questions majeures de la chronologie et des causes de changements marquant l'histoire du site. Si de nouvelles fouilles sur le site ont permis de préciser la chronologie relative, la durée des phases, les causes et rythmes des changements sont plus difficiles à définir et impliquent une réflexion commune avec les spécialistes des sciences naturelles. Quels liens peut-on établir entre les mutations observées par l'archéologie et les évolutions ou ruptures enregistrées dans l'environnement ? Comment articuler les échelles chronologiques obtenues intra et hors-site ? Après un rappel des problèmes méthodologiques liés aux datations archéologiques, deux cas d'étude différents sont analysés : d'une part la première phase d'occupation de Malia, au Néolithique et Bronze ancien, d'autre part la période Néopalatiale. Pour chaque exemple, nous montrons la complexité d'une définition de relations claires entre les événements naturels et les changements matériels observés. Les témoignages d'un impact direct de l'éruption du volcan de Santorin sur l'environnement et la ville minoenne de Malia sont cependant de plus en plus probants. Les résultats, bien qu'encore provisoires,

montrent combien la recherche pluridisciplinaire, menée à différentes échelles (chronologiques et spatiales) peut être fructueuse pour bâtir ou préciser des scénarios historiques plus solides.

Mots clés : Crète, Archéologie, Protohistoire, Chronologie, Géoarchéologie

The Minoan palatial town of Malia, excavated since the beginning of the 20th century (see history of research in Poursat 2010a), is located on the north-eastern coast of Crete, in an area that has been densely occupied for a long time (Figure 1). The area was first settled during the Final Neolithic and a palatial town flourished during the Middle and, to a lesser extent, the Late Bronze Ages, before its abandonment in Late Minoan IIIB in the 13th century BC. Close to the archaeological site, a small marsh located near the sea offers rich sedimentary archives (Figure 2). After a first program of investigations on the paleoenvironment, which remained unfinished (Dalongeville 2001; Lespez *et al.* 2003), new research was undertaken in the marsh in 2015. The new paleoenvironmental data can now be combined with archaeological data from recent excavations conducted at Malia in the area Pi (Gomrée *et al.* 2012; Pomadère 2011; Pomadère *et al.* 2015-2016) and allow addressing some important questions on the history of the site. The question of chronology is at the core of this research.

The Minoan chronological framework has been established long ago by Arthur Evans, after the stratigraphy and typology of the pottery from the palace of Knossos (Evans 1921). His tripartite chronological frame (Early/Middle/Late Minoan), considerably refined since, is still in use for the pottery sequence, but the absolute chronology is fluctuating and under debate, especially for the Late Bronze Age (Wiener 2003; Warburton 2009; Manning 2014) (Table 1). The new excavations in the area Pi of Malia have improved our knowledge about relative chronology at the site (Knappett *et al.* 2018). Nevertheless, the duration of specific events and phenomena, their causes and rates of change are difficult to define and call therefore for a dialogue with specialists of natural sciences in order to explore diverse explanatory frameworks.

The main aim of this paper is to consider the correlation of the different temporal frames yielded by intra and off-site data, in order to get a better understanding of specific events or disruptions but also of the more durable interactions between men and environment. Can we link the major shifts identified in the material culture and history of the site with broader environmental changes, either sudden or progressive? Could we get a more precise idea about the tempo of these processes, and not only about the dates of the events?

In order to answer to these questions, a real interdisciplinary work needs to be undertaken, which is not such an easy task: as specialists of different disciplines, we have different goals, rooted in

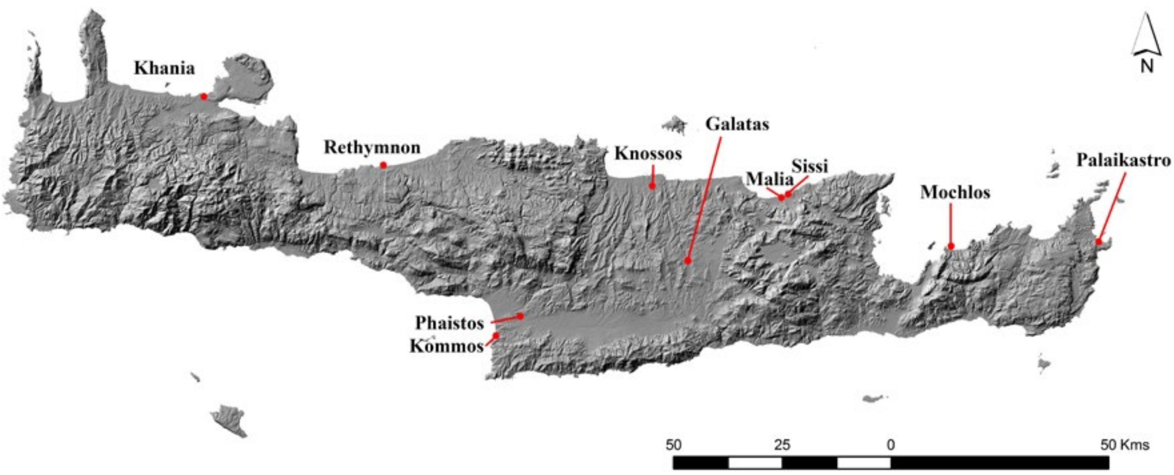

Figure 1. Map of Crete with the sites mentioned in the paper (© IMS-FORTH/Q. Letesson).

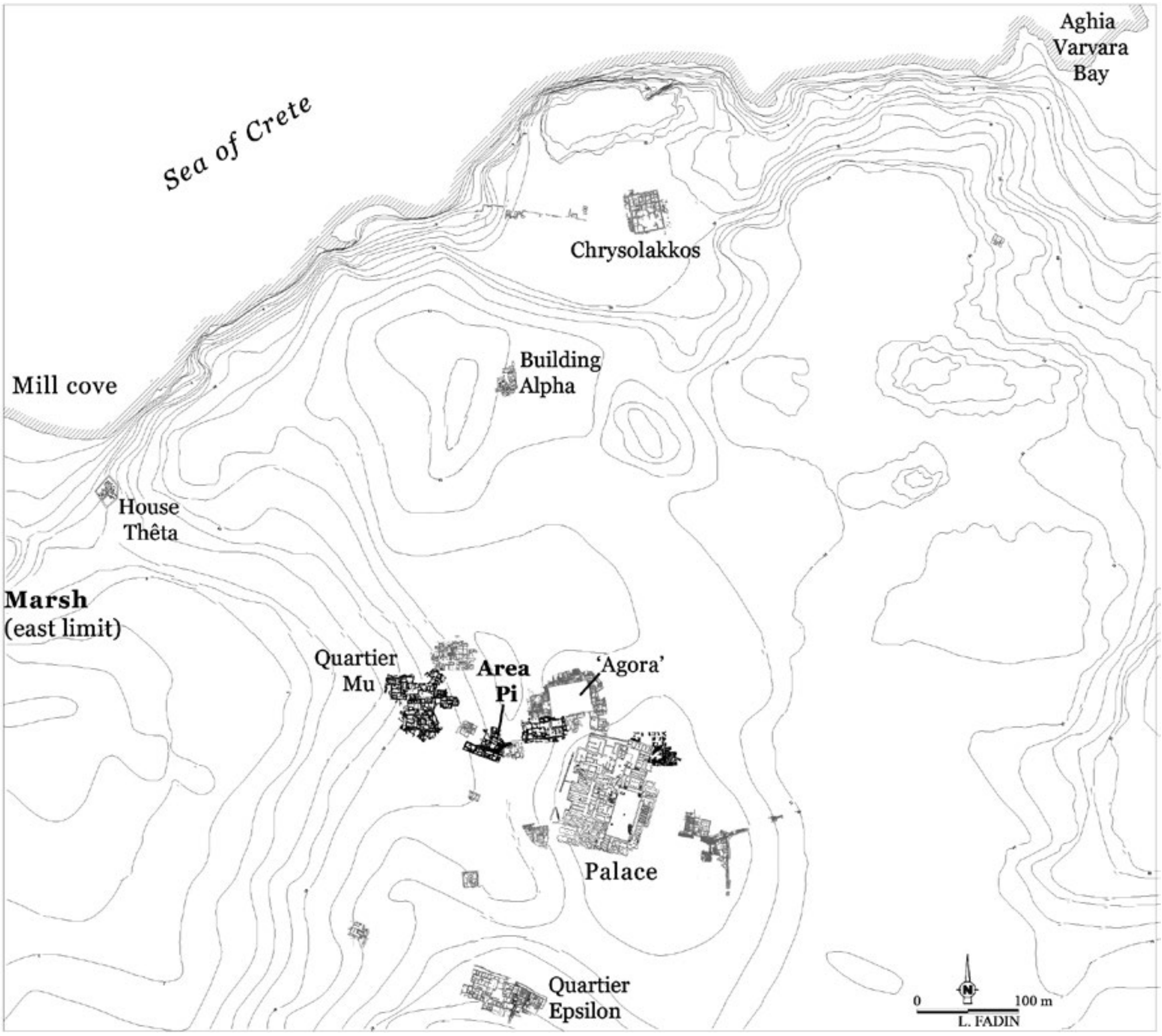

Figure 2. Map of the archaeological site of Malia (© EFA/L. Fadin).

different timescales. Archaeologists are concerned with material and cultural changes at the human scale (short to mid-term), including episodes of building or destruction on a site, and the investigation of their causes. Geomorphologists are interested in broader evolutions within a deeper scale of time, the so-called 'longue durée' (Braudel 1958).

1. Study Area and dating methods

1.1. Environmental and archaeological contexts

The Bronze Age town of Malia was established at the foot of the Selena Mountain (1600 m), on a low plateau (15-20 m above sea level) closing the eastern part of a small plain and overlooking a small coastal marsh (Lespez *et al.* 2003). During the Middle Minoan period, the town extended as far as the east border of the marsh and the coastline to the north, covering ca. 50ha, while the palace was built at 1300 m from the sea (Figure 2) (Müller 1991; Müller Celka 2007; Lespez *et al.* 2016: 248). The marsh is separated from the sea by a low, rocky coast composed of Pleistocene calcarenites, partly covered by a sandy beach ('Mill Cove'). Today, there is no perennial stream to supply the marsh, but thanks to aquifers hosted in the Cretaceous and Neogene limestones, it is never completely dry.

Only one of the six cores drilled in 1993 in the marsh has undergone laboratory analyses and provided radiocarbon dates. The results showed that this was a freshwater marshy area during most of the Holocene and highlighted some sedimentary events, but they lacked chronological precision

Periods in Crete	*Sub-phases in Crete*	Warren and Hankey 1989: 169 (EM-MM III); Warren 2006 (LM I-III) *Low Chronology*	Manning 1995: 217 *High Chronology*	*Main phases and pharaons in Egypt*
Prepalatial period	**Early Minoan I**	3650/3500-3000/2900	3100/3000-2700/2650	**Old Kingdom** (Dynasty 3 to 6)
	Early Minoan IIA	2900-2300/2150	2650-2450/2350	
	Early Minoan IIB		2450/2350-2200/2150	
	Early Minoan III	2300/2150-2160/2025	2200/2150-2050/2000	
	Middle Minoan IA	2160/2025-1900	2050/2000-1925/1900	
Protopalatial period	**Middle Minoan IB**	1900-1800	1925/1900-1900/1875	
	Middle Minoan II	1800-1700/1650	1900/1875-1750/1720	
Neopalatial period	**Middle Minoan IIIA**	1700/1650-1640	1750/1720-1700/1680	**Middle Kingdom** Dynasty 11 and 12
	Middle Minoan IIIB	1640-1580		
	Middle Minoan IIIB/ Late Minoan IA		1700/1680-1675/1650	
	Late Minoan IA	1580-1480	1675/1650-1600/1550	**Second Intermediate Period** (Dynasty 13 to 15: Hyksos)
	Eruption of Santorini volcano	*1550-1530*	*1628; 1613±13 (Heinemeier et al. 2009)*	
	Late Minoan IB	1480-1425	1600/1550-1490/1470	
Final Palatial period	**Late Minoan II**	1425-1390	1490/1470-1435/1405	
	Late Minoan IIIA1	1390-1370	1435/1405-1390/1370	
	Late Minoan IIIA2	1370-1330	1390/1370-1360/1325	**New Kingdom** Dynasty 18
Post-palatial period	**Late Minoan IIIB**	1330-1200	1360/1325-1200/1190	Thutmosis III Amenhotep IV/ Akhenaton Dynasty 19

Table 1. Chronological table and concordances with Egyptian chronology.

(Dalongeville 2001; Lespez *et al.* 2002; Lespez *et al.* 2003). This is why new core drillings were made in 2015 (Figure 3): 11 cores, which have produced 45 radiocarbon dates, are currently under study (Lespez and Pomadère 2015-2016; Lespez *et al.* 2016). Current analyses include sedimentology, magnetic susceptibility, geochemistry (XRF); palynology, NPPs and Fire signature; foraminfers and ostracods.

On the archaeological site itself, excavations in the Area Pi, one of the town blocks situated 150 m west of the Minoan Palace of Malia, were conducted through five campaigns between 2005 to 2014. The main goal of this research programme was to better define the nature of the various activities held in the town of Malia and the material culture, with special emphasis on local developments throughout the different phases of the Neopalatial period. It also encompassed the question of the interactions between the population and its environment. Unfortunately, the alkaline nature of the sediment leads to poor conservation of seeds and phytoliths and limits the potential results on this issue.

If the two projects, on- and off-site, were independent at their beginnings, it soon appeared that crossing the questions and results would enrich our understanding of the local human and environmental dynamics.

1.2. Time reading on and off-site: problems of methods

Archaeologists are, most of the time, unable to distinguish very short terms events (i.e. daily or even seasonal) in the archaeological records (Foxhall 2000; Gilchrist 2000: 325). We can mostly

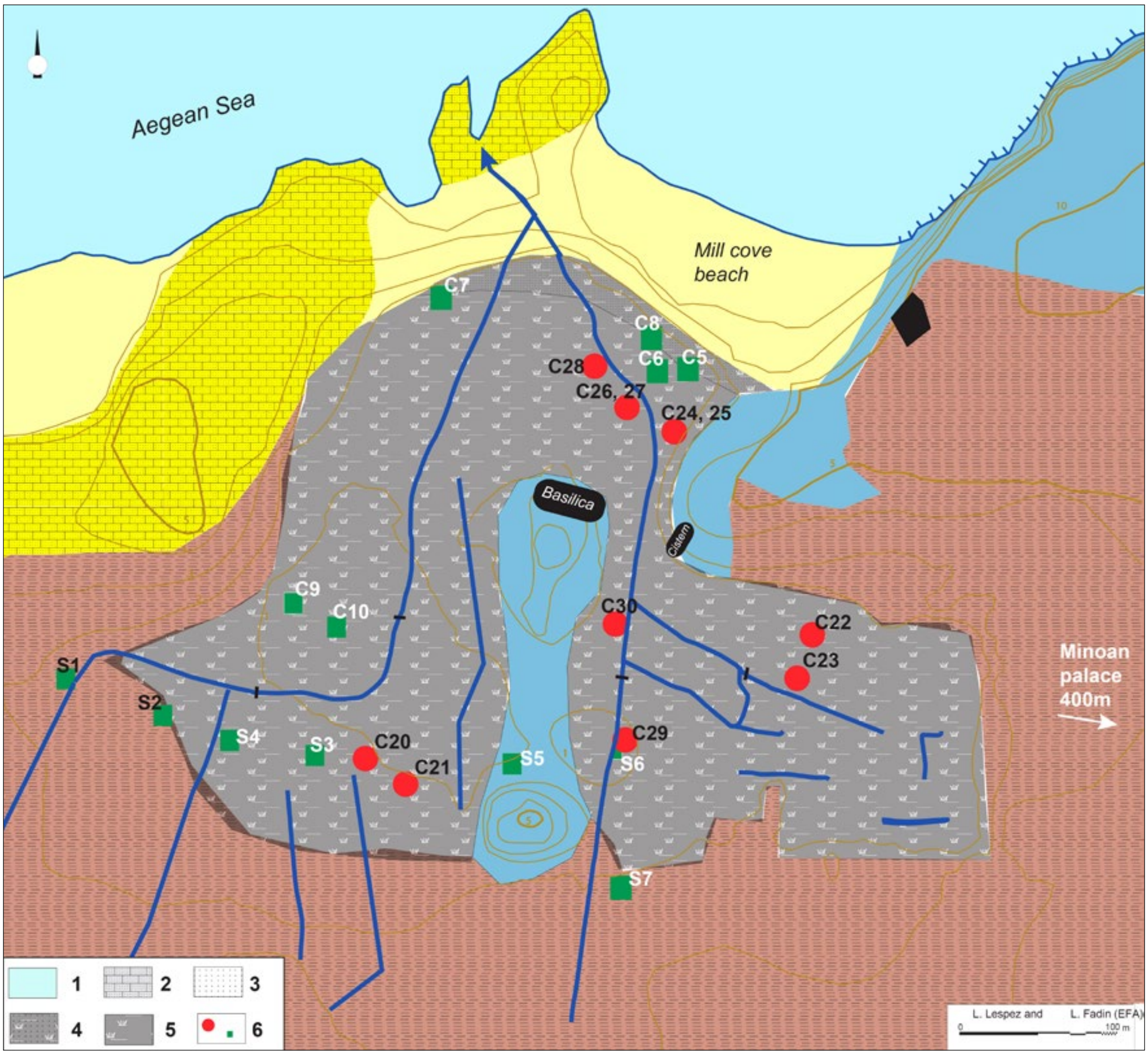

Figure 3. Geomorphological map of the Malia marsh and investigations conducted before 2003 (Lespez *et al.* 2003) and in 2015 (© L. Fadin/L. Lespez). 1. Cretaceous limestone (*sideropetra*); 2. Tyrrhenian calcarenite (*ammouda*); 3. sandy beach; 4. sandy barrier beach covered with reeds; 5. Holocene marsh deposits mainly covered by a reed bed and its belt of hygrophyl plants (rushes, etc.); 6. Ante 2015 surveys and cores (green square) and 2015 campaign cores (red circle).

approach short to mid-term changes (estimated to more or less one generation, i.e. 20 to 25 years). These changes are however embedded in conventional stages, those relative phases delineated by the analysis of sites' stratigraphy and ceramic developments (ex. in the case of Minoan Crete, Middle Minoan IIB). Although crucial for our diachronic understanding of a site's history, these conventional subdivisions are not without raising some questions and methodological problems: they seem indeed to 'freeze' some portions of time in a rigid framework, assuming a high cultural coherence and underestimating the dynamism and evolutions *within* each phase (Adams 2007: 391). Moreover, pottery decoration and morphology ('style') have long been the main criteria for dating, regardless of technical traditions and techno-stylistic trends, which can also offer a solid base for establishing chronology (Roux 2010; for studies in this perspective in Crete, Van de Moortel 2006; Caloi 2011).

The definition of the relative chronological sequence of the Minoan occupation at Malia only became a major concern from the 1960's onwards (Pelon 1970, 1983). French archaeologists that worked previously on the site had a limited interest in stratigraphy. At the scale of the island, the synchronism between the ceramic sequences as defined in the different sites and regions still constitutes a major challenge within Minoan archaeology and research (e.g. Brogan and Hallager 2011; Macdonald and Knappett 2013; Langohr 2017). Moving to absolute chronology, archaeologists of Aegean prehistory mainly rely on a chronological system based on synchronisms between Aegean/Cretan and Egyptian/Near Eastern contexts within which Cretan imports (mainly pottery) have been found, and vice-versa in the Aegean. The method is far from perfect: we are aware that sherds only give a *terminus post quem* to a material assemblage, and that the latter possibly reflects the aggregation of successive activities, and not necessarily a well-defined event or specific action. Therefore, it is certainly more accurate to recognize that archaeologists define intervals of time, rather than precise events (Boissinot 2015: 137). Regarding laboratory methods, radiocarbon dating is the main method used to date archaeological deposits, but its use has been sporadic until now at Malia as at Cretan sites in general. Most available radiocarbon dates from archaeological levels are indeed imprecise and cover such a broad chronological range that they are of little use (Poursat 2010b: 62; Darcque 2014: 165). We will show later that the same remarks apply to radiocarbon dates from off-site contexts.

2. Case studies

In order to pinpoint the kinds of 'time reading' problems frequently encountered in the case of Minoan Crete, we present here two specific time lapses in the occupation of Malia and attempt to compare the results of our intra- and extra-site research works.

2.1. The Neolithic and Early Bronze Age: from the first settlers to the first village

The Neolithic is the longest as well as the less well known phase of the early history of Malia. The new cores show that the coastal wetlands especially developed from the 5th millennium onwards, during the Late Neolithic. The increase of freshwater resources, although generally considered to be favorable for human settlement, was apparently not paralleled by any installation in the plain, near the marsh. A unique Final Neolithic site (i.e. 4th millennium BC, more likely FN IV according to the material) has been identified by the regional survey on the slopes of a hill overlooking the plain of the later town, the Arkovouno (Müller 1998: 549). Nevertheless, the study of cereal pollens from a core made in the marsh in 1993 suggested anthropisation of the environment already during the 6th millennium, i.e. in the Middle Neolithic (Dalongeville 2001). This result needs to be further assessed by the current palynological analyses. In fact, we ignore everything about the location, extension and nature of the settlement(s) of the local communities in the area of Malia before the 4th millennium. This is a major discrepancy between archaeological and environmental data. It echoes the widespread archaeological invisibility of Neolithic sites in the entire Crete until the last stage of Final Neolithic, at least partly due to taphonomic and research biases (Tomkins 2008: 36-41; 2014: 353). The situation at Malia also reminds the complexity of the relations between human and environmental dynamics during this period, recently enhanced on a broader scale for the Greek mainland (Weiberg *et al.* 2019).

The first consistent occupation of the site of Malia, below the subsequent town and palace, is dated to Early Minoan II period (ca. 2900-2300 BC). Two key features are worth mentioning as regards the evolution of the wetland. Although the wetland continued to extend during the period of the Early Bronze Age, some rapid events have destabilized the marsh environment. On the seashore, marine sand input into the marsh has been observed, testified by the sedimentological analyses and the presence of some specific microfossils (Lespez *et al.* 2003), whereas into the marsh, a deposit suggests a high energy event of continental origin (flood). The latter event is more difficult to interpret and needs further examination. These deposits, at the seashore and at the back of the marsh, are not yet well dated, neither is it clear if they are coeval, but they fall within a time interval between 3300 and 2000 BC. This/these probable short-term event(s) did not alter the marshy environment, while its/their impact(s) on human settlement, not well known for this period, is unclear. A second feature is a concentration of charcoals recorded in the cores and dated at ca. 2600 BC. It points to large fires, which could correspond to the first important exploitation of the marsh and the plain in relation with various human activities (agriculture, building, etc.).

The Malia Palace was erected during the Middle Minoan I phase (later abbreviated MM I, ca. 2000 BC) and a town flourished until MM IIB, during two to three centuries (Poursat 2010a, 2010b; Devolder 2016), following a process that appears quite continuous. In the same period the marsh continued to extend in surface. This period was also marked by a multiplication of rural sites in the plain and the surroundings mountains (Müller Celka 2007). The likely intensification of agriculture around the town of Malia probably left some traces in the pollen records. The palace and town were destroyed by fire at the end of MM IIB. This violent destruction marks the end of the first palace and a main rupture in the history of the town, although it was followed by the rebuilding of parts of the settlement and of a new palace. This next stage is usually labeled the 'Neopalatial' period.

2.2. The Neopalatial phase (MM III – LM IA) and the question of the Santorini eruption effects

The recent excavations in the area Pi at Malia focused on the first part of the Neopalatial era, i.e. the MM III-LM IA phases, which was considered until recently as a blurry period in the settlement's history, although it included, precisely, the rebuilding of the palace, probably in two stages (Poursat 2010a). The MM III phase is not properly distinguished in the stratigraphy and ceramic sequence of all parts of the site. For instance, in the area to the north-east of the palace, the main change within the Neopalatial period is associated with the LM IA phase but the latter forms one and a same chronological period *with* the MM III phase (Darcque 2014: 180-181). At the scale of the island, the confusing label of 'transitional phase' for the MM III period reflects above all a lack of knowledge, since the MM III phase had spanned around one and a half century (MacGillivray 2013; for a thorough presentation of the MM III period and remaining issues, see Macdonald and Knappett 2013).

One of the main results of the excavations in the area Pi is the recognition of material evidence for an extended length as well as sequencing of the MM III phase, broadly bearing out the subdivisions previously outlined by O. Pelon (1970, 1983, 2005) at the site. This phase now appears as a pivotal point between the old and new palatial systems at Malia, in accordance with the results from other Cretan sites (especially Knossos, Galatas, Kommos) although the gradual processes and dynamics that led to the formation of a new political geography for Crete during the Neopalatial period still need to be clarified. Moreover, the stratigraphical, ceramic and architectural study of the building Pi (the Neopalatial building of Area Pi) allowed us to recognize four neopalatial sub-phases (Gomrée *et al.* 2012). We have distinguished secondary evidence for both MM IIIA and MM IIIB occupation horizons within the building: they are defined by large homogenous fills whose rapid deposition can be explained as the result of cleaning operations following a destructive event. Each of these two phases is also associated with significant changes in ceramic production. The building Pi underwent a major rebuilding after the MM IIIB destruction but a new, widespread destruction struck the town and the palace during the LM IA (Driessen and Macdonald 1997: 88-89; Pelon 2005; Poursat 2010a: 265; Devolder 2012-2013; a unique destruction is challenged in Darcque 2014: 180), as evidenced again in area Pi by massive fills spread in several rooms, resulting from the large-scale cleaning operations.

Among these LM IA fillings were several bones of fetus of caprine, which suggest a destruction during spring. It is worth mentioning this unusual seasonal detail, as this large destruction could be an effect of the Santorini eruption that occurred in mature LM IA, and likely during the spring (Johnston *et al.* 2012). It is assumed that the Santorini eruption left a layer of tephra over a large region in East Mediterranean and that it triggered a tsunami which could have devastated the north coast of Crete (Minoura *et al.* 2000; Bruins *et al.* 2009; Novikova *et al.* 2011; Athanassas *et* *al.* 2018). Material traces of the eruption have been reported from several sites of Eastern Crete (Mochlos: Soles *et al.* 1995; a layer of tephra up to 20 cm at Palaikastro: Bruins *et al.* 2009), and could tentatively be extended to the region of Malia, as some Theran ash has recently been evidenced at the neighbouring site of Sissi, 4km east of Malia. Nevertheless, it is properly identified in a single part of the site for now (Jusseret 2018a: 237; Claeys 2018: 279), while no tephra has been noticed in the cores drilled in the Selinari lowlands surrounding the settlement of Sissi (Jusseret 2018b: 336).

The palaeoenvironmental research at the site of Malia should bring some new data on this point. Sedimentary analysis reveals some perturbations between the 18th and 15th c. BC. Near the seashore, a 20 cm thick sandy tsunamogenic deposit has been identified on the core drilling C6 (Lespez *et al.* 2003), while the recognition of layers deposited by the tsunami and/or of evidence for erosion of the Holocene sedimentation by the waves generated by the explosion of the Santorini volcano is one of the main aims of the last core drilling survey. The analyses are in progress but it is now clearly established that a tsunami destabilized the beach ridge and has affected the palaeogeography of the Malia marsh (Lespez *et al.* 2016).

No layer of Theran ash was recorded in the previous excavations at Malia (Darcque 2014: 170) and traces of a tsunami remain imperceptible in the archaeological record (a unique layer of pumice has been observed on the coast during the survey, Müller Celka 2000). However, a significant amount of pumice and layers of greenish ashes were found in the LM IA fills of building Pi (a heap of more than 800 pumice stones in the mature LM IA backfill of one room): they still wait geochemistry analysis which could determine an origin in the Santorini volcano. They could result though from various anthropogenic (ashes from domestic fires, pumices brought with other building material, such as sand from the beach) or environmental events (earlier eruptions), other than the big Santorini eruption. The hypothesis, also considering the possibility of a ‘Minoan flood’ cleaning the tephra at Malia (Athanassas *et al.* 2018), needs to be further explored.

The absolute chronology of the eruption is still debated and the results from Malia do not change this situation. In general, the uncertainty associated to the radiocarbon dating does not allow determining precisely the time of the event from off-site contexts. The sandy layer of the C6 core drilling from the Malia marsh is attributed to a period lasting from the middle of the second millennium BC to the beginning of the first Millennium AD (Lespez *et al.* 2003; Lespez *et al.* 2016). The probable tsunamogenic sand deposits have been described but unfortunately, in the absence of organic remains, they cannot be dated. Their examination shows an erosional contact with underlying marshy deposits but it is not possible to estimate the extent of erosion and truncation of the deposits underlying the sands. Furthermore, with a usual margin of error of two standard deviations, the deposit of the marshy layer located just below the sandy layer has been set up between 1744-1506 BC. This date, too imprecise, prevents us from assigning the erosion of this deposit to a precise time, and thus from shedding new light on the ‘low’ and the ‘high’ chronology still under debate for the eruption of the Santorini volcano and its consequences (see Table 1). Indeed, the scientific community is faced since a few decades now with a discrepancy between the traditional archaeological sequence (‘low chronology’, dating the eruption around 1530-1500 BC: Warren and Hankey 1989; Warren 2006) and the radiocarbon dates obtained on the volcano deposits and on the island of Santorini or on the ice core (‘high chronology’, often pointing to a date one hundred years earlier around 1628 BC: Heinemeier *et al.* 2009; Manning 1995, 2014). Although there is now an important bibliography admitting that radiocarbon heads towards a ‘high’ eruption date, it raises significant problems. On one hand, statistical interpretation of the radiocarbon results is subject to caution and critics (Fantuzzi and Antolini 2018). Archaeologists are not usually experienced for a critical analysis of radiocarbon dates, which can lead to overconfidence on the results (Hamilton, Haselgrove and Gosden 2015: 656). Moreover, some results on radiocarbon calibrations were not taken into account: revised calibrated ranges for the eruption of Thera indicate a date around the middle of the 16th century, compatible with traditional, archaeological dates of Egyptian chronology (Pearson *et al.* 2018).

On the other hand, the results pointing to the higher date are problematic for the Egyptian chronology and political history of East Mediterranean (Cherubini *et al.* 2014). It explains why most archaeologists are still in favor of the low, traditional date for the eruption, in the late 16th century BC. In the time being, the results obtained at Malia do not favor one or the other hypothesis.

It is now fully accepted that the Santorini eruption did not mark the end of the second Minoan palaces, but it could have initiated a decline at Malia, and more broadly within the Minoan society, for different reasons (Driessen and Macdonald 1997). In spite of the severity of the destruction(s) that struck the site during the LM IA, the area Pi and some other buildings of the settlement of Malia were rapidly and at least partly reoccupied and rebuilt during a final stage of LM IA, before their final abandonment at the end of LM IA or during LM IB (Pelon 2005; Poursat 2010a; Darcque 2014: 181). The mid to long-term effects of the Santorini eruption and its impact on economy and society (crisis, decline, disintegration process, Driessen and Macdonald 1997; Driessen 2002, 2018) remain debated and must be considered at a regional scale, within the different parts of Crete.

Lastly, the perception of changes again differs when one considers different geographical scales of data. The destruction, or short-term events evidenced in the Neopalatial stratigraphy of the town of Malia through excavations are not corroborated by the data recovered from the survey undertaken within the surrounding territory, at the exception of the LM IA massive destruction. For instance, the MM III disruptions identified in the settlement are not visible, at the moment, in the rural sites identified by surface material. This lack of recognition can however be mainly due to the fact that MM III and LM IA pottery is not differentiated in survey material (Puglisi 2007). The chronological resolution of survey data, based on very fragmented and eroded ceramic material, therefore rather corresponds to the mid-term scale. In the specific case of the Malia survey, the resolution of the collected data confirms that the town and its territory reached their acme during the MM II, before a gradual decline in population density during the Neopalatial phase, but does not allow a finer restitution of the chain of events (Müller Celka 2007).

The influence of climate changes over the long-term, with dryer conditions during the LBA, remains to be evaluated for the region of Malia as well as for the whole Crete.

Conclusion

The need to better define the rates and factors of human and environmental change at Malia prompt us to organize an interdisciplinary research program combining intra-site archaeology and off-site geomorphology. Even if it is now the rule for archaeological projects to involve multidisciplinary teams, a real combination of approaches, implying discussions between distinct specialists on specific questions or working hypotheses beforehand, is neither frequent in Crete, nor easy (Livarda, Orengo and Veropolidou 2015; Weiberg *et al.* 2019). Building chronologies using intra-site time frames and chronological markers provided by the study of the surrounding environment remains a challenge, because it implies the critical use of several methods and the combination of both relative and absolute dating, as well as the consideration of different timescales. As John Bintliff underlined, the result would produce at best 'a mapping of interactions between temporal processes and societal and ecological structures, with discrete events and individual people, without predictable and a priori interrelations' (Bintliff 2006: 192). The present overview, in an attempt to define our main aims and methodological processes in the specific case of Malia, has hopefully shown that the combination of datasets from intra- and extra-site investigations may help to build new or more precise narratives for the history of a site. Forthcoming results will provide new input to this research programme and refine, modify or even refute some of the current hypotheses related to our diachronic understanding of main events or disruptions that had punctuated (and then, for us, structured) this long history.

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Environmental change and population responses in the Sechura Desert during the late Holocene

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Abstract

The Sechura desert, on the north Peruvian coast, is a region characterized today by a hyperarid climate and regularly affected by extreme rainfall events linked to ENSO. The current hydro-climatic variability and its effects on coastal environments raise the question of ENSO's occurrences and evolution during the Holocene. The Sechura desert is now very sparsely occupied, while many archaeological sites indicate a significant human presence from the 5th millennium BC. Our research focuses on the adaptation of these local populations to variation in climate and evolution of the coastal environment over time. A regional approach, integrating off-site data from sedimentary archives in the Las Salinas and Nunura bay regions and on-site data from the Bayovar-01 and Huaca Grande archaeological sites, highlights the variety of responses of these populations, which adapted their subsistence economies to these environmental fluctuations. Our results show that, over the past two millennia, the Sechura desert has experienced both permanent occupations that adapted to diverse resources and that varied over time, as well as short-term, opportunistic occupations that focused on specific and temporarily available resources. Thus our reconstructions testify to the strong reactivity of landscape and people to recent Holocene environmental change affecting the coastal areas of the Sechura desert.

Keywords: Sechura desert, Late Holocene, geomorphology, archaeology, Las Salinas, Nunura

Résumé

Sur la côte nord-péruvienne, le désert de Sechura est une région caractérisée aujourd'hui par un climat hyperaride et régulièrement concernée par des épisodes de pluies extrêmes liés à ENSO. La variabilité hydro-climatique actuelle et ses effets sur les milieux littoraux posent la question de son existence et de son évolution passée, durant l'Holocène. Alors que ce désert est aujourd'hui très faiblement occupé, de nombreux sites archéologiques indiquent une présence humaine importante à partir du Ve millénaire av. J.-C. Notre recherche s'intéresse ainsi à l'adaptation de ces populations locales aux variations du climat et des milieux côtiers. Une approche régionale, basée sur l'intégration de données hors-site provenant d'archives sédimentaires dans les régions de Las Salinas et de la baie de Nunura et des données intra-site issues des sites archéologiques de Bayovar-01 et de la Huaca Grande, nous permet de mettre en évidence diverses modalités dans la réponse des populations et de leur économie de subsistance aux fluctuations environnementales. Au cours des deux derniers millénaires le désert de Sechura a connu à la fois des occupations pérennes qui s'adaptaient à des ressources diverses et qui variaient dans le temps mais aussi des occupations opportunistes de courte durée, centrées sur une ressource spécifique et ponctuelle. Ainsi nos reconstitutions témoignent de la forte réactivité des paysages et des hommes aux changements environnementaux de l'Holocène récent qui ont affecté les espaces côtiers du désert de Sechura.

Mots-clé : désert de Sechura, Holocene tardif, géomorphologie, archéologie, Las Salinas, Nunura

1. Introduction

The Sechura Desert is a vast area (lat. 6°S–7°S) that extends over approximately 20,000 km^2 along the Peruvian coast, from the Piura valley to the Lambayeque valley. It is located between the Pacific Ocean and the Andes, and its width varies from some kilometres to a maximum of 100 km in its central part, which is covered by thick sand accumulations. This region is characterised by desert conditions resulting from a combination of two main factors: (i) the Peruvian upwelling–Humboldt Current system along the coast, associated with the high pressure of the Eastern Pacific to the west and (ii) the rainshadow effect of the Andes to the east (Sandweiss 2003). Currently, the region is affected by rainfall episodes of varying intensity due to ENSO (El Niño Southern Oscillation) that occur with irregular frequency (since 1976, every 3-7 years) (Sandweiss 2003; Rein 2007; Ramírez and Briones 2017).

The Sechura Desert is today very sparsely occupied, while many archaeological sites indicate an almost continuous occupation since the Preceramic, right up to the Inka period (Milla Villena 1989; Cárdenas *et al.* 1991, 1993; Goepfert *et al.* 2016, 2018, 2019). This archaeological setting suggests available natural resources exploited by local human communities for their subsistence during several millennia. However, at present the Holocene environmental history of the region is not well-known due to a lack of high resolution palaeoenvironnemental and climatic local archives (continental or marine).

We can refer to many previous studies which highlighted strong environmental and climatic variability at a macro-regional scale. Marine sedimentary records and archaeological data (archaeofaunal assemblages) indicate that the climate (South American monsoon influence) was different from the current one and that ENSO activity varied significantly (Sandweiss *et al.* 1996; Sandweiss 2001; Rein *et al.* 2005, Carré *et al.* 2012, 2014).

After a humid phase with maximum ENSO activity during early Holocene, a shift to cooler and drier conditions and reduced ENSO activity is attested to during the middle Holocene (Rein *et al.* 2005; Carré *et al.* 2012). At 5.8 ka BP, archaeological evidence records a reactivation of ENSO activity after a pause of several millennia (Sandweiss 2001). A rapid increase in ENSO frequency was recognized around 3000 cal BP (Sandweiss 2003).

The last two millennia can be divided in three different phases: (i) between 0 and 750 AD, humid climate with rare strong ENSO events (similar to the 1982-83 event), (ii) between 750 and 1250 AD, a dryer period with weak ENSO activity and (iii) after 1250 AD, more humid conditions and a higher frequency of intense ENSO events (Rein 2007).

This climatic variability is an essential key to understanding human frequentation of the Sechura desert during the Holocene. Our research focuses on the adaptation of local populations to variations in coastal environments in relation to regional and macro-regional geomorphological and hydro-oceanic-climatic forcing.

Our research is based on a regional multiproxy approach, involving the excavation of two archaeological sites, located in the north-west of the Sechura Desert, and the geomorphological study of the surrounding areas (Figure 1). In this article, we present a synthesis of the data acquired for the Bayovar-01 site, located on a marine Pleistocene terrace on the edge of the Las Salinas depression, and compare them with the new data from the archaeological excavations of the Huaca Grande site and the geomorphological investigations carried out in Nunura Bay (Figure 1).

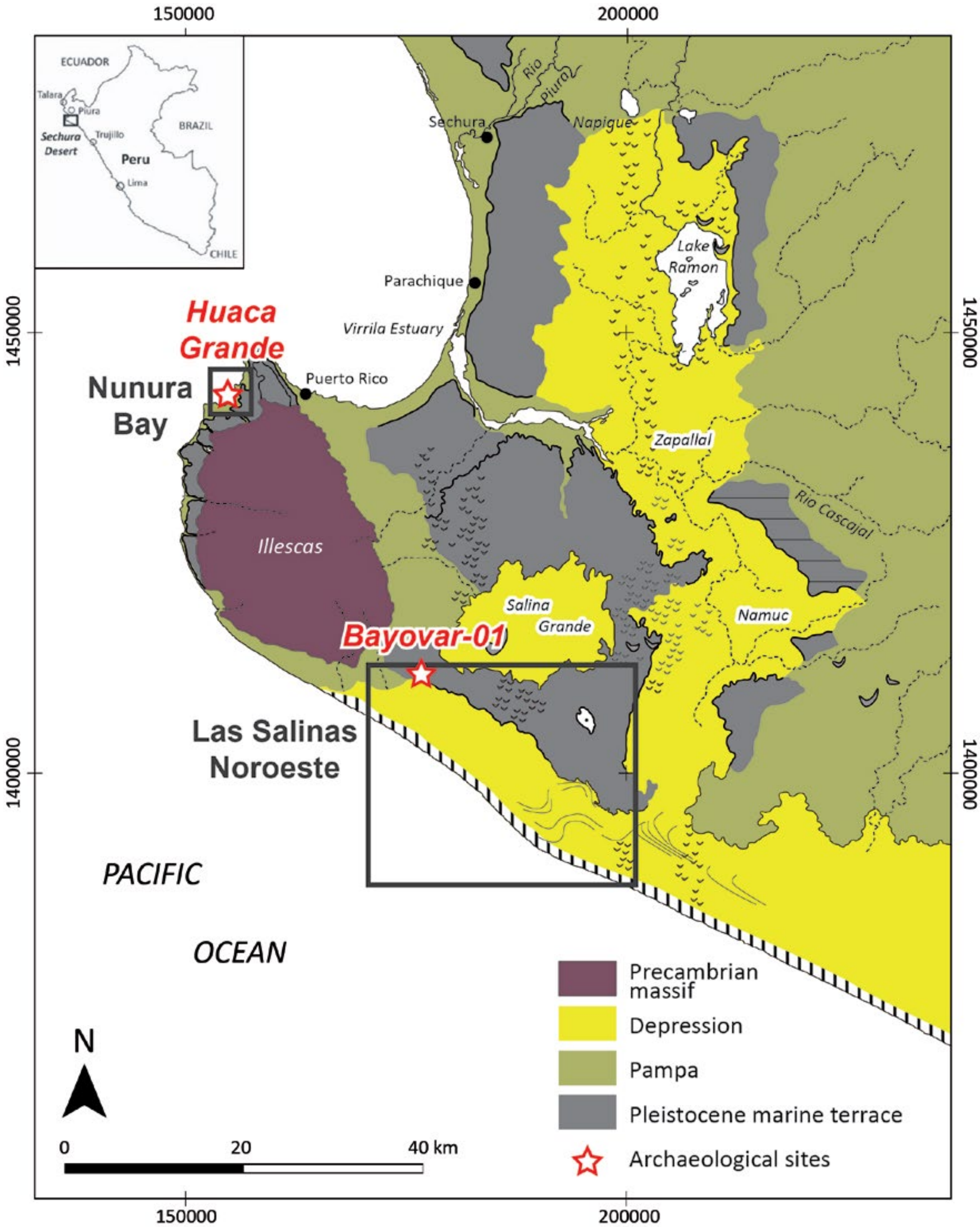

Figure 1. Geomorphological setting of the studied area (in green for palaeogeographic survey) and location of the Bayovar-01 and Huaca Grande archaeological sites (red stars). Drawn with data compiled from ASTER GDEM (2011), IGN (1996-2005), INGEMMET (1980-1999), and LANDSAT (2001).

2. Methods

The archaeological occupations of Bayovar-01 (Goepfert *et al.* 2016) and Huaca Grande (Goepfert *et al.* 2017) have been the subject of detailed studies (stratigraphy, zooarchaeology, malacology, archaeobotany) in order to identify the activities carried out and the resources exploited by the communities that inhabited these sites, as well as the nature of these facilities (opportunistic or permanent). In parallel with the archaeological excavations, we collected field data in the areas surrounding the two sites.

In Las Salinas, a geomorphological study of the entire depression and surrounding areas was combined with a geomorphological profile (6 km long; 18 pits, each 1-2 m deep) perpendicular to the coastline, located between the archaeological site of Bayovar-01 to the west and the shore bar to the east (Figure 2). Chronostratigraphic, geochronological, and malacological studies have been carried out on sedimentary successions identified along this profile (Christol *et al.* 2015, 2017).

At Nunura, we carried out geomorphological surveys and sampled the best preserved and more representative sedimentary sequences. We opened ten pits in the intertidal zone, mainly along the main and secondary channels. We present below the sedimentary succession of the main profile, named Nunura 1 (172 cm deep), which was the object of multiproxy sedimentological analyses (laser granulometry, magnetic susceptibility, Total Organic Carbon and $CaCO_3$ content, pH).

On-site and off-site data were then combined to understand human occupations, their subsistence economies, and their relationship with climate and environmental change.

3. Results and Interpretations

3.1. Archaeology

3.1.1. The Bayovar-01 site

The Las Salinas area is a large depression (about 2000 km^2) partly located below sea level, bordered by a Pleistocene marine terrace and separated from the ocean by a shore bar. The Bayovar-01 site is located on the top of this Pleistocene terrace at 9-18 m above sea level, 6 km from the shore inland. The site was occupied between cal AD 469 and 766 (Goepfert *et al.* 2016), a period corresponding to the transition from the Early Intermediate Period (200 BC–AD 600) to the Middle Horizon (AD 600-1000). The archaeological excavation revealed the presence of two structures formed by several rows of marine formation blocks. A large activity area was also discovered, formed by the accumulation of fish remains, charcoal and other charred materials, such as seeds and camelids faeces, found in several superimposed hearths. The large amount of fish bones and otoliths of species living in warmer and shallow coastal waters (e.g. *Micropogonias altipinnis*, *Albula* sp.), indicate different environmental and climatic conditions than those prevailing today (Goepfert *et al.* 2016). They suggest the presence of a lagoon, which could have been formed by the flooding of the sandy depression of Las Salinas by fluvial and/or marine inputs (Christol *et al.* 2015, 2017). In this area, episodes of flooding and coastal lake/lagoon settlements are attested to during the 20th century and were observed in 2017 during one '*El Niño costero*' (*tr.* coastal El Niño) phenomenon (Figure 3), related to episodes of intense ENSO activity.

We conclude that the fisherfolk who inhabited Bayovar-01 took advantage of such favourable environmental conditions to settle in this spot. The site appears to have been a specialised site for fishing and the preparation of fish for transport to other areas (Bermeo *et al.* 2019; Goepfert *et al.* 2019).

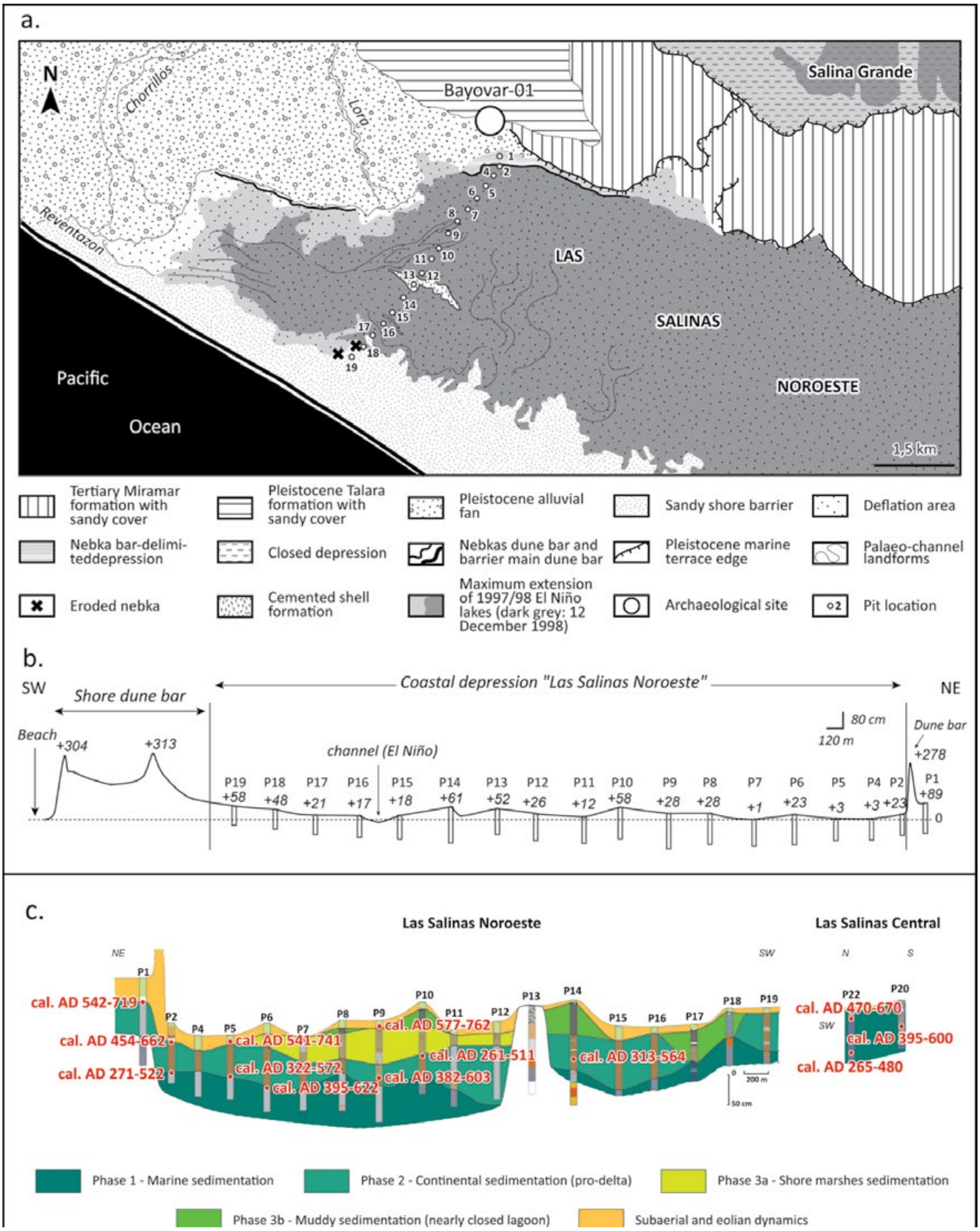

Figure 2. Las Salinas Noroeste. a) Geomorphology. Drawn from LANDSAT (12 December 1998). b) Topographical profile, transect and pit locations (P), and elevation asl as measured at Reventazon in February 2014. c) Chronostratigraphy of the Las Salinas Noroeste infilling and lagoon phases (modified from Christol *et al.* 2017).

3.1.2. The Huaca Grande site

Huaca Grande is a big mound, measuring 176 m long, 73 m wide, and 7-8 m high, located at approximately 400 m from the Pacific Ocean, on the edge of Nunura Bay (Figure 4). The site was partially excavated by Cárdenas (Cárdenas *et al.* 1991, 1993), who dug three pits. Investigations

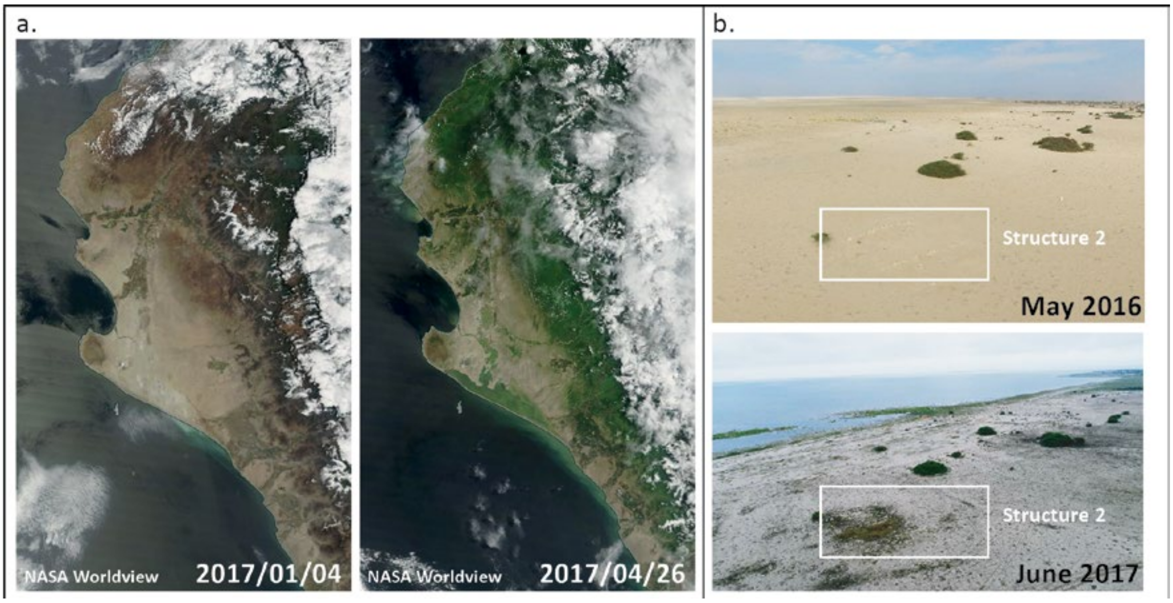

Figure 3. Effects of the *El Niño costero* that occurred during spring 2017. a) Satellite view of the Sechura Desert in January 2017 and at the end of April 2017. b) View of the Bayovar-01 archaeological site in May 2016 and in June 2017.

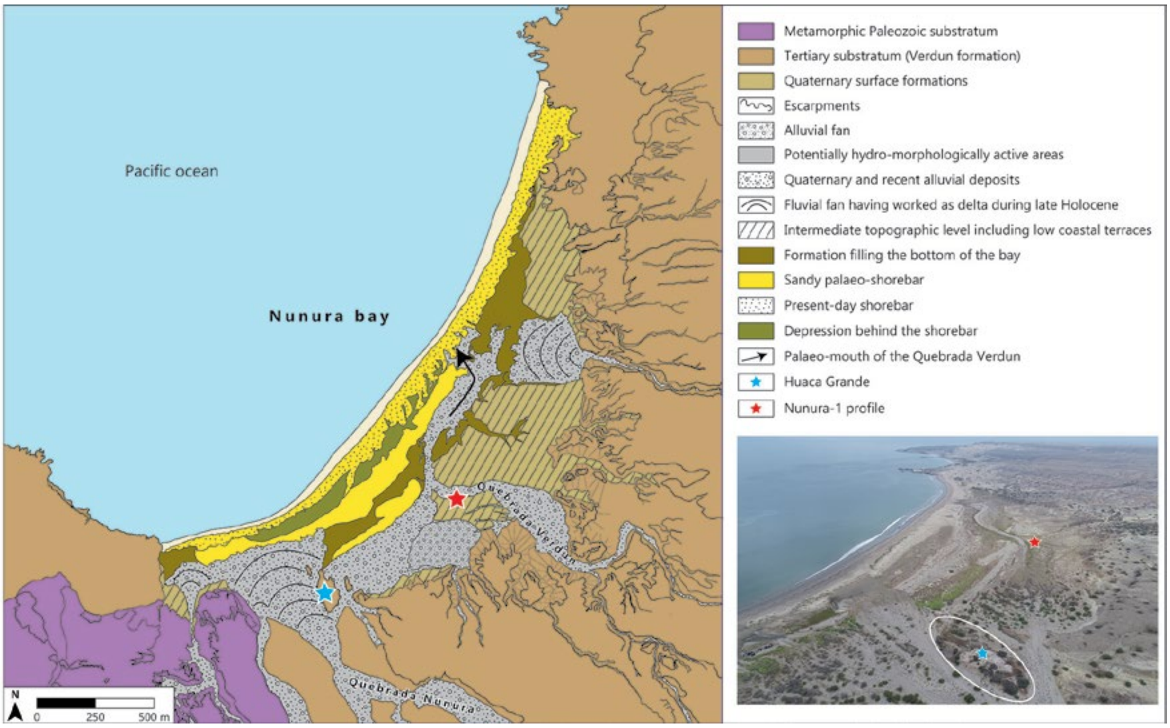

Figure 4. Geomorphological map of the Nunura area (drawn from Google Earth © and field data), location of the Huaca Grande archaeological site (blue star) and the Nunura 1 stratigraphic profile (red star), and aerial view of the bay in May 2018 (credit N. Goepfert).

restarted in 2015 with the objective of establishing a precise chronological and cultural framework for the archaeological sequence preserved at this site. The recent excavations revealed an exceptional stratigraphic succession, about 2.6 m thick.

The sedimentary succession includes deposits with a generally sandy texture, extremely rich in organic debris of various types. Layers of mollusc shells and fish remains without matrix alternate with finer, sandy-clayey, dark brown levels, rich in charcoal, burnt seeds and camelid faeces. Powdery whitish layers, most likely composed of ash, are quite frequent (Figure 5). The archaeological excavation appears to have reached the sterile substrate, located at a depth of about 2.6 m. The succession of occupation levels can be subdivided into five main phases (Figure 5).

In the first stage at the base, the space seems well organized. A compact, east-west oriented clay wall more than 3 m long has been identified at a depth of 2.2 m (Figure 6a). Given its width and height (50 x 50 cm), it is probably a collective structure rather than a housing structure. Circular depressions are present on the upper surface of the wall (Figure 6b). They are most likely postholes,

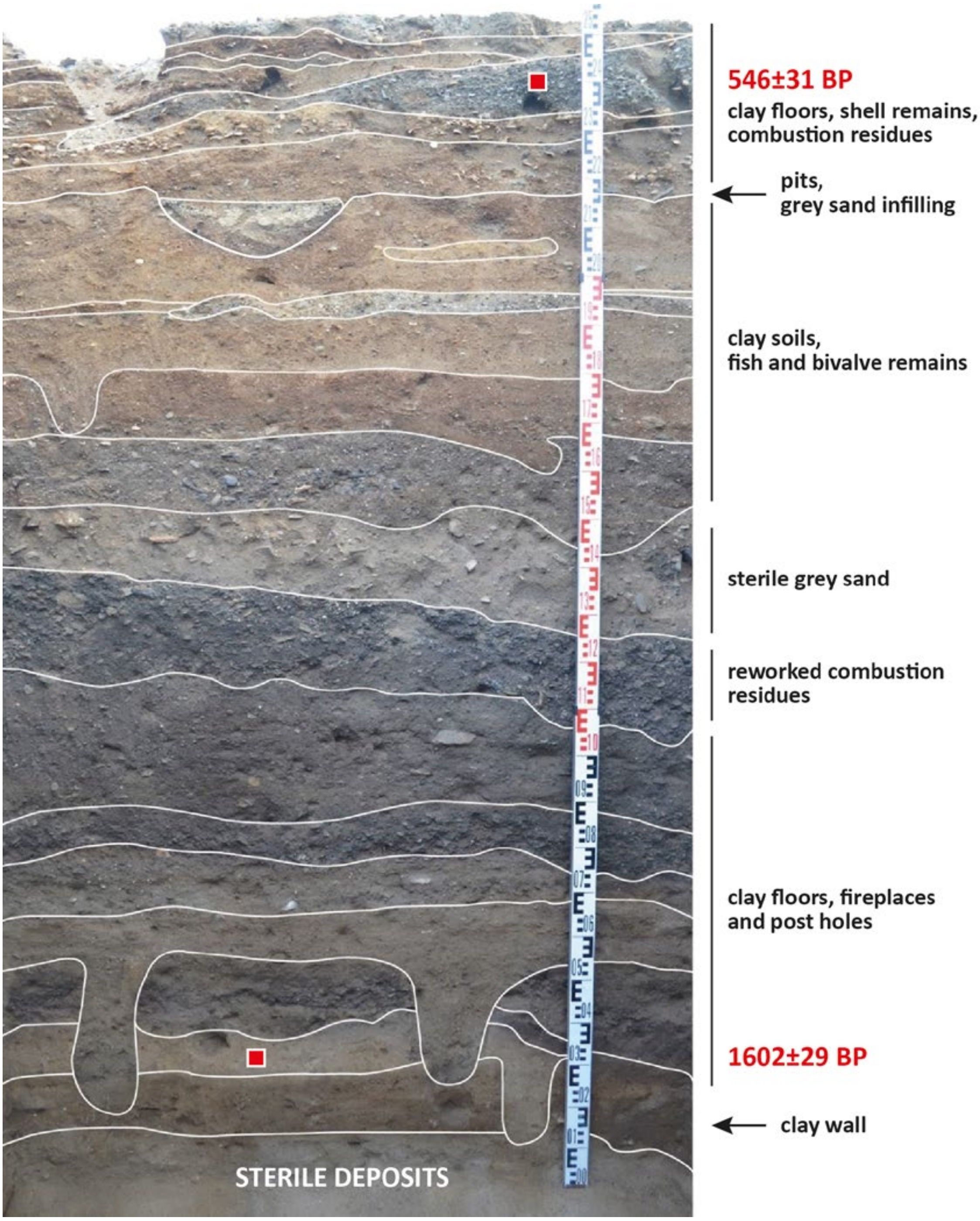

Figure 5. Archaeological sequence of the Huaca Grande site with a brief description and/or preliminary interpretation of the stratigraphic units. The location of the two radiocarbon dates constraining the occupation of the site is also indicated.

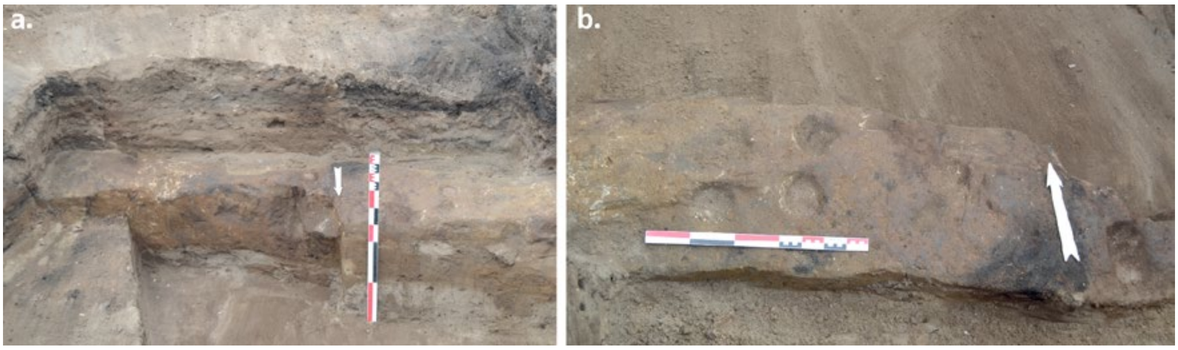

Figure 6. a) Front and b) upper views of the wall discovered at the base of the Huaca Grande archaeological site (credit N. Goepfert).

which may represent the remains of a roof made of perishable material. At this time, we do not have any additional information on this impressive structure, but further research and archaeological excavations will allow us to identify it more clearly and to specify its scope and function. More recent layers that cover the wall consist of a superimposed clay floor, well-preserved fireplaces, and postholes that seem to indicate a later domestic occupation.

In the next phases, Huaca Grande is clearly used as a dumpsite, recorded by a thick black layer (up to 80 cm thick) of reworked combustion residue, comprising mainly plant remains, seeds, and camelid faeces. Afterwards, sedimentation continues with a layer of sterile grey sand covered by a succession of clay soils that alternate with layers composed exclusively of fish and bivalve remains.

A new phase of occupation is attested to by a series of pits that deeply cut the underlying layers. They contained large-sized vases (*tinajas*), whose profiles are well preserved. The fill of these pits consists of a sterile grey sandy sediment that appears to be of natural origin and could indicate a (short?) phase of abandonment of the site. The occupation sequence finally ends with a new succession of stacked clay floors, shell remains, and combustion residue.

The study of the faunal and botanical remains is in progress, but a major distribution within the sequence can already be recognized regarding the resources exploited by the inhabitants of Huaca Grande. The remains of marine mammals, frequent in the lower part of the sequence, decrease considerably over time (four times less frequent in the upper layers than in the lower ones), whereas the opposite trend is apparent for malacofauna, whose importance in the wildlife spectrum increases significantly, from 714 remains at the bottom of the sequence, under the thick black layer (Figure 5), to 19,611 at the top. The abundance of seabirds remains constant throughout the occupation. The most represented species are *Donax obesulus*, *Olivella columellaris*, *Acanthopleura echinata*, *Policines uber,* and *Argopecten purpuratus*. The great majority of the species found at Huaca Grande are still currently present in the region surrounding the archaeological site. However, some species are rather typical of tropical waters in regions located at lower latitudes than Nunura Bay, such as *Cerithium muscarum*, *Semicassis centiquadrata*, *Mazatlania fulgurata,* and *Oliva incrassate* (DeVries and Wells 1990; 'WoRMS – World Register of Marine Species – Mollusca,' n.d.).

Two ^{14}C dates (Figure 7) allow us to place the archaeological sequence between cal AD 423-575 (1602±29 BP; UBA-30844) and cal AD 1399-1448 (546±31 BP; UBA-35563). The site has therefore been occupied for more than a thousand years. Research is still ongoing, and we plan to run several more dates in the future. They are expected to provide a more detailed chronology of the five main occupation phases identified, and to evidence possible phases of abandonment as well as their duration.

				Unmodelled AD		
Name	Material type	14C date	Uncertainty	from	to	%
R_Date UBA-35563	seed	546	31	1399	1448	95.4
R_Date UBA-30844	camelids faeces	1602	29	423	575	95.4

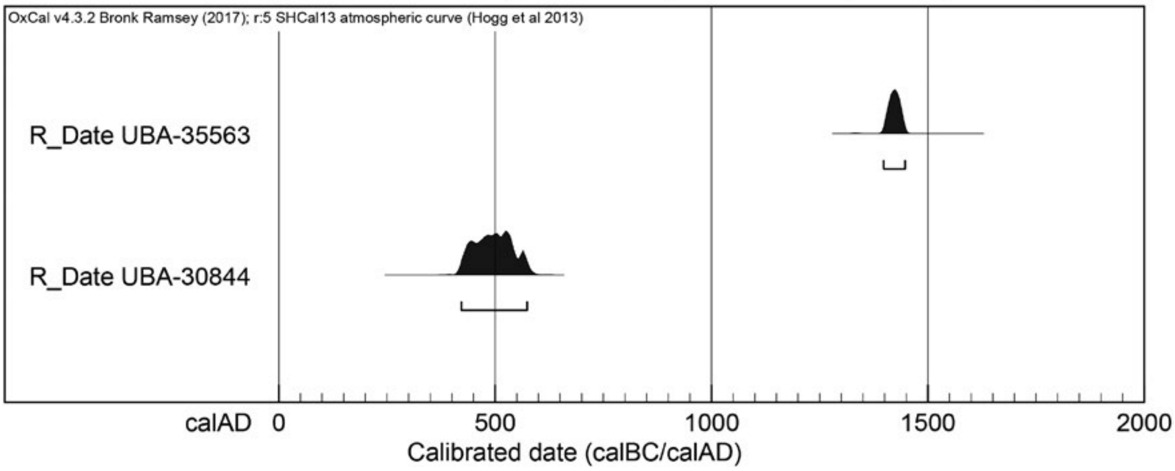

Figure 7. Chronology of the Huaca Grande archaeological sequence. ^{14}C and calibrated dates.

3.2. Geomorphology

3.2.1. Las Salinas

The wide variety of sedimentary facies identified along the geomorphological profile through the Las Salinas depression illustrates the complexity of its history and the deposition environments that occurred during the Middle and Recent Holocene (Figure 2) (Christol *et al.* 2015, 2017). During the past two millennia in particular, the deposits attest to the evolution of a large, open lagoon system, drained but regularly filled with inputs from both marine and continental sources, which led to continuous sedimentation until the 8th century AD. Marine sedimentation was predominant until the 3rd century AD, before being replaced by continental inputs typical of pro-deltaic environments, with the most recent ones dating back to the 6th century AD. From the 8th century, the depression was disconnected from the ocean, causing the filling-in and the drying up of the lagoon (Christol *et al.* 2017).

The geomorphological data thus confirm that the site of Bayovar-01 was established on the edge of a warm-water lagoon, rich in fish and probably bordered by tropical, mangrove-type vegetation. This lagoon environment was subject to several low water level/drying phases (salt crusts were observed within sedimentary sequences). It persisted for more than 500 years due to continental water inputs responding either to a mean-climate and/or to ENSO activity. Bayovar's fisherfolk would have benefited from such an environment, which offered abundant tropical resources. This opportunistic human occupation was highly responsive to environmental changes. Indeed, the site was abandoned in the 8th century AD, when, because of a shift to more arid climatic conditions, the lagoon dried up (Christol *et al.* 2017).

3.2.2. Nunura Bay

Nunura Bay is located north-west of the Illescas massif (Figure 4). It is a small bay, measuring about 3 km wide, bordered by two rocky outcrops cut into Palaeozoic rocks covered by tertiary formations eroded into glacis (with a marine erosion and tectonics origin) during the Pleistocene (Figure 4). The bay is supplied by two main *quebradas* (*tr.* ravines), the longer being the *quebrada* Nunura, which opens to the south after being connected to the secondary, shorter *quebrada*, the *quebrada* Verdun, which connects to the bottom of the bay in its central part (Figure 4). These *quebradas* show active and inherited forms reflecting the activation of these talwegs during older, more humid climatic phases (prior to the 9th century AD – see Las Salinas) or during more recent ENSO events. Within this context, Nunura Bay forms a hydro-sedimentary system connecting upstream a relatively modest catchment area of about 35 km^2 and a maximum altitude of 478 m, downstream to the sea. The slopes of this system are not insignificant but are nonetheless quite moderate, with an average of 2.5% in the Precambrian piedmont. Accordingly, the detrital elements discharged from upstream and passing through the *quebradas* present proximal characteristics with a fairly homogeneous mineralogical composition.

3.2.3. Description of Nunura 1 sequence

3.2.3.1. Location and geomorphological context

The studied sequence is located close to the sea-side on the south bank of a channel about 50 m wide (Figure 4). This channel corresponds to the extension of the *quebrada* Verdun, which, originating at an altitude of slightly more than 300 m from the Palaeozoic metamorphic formations of the Illescas massif, incises the yellow Tertiary deposits of the Verdun Formation. The channel crosses the coastal zone in a northward curve before its morphology, clearly identifiable in the field and on satellite images, disappears at the back of the shore bar (Figure 4). Because of its position, this channel could have functioned as much as a river channel with a palaeo-mouth, as it could have as a tidal channel only. Its prominent shape and important bed load suggest different hydro-sedimentary dynamics than today, with a dominant alluvial sedimentation in the area.

3.2.3.2. Associated sedimentary forms and deposits

The channel edges, slightly less than 50 cm high and still well defined on both sides of the active bed, suggest relatively recent erosional processes. These processes exposed deposits underlying a small terrace whose surface corresponds to the main topographical level of the studied area and leads to the Huaca Grande mound. Along the embankment, several profiles were cleaned on both the left and right side over a length of about 100 m. The sedimentary successions are thick and continue several tens of centimetres below the current channel bottom. It was however often impossible to excavate stratigraphical profiles more than 1 m deep, except for the Nunura 1 sequence, which reaches a thickness of 172 cm.

3.2.3.3. Description of the Nunura 1 sequence sedimentary units

The sequence is composed of five more or less homogeneous groups that can be easily distinguished in terms of facies or assemblage of sedimentary facies (Figure 8). The contacts between these different groups are quite regular and rather horizontal.

At the bottom of the sequence, Unit 1 is formed by a massive grey, sandy-silty facies. It is 69 cm thick, and its upper limit is 103 cm below the surface. Then, between 103 and 75 cm deep, Unit 2 develops, having more diversified layers, ranging from brown to yellowish silty-clayey deposits. Some of these thin facies show relatively large bedding, with horizontal structures. The upper part of this unit shows undulating contact with Unit 3, where a more silty-clayey bed is present, suggesting ripple marks in the sandy deposit. Unit 3 develops between 75 and 58 cm. It consists of grey, sandy-silty deposits, similar to the lower unit, Unit 1. This central part of the profile also shows frequent traces of oxidation, mainly impregnation and stains, but also lenticular forms at the contact with some beds. Unit 4, more homogeneous in its texture and developed over a thickness of about 40 cm (58-20 cm), shows yellowish, brown silty facies with thin silty-clay beds. The structure is generally well bedded, highlighted by variations in colour from one bed to another. According to the colours, three main sub-units can be identified: i) a first, yellowish one delimited by two clayey yellow beds (layer 8); ii) a brown layer in slightly gullying contact with the lower one and showing undulations (layer 9); and, finally, iii) a brown layer whose structure is less visible, with convolutions in its lower part (layer 10). The upper part of the sequence (Unit 5) corresponds to a slightly gresified medium beige sand (with concretions of salt) without any visible structure, underlying the roof of the terrace. This deposit covers the finer deposits on the various stratigraphic profiles observed along the channel.

3.2.3.4. Interpretation and reconstruction of sedimentation environments

In terms of texture, except for the subsurface unit, the deposits observed in the Nunura 1 profile vary from massive sandy-silty facies to rather bedded silty-clayey facies. Moreover, the yellowish colour of most of the finer deposits, particularly in the upper part of the profile, suggests a direct influence of the catchment area and erosion of the Verdun Tertiary Formation. The grey colour of the sandy units suggests a marine influence with material inputs from the ocean and coastal drift associated with sea breezes. The brown and quite dark colour of some silty facies can be explained by a higher organic matter content (Figure 8). Thus, the silty deposits of the middle and top of the sequence could correspond to a reworking of continental elements in a relatively calm water environment allowing bedded sedimentation. The more or less undulating and discontinuous bedded structure of the deposits indicates at least a low-energy current associated with either a restricted opening of the system to the ocean or limited water inputs from the inlands, or a combination of the two. As for the grey sandy deposits, they could correspond to old beach levels or ridges deposited either in a shallow water context, as suggested by the oxidation of Unit 2 and Unit 3, or in sub-aerial conditions. The range of sedimentation environments observed at Nunura is similar to that of the deposits studied at Las Salinas Noroeste (Christol *et al.* 2015, 2017).

3.2.3.5. Relative chronostratigraphy and evolution of the Nunura coast

The absence of precise chronological markers prevents us from placing the Nunura 1 sedimentary record in a broader temporal context and cross-referencing these off-site data with the on-site data. However, these deposits, eroded by a channel incision somewhat recent in the longer history of the coastline, provide a first relative chronology of an environmental evolution preceding the aridification phase recorded at the end of the 1st millennium AD (Christol *et al.* 2017). The diversity and the succession of these environments suggest periods of impoundment of the low topographical areas in the form of lagoons alternating with periods of coastal aggradation under sub-aerial and evaporative conditions.

Nunura 1 record thus begins with a coastal aggradation phase that has allowed the accumulation of almost 1 m of sand (Unit 1; this deposit continues deep into the ground). The low organic matter content of this deposit supports the hypothesis of dominant wind dynamics with ocean material (Figure 8).

Afterwards, the coastline undergoes water infilling and lagoon formation associated with dominant inputs of detrital elements rich in organic matter from the catchment area (Unit 2). This lagoon phase is interrupted by a temporary and unstable period of sandy accumulations (Unit 3), starting with the deposition of a fine, yellow silty-clay bed interbedded in the grey sands at a depth of 75 cm (Figure 8).

Then a rather calm water sedimentation begins, which lasts long enough for 40 cm of sediment to be deposited (Unit 4; Figure 8). This sedimentation occurred in three stages that could reveal changes in environmental conditions. In the first stage, the detritic influence of the continent is clearly visible, with a yellowish colour indicating, however, low organic matter contents (yellow facies). This could be linked to a lower vegetation cover and rhexistasy in the upstream part of the *quebrada* outlet in the lagoon. In the second stage, organic matter inputs seem to increase (Figure 8), potentially signifying production conditions in the lagoon and/or biostasy in the upstream

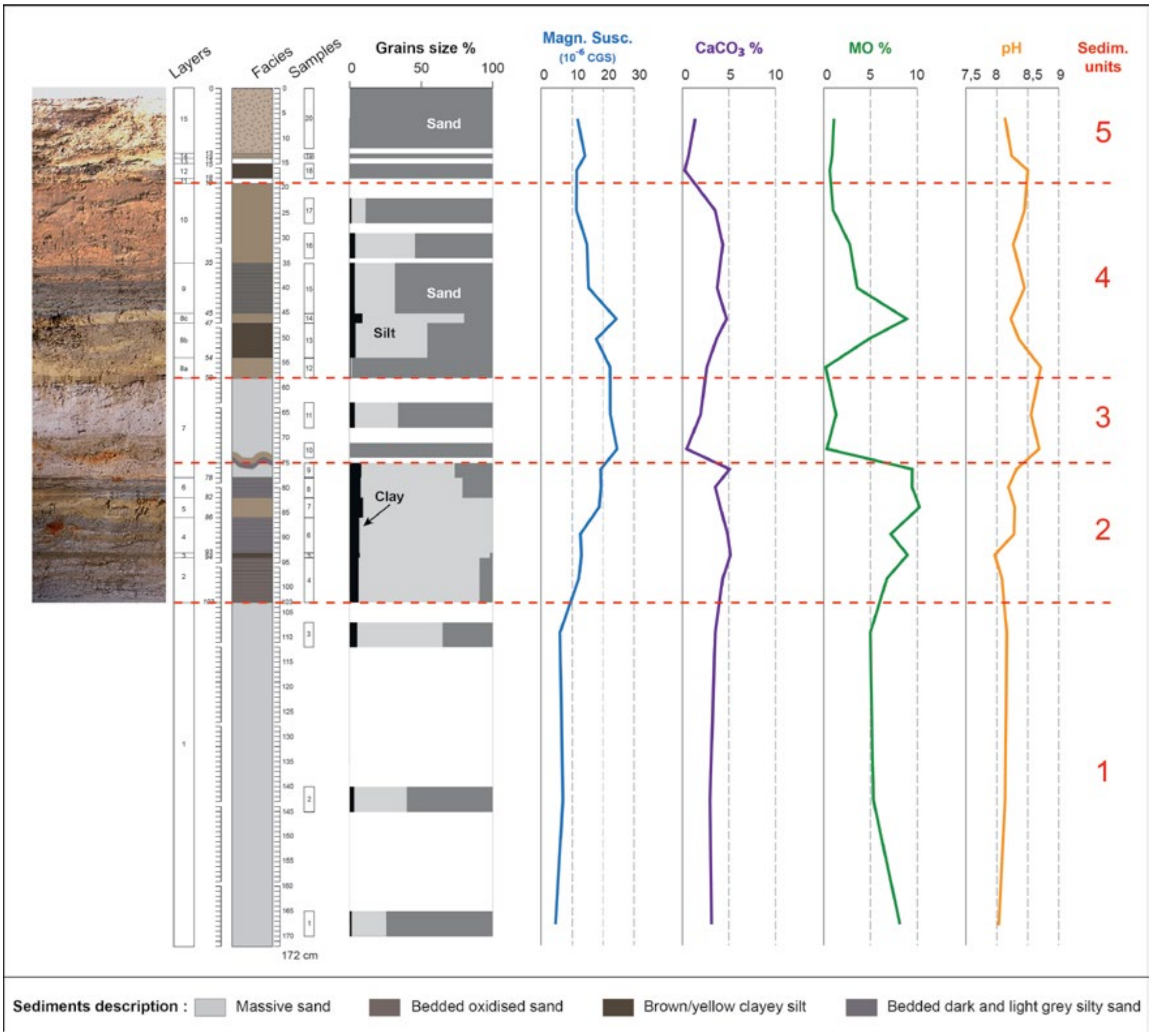

Figure 8. Nunura 1 profile. Description of the sediments; location of the samples; and results of the grain size, magnetic susceptibility, $CaCO_3$, TOC, and pH analyses. The five major sedimentary units are also identified on the profile.

area. This environment is similar to the marsh lagoon phase identified at Las Salinas Noroeste. The final stage is not associated with significant organic inputs, but sedimentation still seems to be sustained by the erosion of the inland from catchment area.

Finally, the upper deposit of the Nunura 1 sequence indicates, as at Las Salinas Noroeste, an aridification of climatic conditions (Unit 5; powdery sand with salt nodules and crusts). This succession represents a major change compared with the lower units, which record relatively humid climatic conditions, which would have been necessary to both activate the hydro-sedimentary dynamics eroding the Illescas massif upstream, and a stream discharge maintaining yearlong a minimum water level in the Nunura lagoon.

4. Discussion

All data exposed above give us information on the landscape and climate evolution of the northern Peruvian coast and on the human occupation of these territories over the past two millennia. Geomorphological data indicate that the region possesses a high environmental sensitivity, which has been and is still being influenced by several factors. Sedimentary archives record environmental changes over several centuries in relation to the variability of the mean climate, but they also reveal the effects of ENSO activity timing and intensity.

Both in Nunura and Las Salinas, a major contrast can be observed between humid and arid climatic phases. During these periods, sediment inputs come from both the ocean and the continent: marine sedimentation alternates with aeolian and alluvial deposits. Particularly significant are the lagoon phases identified at the two sites studied, which correspond to climatic periods which are in average more humid than the current one (Figure 9). In addition to this long-term evolution, ENSO's activity also probably had an influence on the maintaining of lagoon environments. Their presence at Las Salinas up to the 8th century AD was made possible by constant freshwater inflows from the continent, but was most likely enhanced also by one or more intense ENSO events during this period (Rein 2007).

Regarding Nunura, information is currently more limited and less precise, although the presence of lagoon environments is well documented. In addition, the hypothesis of climatic conditions more humid than the current ones is corroborated by the presence of organic sediments indicating vegetation development phases, either along the coast or farther upstream. Afterwards, the sedimentary archives of both sites record the drying of the lagoons, attested to by evaporate deposits with high salt concentrations. This environmental change occurred at Las Salinas around the 8th century, when more arid climatic conditions became established. At Nunura a similar evolution can be observed, but the lack of chronological data does not allow us to affirm that it corresponds to the same aridification phase recorded at Las Salinas, as seems possible.

The coastal environments of northern Peru appear to be particularly sensitive and reactive to the climate changes that have characterized the past two millennia. Consequently, populations living in the Sechura desert had to face several changes over time, in terms of both the variety and the abundance of resources.

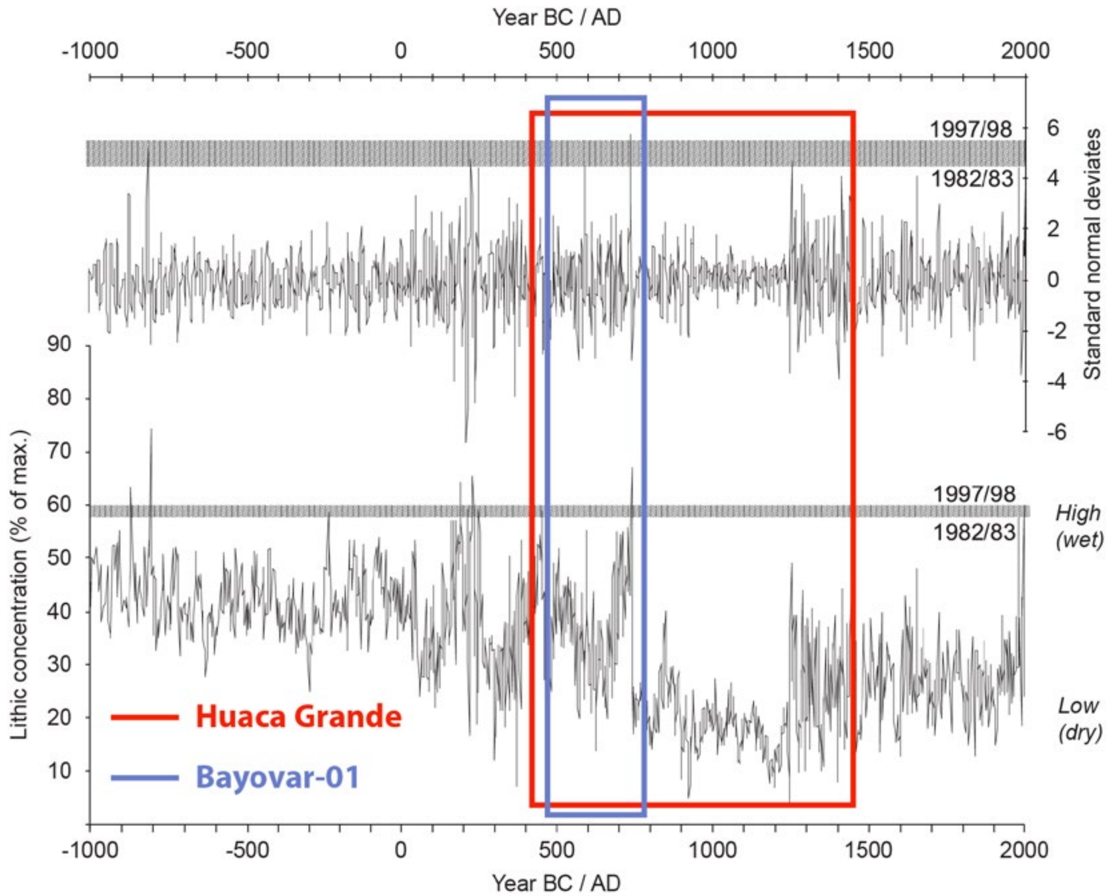

Figure 9. Climatic variability (highlighted by the El Niño flood proxy) during the occupation of the Bayovar-01 and Huaca Grande sites. After Rein (2007). The hatched horizontal bars indicate the magnitude of the 1982/83 and 1997/98 El Niño flood signals.

The archaeological sites of Bayovar-01 and Huaca Grande illustrate two different and complementary ways in which these populations adapted. Bayovar-01 corresponds to a continuous occupation, over a short period of time (at most three centuries), related to the exploitation of a particular resource. Indeed, Bayovar fisherfolk settled on the edge of the Las Salinas lagoon and took advantage of favourable conditions that allowed the development of a new fauna of warm-water fish and molluscs coming from the north. This is an ephemeral and opportunistic occupation, as the site was abandoned when the lagoon dried up during the 8th century AD, and it was not occupied after that time (Goepfert *et al.* 2016, 2019).

On the contrary, the Huaca Grande site hosted a very long-lasting installation, which extends over about a millennium, between the 5th and 15th centuries AD. During this period, the site appears to have been reorganized, changing its function several times, and it was abandoned at least once.

For the moment, the most significant data concerning the occupation are the faunal remains, which indicate an important change in habits and resource supply for the inhabitants of the site. Marine mammals, which are very common in the lower part of the sequence, seem to be progressively replaced by molluscs and fish in the more recent occupation phase. It is necessary to try to understand whether this change is the result of a deliberate choice or whether it is linked to climatic and environmental pressure that would have led to a modification of the resources available near the site. The settlement of Huaca Grande corresponds to a period during which the average climate is affected by several variations (Figure 9): i) a wet phase characterized by a high frequency of extreme ENSO events comparable to 1982/1983 and 1997/1998 until the middle of the 8th century AD, followed by ii) an arid phase marked by the weakening of ENSO between AD 750 and 1250, and then iii) a return to more humid conditions with a restart of ENSO activity (Rein *et al.* 2004; Rein 2007). Thus, climate data show that the inhabitants of Huaca Grande faced significant climate changes. We do not have off-site archives that enable us to reconstruct the evolution of the landscape during the occupation, but the malacological data provide some important information. Nunura Bay is located on the 6th parallel, in the area where the warm waters of the Ecuador–Peru Coastal Current (EPCC) and the cold waters of the Peru Coastal Current (PCC) converge. In biogeographical terms, this corresponds to the transition between the Panamic Province (3.5-4.5° S), characterized by tropical species, and the Peruvian Province (6-13.5° S), dominated by cold water species (Ibanez-Erquiaga *et al.* 2018 and references therein). Nunura Bay is therefore located at the northern limit of the Peruvian Cold Province.

Considering these data, the presence of tropical molluscs in the Huaca Grande site is of particular concern in relation to the evolution of the climate and coastal landscapes of Nunura during the Holocene. It could indicate i) a coastal landscape different from the current one, including confined lagoon environments characterized by warm waters and/or ii) a variation in ocean circulation related to ENSO activity. Indeed, during ENSO events, the species distributed primarily in the equatorial region spread into latitudes where normally cold-upwelling species occur along the southeast Pacific coast (Paredes *et al.* 2004; Hooker 2009). Some of these tropical species can therefore settle and persist in refuge areas for some time after events (Ashton *et al.* 2008; Gárate and Pacheco 2016). If these hypotheses are correct, the third occupation phase identified at Huaca Grande would date to after AD 1250.

Indeed, from that moment on, a more humid climate became established in the area, allowing the conservation of lagoon-type environments. Furthermore, ENSO events were stronger and could have caused shifting of warmer waters southwards, carrying tropical mollusc species to Nunura.

The sedimentary sequence of the Nunura 1 profile cannot be replaced chronologically in relation to human occupations, but it clearly indicates that such environments occurred in the bay and lasted for some time (see Unit 2 and Unit 4; Figure 8). New dates are required to specify the times of occupation of Huaca Grande, but the available data show us a very different type of occupation from that at Bayovar-01, extending over a long time span and based on varied resources, whose diversification is probably linked to the evolution of the environment around the site in relation to climatic oscillations.

5. Conclusion

Our research highlights the high sensitivity of the Sechura Desert's coastal environments to successive climatic changes over the past two millennia and provides insight into how humans adapted to them. Data from sedimentary archives indicate the establishment of lagoon environments characterized by warm and shallow waters during phases of average climate more humid than the current one, between the 3rd and 8th centuries AD, and again from the middle of the 13th century onwards. These environments persisted for several centuries, probably favoured by the occurrence of some particularly intense ENSO events. A shift was recorded during the 8th century AD, when more arid conditions set in and caused the lagoon of Las Salinas to dry up.

The populations living in the Sechura Desert adapted to these changes in two different ways, as illustrated by the two archaeological sites of Bayovar-01 and Huaca Grande. A fishing community settled in Bayovar-01 in an ephemeral and opportunistic manner, exploited the important resource represented by the fish living in the Las Salinas lagoon, and abandoned the site three centuries later, when the lagoon dried up due to more arid climatic conditions and the disappearance of the resource.

In contrast, Huaca Grande corresponds to a more or less continuous and permanent occupation of the same site where people changed their subsistence economy according to the resources available in the vicinity of the site. However, these two modes of occupation are not opposed, but, rather, are integrated in a complementary way into an occupation strategy that had to be flexible to be able to adapt to the very marked constraints that characterize the Sechura desert. Bayovar-01 is most likely part of a larger commercial network linked to other sites. Further research is needed at Huaca Grande to define its function and possible links with contemporary sites.

Our study therefore shows the need to apply a regional approach integrating off-site data from sedimentary archives and on-site information from archaeological excavations in order to assess the variety of human occupation patterns in a highly variable environment, such as the northern Peruvian coast.

Acknowledgments

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Archaeological and paleoenvironmental reconstructions in the tropical Maya area: the case of Naachtun (Guatemala)

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Abstract

Since 2013 a joint team of archaeologists and paleoenvironmentalists has been conducting an interdisciplinary program on the Maya regional capital of Naachtun (Guatemala), in order to reconstruct its history and the management of local resources by the ancient Mayas (mainly water, soils, fauna and wood). In parallel, intensive archaeological excavations conducted since 2010, and environmental works both in the site epicenter and in its surroundings areas, allowed us to draw a sequence of intra-site occupation during roughly a millennium (150 – 950 AD). The archaeological and environmental reconstructions differ greatly as the latter cover the last four millennia. The sedimentary archives studied result from and testify to lateral and vertical gradients of anthropization (settlements, reservoirs, marsh and fields).

In this contribution, we aim to present the focal points and the points of divergences between the two sequences in progress (archaeological and environmental): one mainly based on chrono-ceramic data and radiocarbon dates from residential contexts; the other on radiocarbon dating of charcoal and organic matter in soils within agrarian fields or within flooded and colluviated sedimentary environments both in intra-site and in off-site areas. On the one hand, the interdisciplinary dialogue allows us to identify and date the main societal changes (during emergence, growth and decline of the city) and environmental changes (fluctuations in local water supplies, episodes of soil erosion, forest dynamics and farming practices). On the other hand, it allows us to characterize the nature and timescales of environment-societies interactions or to identify points of divergence between the two sequences.

Keywords: Naachtun, occupation sequence, paleoenvironmental sequence, land use, Maya collapse

Résumé

Depuis 2013, une équipe d'archéologues et de paléo-environnementalistes développe un programme pluridisciplinaire dans la ville maya de Naachtun (Guatemala), une grande capitale régionale, dans le but de retracer l'histoire de la cité ainsi que la dynamique et la gestion des ressources du milieu par les anciens Mayas (principalement, l'eau, les sols, la faune et le bois). En parallèle, des fouilles archéologiques intensives, conduites depuis 2010, et des travaux environnementaux menés tant dans l'épicentre du site que dans les zones alentours, ont permis d'établir la séquence intra-site au cours du millénaire d'occupation (150 -950 apr. J.-C.). La comparaison entre les reconstitutions archéologiques et environnementales n'est pas chose simple ; celles-ci diffèrent grandement car les dernières, à la différence des premières, portent sur les quatre derniers millénaires. Les archives sédimentaires étudiées résultent et témoignent de gradients d'anthropisation latéraux et verticaux (entre habitat, réservoirs, marais et champs cultivés).

Dans cette contribution, nous passerons en revue l'histoire de la cité et présenterons les points de convergence et de divergence entre ces deux séquences en cours d'élaboration, l'une, archéologique, basée sur une séquence chrono-céramique et des datations radiocarbones en contexte résidentiel ; l'autre, environnementale, basée sur des datations de charbons et de matières organiques à l'intérieur de sols cultivés ou au sein d'archives sédimentaires en zones inondées, le tout en intra-site comme en hors site. D'un côté, le dialogue entre disciplines nous permet d'identifier et de dater les principaux changements sociétaux (durant l'essor, l'apogée et le déclin de la cité) et les changements environnementaux (fluctuations de la réserve en eau, épisodes d'érosions des sols, dynamiques forestières et pratiques agraires). De l'autre, cela nous permet de caractériser la nature et le cadre des interactions Homme-milieu ou d'identifier des divergences majeures entre les deux séquences.

Mots-clés : Naachtun, séquence d'occupation, séquence environnementale, gestions des sols, l'abandon des cités mayas

Introduction

Naachtun is a major Maya Center dated from the Classic period (AD 150 – 950/1000). Located in northern Petén, Guatemala, it was first reported in 1922 by Sylvanus Morley. Its epicenter, mapped in 1934 by the Carnegie Institution, is composed of three main monumental groups labelled Group A, B, and C settled on two elevations. These two hills are separated by a seasonal stream located in an incised thalweg that runs S-N (Ruppert and Denison 1943). Naachtun was a powerful regional capital, judging from the presence of no fewer than 70 stone monuments dedicated by the local royal dynasty established in the city from at least AD 325 to AD 760 (Cases and Lacadena 2014a, 2014b; Nondédéo 2017, Nondédéo *et al.* 2020).

Despite its key location midway between Tikal and Calakmul, the two superpowers of the central Maya lowlands during the Classic period (Figure 1), Naachtun has received little attention from researchers, except from a Canadian-Guatemalan project that investigated part of its epicenter in 2004-2005 (Rangel and Reese-Taylor 2005, 2013). In 2010, a French and Guatemalan archaeological project was initiated in Naachtun, and combines since 2013 archaeological excavations and environmental approaches. Among the primary goals of this ongoing interdisciplinary program, we aim at reconstructing the political history and the social and economic organization of the city as well as the management and exploitation of local resources.

Like many ancient Maya cities, Naachtun reached its apogee during the Late Classic period (AD 600-950). Its chronological sequence was, however, longer, dating back to the Preclassic period (around 400 BC), during which no public structure in the epicenter and only a few dispersed households in the residential area have been identified. However, Middle Preclassic occupations have been detected about 4.5 km east of Naachtun, in Kunal, a major Preclassic Center also located in its hinterland (Morales-Aguilar 2020). During the Early Classic period, the Bat dynasty started to rule during the first quarter of the fourth century AD. At that time, Naachtun converted into a major capital with a strong regional influence materialized by the construction of a vast causeway network connecting its epicenter to subordinate centers located more than 10 km away (Nondédéo *et al.* 2018, 2019, in press). This first apogee of Naachtun, a political one, during the Early Classic period between roughly AD 250 and 550, corresponds to the city's monumental and demographic growth (Hiquet 2020; Hiquet *et al.* in press). After a period of relative decline, another apogee, a demographic one both in the epicenter and in residential areas, occurred during the second half of the Late Classic period, i.e. AD 750 and 850/900, just before the famous Maya collapse, and just after the city experienced emancipation from Calakmul political control that had lasted for about a century in the first half of the Late Classic period (Nondédéo *et al.* 2020).

Naachtun is located on a karstified limestone plateau at an altitude of 300 m.a.s.l. Hilly areas (uplands) alternate with flat and low areas (lowlands, karst poljes), depressions called *bajos* (Beach

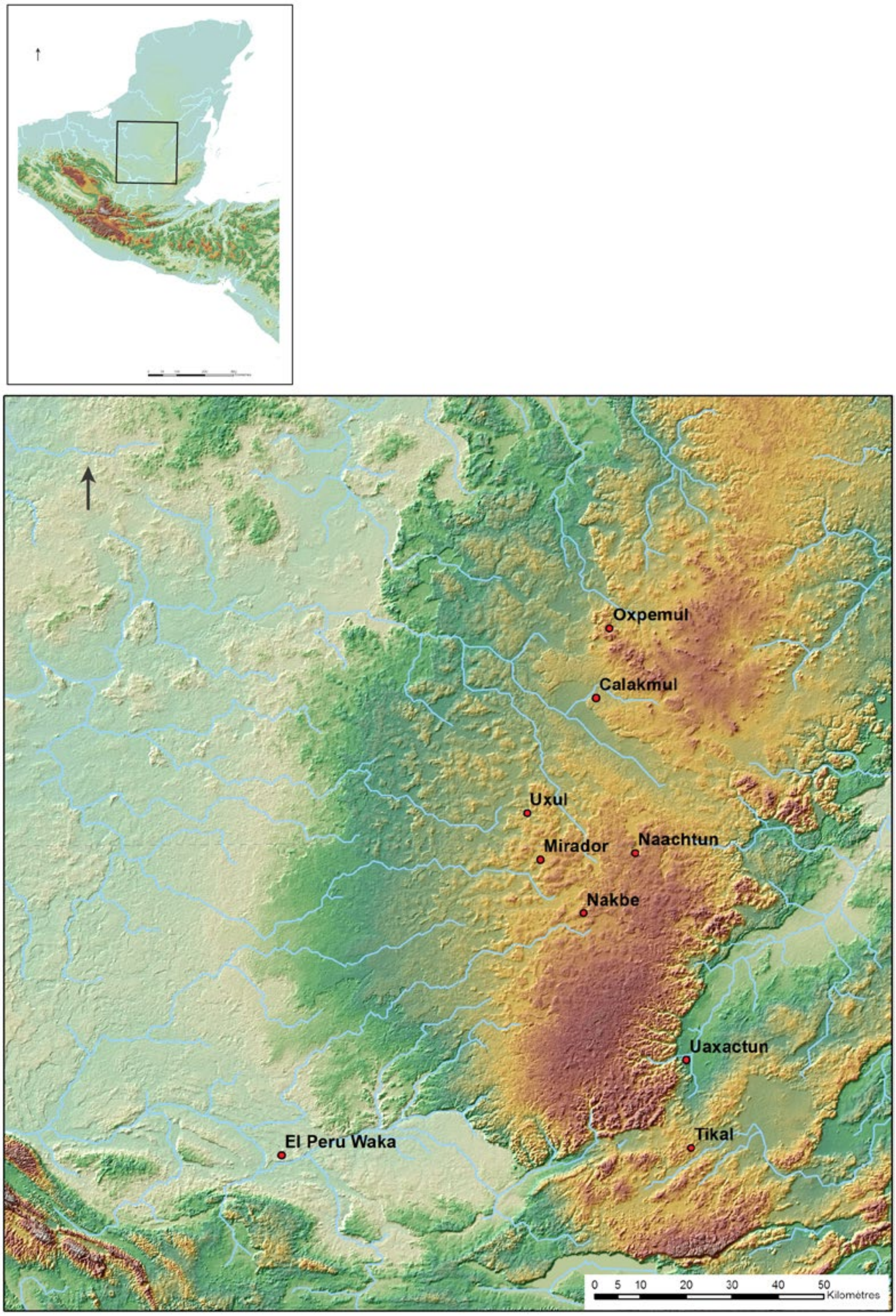

Figure 1. Map of the central Maya lowlands with the location of Naachtun.
(Map by J.F. Cuenot).

et al. 2003). The city is located on the southern hills of a large and deep *bajo* and is surrounded to the south by another smaller one. The soils currently developed on the hills are relatively thin, and are mollisols, inceptisols and alfisols, while the soils encountered on the *bajos* are thicker and histosols and vertisols (Beach *et al.* 2003). The hills are drained by small seasonal streams located in deep thalwegs. During the rainy season, these *arroyos* mainly supply the northern *bajo* of Naachtun, which is flooded. Within this *bajo*, three small water bodies called *civales* are still present at the end of the dry season. These seasonal environments present flooding intensity and low water levels characterized by high seasonal and inter-annual variability. The climate is tropical, seasonally humid and dry (Aw) (García 1981). Alternating dry and very rainy seasons last six months each. The natural storage of surface water being very low because of the permeability of the limestone substratum, two periods are critical in terms of water resources: (1) the end of the dry season and (2) the rainy months when the higher water levels lead to soil erosion and floods in the cultivated and/or occupied areas. Regarding the vegetation, the landscape is currently closed by the Petén's sub-perennial rainforest. Hilly areas are forested by a high forest formation and the *bajos* by low forest formations, while bushes bring together terrestrial and aquatic communities (Castañeda Salguero and Hansen 2008; Testé *et al.* 2020). Partially deforested during the Preclassic and Classic periods, the landscape of Naachtun and its surroundings is included today in the biodiversity-rich Naachtun – Dos Lagunas Biotope of the Mayan Biosphere Reserve (CONAP 1996).

Intra-site/off-site investigations, methodology and proxies

After five field seasons of pedestrian survey, and nearly 100 test pits dug in the patio groups of the residential area, along with nine field seasons of intensive excavations in the monumental epicenter, we now have a rather good idea of the spatial organization and occupation sequence of Naachtun whose core zone occupies approximately 2.5 km^2 (Figure 2) (Nondédéo *et al.* in press; Hiquet *et al.* in press). The chrono-ceramic sequence is mainly based upon ceramic data with the addition of 34 radiocarbon dates (Table 1). Intensive pedestrian survey allowed the identification

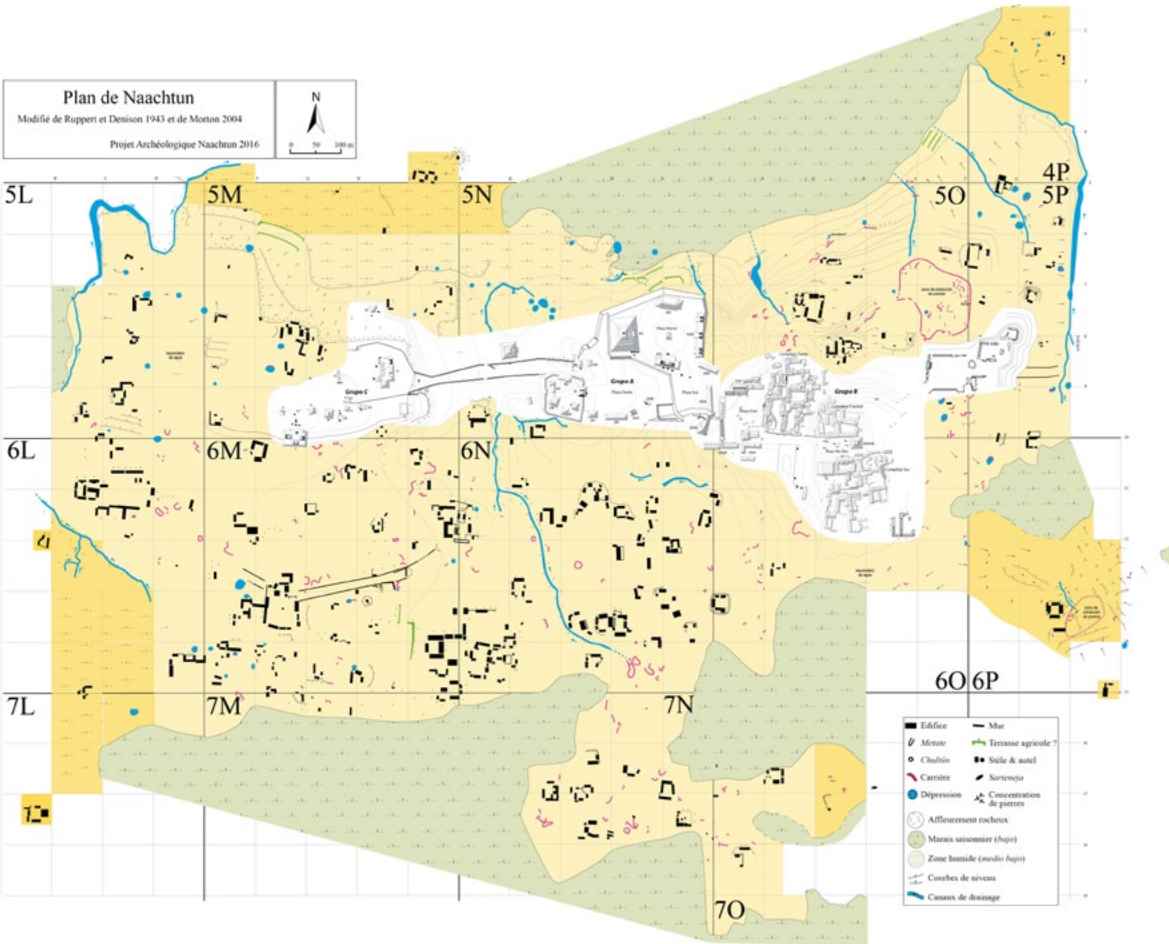

Figure 2. Map of Naachtun core zone. In white: the monumental epicenter of 33 ha; in pale yellow: the residential area of 15 ha; in yellow: the beginning of the rural zone. (Map and data E. Lemonnier and J. Hiquet).

Context/Phase	Ceramic phase	US	Lab-#	Provenience	Material/Taxon	Conventional 14C Age BP	2σ cal range
Group B/Post-abandonment							
	Muuch 2?	N11-584	UBA-24869	On-floor burnt deposit in central room, structure 5O-5	Charcoal/cf. Sapindaceae	860 ± 27	AD 1051-1082 (7,9%) AD 1129-1132 (0.6%) AD 1151-1254 (91,5%)
	Muuch 2?	N11-584	Poz-89390	On-floor burnt deposit in central room, structure 5O-5	Charcoal/Sapindaceae, *cf. Thouinia*	910 ± 30	AD 1033-1090 (94%) AD 1198-1204 (1,4%)
	Muuch 2?	N11-549	Poz-89391	On-floor burnt deposit in front of niche, structure 6O-5	Charcoal/Sapindaceae, *cf. Thouinia*	985 ± 30	AD 990-1056 (51,3%) AD 1077-1154 (44,1%)
Group B/Terminal Classic							
	Muuch	N13-2244	UBA-24874	On-floor ash layer in room d, structure 5O-131	Charcoal/Fabaceae	1141 ± 27	AD 777-792 (5,2%) AD 856-979 (84,8%) AD 802-845 (10%)
	Muuch	N14-2058	Poz-89844	On-floor burnt deposit inside room 1, structure 5O-120	Seed/*Zea mays*	1155 ± 30	AD 775-969 (95,4%)
	Muuch	N13-2408	UBA-24873	Burnt deposit within the collapsed structure, structure 6O-16bis	Charcoal/*Astronium sp.*	1169 ± 29	AD 772-902 (84,9%) AD 919-963 (15,1%)
	Muuch	N12-1377	UBA-24871	On-floor domestic midden, structure 6O-9	Charcoal/*Byrsonima sp.*	1143 ± 38	AD 776-794 (7,7%) AD 797-980 (92,3%)
	Muuch	N13-1872	UBA-25218	On-floor domestic midden, structure 6O-43	Charcoal/Moraceae, *cf. Brosimum*	1194 ± 27	AD 725-738 (2,2%) AD 768-894 (96,6%) AD 930-938 (1,2%)
Group C/Late-Terminal Classic							
	Maax 3	N17-7029	Poz-105653	On-floor burnt deposit, back room, structure V-f	Charcoal/*Pinus sp.*	1255 ± 30	AD 672-779 (80.3%) AD 790-868 (15.1%)
	Maax 3/Muuch ?	N17-7029B	Poz-105639	On-floor material (midden?) on platform, structure V	Charcoal/*Pinus sp.*	1220 ± 30	AD 692-748 (20.9%) AD 762-887 (74.5%)
	Maax 3	N17-7002	Poz-105638	On-floor material (midden?) between structures V-f and V-g	Charcoal/*Lysiloma aurita*	1285 ± 30	AD 666-771 (95.4%)
Group B/Late Classic							
	Maax 2	N11-105	UBA-24867	Construction fill, structure 6O-18	Seed/*cf. Brosimum alicastrum*	1257 ± 25	AD 672-777 (93,8%) AD 840-861 (2,9%) AD 813- 825 (1,3%) AD 791-804 (2%)
	Maax 2	N11-1336	UBA-24870	Construction fill, structure 6O-7	Charcoal/*Gymnopodium floribundum*	1295 ± 25	AD 664-727 (65,8%) AD 737-768 (34,2%)
South residential area/Late Classic							
	Maax 3	N14-2759	Lyon-12476	Burial 43 ashy matrix, structure 5N-6	Charcoal/Poaceae	1265 ± 30	AD 666-779 (89,1%) AD 840-863 (2,8%) AD 812-826 (1,5%) AD 791-805 (1,9%)
	Maax 2-3	N11-131	UBA-24868	Construction fill, structure 5N-9	Charcoal/Sapotaceae	1290 ± 28	AD 665-732 (64,6%) AD 735-769 (35,4%)
	Maax 2-3	N14-2783	Lyon-12475	Burial 41 ashy matrix, structure 5N-6	Charcoal/*Lonchocarpus sp.*	1340 ± 30	AD 645-715 (84,1%) AD 744-765 (11,3%)
	Maax 2	N14-2776	Lyon-12476	Burial 45 ashy matrix, structure 5N-6	Charcoal/*Diospyros sp.*	1325 ± 30	AD 650-722 (75,4%) AD 740-768 (20%)
Group A/Early Classic							
	Balam 2	N17-7246	Poz-105949	Platform floor, structure XXIIIB	Charcoal/*Gymnopodium floribundum*	1650 ± 30	AD 264-274 (1.1%) AD 330-433 (85.3%) AD 461-466 (0.5%) AD 489-533 (8.5%)
	Balam 2	N14-2135A	Poz-105651	Buried burnt deposit, Walled compoud	Charcoal/*Lonchocarpus sp.*	1600 ± 30	AD 399-539 (95.4%)
Group C/Early Classic							
	Balam 2	N17-7035	Poz-105641	Construction fill, platform, structure V	Charcoal/Fabaceae, *Cojoba/Pithecellobium* type	1735 ± 30	AD 240-385 (95.4%)
	Balam 2	N17-7037	Poz-105953	Construction fill, platform, structure V	Charcoal/*Gymnopodium floribundum*	1650 ± 30	AD 264-274 (1.1%) AD 330-433 (85.3%) AD 461-466 (0.5%) AD 489-533 (8.5%)
South residential area/Early Classic							
	Balam 3	N15-4596	Poz-84605	Buried occupation level, below structure 6M-100	Charcoal/Fabaceae, *Cojoba/Pithecellobium* type	1550 ± 30	AD 423-574 (95,4%)
	Balam 3	N14-3795	Poz-84606	Burial 48 matrix, structure 6L-21	Charcoal/*Lysiloma aurita*	1555 ± 30	AD 421-570 (95,4%)
	Balam 3	N14-2765	Lyon-12474	Burnt deposit in construction fill, below structure 5N-6	Charcoal/*Eugenia sp.*	1615 ± 30	AD 387-538 (95,4%)
	Balam 3	N13-1476	Poz-105637	Ash deposit (possible hearth) in fill, below structure 6M-21	Charcoal/Myrtaceae, *Eugenia/Psidium*	1485 ± 30	AD 474-485 (1.2%) AD 536-646 (94.2%)
	Balam 2	N14-3799	Poz-84602	Buried deposit, structure 6L-21	Charcoal/*Gymnopodium floribundum*	1685 ± 30	AD 257-297 (13,4%) AD 320-419 (82%)
	Balam 2	N14-3757	Poz-84604	On-floor material buried by fill, structure 6M-53	Endocarp charcoal/Indet	1670 ± 30	AD 258-285 (6%) AD 321-428 (89%) AD 290-295 (0,4%)
	Balam 2	N13-1780	Poz-105951	Floor fill, structure 6N-60	Charcoal/*Coccoloba sp.*	1575 ± 35	AD 406-560 (95.4%)

Table 1. Radiocarbon dates obtained from archaeological contexts that cover the entire occupation sequence.

Context/Phase	Ceramic phase	US	Lab-#	Provenience	Material/Taxon	Conventional 14C Age BP	2σ cal range
	Balam 2	N13-1782	Poz-105652	Floor fill, structure 6N-60	Charcoal/*Lysiloma aurita*	1650 ± 30	AD 264-274 (1.1%) AD 330-433 (85.3%) AD 461-466 (0.5%) AD 489-533 (8.5%)
	Balam 2	N13-2520	Poz-84603	Buried deposit, structure 6M-74	Charcoal/*Pinus sp.*	1770 ± 30	AD 138-345 (95,4%)
	Balam 1	N15-4588	Poz-105950	Paleosol on bedrock, below structure 6M-18	Charcoal/*Gymnopodium floribundum*	1770 ± 30	AD 138-345 (95,4%)
South residential area, Late Preclassic							
	Kuts'-Balam 1	N14-3733	Poz-84600	Levelling on bedrock, below structure 6L-40	Charcoal/*Piscidia piscipula*	1770 ± 30	AD 138-345 (95,4%)
	Kuts'	N14-3704	Poz-84598	Levelling on bedrock, below structure 6M-64	Charcoal/Sapotaceae	2250 ± 30	395-347 BC (31,3%) 321-206 BC (64,1%)
	Kuts'-Balam 1	N15-4537	Poz-84599	Buried deposit in construction fill, structure 6L-22	Charcoal/Fabaceae, *cf. Gliricidia*	2265 ± 30	399-350 BC (44.4%) 306-209 BC (51%)

Table 1. Continued.

of three main sectors defined on the basis of densities, size, and arrangement of buildings. An epicenter, composed of public plazas and political buildings, occupies 33 ha over which structures are very dense (8.6 str/ha). A residential area of 150 ha, showing a lower density (3.9 str/ha) encloses the epicenter, mainly to the south, east and west. Finally, a rural zone (scarcely explored) is characterized by a density drop (1.6 str/ha). Towards all cardinal points around Naachtun urban core, geotopographical limits were identified and helped to distinguish residential areas from rural zones. These borders are formed by wetlands areas to the north and south, and deep incised thalwegs to the east and west.

Since 2016, our knowledge of Naachtun history and settlement pattern has been increasing with the exploitation of new data provided at a micro-regional scale by a LiDAR survey of 135 km² around the city, which allowed us to initiate a thorough study of the hinterland. For instance, the rural zone we had identified corresponds in reality to decreasing density due, in *trompe-l'oeil*, to the presence of the narrow deep thalwegs. Once these drainage zones unsuitable for human occupation are crossed the settlement pattern continues and the density of the residential areas increases again up to numbers almost equivalent to that of the epicenter, but without public architecture (Figure 3). From an urbanistic point of view, we consider here that the urban core of the city (intra-site Naachtun) is composed of its epicenter and associated residential areas, while rural and swampy zones are considered off-site sectors.

In parallel with these archaeological data, a geomorphological and geoarchaeological survey and test pits program has been systematically conducted since 2013 in intra-site and off-site sectors. Results aim at reconstructing local resource management for soils, water, wood and fauna through (1) pedological excavations, core samplings in *bajos*, *aguadas* and in potential agricultural fields, and (2) charcoal analysis of ancient firewood. Another objective is to measure the impact of human activities prior to, during, and after the site occupation, especially when recorded by erosion processes. Methods include sedimentological, pedological and paleoecological studies, with a specific attention given to sedimentological, geochemical, micromorphological and palaeoecological analyses. Because pollen content remains usually very low in swampy contexts, paleoecological proxies are mainly charcoals, phytolith and molluscs. The data from these analyses are framed by 33 Radiocarbon dates (Table 2) which provide a record spreading over the last fourth millennia. The sequence, still under construction, is not discussed in this paper.

Results and discussion

Preliminary results presented here concern societal, environmental and socio-environmental dynamics. They are discussed below, in a diachronic way, from early occupations to the abandonment of the city of Naachtun.

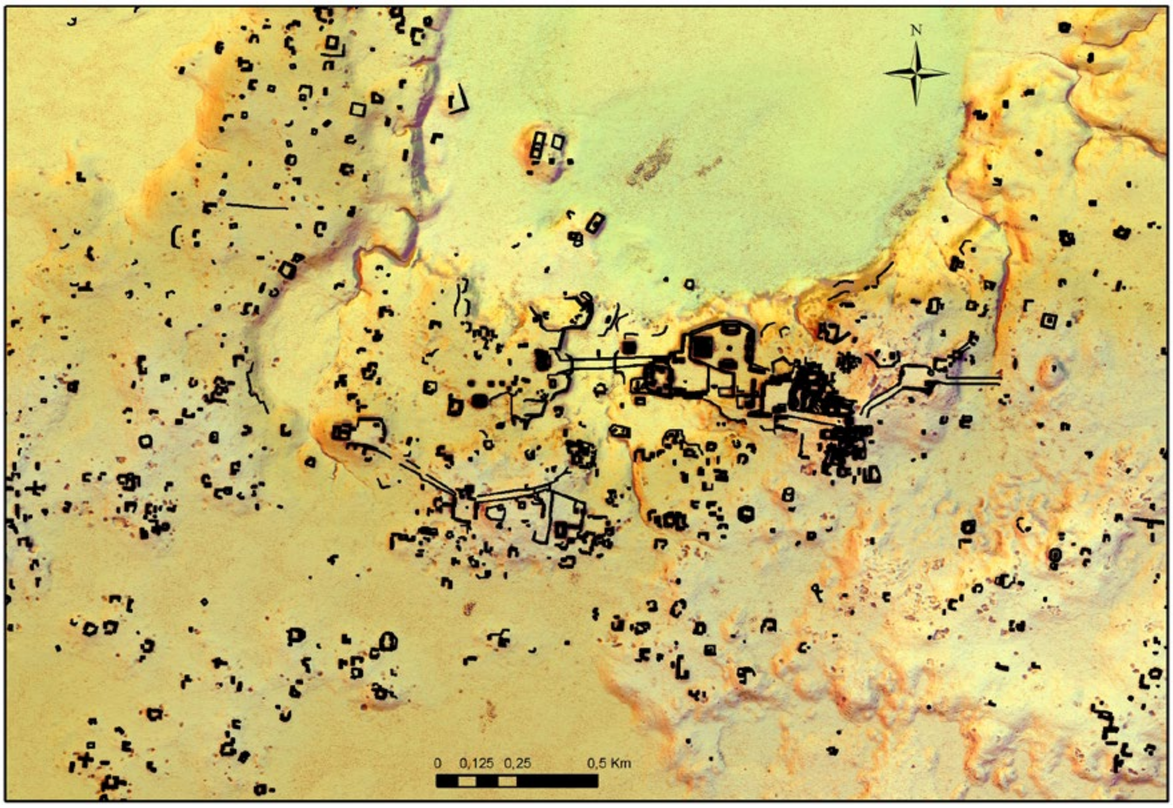

Figure 3. Naachtun settlement pattern (8.5 km²) out of the core zone.
We can observe the strong density west of the Naachtun epicenter.
(DEM courtesy of Pacunam; Data: Naachtun archaeological Project).

Cross section / Core	Lab. no.	Radiocarbon date (BP)	Calibrated age (2σ) (cal. BC/AD)*	Material
M1S2C	Poz-68786	**1775 ± 30 BP**	[cal AD 138: cal AD 200] 0,137308 [cal AD 206: cal AD 339] 0,862692	Organic clayey alluviums
M1S2C	Poz-70743	**3105 ± 35 BP**	[cal BC 1441: cal BC 1272] 1	Organic clayey alluviums
M2S1	Poz-68448	**1480 ± 40 BP**	[cal AD 433: cal AD 458] 0,036697 [cal AD 467: cal AD 488] 0,036062 [cal AD 533: cal AD 651] 0,927241	Organic clayey alluviums
M2S10	Poz-75252	**3190 ± 60 BP**	[cal BC 1615: cal BC 1374] 0,927847 [cal BC 1351: cal BC 1303] 0,072153	Organic clayey alluviums
NA 14, T7, US 3234	Poz-89877	**3155± 35 BP**	[cal BC 1699: cal BC 1598] 0,725 [cal BC 1741: cal BC 1711] 0,094 [cal BC 1587: cal BC 1533] 0,134	Microcharcoal
NA 14, T7, US 3234	DeA-8042	**3706± 25 BP**	[cal BC 2179: cal BC 2029] 0,851 [cal BC 2197: cal BC 2168] 0,103	Microcharcoal
NA 14, T7, US 3234	DeA-8042	**1704± 24 BP**	[cal AD 255: cal AD 302] 0,232 [cal AD 316: cal AD 400] 0,702	Microcharcoal
NA 14, S1, US 3110	DeA-8038	**1657± 23 BP**	[cal AD 336: cal AD 426] 95,4	Charcoal

* CALIB 7.0 uses the 2013 international calibration datasets (Reimer et al. 2013)

Table 2. Radiocarbon dates obtained from Holocene sediment sequences of cross sections and cores from the *bajo* El Infierno (M1S2C, M2S1 and M2S10), the *bajo* footslopes (T7), and the epicenter (S1).

Early occupations

As indicated by ^{14}C dating obtained on wood charcoal associated with sherds from very few intra-site contexts (Tables 1, 3), the first archaeological evidence of Naachtun occupation dates back to the Late Preclassic period, between 400 and 200 BC. The settlement was then very dispersed in the residential area, with very rare residential units clearly occupied. On the larger scale of the 2018-2019 field seasons of ground-truthing intended to verify LiDAR features, this Preclassic scenario is being revised as substantial Preclassic occupation and monumental constructions have been identified in Kunal and in El Saraguate, another monumental group located 2.8 km south of Naachtun.

The combined analysis of both archaeological and environmental sequences widens our knowledge about the occupation of the area. Environmental sequences reveal human activities dating back to the midst of the second millennium BC and mainly located in the northern *bajo* El Infierno. There, lithofacies, geometry and age of a carbonated sedimentary layer suggest the presence of a shallow lake very early during the Preclassic period, at least from 1600 BC on. The data suggest fluctuations in the extent and depth of this lake until ca 400/200 cal BC or somewhat later, when it was progressively replaced by a seasonal swamp (Castanet *et al.* 2016).

This 1600 BC date corresponds to the oldest evidence of a human occupation in the area, i.e. one millennium before the first archaeological remains detected. The evidence consists of:

- erosion/sedimentation records on the slopes of the *bajo*, which we attribute to episodes of forest clearance probably for agricultural purposes (resulting in a soil degradation and increased runoff: Figure 4), as described in fluviokarst landscapes of the southern and central Maya Lowlands by Beach (*et al.* 2008);
- the presence of artifacts and other ecofacts in alluvial deposits associated with ^{14}C dates ranging from 1500 to circa 100 BC;
- three areas in the city itself that provided traces of human activities. In the central west of the city, small depressions have been interpreted as ancient cultivated fields as they caught both soil and water from surrounding areas (Purdue 2018). Using charcoal and organic matter, these ancient fields are dated from circa 1400 BC on. But this chronology needs to be refined as some carbonized maize seeds have been also dating back to 2800 BC. In the hilly areas of Naachtun and on the footslopes of the city close to the *bajo*, two sectors with evidence of several ancient paleosoils rich in charcoal indicate their exploitation during the Preclassic period (Figure 5A). These formations are also dated from 1700/1600 BC.

As a first observation, evidence of an environmental disturbance, probably related to human activity, is recorded around 1600 BC in Naachtun. These early indirect traces of human occupation cannot be correlated for the moment with archaeological data as all Preclassic archaeological contexts only date back roughly to 400 BC. Another complementary source of information, that confirms this early scenario from environmental data, comes from archaeological charcoals. The latter demonstrate that during the first clearly established ceramic complex of Naachtun, (Balam I, AD 150-300), at the beginning of the Early Classic period, the landscape was already open (Dussol 2017). This clearing probably dates back to Preclassic times, as the anthracological records show an important proportion of secondary vegetation taxa used as firewood (Dussol 2017).

The comparison between the archaeological and paleoenvironmental sequences (cf. Table 3) suggests the presence of a substantial invisible population established nearby Naachtun and around the *bajo*, far earlier than the first archaeologically attested occupation, a population who impacted the local environment to such an extent that traces of landscape transformation are detected in sedimentary records. This situation affects the representativeness of archaeological records and may also suggest that intense landscape transformation during later periods may have occulted or completely removed early and probably aceramic human occupations and activities that may have been associated with thatched roof structures that are undetectable today.

A

B

Figure 4. Photograph of a stratigraphic section studied in the *bajo* El Infierno located north of Naachtun (section M1S2C) (Photos: C. Castanet). The basal sedimentary body is characterized by the alternation of alluvial (Al.) and colluvial deposits. (Col.) A: Overview. B: Detail view of the basal part of the section (yellow box).

In addition, the first results of the LiDAR coverage analysis show the presence, in most of the swampy zones and particularly in the northern bajo, of vast systems of wetland features, similar to those pertaining to raised field systems (Castanet 2019a, 2019b). Consisting of a network of parallel and shallow canals (probably for both drainage and irrigation) enclosing small and narrow raised fields (Castanet *et al.* 2019), these features were probably used for agriculture and hydraulic purposes (Figure 6). For the moment, we ignore whether these sophisticated features date from the Preclassic period or if their construction is to be attributed to the Early Classic period that marks the real start of Naachtun growth.

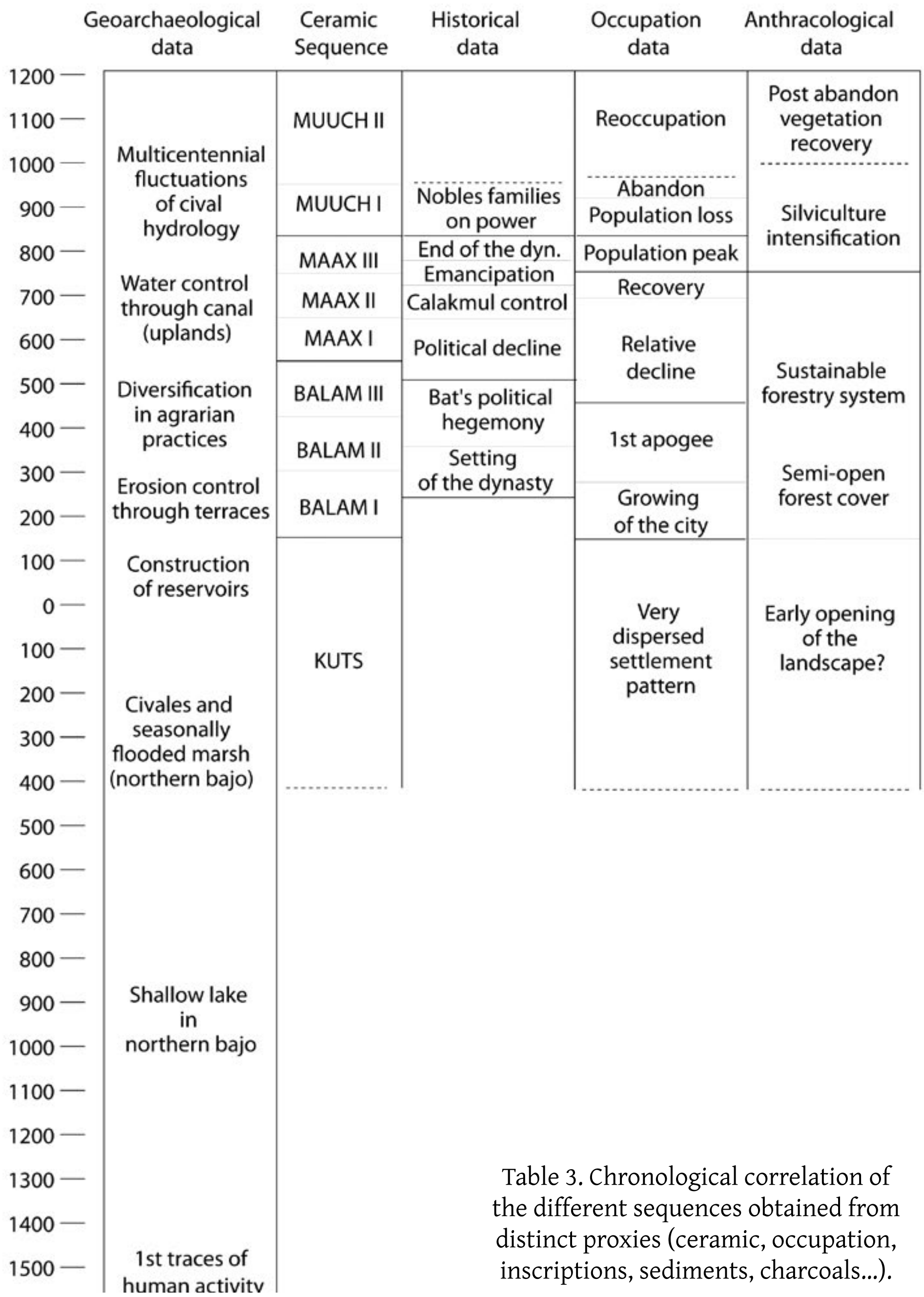

Table 3. Chronological correlation of the different sequences obtained from distinct proxies (ceramic, occupation, inscriptions, sediments, charcoals...).

The Early Classic period

By the Early Classic period, both archaeological and environmental sequences converge as the city reached its first demographic peak. With the establishment of a royal dynasty in Naachtun and its alliance with Teotihuacan, Naachtun became a regional capital characterized by the construction of various monumental complexes and the absorption of new inhabitants (Nondédéo *et al.* 2016). Environmental and geoarchaeological studies established that, by this time, the city was structured and planned with open spaces (vacant spaces) dedicated to agrarian activities (Nondédéo *et al.* in press). This period experienced also, simultaneously in the residential areas, the epicenter as well as in the rural zone, a diversification in agricultural practices aiming perhaps at controlling the effects of overexploitation practices on soil and water resources. These practices range cultivated natural soils to agricultural terraces either in the immediate vicinity of the residential units or on the margins of the *bajo*

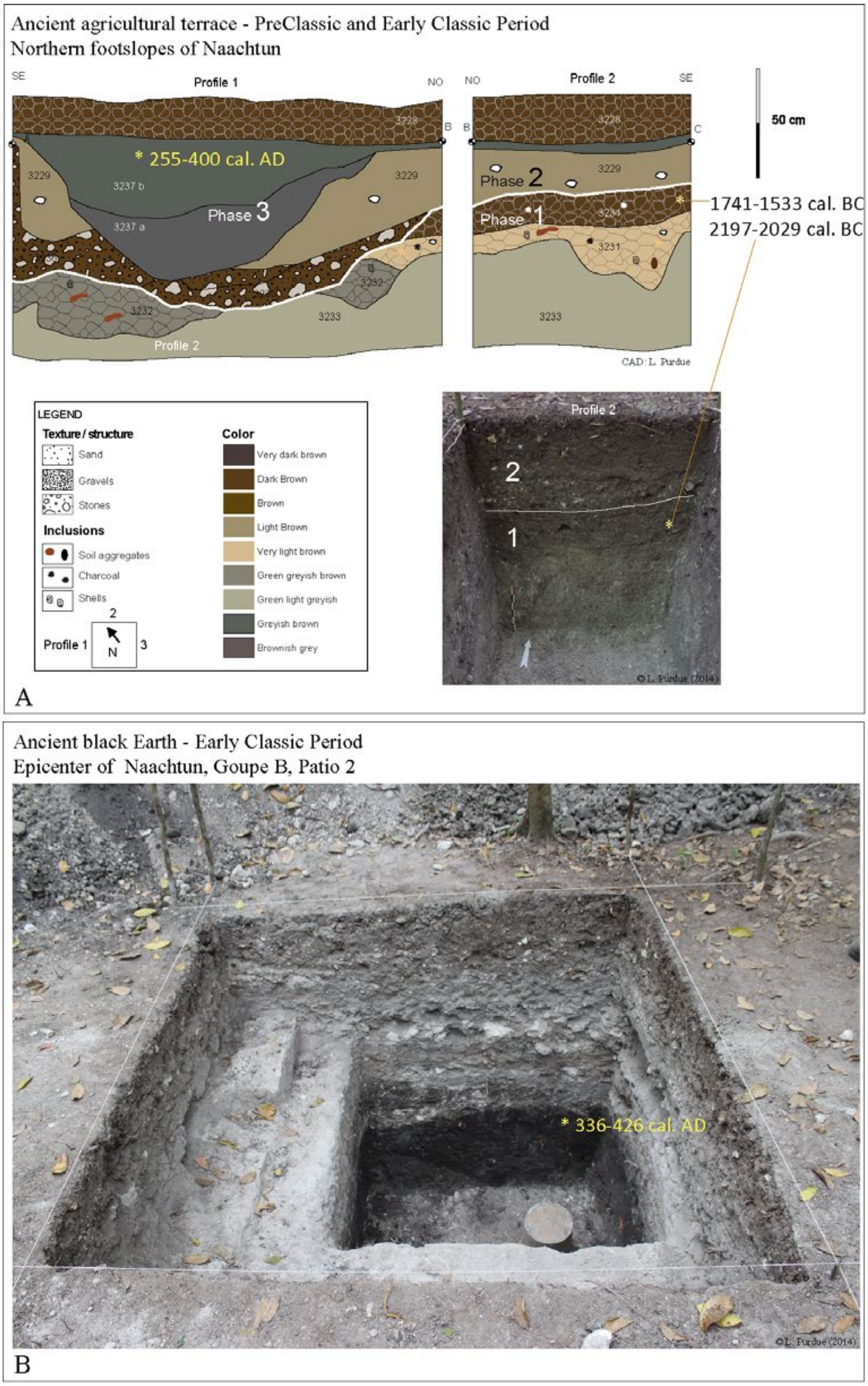

Figure 5. Photographs, sections and phasing of two agricultural sequences identified in the city of Naachtun (Data: L. Purdue). A: Ancient foot-slope terrace in the vicinity of the northern *bajo*. Phase 1 corresponds to the development and further exploitation of a paleosoil during the Preclassic period. Phase 2 indicates an episode of erosion initiated during the middle of the 1st millennium BC up until the early Classic period, while phase 3 indicates the construction of a pit, probably a small local reservoir, around 300/400 AD. B: View from the south of dark black soils dated from the Early Classic period and located in the city core zone.

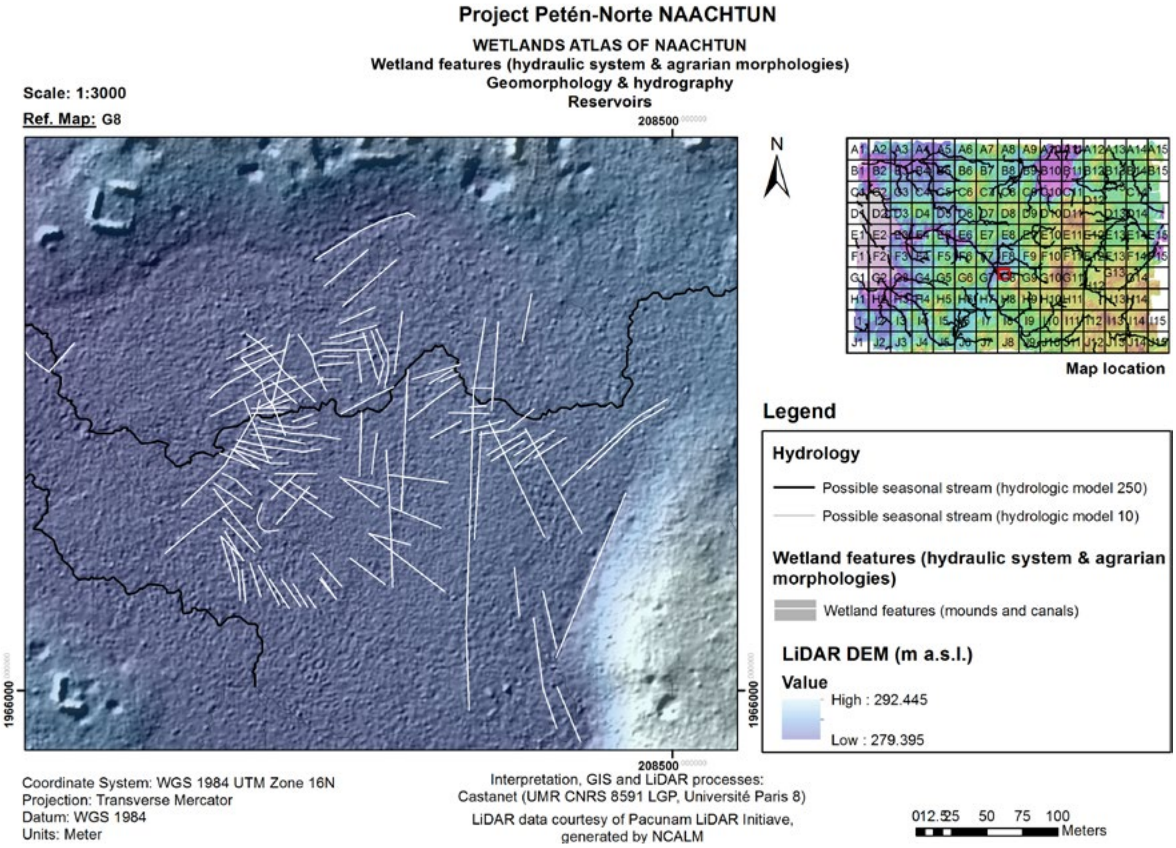

Figure 6. Wetland features observed in the territory of Naachtun. LiDAR DEM resolution: 1 m (from the Wetlands Atlas of Naachtun: Castanet 2019a, 2019b).

(cf. Figure 5A). In parallel, recent works have also demonstrated the presence of artificial and highly productive dark organic soils in different parts of the city core zone (Figure 5B). A similar management of local resources has also been observed in the firewood economy. Indeed, charcoal data show that a wide range of wood taxa were exploited as fuel and that they were collected in the old forests and in the fallow lands on higher zones, as well as in the low scrub forests of the *bajos* (Dussol *et al.* 2020). The diversification of both the wood used and their areas of supply may reflect a conservation strategy aiming at avoiding the exhaustion of certain 'preferred' species and resources. The same is true for local fauna and fresh water shells (Cotom 2019).

During this period, a series of reservoirs capable of sustaining water needs for an important population, were conditioned in intra-site and off-site areas. A total of no fewer than 14 reservoirs have been detected around the Naachtun core zone along a radius of 1 km from the city center (Castanet *et al.* 2019). In the epicenter, reservoirs were used for ceremonial and ritual purposes and for elite consumption too. In the residential areas, some were also built for agriculture or domestic purposes (Purdue 2018), whereas in the northern b*ajo* these reservoirs, characterized by larger water storage capacities, were devoted to the water consumption of the commoners (Castanet 2018). This transformation of the landscape was intense. The Early Classic inhabitants, while maintaining natural ditches, might have channelized runoff water from the southern part of the city towards the main reservoirs in the north *bajo* (Castanet and Purdue 2014). This is particularly evident in the central drainage system that crosses the epicenter between Groups A and C. These hydraulic and collective efforts could be interpreted as a response to an increasing social demand and/or the progressive shrinking, since Preclassic times, of the shallow lake of the north *bajo*.

Along with these landscape transformations, geoarchaeological observations suggest that terraces were built in and around the city, notably to prevent further erosion (Castanet *et al.* 2016). In the northern *bajo*, sedimentation rates are sometimes lower than those of the Preclassic period. This observation suggests a reduced stock of erodible sediment over the slopes and the management of soil erosion by the population of Naachtun. Indeed, a vast terracing work is now evidenced by the LiDAR survey, with more than 18,000 of such earth features in Naachtun hinterland. If we put all that together, these linear features represent a huge effort of more than 500 km of cumulative length (Castanet *et al.* 2019). Although they are not dated yet, we can reasonably suppose that some of these features belong to the Early Classic period.

Late Classic period

By the Late Classic period (AD 600-830), the city reached its demographic apogee as most of the residential units were then occupied. This scenario seems to echo a similar occurrence in all the hinterland, where most of the densest residential areas identified on LiDAR images were built. As shown by first evidence from the 2019 ground-truthing campaign, occupation of these residential areas dates mainly from the Late Classic period (Late Classic sherds have been collected in most —if not all— looting trenches observed in these residential areas). In the eastern part of the epicenter, new monumental and residential sectors were built in Group B, around East Plaza and Río Bec Plaza (cf. Figure 2), in response to the growth of the royal court and noble families. Surprisingly, despite the highest occupation densities observed in the residential area around Naachtun political epicenter, most of the Early Classic spaces previously devoted to agriculture were maintained as such, the new constructions avoiding carefully these continuously productive sectors. Only the black organic soils zones in the monumental epicenter (Groups A and B) were abandoned, and covered by rubble fills for the new constructed Late Classic plazas and elite residential compounds (West Complex of Group B).

The management of local resources is also obvious through the transformation of earlier drainage ditches into true canals, such as in the central thalweg of Naachtun (Castanet and Purdue 2014). Despite this demographic peak, which occurred most probably between AD 750 and 830, population pressure on the woodlands does not appear to have been critical as slow-growing trees such as those belonging to the Sapotaceae family were still heavily exploited for firewood. Furthermore, during the second half of this period, from AD 750 on, we observe a selective use of certain multi-purpose species and fruit trees for firewood (Dussol *et al.* 2017). At the same time and from a micro-regional perspective, if the huge amount of agricultural terraces observed in LiDAR images are a response —even partly— to the growing density of the Late Classic residential areas in the Naachtun hinterland, we can conclude that there was an increasing exploitation and control of land and soils allowed to maintain an important population. Future fieldworks will have to confirm this scenario.

By the end of the Classic period and the Terminal Classic period, (circa AD 830-950/1000), the city experienced the fall of its royal dynasty and the loss of a significant part of its population. These events led to a concentration, with some exceptions, of the remaining families in and around Group B (Hiquet *et al.* in press; Sion 2016). The impact, probably significant, of this population decrease on the wetland areas, is still difficult to measure. One immediate effect must have been the interruption of the maintenance of the large reservoirs in the northern *bajo*. We are now quite certain that few families reoccupied the midst of the ancient public plazas of Naachtun during the Early Postclassic period, between 1000 and 1200 AD, while the city no longer existed as such. A 'C' shape structure associated with *Tohil Plumbate* sherds and with *Silho Fine Orange* wares was found in the main plaza of the Early Classic Group C (Sion 2019). But activities related to the presence of these few families do not seem to have impacted significantly the local ecosystem (anthracological evidence). Moreover, late fire rituals observed in abandoned political buildings suggest, at the same time (1000-1200 AD), a recovery of the vegetation possibly linked to the agricultural demise. In that respect, selected wood taxa used for these rituals (taxa from the Sapindaceae family) reappeared in the local environment. Indeed, the use of such woods had decreased progressively from the end of the Preclassic period into the Terminal Classic, at the end of which these taxa had nearly disappeared from the assemblages of charcoal (Dussol 2017; Dussol *et al.* 2019).

In the northern *bajo*, variations in the sedimentology and paleoecology of alluvial deposits have been identified, characterized and dated to the Classic period. They suggest variations in the hydrological, sedimentary and ecological conditions of the lacustrine and swampy environments of the *bajo*. These fluctuations occurred several times during the Classic and at the end of this period, around AD 900-1000. The nature of the change, as well as its origin and consequences, is still under study. On the one hand, the change could be correlated with the abandonment of the nearby city and with the agricultural demise; on the other hand, it could mirror a regional climate change (as described by Kennett *et al.* 2012, Douglas *et al.* 2015). Each of these external drivers had an impact on the water balance of the water bodies in the *bajo*; in turn, the latter impact directly affected the seasonal variability of the water resource available in this wetland for the soils and the populations of Naachtun.

Conclusion

To conclude, the combined analysis of the two complementary sequences, both archaeological and paleoenvironmental, shows a quite different scenario concerning the earliest occupations, during Preclassic times. For the later periods, they allow for interesting discussions about the spatial and temporal conections through time between the populations, their environments and their management of local resources. To come to a thorough understanding of this Maya site, its societal and socio-environmental dynamics, using these two complementary approaches is fundamental and results in an important enrichment of data, each sequence exploiting different proxies. Together they shed new light on Naachtun history.

Divergences of data when confronting both sequences, particularly in relation to early dates, have been observed in other Maya sites too, such as in the Bajo Cob near Colha, where maize (*Zea* maize) and manioc remains (*Manihot Esculenta*) were dated from 3400 BC, although forest clearance is not attested before 2500 BC (Pohl *et al.* 2000: 159). In the Rio Hondo region, early dates were recorded between 3000 and 2500 BC, while in the Puerto Arturo Lake, close to Mirador, Dunning *et al.* (2014: 119) recorded dates from 2650 BC. In most of these sites, evidence of early environmental disturbance related to human activities and radiocarbon dated precedes by a thousand years the earliest remains of occupation detected by archaeological data around 1000/900 BC. This is particularly the case in the sites near Colha for the first maize evidence, and may also be the case in La Joyanca (Carozza *et al.* 2007, Fleury *et al.* 2014).

The use of interdisciplinary approaches in such contexts thus promises to be very fruitful. One of the main issues revealed by our results is related to chronology, although time periods may be different (and complementary). Dating procedures do not always allow for a similar chronological resolution because time-scales of the dated material may be different. Another enrichment arises from the spatial scales of complementary reconstructions established on archaeological data and environmental data. Future research will aim to reinforce the systemic and multiscale (space and time) approach, in order to constrain possible impacts of differences in conceptual and methodological reconstructions pertaining to archaeological and environmental systems.

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Tracing the hidden history of the Maya forests through anthracological sequences

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Abstract

Different time scales evidenced by archaeological data from excavations on one hand and by palaeoenvironmental datasets from lake sediment cores on the other hand, challenge up-to-today established models of social-environmental interactions in the Maya Lowlands. In particular, the hypotheses that concern the intensification of forest clearance during the Preclassic and Classic periods and the post-collapse reforestation are increasingly debated. Even though scarce in the Maya area, anthracological (archaeological charcoal) records can make the link between archaeologically-based chronologies and palaeoenvironmental sequences. This implies to take into account some methodological issues anthracological studies face in Maya sites. A case study from the Classic city of Naachtun, Guatemala, is used here to highlight how anthracological sequences can help reconsidering socio-environmental models especially when they reflect human impact on landscapes beyond the spatio-temporal boundaries of human settlements.

Key words: Vegetation changes, human impact, anthracology, parallel sequences

Résumé

Des différences d'échelles spatio-temporelles entre les données archéologiques issues des fouilles et les données paléoenvironnementales issues des carottes lacustres remettent en question certains modèles d'interactions société-environnement publiés jusqu'à présent dans les Basses Terres mayas. En particulier, les hypothèses qui concernent l'accélération de la déforestation au cours des périodes Préclassique puis Classique, ainsi que la reforestation postérieure à l'effondrement des cités mayas sont de plus en plus discutées. Bien qu'elles soient encore rares dans la zone maya, les séquences anthracologiques (charbons archéologiques) peuvent faire le lien entre les chronologies archéologiques et les séquences paléoenvironnementales. Cela implique de prendre en compte certains problèmes méthodologiques de l'anthracologie spécifique à la zone maya. Un cas d'étude issu de la cité Classique de Naachtun au Guatemala permet de souligner comment les séquences anthracologiques peuvent conduire à reconsidérer les modèles socio-environnementaux, notamment lorsqu'elles reflètent l'impact anthropique sur les paysages au-delà des limites spatio-temporelles des établissements humains.

Mots-clés : Changements de végétation, impact anthropique, anthracologie, séquences parallèles

Introduction

Over the past 40 years, our knowledge of the Maya lowlands' forest history expanded with the multiplication of palaeoecological reconstructions throughout the Yucatan Peninsula (Figure 1). These studies have shown that the Holocene was characterized by climatic oscillations and vegetation changes, raising serious questions concerning the chronology and degree to which societies impacted the extension and composition of forests during pre-Hispanic times (Piperno 2006). In the meantime, archaeological investigations have continually refined the chronologies and extent of human occupation at the spots and areas around Maya cities. Putting these growing datasets together can lead to challenging experience as one tries to disentangle the causal effects between climate, vegetation and human trends, especially as many of the phenomena observed are asynchronous among the sites (Brenner *et al.* 2002; Leyden 2002). As Hodell accurately

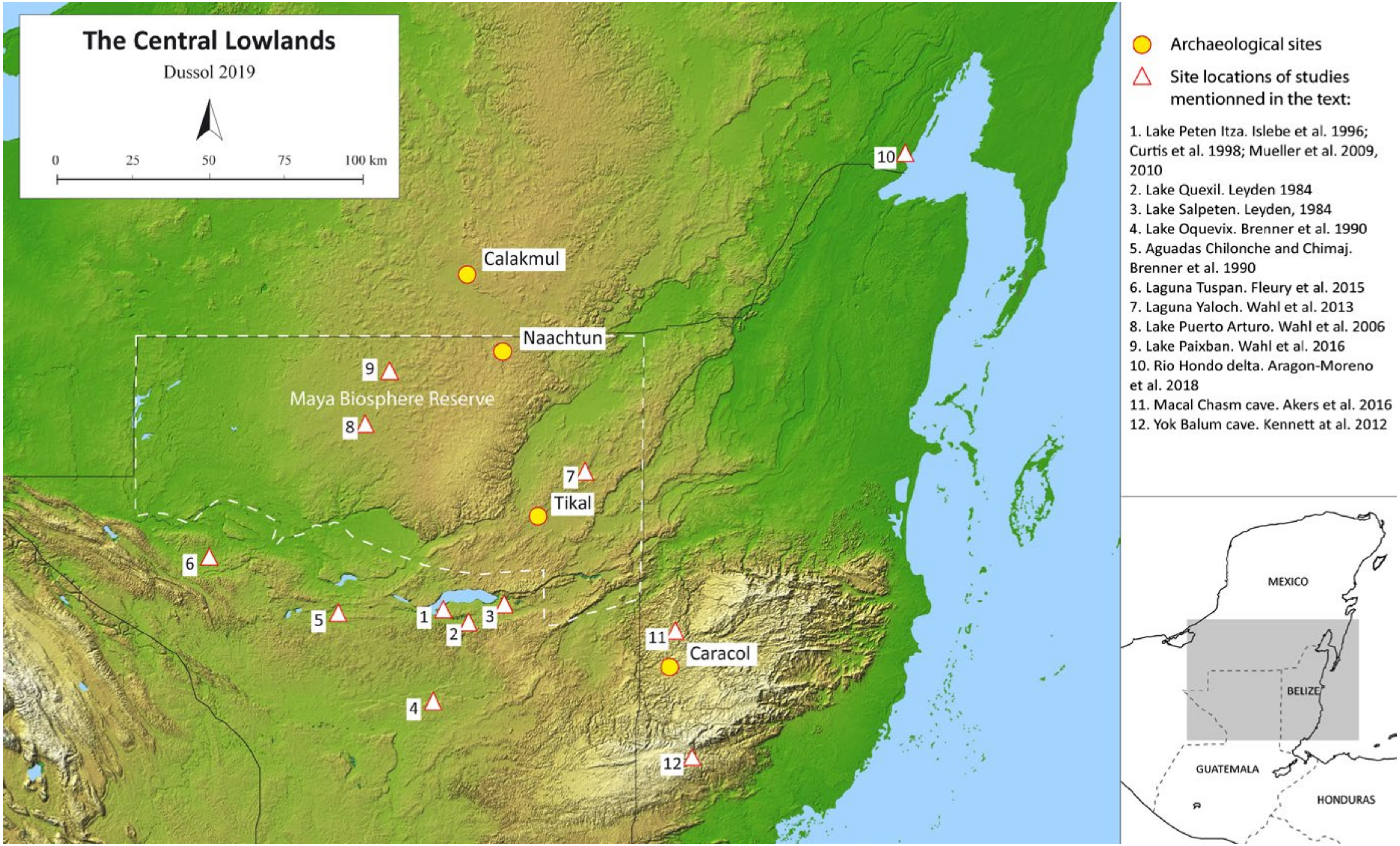

Figure 1. The central Maya lowlands with location of sites concerned by palaeoecological and palaeoclimate studies mentioned in the text.

states (Aimers and Hodell 2011, p. 45), 'the data sets inadequately resolve spatial and temporal variability in climate and cultural systems, and both are dated with uncertainty'. In this paper, I present some striking examples of vegetation-climate-human missing links in the Maya lowlands. After underlining specific lacunae related to anthracology in Maya sites, I use a case study from the Classic city of Naachtun (Guatemala) to highlight how anthracological sequences can widen our knowledge about the population dynamics and long-time evolution of forests in the Maya lowlands.

1. The history of the Maya forests between archaeological and environmental data

Initially perceived as a long-term stable tropical environment, we now know through pollen, phytoliths, diatoms, fire signature and mineralogical records from regional lake sediment cores that the forests of the Maya lowlands have undergone considerable changes over time. The main features of the modern tropical forest date back to the early Holocene towards 9000–8000 BCE (Leyden 1984; Brenner *et al.* 2002). Before that date, palaeoecological records from the Peten lakes document that the late Pleistocene climate was cooler and drier than today, and that Peten palaeovegetation consisted in open, xeric savannas, swamps and juniper thickets (Leyden 1984). The rise of a temperate forest dominated by pines, oaks and elms predated the semi-evergreen tropical forest whose expansion is primarily marked by the appearance of Moraceae pollen.

During the middle and late Holocene (from approximately 4000 BCE), fire signatures and pollen records from several lacustrine sediment profiles located near archaeological sites indicate successive episodes of forest reduction and expansion (Islebe *et al.* 1996; Curtis *et al.* 1998; Wahl *et al.* 2006, 2013; Mueller *et al.* 2009). Whether these phenomena were climate or human driven is still a subject of stormy debates among the scientific community (Brenner *et al.* 2002; Leyden 2002). Indeed, while the expansion of the tropical forest in the early Holocene was clearly associated with a much wetter and warmer climate than today, forest decline in central northern Peten starting from the middle Holocene (~3650–1050 BCE) is not only concomitant with the first evidences of human occupation and agriculture in the lowlands, but also to increasing aridity. Deforestation accelerated from 1550–1050 BCE, with evidences of human disturbance (higher frequency of *Zea* and *Ambrosia* pollen) becoming prominent in all sediment cores of the Central Lowlands (Pohl *et al.* 1996).

However, the late Holocene also experienced dramatic climatic variations as demonstrated by the study of oxygen isotopes and geochemical elements in cave speleothems and lake sediment cores. Driest periods and episodes of extended droughts have been clearly identified at different locations throughout the Maya region since about 1650–1150 BCE (Fleury *et al.* 2015; Akers *et al.* 2016) and these are often correlated with lowest forest cover (Aragón-Moreno *et al.* 2018). But palaeoclimate records usually suffer from dating uncertainties and display important time discrepancies among the sites. Their comparison is further limited by the fact that palaeoclimate changes evidenced in lake sediments and cave speleothems of distinct areas may have been controlled by processes with different timing and magnitudes depending on local environmental factors (Douglas *et al.* 2016). Several scientists thus underlined the difficulty to distinguish clearly between climatic and anthropogenic forcing during some episodes of forest cover variations in the Maya Lowlands (for example Hodell *et al.* 1995; Brenner *et al.* 2002; Leyden 2002; Douglas *et al.* 2016).

By the end of the first millennium CE and later on, increasing Moraceae pollen representation and the disappearance of maize (*Zea*) pollen in the lake sediment cores of the central lowlands is usually interpreted as the return of forest cover after the general abandonment of the region by the Maya during the Terminal Classic period (800–1000 CE). There again, troubling time discrepancies have been pointed out at several Maya sites between radiocarbon dates, archaeological data and palaeoclimate records (for a detailed synthesis, see Brenner *et al.* 2002). It has been assumed that the timing of the central lowlands reforestation varied greatly among the sites, to the extent that it could have occurred as late as post-European contact in some regions (Brenner *et al.* 1990; Wahl *et al.* 2016). More importantly, reforestation would have been at least partly the result of more humid conditions after the last mega-drought that occurred around 1000–1100 CE, a time when human activities had already decreased in the region (Mueller *et al.* 2010; Kennett *et al.* 2012; Akers *et al.* 2016). Indeed, increasing archaeological evidences indicate that populations persisted around the abandoned cities during the Early Postclassic period (1000-1250 CE), well after the demise of Maya polities (e.g. Dussol *et al.* 2019; Rice and Rice 2004).

These spatial-temporal issues directly relate to critical aspects of historical ecology in the Maya lowlands, especially with regard to the diffusion of agriculture or the nature and magnitude of the Late to Terminal Classic crisis called 'the Maya Collapse' (Demarest *et al.* 2004; Aimers 2007; Turner and Sabloff 2012; Rice 2013). They also highlight the complexity of climate-human-forests interactions in the neotropical lowlands that should not be limited to global, straightforward interpretative models (Aimers and Hodell 2011).

2. Archaeological charcoal: an unrecognized palaeoenvironmental proxy in the Maya area

Wood charcoal are remains of innumerable fires made by people over centuries for cooking, lighting, burning incense, firing ceramic and making lime, and thus occur ubiquitously at Maya sites. But despite their demonstrated informative potential regarding palaeovegetation reconstructions in tropical regions (Scheel-Ybert 2000; Moutarde 2006; Dotte-Sarout 2010; Bachelet 2011; Dotte-Sarout and Kahn 2017), archaeological charcoal are still under-exploited in the Maya area.

Generally speaking, anthracology is based on the identification and counting of charcoal fragments and on the interpretation of the variations in relative proportions of taxa that are represented in anthracological diagrams (Chabal *et al.* 1999). A remote and persistent skepticism towards anthracology in the English-speaking world (Asouti and Austin 2005), along with a lack of archaeobotanists trained in neotropical wood anatomy, probably explains in part why charcoal studies have not usually been involved in Maya palaeoenvironmental research programs (but see for example Miksicek 1983, 1991; Lentz *et al.* 1996, 2014; Robinson and McKillop 2013; Thompson *et al.* 2015; Dussol *et al.* 2017a). However, it is also true that anthracology faces specific methodological issues in Maya sites where the palaeoecological interpretation of charcoal records represents a real challenge (Dussol 2017). In particular, the successive architectural transformations involved in such urban contexts of long occupation often make uncertain the origin and dating of the dispersed charcoal found in archaeological levels. The relative scantiness of charcoal in soils can also makes it difficult to achieve statistically representative samples – at least 400 charcoal pieces per level according to Scheel-Ybert (1998). This is especially true in Maya sites where excavations usually consist only in pits and trenches of limited extension, preventing extensive archaeobotanical sampling. Finally, the identification of both the taxa and the vegetal formations represented in the charcoal assemblages can be a real brainteaser in such high biodiversity environments where the anatomy of many wood species is still unknown.

Assuming the palaeoecological representivity of archaeological charcoal does not mean that these are expected to faithfully reflect the woodlands. First, fuel wood may be subject to species selection among Maya people (Metzger and Williams 1966), and second, charcoal are subject to differential preservation under combustion and post-depositional taphonomic processes (Théry-Parisot *et al.* 2010; Chrzazvez *et al.* 2014; Dussol *et al.* 2017b). Accordingly, charcoal records may not provide a fair picture of the woody vegetation around a site. They are nevertheless unique empirical evidence of the firewood used over time, which depends on the woodlands available locally (Shackleton and Prins 1992). Therefore, when they are statistically valid and chronologically accurate, anthracological sequences yield significant insights into past vegetation changes.

3. Reconsidering the human-forest dynamics in the Maya lowlands based on anthracological sequences

Theoretically, the human-forcing hypothesis as an explanation for vegetation changes during the pre-Hispanic period supposes that there is an inverse correlation between population and forest cover variations. Indeed, one may expect that as human settlements developed and expanded in new, 'wild' areas, more woodland was cleared for construction and cultivation purposes, or managed, selectively or not, for wood consumption at least and probably for silviculture as well (McKillop 1994; Fedick 1996; Lentz and Hockaday 2009; Dussol *et al.* 2017a). Such dynamics should be reflected in the anthracological sequences by the reduction of the use of woods from mature forest while the use of woods from secondary or disturbed vegetation would increase, indicating vegetation opening concomitantly to population growth. Yet when comparing archaeological and anthracological sequences at Maya sites, different trajectories arise, which question our interpretative models of the simultaneous development of people and forests.

The city of Naachtun is an excellent example of the discrepancies that may exist between population and forest trends in the Maya Lowlands. Located in the extreme north of the Guatemalan department of Peten (Figure 1), Naachtun was an important urban center during the Classic period (250-950 CE). For centuries, successive generations of people profoundly modified the landscape for agriculture and water control (Castanet *et al.* 2015, 2018; Lemonnier 2016), in an extent that we are just beginning to realize thanks to a recent LiDAR survey (Canuto *et al.* 2018; Castanet 2019).

According to the archaeological and epigraphic data accumulated since the first fieldworks carried out in 2004-2005 (Nondédéo *et al.* 2013; Patiño 2013; Rangel and Reese-Taylor 2013; Sion 2016), such a heavily modified landscape in the Naachtun region should be attributed to its Classic period society (Nondédéo *et al.* in press). Indeed, the history of the city of Naachtun spans over approximately eight centuries (150–950/1000 CE) during the Classic period (250–950 CE). It started with its foundation and establishment of a royal dynasty during the transition between the Late Preclassic to the Early Classic period (150–350 CE), reached its apogee during the second half of the Late Classic (750–830 CE) and ended with the departure of the last inhabitants at the end of the Terminal Classic (830–950 CE) (Nondédéo *et al.* 2019, 2020, this volume). Up to the end of Late Preclassic, human presence on the site was supposed to be very scarce, as suggested by few Preclassic ceramic sherds scattered across the site (Hiquet *et al.* 2016; Hiquet 2020).

However, palaeoenvironmental records of the ancient forest cover in the site surroundings suggest a quite different pattern of human occupation. I reconstructed forest use through an extensive anthracological study of the domestic uses of firewood based on 3026 charcoal fragments proceeding from 42 household levels across the site (Dussol 2017). This study reveals that the Maya of Naachtun relied on a wide range of wood species for energy consumption since no less than 94 different taxa were identified. Among them, sapodilla and sapote trees (Sapotaceae family) were the most common firewood during the whole history of the city (Dussol *et al.* 2017a).

Once juxtaposed (Figure 2), both population trends and forest cover changes highlight an unexpected correlation. During the first six centuries of the Naachtun history (150–750 CE), firewood was collected equally from both mature and disturbed woodlands, depicting a long-lasting semi-open landscape (Dussol 2017). But against all odds, no evidence of actual forest clearance was detected in the charcoal records. No decreasing forest taxa or increasing pioneers seems to indicate an opening landscape associated with the establishment of new population during the Early Classic period (250-600 CE). Instead, the stability of such semi-open woodlands as despite population growth, indicates that the landscape was already a sustainable human-modified landscape as soon as the very beginning of Naachtun occupation. This landscape is interpreted as resulting from an agroforestry system in which different forest successions were

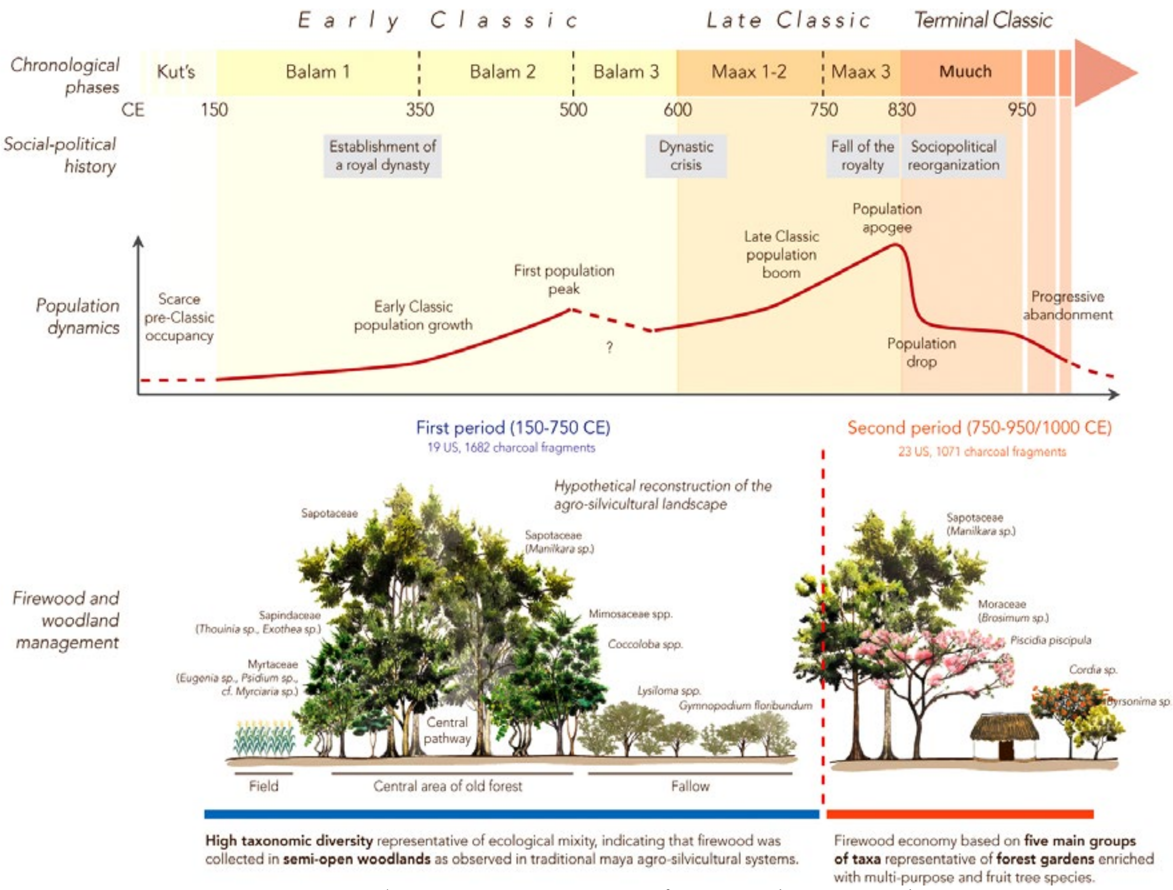

Figure 2. Schematic representation of compared society and agroforestry histories at Naachtun over the Classic period, based on anthracological and archaeological sequences

mixed and managed together, perhaps in the frame of a rotation system that continued with the traditional Maya agroforestry (Atran *et al.* 1993; Ford and Nigh 2010).

The anthracological sequence of Naachtun thereby provides insights into a longer human occupation history than suggested by the archaeological dataset from the Classic period. Other palaeoecological data strengthen this assumption, as phytoliths and mineralogical records from the closest seasonal swamp indicate a reducing forest cover and increasing soil erosion on the uplands as soon as the beginning of the Late Preclassic period or earlier (600-400 BCE) (Castanet *et al.* 2016; Testé 2020). It is likely that farmers settled in the area before the first architectural development of Naachtun, and managed forests, soils and water for their subsistence in such a sustainable way that this system was maintained afterward throughout the development of the city. Even though several issues remain to be addressed, concerning in particular the role of climate in forest changes, these findings seriously question the timeline and degree to which the Naachtun landscape was modified by people during the pre-Hispanic period.

Human impact on the landscapes is diverse across time and space and cannot, obviously, be reduced to a simplified theoretical model, nor be explained by a unique factor. Many studies have suggested indeed that trees and forests were managed and even cultivated by the ancient Maya (McKillop 1994; Lentz and Hockaday 2009; Lentz *et al.* 2014; Dussol *et al.* 2017a), highlighting that the availability of forest resources were not simply determined by the uncontrolled effects of population expansion versus reduction. Nonetheless, the case of Naachtun underlines the potential of charcoal sequences for reassessing our views of the human-forest relationships in the Maya lowlands, especially when they reveal human-induced forest modifications beyond the time frame of archaeological chronologies.

Conclusion

Our understanding of the causal links between human, climate and forest trajectories in the Maya lowlands is faced with methodological biases that make difficult the interpretation of palaeoenvironmental sequences. In the central Maya lowlands covered by a dense tropical forest, environmental constraints caused archaeological investigations to have primarily focused on monumental urban Centers. As a consequence, our knowledge of the history of ancient Maya societies has been mainly shaped through archaeological and epigraphic data that mostly reflect the lives of urban, high-status people. Yet some human activities may leave no, or only slight archaeological traces that are undetectable when they occur away from the spatial boundaries of masonry constructions. But their impact can be printed lastingly in the landscape and might thus be perceived through palaeoenvironmental sequences.

Through the comparison between anthracological and archaeological sequences provided by studies in the Classic period Maya city of Naachtun, we suggest that the local forest economy was not directly and simply influenced by urban population trends. Instead, demography may lead to unsuspected technology and practice shifts that can be traced through anthracological data. How these socioenvironmental changes truly relate to each other and to what extent they were influenced by climate forcing remain pending issues. More systematic cross-cutting approaches between archaeologically based chronologies and palaeoenvironmental sequences will enhance knowledge about human occupation and forest history in the Maya Lowlands.

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