Universitat Autònoma de Barcelona

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SUMMARY

Reconstruction of the biography of the site of La Draga (Lake Banyoles) was attempted in this research through the identification of a set of depositional events as the consequence of both anthropic activities and geogenic key forces altering the deposition of materials. Depositional events are thus defined by what, how and when something happened. *"How"* and *"when"* build the chronological context of human and natural activities, while *"what"* helps identifying the activities *per se.*

62 ^{14}C dates are analyzed in combination with a recently established local floating tree-ring sequence for the Early Neolithic site of La Draga (Banyoles, Northeast Iberian Peninsula). Archaeological data, radiometric and dendrochronological dates, as well as sedimentary and micro-stratigraphical information are used to build a Bayesian chronological model, using the ChronoModel 2.0 and OxCal 4.4 computer programs, and IntCal 2020 calibration curve. The dendrochronological sequence is analyzed, and partially fixed to the calendrical scale using a Wiggle-Matching approach.

Depositional events and the general stratigraphic sequence are expressed in expanded Harris Matrix diagrams and ordered in a temporal sequence using Allen Algebra. Post-depositional processes affecting the stratigraphic sequence are related both to the phreatic water level and the contemporaneous lakeshore. The most probable chronological model suggests two main Neolithic occupations, that can be divided into no less than three different "phases", including the construction, use and repair of the foundational wooden platforms, as well as evidence for later constructions after the reorganization of the ground surface using travertine slabs. The installation horizon at La Draga is dated at 5292 cal BC and is characterized by the construction of pile-dwellings on a lake marl substrate. This is a usually applied practice in the pile-dwellings settlements in Europe.

The chronological model is discussed considering both the modern debate on the Climatic oscillations in the period 8000-4800 cal BC, and the origins of the Early Neolithic in the western Mediterranean region.

CONTENTS

1. INTRODUCTION

1.1. Problem description

Life on the wetlands has been preferred by humans since the dawn of time due to the favorable conditions they offer (Nicholas 2007). Apart from great sources of water, wetlands host a variety of biota that have been easily exploited by humans being in the interface between terrestrial and aquatic systems (Mitsch and Gosselink 2015). Lacustrine settlements in general, have been the subject of archaeological debate during the last decades following the discovery of the rich material that accompanies them (Menotti 2012). Due to the unusual state of preservation of the organic material, lacustrine settlements have permitted gaining insight on technological improvements, economic strategies, subsistence, agricultural and husbandry practices. Furthermore, thanks to the preservation of seeds, the alimentation of the humans since the Neolithic period has been completed, while the insight on agricultural practices and the domestication of plants and animals helped reconstruct the idea of the neolithization process in the Mediterranean region (Piqué *et al*. 2021b).

A lot of research has been carried out about the widely known *"lake-dwelling phenomenon",* a type of lakeside settlement dated since the Neolithic to the Iron Age in Europe. Special interest has been shown since the discovery of a group of pile-dwellings built on the lake shores in the Circum-Alpine region (Keller 1866; Pétrequin 1986; Pétrequin and Pétrequin 1988; Pétrequin and Bailly 2004; Menotti 2001a; 2004; 2012a; Hafner 2004; Marzatico 2004; Ruoff 2004; Ruttkay *et al.* 2004). A series of interdisciplinary methods have come together to decipher the social structure and the human activities hidden behind this material culture.

Being so close to the natural environment of the lakes, the human-environment interactions would have been crucial to understand cultural choices and adaptability. Paleoclimatic reconstructions have been possible due to archaeobotanical studies such as pollen analysis, carpology and anthracology, as well as paleolimnology. The *intra-site* analyses are further focused not only on deciphering the anthropogenic activities behind the recovered archaeological material, but also reconstructing architectural patterns.

More recently, the depositional and post-depositional processes affecting the preservation of the artifacts has been brought into attention through the introduction of geoarchaeological analysis in the field. This has been further implemented by more specific methodology such as high-resolution microstratigraphic analysis for the observation of site formation and deformation processes (Courty *et al.* 1989; Goldberg and Macphail 2006; 2008) on lakeside settlements across Europe (Karkanas *et al.* 2011; Ismail-Meyer *et al*. 2013; Ismail-Meyer 2014; Gkouma 2017). However, although it has been a usual technique in earth sciences, it hasn't been until recently that micromorphology of archaeological soils and sediments has begun to gain traction on the archaeological research (Goldberg and Aldeias 2018).

Apart from the site formation processes that lead to a better understanding of the life cycle of a settlement, temporal reconstruction of the biography of a site has been possible through the implementation of dendrochronology in combination with radiocarbon dating when available (O' Sullivan and Van de Noort 2007a; Brown and Baillie 2007; Bleicher and Harb 2018; Andreaki *et al*. 2020; Hafner *et al.* 2021).

The lakeside settlement of La Draga is located in the northern part of the Iberian Peninsula, on the eastern shore of Lake Banyoles. The site is located at an intermediate point between the Pyrenean Mountain ranges - 40 to 50km - and 35 km away from the current Mediterranean coastline (Figure 1.1). The fact that nowadays the site is partially on dry land and partially covered by the lake water table, has favored the extraordinary state of conservation of built structures remains and objects made from wood and vegetable fibers, as well as other organic materials**.** The location of the site corresponds to a repeated pattern during the first Neolithic occupations of the western Mediterranean. These are humid areas, on the shore of lakes, lagoons, or marshes, and close to land potentially suitable for agricultural practices, in areas of great ecological diversity (Bernabeu *et al.* 2017; Guilaine 2018; Revelles *et al.* 2018; Martínez-Grau *et al.* 2020; Piqué *et al.* 2021b).

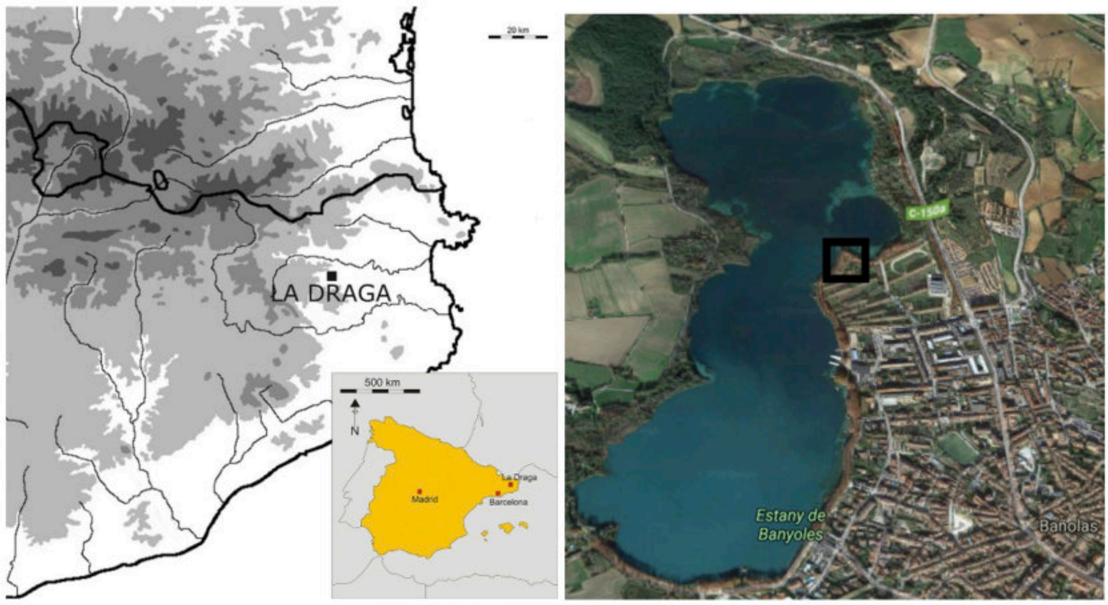

Figure 1.1. Location of the site of La Draga in the northeastern part of the Iberian Peninsula (on the left) and position of the site on the shore of Lake Banyoles (black square on the right).

Discovered in 1990, archaeological excavations have documented various structures that would correspond to an Early Neolithic settlement in which evidence of Cardial pottery has been identified (Bosch *et al.* 2000; 2006; 2011; Palomo *et al.* 2014, Bogdanovic *et al.* 2015, Tarrús 2008; Terradas *et al*. 2020). Archaeological studies and fieldwork surveys suggest that the prehistoric settlement covered an area greater than 15,000 m^2. Topographically, the settlement lies on a smooth downward slope from east to west and from south to north, inclined towards the lakeshore. So far, a total extension of 1000m^2 has been excavated, distributed into three sectors (*A, B-D* and *C*) (Figure 4.11).

The oldest well-documented human occupation at La Draga is characterized by the construction of wooden platforms on piles driven into the lake marl substrate, on the shore of the lake, above the water table of that time. On top of these wooden platforms, the dwellings were built, probably with a gable roof (Figure 1.2). After the abandonment of this first settlement, a new pavement was built to insulate from the phreatic level, and a new habitation took place over the same area and sectors (Figure 4.12).

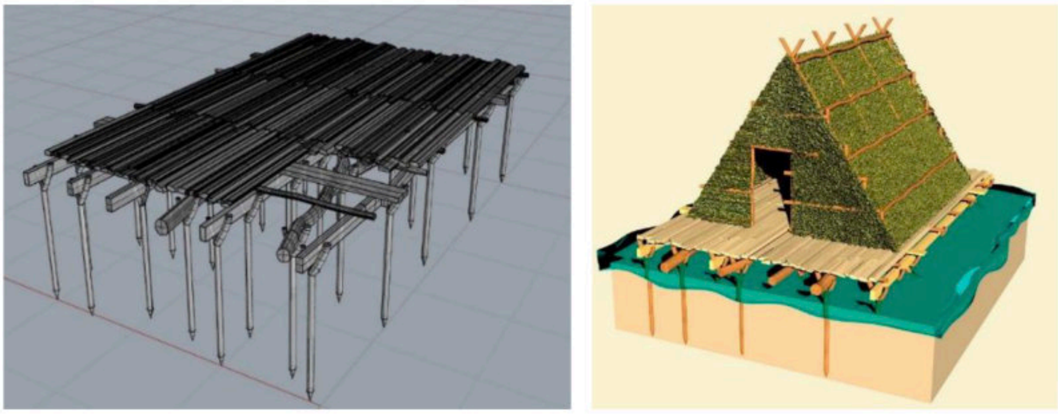

Figure 1.2. Virtual reconstruction of a probable hut that may have been built at La Draga during its early occupation (Campana 2019; Barceló *et al.* 2020). Pile alignment in the geometrical model does not reflect the reality of the terrain.

The entire settlement was situated above the lake water table in prehistoric times. In sectors B-D and C, the oldest stratigraphic layers are found below the water-table, which has favored the preservation of organic materials. In contrast, in sector A, archaeological layers remained above the water table for most of their post-depositional history and plant remains have only been preserved by carbonization, except for the ends of the pillars, sunk into the lake marl substrate. The different states of preservation of the archaeological record at the three excavated areas of the site, and the distinct post-depositional processes generate additional problems when correlating the structures of the different sectors. This is not only due to the site's elevation in relation to the groundwater, but also the dynamics of the hydrological regime (Figure 1.3).

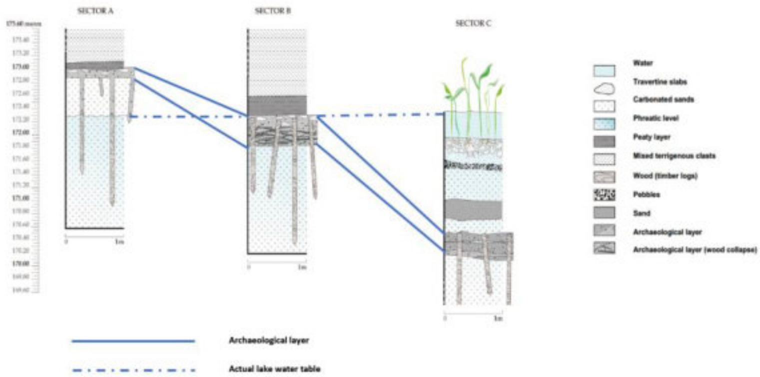

Figure 1.3. Schematic view of the stratigraphic sequences of all excavated sectors at La Draga and their correlation in depth according to the actual lake water table and the archaeological layers in each sector (*Modified after Bosch et al. 2000*).

Stratigraphic analysis suggested the existence of a minimum of two different site occupations. They are clearly differentiated at the sector B-D, as the travertine pavement overlaps the previous wooden layer. In sector A, stratigraphical dynamics are totally different, and the correlations of the layers and phases remained unclear (Palomo *et al.* 2014) because of the limited information of the stratigraphical features registered during the old excavations. A simple description of the sedimentary characteristics of the stratigraphic units is not always informative about the depositional environment. A more complete stratigraphic record was implemented in recent excavation campaigns since 2010, while geoarchaeological practices in the site have been implemented since 2013.

1.2. Research goals

The principal goal of this research consists in the reconstruction of the biography of the lacustrine settlement of La Draga (Lake Banyoles). The intention of this is twofold: first, by identifying the processes that formed and deformed the site and secondly, by reconstructing the temporal framework of human activities in La Draga.

The site formation processes are addressed by offering a high-resolution microstratigraphical analysis of the soils and sediments from the lacustrine settlement of La Draga in Lake Banyoles. This is the first time that micromorphological analysis of the site has been undertaken in La Draga with the aim, among others, to address the problem of little geoarchaeological studies implemented on archaeological sites. The use of undisturbed samples in order to decipher the sedimentary dynamics under the microscope has been proved an effective method at the time to distinguish between anthropogenic and geogenic formation processes.

As already mentioned before, the excavated sectors at La Draga have been found under distinct conditions, thus affecting the preservation of the artifacts they include. The archaeological record has been recovered in different state of preservation from sector to sector, reflecting this way different depositional processes, as well as post-depositional deformations. As a result, the information retrieved is not homogeneous among all sectors. In addition to these general questions, specific processes of deposition need to be deciphered. Lakes are dynamic hydrological regimes and would have affected actively the life of the dwellers during the occupational history of the lake shores. Lake-level changes and flooding episodes associated to erosion, redeposition and bioturbation are only some of the post-depositional processes taking place near the lake.

The construction of pile-dwellings is also relevant to the problem of primary deposition, which leads to misunderstanding at the time of defining the actual occupational surfaces or else called *'living floors'*. The evidence is easily misleading as life on pile-dwellings includes both deposition *on* the platforms above the water level and *below* them. As a result, a lot of the artifacts would have been naturally moved from their original depositional context. To reconstruct the processes of discard and deposition, micromoprhological analysis has been applied on the sediments. Apart from defining the occupational surfaces, stratigraphical analysis on a macro scale and micromorphological analysis of the sediments under the microscope have been implemented in order to reconstruct the interplay between geogenic and anthropogenic processes as well as taphonomical alterations that contributed to set up the settlement.

The second part of this research consists in placing all Neolithic occupations at La Draga in the calendrical scale by integrating radiometric and dendrochronological dates, as well as sedimentary and micro-stratigraphic information. The resulting chronological model is discussed then in the midst of current debates on the origins of the Early Neolithic in the western Mediterranean region. The chronological methods include both relative (stratigraphy) and absolute chronology (radiometric dates) retrieved from the site. Apart from the radiocarbon data, dendrochronological results are included in a Bayesian model integrating all archaeological information. Even if not always informative, occasional dates were acquired from lacustrine sediments through dating with Uranium-Thorium (U/Th) technique.

This way, a reconstruction of the biography of the sites' formation processes through time is attempted. For these purposes, the main concept where this research is based is the depositional event. The depositional events have both physical (spatial parameter) and temporal limits (start, end, duration). All depositional events are described in relation to other depositional events and are defined according to the archaeological material they contain (*what has been deposited*), the microstratigraphical information revealing the formation processes *in situ* (*the way the ground was altered as a result of deposition*) and the relative (stratigraphic order) and absolute chronological information (dendrochronological and radiocarbon data) for each one of them (the particular order in which different depositions occurred, and *the position of each deposition in the calendar scale*) (Barceló and Andreaki 2020). By specifying the origin of the sedimentation, we can determine the formation processes associated to their deposition. The overarching goal of these research questions is to reconstruct the timeline of the depositional processes forming and altering the settlement.

1.3. Overview of chapters

The introductory chapter (*Chapter 1*) provides an overview of the problems encountered in the site of La Draga and the research gaps that this analysis attempts to resolve. The principal aims of the research are also pointed out here.

In *Chapter 2* the theoretical framework of the present research is presented in detail by explaining basic concepts crucial to the research. These are basically surrounding the definition of depositional events and their start, end and duration. The organization of depositional events as well as the appropriate methods for their reconstruction are further discussed. High-resolution microstratigraphical analysis, as well stratigraphic analysis represented in Harris Matrix Diagrams address the issue of site formation processes. Further ordering of the formation processes in time is attempted though the Bayesian approach, by integrating all available chronological data. In the end, Allen Algebra based representation of the depositional events in the spatiotemporal scale is discussed.

In order to better understand the formation processes taking place at La Draga, a brief summary of the formation processes taking place in wetlands in general and in lakeside settlements more specifically has been included in *Chapter 3*.

In *Chapter 4*, the case study of the Neolithic lakeside settlement of La Draga is presented including the geomorphological setting of Lake Banyoles and the formation processes triggered by the hydrological regime and the tectonics of the lake. These are further affected by regional climate and vegetation. After a brief introduction to the cultural context during the Neolithic period in the northern Iberian Peninsula, the site of La Draga is presented. The environmental setting is discussed by introducing the subsistence and economic practices by the dwellers during the Neolithic period.

The methodology applied is explained in detail in *Chapter 5*, where sampling strategies and implemented methods are presented. Micromorphological analysis of sediments and stratigraphical analysis were applied for the reconstruction of the depositional events. For the chronological modelling of the depositional events, the methods implemented in the context of the Bayesian approach include wiggle-matching of both available tree-ring data and radiocarbon dating in La Draga. Chronological modelling was possible through the use of special software such as Chronomodel and OxCal, using the latest calibration curve IntCal 20.

Chapters 6, 7 and *8* belong to the results section of this research. They include the results of the stratigraphical, micromorphological and chronological analyses in respective order. After the presentation of the research results, *Chapter 9* discusses them in a synthetic way, in an attempt to reconstruct the formation processes taking place at La Draga in chronological order.

The dissertation's final chapter concludes with a summary of the research, as well as the restrictions encountered and future research perspectives (*Chapter 10*).

The Annexes I, II and III added in the end of the dissertation include microphotographs and sediment samples relevant with the micromorphological analysis presented in *Chapter 7*.

2. STRATIGRAPHY AS A RECONSTRUCTION OF TIME

In the absence of radiometric dating, it is generally accepted that the stratigraphic order between depositional events provides a sufficient ordering of archaeological events. This coincides to such an extent with a temporal ordering, that is usually referred as relative chronology (Ramenofsky 1998; Simonetti 2015). First formulated by Worsaae, in Denmark, in the 1880s, the possibility of a relative chronology responds to the intuitions of earlier antiquarians. Among others, Thomas Jefferson (1784) compared an archaeological site to a book made up of different *"pages",* which must be separated in order to be read properly. In the same way that the first page must be read before the second, and so on, the "pages" into which the archaeological site is divided must be separated and *"read"* consecutively in order to reconstruct the plot or storyline that explains the site. Therefore, to understand and explain an archaeological site, it should be divided into *"pages"*, that afterwards would be read consecutively.

In an archaeological site, each of the pages of this book appears in the form of depositional events, which are distinguished from each other by: (1) what was deposited; (2) how it was deposited; and (3) when it was deposited. Based on these criteria, it is the archaeologist's job to put the pages together in their correct order and rebuild the book.

2.1. The order of deposition and the *"arrow of time"*

The analogy between a supposedly temporally ordered sequence of depositional events ("relative chronology") and the successive pages of a book would be supported by the so-called "*principle of geological superposition*". This principle was first proposed by the Danish physician Niels Steensen (1638-1686) - better known by the Latin translation of his name and surname Nicolaus Steno - in his work *De solido intrasolidum naturaliter contento dissertationis prodromus*[1], published in 1669, and can be formulated as follows:

"In any undisturbed continuum of geological strata, any stratum will be younger than the stratum on which it rests, and older than the stratum resting on it. In other words, in a stratigraphic column, rock

[1] A translation in English can be found in Scherz 1969.

strata are arranged in order of their formation from oldest (at the bottom of the column) to youngest (at the top of the column)" (Kravitz 2014; p.692).

This implies that all deposited material must conform to the contours of the pre-existing depositional basin that accommodates it. This principle can be argued as follows: in the same temporal position in which a stratum must have formed, there was another substance beneath it that prevented later deposited materials from sinking further. Therefore, at the time position where the upper stratum was formed, the lower stratum had already acquired a solid consistency and prevented what was deposited or accumulated later from sinking below it (Figure 2.1).

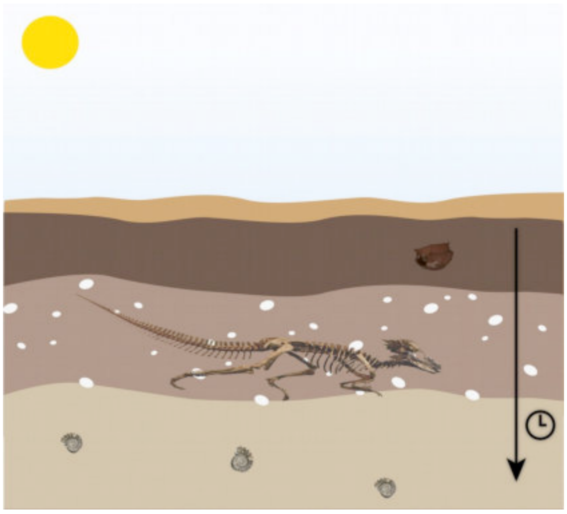

Figure 2.1. Representation of the *principle of superposition* of archaeological strata and the arrow of time (black arrow) (*Figure after Mar Crego*).

The principle of superposition is based on the idea that sedimentary layers were originally deposited horizontally, simply because of the law of gravity, in the absence of any other factor. Steno formulated the subsidiary *principle of original horizontality*, which states that any material deposited in an unconsolidated form will tend towards horizontal accommodation. On the other hand, another basic principle of stratigraphy is that stratigraphically deposited layers are laterally continuous until they meet another unit of a different nature, but with the same temporal position. This principle is deduced from the assumption that the relative time set for a stratification unit at a certain location should be the same as that of any other location in the continuum of the same unit. Based on the *principle of lateral continuity*, it can be assumed that any contact surface cutting the horizontal continuum occurs after the stratification of the original sedimentary layers. Consequently, any geological structure, removal caused by biological action -animal or plant- or any taphonomic process that may alter the natural arrangement of geological strata is younger than the rocks it intersects (Figure 2.2).

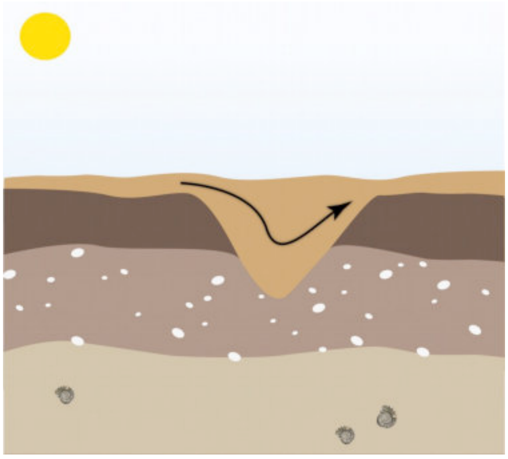

Figure 2.2. Cross-cutting relationships between archaeological strata, where the cut (arrow) is younger than the horizontal strata it intersects (*Figure after Mar Crego*).

Thus, the layering process occurs along a linear dimension with a clearly defined direction. This allows a causal relationship to be established between what was deposited before and what will be deposited afterwards on top of it. Given the universality of the law of gravity, all deposition, whatever the mechanics by which a material *m* has been accommodated at a location in physical space with coordinates *x, y, z,* and with a time position *t*, constitutes a causally irreversible unidirectional process (Embry *et al.* 2007; Catuneanu *et al.* 2011, MacEachern *et al.* 2012; Kendall 2013; Kravitz 2017). In this way, stratigraphic order allows us to establish a structural relationship between two solid bodies in firm, generative contact. To this extent, if a change in depositional trend is detected, we should be able to distinguish which chronostratigraphic unit formed first and which unit has formed last (Miall and Miall 2004; Aubry 2007; 2009; Hansen 2009; Embry *et al.* 2007). This relationship imposes a sequence represented by the vertical succession of chronostratigraphic units and their respective discontinuities or unconformities. These appear as enveloping surfaces of the stratigraphic unit itself. In geology, stratigraphy is the science that investigates variations in the way different types of rocks have been deposited on top of each other, i.e., stratifying. A sequence is the main unit of sequence stratigraphy and is defined generically as a unit bounded by a specific type of discontinuity and its correlative surfaces (Embry *et al.* 2007).

Chronostratigraphy is a way of studying stratigraphy, but its approach and consequent perception of sedimentary events interprets the separation of strata in terms of distinct time intervals. The starting point is that one stratigraphic unit can be differentiated from the next according to its position on the time scale. The result is isochronous units, separated by synchronous contact surfaces and formed during the same time interval (Cremeens and Hart 1995).

The apparent isomorphism between stratigraphic order and temporal order has suggested the definition of temporal units as aggregate entities. These consist of those individualizable chronostratigraphic units that formed in the same time interval, depending on the specific mechanics of the site formation process (Aubry 2007; 2009). In other words, they are groups of stratification units, initially differentiated, but compressed, freezing a moment in the underlying dynamics of the stratigraphic sequence they represent. The most common term to refer to these groups of stratigraphic units is *phase.* The discontinuity that separates one phase from another is pointed here as a boundary, an *interface*[2] or phase transition.

Stratigraphic temporality is therefore defined based on the distinction between two types of reference units; the stratigraphic units, which are nothing more than the distinction of visually or analytically distinguishable deposits, and the temporal (chronostratigraphic) units, which are defined as discrete partitions on the time scale. Their definition differs in fundamental ways. The former ones refer to a possible estimate of the relative temporal position of a certain depositional event or related depositional events, whereas the latter ones refer to a geometric partition of the volume of physical space. They also differ in their stability. Once a stratigraphic unit has been defined by physically fixed boundaries, its duration is confined to those boundaries. In contrast, the "temporal" boundaries of a phase can vary considerably.

The temporal units (*phases*) thus constructed are therefore intangible. Although this does not prevent that their existence is suggested by inference from tangible data. Temporal units defined according to the stratigraphic order would then be conceptual

[2] In the physical sciences, an interface is the boundary between two regions with different properties or characteristics (Prutton 1994; Menon and Callender 2011; Schech 2013).

units defined by inclusion[3], whereas stratigraphic units are real entities, defined by extension[4] and located in physical space. The understanding of an ideal concept (an apparent 'block' of time) depends on the meanings (the criterion used to determine 'contemporaneity') and not only on the reference (the observed stratigraphic discontinuity). Considering that, the extent of an observed empirical referent is the set of things to which it refers (the alteration that soil has undergone; it has been excavated, terraced, built upon; the things that have been deposited on it, etc.).

2.2. Geology and Archaeology

If we assume that most of the anthropogenic activities that generated the deposition of something in a certain place at a certain time are subject to the same principles as deposits generated by natural processes (especially the law of gravity and the mechanics of the specific actions that led to deposition), then the basic principles that in geology link depositional order - stratigraphy - with temporal order will also be applicable in archaeology (Harris 1979; Gasche and Tunca 1983; Stein 1987; Brown III and Harris 1993; Carandini 1991; Goldberg and Macphail 2006; Rapp and Hill 2006; Berry 2008; Desachy 2008a; Düring 2012; Edgeworth 2013; Benito-Calvo *et al*. 2014; Mallol and Mentzer 2017; Karkanas and Goldberg 2019). In other words, the three-dimensional order of all the elements contained in a deposit records the action of forces associated with human movements and behavior, as well as natural processes that have been altering the original deposition. In this case, we refer to the final state of the deposit, and not to the specific intentions and purposes of the social agents who lived, worked, and possibly died there (Karkanas and Goldberg 2019).

Thus, the material expression of an archaeological event could be called a depositional event; someone did something in a particular place and during a particular time interval. Rather than a 'place' or 'time', the archaeological event or occurrence whose temporal position is under question should be configured as an intersection between social agents, social actions, products of actions and natural processes (Barceló and Pallares 1998; Estévez and Vila 2000; Vaquero 2001; Sáenz de Buruaga 2003; Barceló *et al.* 2005; 2009a; McAnany and Hodder 2009; Salisbury 2012; Quintana and Sáenz de

[3] Inclusion: the set that determines the properties that characterizes all the elements.
[4] Extension: the set that lists one by one all the elements.

Buruaga 2015; Munson 2015). This would also be the case even in the absence of radiometric dating. We start from the assumption that both types of events - geogenic and anthropogenic - have the same nature, as they have been defined as units of change (Peuquet 1994). They are regions of three-dimensional space - stratigraphic units - between which a difference has been established; one or several variables take on different values in different places. The space in which all points have the same value is definable. This means that a contour that differentiates the region in which the variable has one value from the region in which the same variable takes another value can be drawn. Differences between stratigraphic units can be expressed quantitatively, distinguishing no variation from linearly decreasing, linearly increasing, or convexly increasing or decreasing variations. The stratigraphic unit, as an event, can represent either the change or the rate of change.

The set of definable depositional events at a site constitutes the 'biography' of that site (Ward *et al.* 2016). To explain this 'biography' it is necessary to recognize both past human activity at a given site and all the key forces that may have modified or altered the deposition of materials. The material consequences of social or natural action often coincide with changes in the 'visual' or 'compositional' properties of the physical space in which the event(s) took place. Apart from accumulation, any action that modifies physical space or matter will cause certain changes in the appearance of the area around the location of the action. According to this, it can be assumed that a depositional event will correspond to the smallest unit of space that is differentiable with respect to neighboring units. This means that the observability of archaeological events is defined as a change of state in the global properties that define the archaeological space. In this respect, it is important to distinguish between what defines an event (the action that deposited something in a certain place for a certain cause) and the physical characteristics of the deposition and of the ground on which it took place. In consequence, these characteristics could help 'distinguishing' an event from others, but not to define it functionally. Social actions and natural processes cause certain regions of physical space to be distinguished from adjacent regions. This is because the values of a certain physical property related to the material consequences of an action are generalized to all locations contiguous to the place where the action occurred. This is true until the locations of the material consequences of another action are encountered. Between the place modified by one action and the place modified by another action, a discontinuity or interface is defined, whose morphology allows the geometrical definition of the chronostratigraphic unit.

Rather than ‘excavating’, what archaeologists do is ‘measure’, observe and record how certain spatially distributed variables vary (Barceló and Pallares 1998; Barceló 2005; Merlo 2004; Katsianis 2012). Each of these variations constitutes a depositional event and corresponds to a delimited region of physical space that is usually identified as a unit of reference. Thus, depositional events exhibit different patterns of occurrence in a specific space and time. Spatially, a depositional event may be fixed, regionally restricted, or it may be considered generalized if it occurs anywhere. Archaeological events may be spatially fixed because of their association with geological features of the physical space in which they occurred, which are fixed. In the temporal domain, events may repeat regularly, repeat irregularly, or occur independently or randomly with respect to time. The regular and irregular repetition of depositional events covers a continuum from a deterministic point of view repeating to generally predictable.

Different approaches have been suggested to proceed with the archaeological differentiation of depositional events:

1. By identifying possible discontinuities in the values of certain property(ies) that characterize each event:

- *Sedimentary properties (predominant lithology; fraction: clay, silt, sand, gravel, clasts, blocks; color of the sedimentary matrix, compactness, geometry of the discontinuity) (Gasche and Tunca 1983; Stein and Farrand 2001; Sáenz de Buruaga et al. 1998; Courty 2001; Goldberg and Macphail 2006; Goldberg et al. 2013; Benito-Calvo et al. 2014; Quintana and Sáenz de Buruaga 2015; Barham and MacPhail 2016).*
- *Archaeological properties (presence/absence of a certain material; average density of a certain type of material; etc.) (Anderson and Burke 2008; Ducke 2015; Wilhelmson and Dell'Unto 2015; Negre et al. 2016; Romagnoli and Vaquero 2016; Martínez-Moreno et al. 2016; Achino and Barceló 2018).*

2. By identifying the planes or surfaces that constitute the basins of accommodation of the deposited materials, established in the previous step (Harris 1979; Fedele 1984; Westman 1994; Carandini 1991; Sáenz de Buruaga *et al.* 1998; Aguirre *et al.* 1999; Sáenz de Buruaga 1999; Roskams 2001). In geology, these differences are manifested in their respective depositional planes. Sometimes an unconformity is clearly visible and is usually called a "shear plane" or, directly, a "shear". The idea is to break up the volume that constitutes the archaeological site by means of surfaces that envelop and enclose discrete geometric bodies of depositional elements (artefacts, building materials, sediments, etc.). These surfaces would have changed characteristics throughout the sequence of soils and deposits (Neal and Abreu 2009). These contact or differentiation surfaces can be positive (i.e., they appear as stratified 'layers'), negative (i.e., observed as shear planes between layers) or neutral (Drap *et al.* 2017). These 'neutral' surfaces are often referred to as *'interfaces'* (Harris 1979; Roskams 2001; Sáenz de Buruaga *et al.* 1998; Berry 2008) and they can be differentiated in:

- *horizontal strata interfaces:* these are strata surfaces that have been created or deposited horizontally (more or less), having an extension equal to that of the stratum, so they have the same stratigraphic relationships as the deposits and are recorded as an integral part of the same stratum.
- *vertical strata interfaces:* these form the surface of a vertical stratum, usually a wall, and are the result of excavation of the ground and are found in most sites. These take the form of pits, ditches, graves, post-holes, etc.
- *destruction interfaces:* identified as a site that has undergone excavation activity and therefore a certain part of the strata has been destroyed.

Each of the empirical expressions of the occurrence of a depositional event must be identified, individualized, described and recorded. Likewise, it is of fundamental importance to note the spatial relationships between them, in order to find out which depositional events belong to which phase. Sharon (1995) suggests two different strategies for defining the time packages called *'phasings'*:

1. The *'ordinal'* model, which attempts to arrange each stratification unit in a sequence according to an assumed depositional order. This form of inference

emphasizes depositional issues and uses a notion of *'strict'* contemporaneity. It allows to produce a continuum of appropriately detailed *'phases'*: virtually every identified deposit will constitute a phase, since it can be placed between the deposit that precedes it temporally and the one that follows it. The above is true, unless it can be shown that a deposit was deposited or accumulated at the same time as other deposits. In this sense, Barricelli and Valtolina (2015) distinguish active, passive and neutral relationships between depositional events or stratigraphic units. Active relationships are manifested in the form of *a) covers*, *b) fills*, *c) tilts, and d) cuts*; passive relationships refer to the relative position of two events: *a) they are covered, b) they are filled, c) they are based on, d) they are cut*. Finally, neutral relations imply the absence of hierarchy between the units: *a) both events are equal, b) both events join, c) both are different.*

2. The *'agglomerative'* model attempts to classify all deposits into a few broadly defined classes ('strata' or 'occupation levels'), under the assumption that all deposits of the same class are 'contemporaneous' in a broad sense. A requirement of this way of breaking down the sequence of successive accumulations in a deposit is the determination of what connects the different deposits of the same stratum to each other. A typical case is that of the construction of a building, where many deposits linked to the construction and/or use of the building are contemporary with, or at least predate, its abandonment and/or destruction. The tricky thing is, therefore, to establish that point of contact or similarity that allows us to group all 'similar' deposits together as being genetically related and therefore contemporary (cf. Munson 2015).

As a result of these attempts to systematize the detection of 'discontinuities' and 'interfaces' in an archaeological site, a hierarchy of reference units, generically described as *stratigraphic units*, is created. One usually starts by defining the *smallest determinable spatial unit*, i.e., the area that can be localized in physical space (Desachy 2005; 2008a; Berry 2008; Lucas 2012; Matskevich and Sharon 2016; Taylor 2016; Karkanas and Goldberg 2019). *Features* (set of contexts) are defined as more general sets with less internal homogeneity, that incorporate several units of minimal inference. *Features* are followed by *structures* (set of features) and *assemblages* (series of connected structures) (Barker 1982; Husi and Rodier 2008; Carver 2013).

Matskevich and Sharon (2016) have suggested defining *the primary locational unit* based on what the excavator assumes was a distinct area of activity within the site. This would then be the minimum unit of record that should be consistent with the decision that has been made at the time of excavation, whether that decision is to remove a sediment, remove an object, take a photograph, or make a measurement. The problem with this proposal is that the minimum unit of reference must be constant for the entire site. Ideally, the minimum reference and recording unit should always be of the same nature in any archaeological excavation, but this is unfortunately impossible, as the preservation conditions of the site and the range of observability is not always the same.

Matskevich and Sharon (2016) continue their proposal by stating that the stratigraphic units themselves, i.e., the spatially defined regions in the site, are second-level units, not minimal recording events. They refer to them as sampling events or *spatial units.* They state that what is important is not so much what these entities represent, but their geometry and location. Each *spatial unit* must be a closed polyhedron, and the complete set of spatial units should form a partition of [excavated] space, i.e., each point in space should belong to one and only one spatial unit (unless it is on the surface of the polyhedron). A *composite unit* is a set of spatial units. A room, a structure, a building are all composites, but so is an excavation area, a plan, or a set of strata. Similarly, materials of the same type (stylistic or functional) or provenance (determinable by their petrographic group, for example) are *collections* or *groups of finds*. *Composites* and *assemblages* can be defined by listing their contents, but also by grouping other *contexts* or *assemblages*. These assemblages can have individual record occurrences ('finds') linked to them, as well as relationships between them (beyond the records and relationships between the primary units that compose them). Matskevich and Sharon (2016) call any chain of records in different compositions and/or collections, accompanied by appropriate connecting texts, a *scenario*. Any 'site history', including the most complete one - the excavation report - can be defined as a *scenario*. Since a *scenario* is a composite entity of a higher level, it is necessary to group other entities in a narrative order to create it. The act of grouping is not exclusive, i.e., members of one group can belong to other groups as well. This allows the presentation of conflicting scenarios, e.g., stratigraphic sequences of alternative sites, qualified by the authors as more or less preferable.

The terms *phase* and *period* belong to this level, and should not be confused with spatial units, neither simple nor composite. In archaeology, there is considerable confusion surrounding these terms, although the most common option is to restrict the concept of phase to a unit made up of all those stratification units with the same temporal position (Desachy 2008a). That is, they have been formed at the same time -with a certain margin of error-, even if the formation process has been different. Therefore, any *phase* should be temporally homogeneous because of a single formation process, even if it does not correspond to a single depositional event. Rodilla *et al.* (2016) qualify the supposed contemporaneity of the events belonging to the same phase by saying that it is a circumstance that occurred over a long-time interval in which no changes in the associated entities are apparent. Other authors (Harris 1989; Traxler and Neubauer 2008) give a phase entity to a grouping of functionally linked structures: that they are contemporaneous in the sense that they predictably acted together. According to this, without a functional linkage between unrelated depositional events, it would be meaningless to speak of a *phase*. They suggest adopting the term *period* to refer exclusively to discrete blocks of time, mere irregular partitions of the time scale, although they are not defined as intervals, since their 'duration' is usually undefined. A *period* would group *phases*, i.e., groupings of stratigraphic units that, while not stratigraphically adjacent, may have relatively close temporal positions (Harris 1979). The relative temporal units (*phases* and *periods*) are therefore intangible, part of a *scenario*, but this does not prevent inference from tangible data suggesting their existence.

2.3. Visualizing the stratigraphical order of depositional events

2.3.1. Harris Matrix Diagrams and the stratigraphical order

For the ordering of stratigraphic units and their integration into temporal units (*phases* and *periods*), the so-called *Harris Matrix*[5] *diagram* is often used in archaeology (Harris 1989; Brown III and Harris 1993; Dalland 1984; Paice 1991; Aguirre 1997; Roskams 2001; Green 2003; Bandini *et al.* 2005; Berry 2008; Desachy 2008a; Traxler and Neubauer 2008; De Roo *et al.* 2016). In such a diagram, each stratigraphic unit is represented by a specific depositional unit and is identified by means of an

[5] General page on programs for creating Harris matrices: http://archaeologic.al/wiki/Harris_Matrix, compiled by John Layt and Guy Harris of the company L - P: Archaeology (last updated 2015. Accessed 23 May 2018).

alphanumeric number or label that is assigned to all identifiable finds and samples within the volume thus formed. Stratigraphic units can be differentiated according to their nature and hierarchical level (context, feature, structure, assemblage, etc.). Interfaces can also be identified independently by assigning numbers or alphanumeric labels, thus differentiating the soil or basin of accommodation from the deposition itself.

The stratigraphic relationship is defined in ordered pairs. For this purpose, a two-column table can be constructed, where each row expresses the stratigraphic overlap between each two units, the first column identifies the unit above, and the second column identifies the unit below (Table 2.1).

Table 2.1. Two-column table representing the possible stratigraphic order and overlap between each two units, by distinguishing the ones found below and the ones above.

BELOW	**ABOVE**
UE7	UE6
UE7	UE4
UE7	UE5
UE7	UE3
UE7	UE2
UE7	UE1
UE6	UE4
UE6	UE5
UE6	UE3
UE6	UE2
UE6	UE1
UE5	UE3
UE5	UE2
UE5	UE1
UE4	UE3
UE4	UE2
UE4	UE1
UE3	UE2

UE3	UE1
UE2	UE1

The fundamental binary relationship that orders the sequence is the stratigraphic position '*A* is below *B*'. Based on the fundamental *principle of stratigraphic superposition*, this special relationship can be translated into the temporal relationship 'prior to'. Additionally, if '*A* is not below *B*', then either '*A* has the same temporal position as *B*', or '*A* is independent of *B*'. The same is true for the stratigraphic position *'A* is above *B'*, which would be translated into 'posterior to'. Thus, stratigraphic location translates into a temporal anteriority-posteriority relationship. Temporal relationships cannot be inferred between unrelated depositional events.

Therefore, the following rules will be applied to each row of the table (Table 2.1):
- *A is temporally earlier than B, when A is situated below B in the stratigraphic sequence,*
- *A is temporally later than B, when A is situated above B in the stratigraphic sequence,*
- *If there is no way of knowing whether A is above or below B, and vice versa, we cannot conclude any temporal relationship between the two deposits or features.*

Harris Matrix diagrams represent the archaeological stratigraphy along a vertical axis, where the upper, and therefore most recent, layer is placed at the top of the diagram. This is directly below the upper surface and where the geological interface forms the lower layer. The contemporaneous stratigraphic units are placed on the same vertical level. We will identify the rectangular box representing the youngest deposit or feature and look below it for the rectangular box representing the oldest deposit or context. A line is drawn from the bottom of the rectangular box representing the oldest context to the top of the rectangular box representing the youngest context (Figure 2.3). The Harris diagramming convention uses a single line and indicates direction by vertical position, so that a younger context appears above an older context with which it shares a stratigraphic relationship. In this way, each stratum, identified structure, deposit and cut (plane or surface delimiting the negative structure resulting from an excavation) is binarily related to any other stratum, identified structure, deposit and cut.

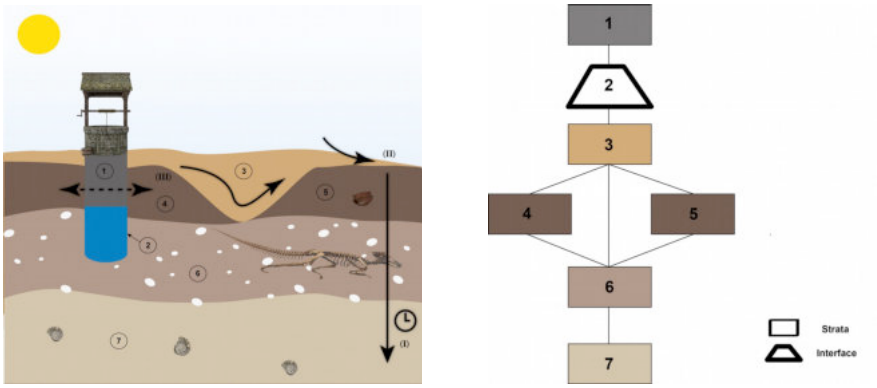

Figure 2.3. Stratigraphic section on the left and associated Harris Matrix diagram of the observed stratigraphic units on the right (*Figure after Mar Crego).*

2.3.2. Harris Matrix Composer

Harris Matrix Composer (http://harrismatrixcomposer.com/ ; Traxler and Neubauer 2008) is a commercial program developed by the Ludwig Boltzmann Institute for Archaeological Prospection & Virtual Archaeology, whose free download version is limited to 50 stratigraphic units. In contrast to previous graphical solutions, it constructs a directed acyclic graph, in which the stratigraphic units are represented as nodes, and the temporal relationships of anteriority-posteriority are represented by arrows.

The main component of the program is a graphical editor to create and update a Harris matrix during the whole excavation period. Deposits and surfaces can be inserted, and their stratigraphic relationships are determined by drawing lines of relationship. In this way, it allows the user to draw his own diagrams, without the need to infer from a list of overlapping stratigraphic units. To this end, it incorporates many solutions in terms of usability and user interaction. For example, it incorporates mechanisms to connect Geographic Information Systems to the tool interface.

The properties of the stratigraphic units are set by means of the property editor and the relationship editor, which displays all the relationships of the selected unit or group in the form of a list where new ones can be added, and existing ones removed. The application supports valid Harris Matrix creation and indicates inconsistent nodes and connections.

In the *Harris Matrix Composer*, stratigraphic relationships imply temporal relationships, but are explicitly different, so they are represented by dotted lines of a different color (Figure 2.4). Lines meaning ‘later’ point to the unit that is ‘earlier’ than the one from which the line originates. ‘Contemporary’ is a bidirectional relationship shown by lines with arrows at both ends. They can be transitive with respect to themselves but also with respect to stratigraphic relationships. Any stratigraphic relationship ‘above’ implies the temporal relationship ‘after’. As in *Stratify* and the other programs, transitive temporal relations can be removed after the validity check. For example, when unit *A* is above *B* and *B* above *C*, then the temporal relationship ‘*A* later than *C*’ is redundant and subsequently removed. The temporal relationship ‘later’ has similar effects on the plot as the stratigraphic relationship ‘earlier’. It positions the units at appropriate levels so that these lines always point from top to bottom. In contrast, contemporaneous units are placed at the same height, so that the lines representing them are horizontal.

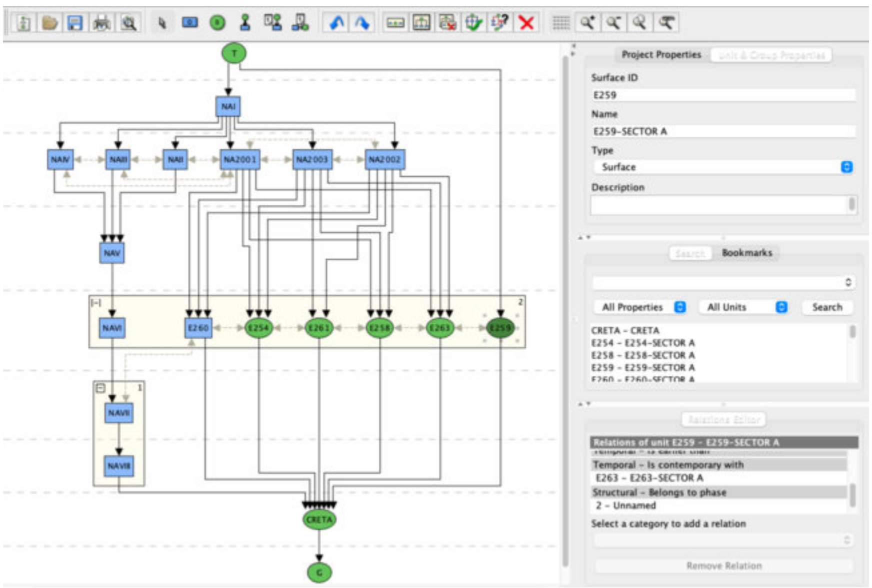

Figure 2.4. Typical layout of a Harris Matrix diagram edited in Harris Matrix Composer. The relationships “later” and “contemporary” are visible through the arrows, while the numbered light-yellow boxes correspond to structural phases.

As with transitivity, cycles can be caused by temporal lines with respect to themselves and to stratigraphic lines. For example, if unit *A* is above *B* and *B* above *C*, then *C* cannot be posterior to *A*. To be consistent, the first stratigraphic relations are checked independently and then the temporal relations are checked based on the stratigraphic ones. The timelines can also be hidden by the user so that only the stratigraphic relationships are visible.

The user can select units and group them into a *phase*. However, in *Harris Matrix Composer*, a *phase* is not a temporal (chronostratigraphic) unit, but results from a structural combination of structural stratigraphic units, e.g., postholes left over from an old dwelling. The only temporal unit is therefore the *period* representing a certain historical epoch. There are no temporal intervals, delimited by contemporaneity, but rather indefinite blocks of time that are given meaning by association with external referents. In the program, *units* and *phases* are assigned to a particular *period* by selecting them in the diagram editor and using the appropriate grouping operator. *Periods* cannot encompass units that are in different layers, as the vertical position has a temporal meaning. Neither *phases* nor *periods* can have any relationship to each other and are defined only by the stratigraphic units they contain.

2.3.3. Alternative methods for the visualization of stratigraphic relationships

Apart from the Harris Matrix Composer, other programs available for the representation of stratigraphic relationships, are discussed briefly in this section. Software such as *Syslat* (http://www.syslat.fr/index.php/documentation/) allows the diagram implementing the Harris matrix to be drawn by hand. However, much will be gained in objectivity and comprehensibility if the Harris matrix is calculated by means of a formal algorithm that translates the stratigraphic relationships into temporal ordering[6](Herzog 2006).

Stratify (Herzog 2004, http://www.stratify.org/)[7] is a program that effectively translates a list of observed overlays into a graph of ordered stratigraphic units. It is also able to work with a hierarchy of groups and with user-defined temporal units (*phases*). The result is a representation of different aggregations of stratigraphic units, where each group can be considered as a Harris diagram of groups and stratigraphic units, until the lowest level of the hierarchy is reached. When the Harris matrix becomes larger, then the grouping of the stratigraphic units becomes useful.

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[6] General page on Harris matrix software: http://archaeologic.al/wiki/Harris_Matrix, compiled by John Layt and Guy Harris of the company L - P: Archaeology (last updated 2015. Accessed 23 May 2018).

[7] Stratify has not been updated since 2006. It is intended to work on Windows 7. While it is usable on current versions of Windows running on 64-bit systems, the installation procedure requires the alternative installation file StratifyUpd. More information at http://www.stratify.org/Links/FAQs.htm

Another program for the interactive creation of Harris diagrams and minimizing the temporal inconsistencies and contradictions that can emanate from stratigraphic relationships is *Le Stratifiant*[8] (Desachy 2008a; 2012; 2016), currently distributed free of charge as a set of macro functions for Excel (© Microsoft, Inc). The underlying algorithm is different from that used by *Stratify*, but the results are perfectly compatible. Desachy (2016) specifies a derivation of the MPM algorithm that uses adjacency matrices.

Like the previous ones, *Strati5* (Sikora *et al.* 2016), is a software that exists in an online version and can also be installed as a simple spreadsheet.

Unlike Harris Matrix Composer, *ArchMatrix*[9] is linked to a database from which it builds and defines all observed stratigraphic relationships. This allows the user to add new information whenever necessary, modifying the resulting matrix interactively. The range of stratigraphic relationships allowed is much wider than in other programs, recognizing the difference between *active* (covers, fills, touches, cuts), *passive* (covers, fills, supports, cuts) and *neutral* (equals, joins) relationships (Barricelli *et al.* 2012; Barricelli and Valtollina 2015).

Unlike other programs that manually edit the Harris Matrix, the *Hm* package (Dye and Buck 2015)[10], is intended to integrate radiometric dates into a chronological directed graph. Its objective, therefore, goes beyond a typical Harris Matrix diagram. It makes it possible to visualize temporal relationships in terms not only of stratigraphic order, but also of the results of Bayesian cross-calibration of those dates available and ordered according to the stratigraphic units to which the samples belong. For this analysis, the correspondence between interpreted stratigraphic formations and chronometric dating is very important, as well as the correct distinction between interfaces and deposits. *GraphViz* [11](Costa 2007) is to some extent comparable to *Hm*.

[8]Original by Bruno Desachy, the programme and all the documentation are available on the following websites https https://abp.hypotheses.org/le-programme-bassin-parisien/les-projets/axe-3-systemesdinformation-et-referentiels-geohistoriques/rct and https://cours.univ-paris1.fr/fixe/03-40-doctorat-archeologie-atelier-sitrada (« outils téléchargeables »).

[9]https://ark.lparchaeology.com/wiki/index.php/ARKmatrix

[10] https://tsdye.github.io/harris-matrix/. Alternatively: http://www.tsdye2.com/harris-matrix/site/doc/hm.html

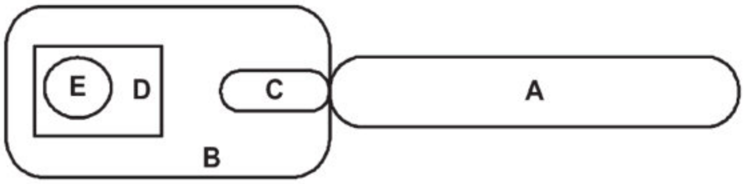
[11] http://www.iosa.it/2007/12/18/harris-matrix-with-graphviz/

2.4. Expanding the Harris Matrix

Although Harris matrices and their derivatives are a popular method today, studied in universities and still recommended for use in official archaeological intervention reports, it is not without its problems and difficulties. Harris (1979), like Wheeler (1964) before him, emphasized the difference between archaeological and geological deposits in terms of the human arbitrariness of the former. But left aside the cognitive or behavioral aspects, insisted on the physical properties of the deposition-accommodation-accumulation-erosion cycle. By only emphasizing overlapping links, the resulting restricted set of relationships distorts the temporal relationships between chronostratigraphic units (Carver 1990; Aguirre 1997; Bailey 2005; Berry 2008; Desachy 2008b; Lucas 2001; 2005; 2008; Sáenz de Buruaga 2003; Quintana and Sáenz de Buruaga 2015).

The basic stratigraphic-temporal relationships usually included in Harris matrices are too limited. There have been several attempts to extend the range of these relationships. Thus, for example, to the basic antero-posteriority relationship, Traxler and Neubauer (2008) introduce the relationship 'later than' (which also appears in the *Le Stratifiant* programme), while Dye and Buck (2015) add the relationship 'older than'. Thus, one chronostratigraphic unit may be older than another, when the time position of the end of the older deposit or feature is older than the time position of the beginning of the newer unit. In this relationship, two deposits or contexts lie on the same (possibly multi-linear) sequence line, but are separated by one or more deposits or features, so that a time interval separates two phases. On the other hand, a depositional event will also be older than another, even if the time position of the end of the older reference unit coincides with the time position of the beginning of the more recent unit. This is the typical situation in archaeology where the two deposits or features directly overlap, and we cannot infer the existence of any intervening event. Finally, a chronostratigraphic unit will also be older than another, even if the time position of the end of the older deposit or feature is more recent than the time position of initiation of the more recent unit.

When a depositional event does not occur randomly, but intentionally takes place in a certain specific place, it is very likely that two actions do not occur in exactly the same place, which is an exception to the law of superposition. Evidence that does not accumulate on top of it will be deposited in proximity, so that it could be asked whether the closer a later action is to an earlier one, the greater the temporal proximity between the two actions. This principle has given rise to what is known in archaeology as *horizontal stratigraphy* (Holst 2001). Cattani and Fiorini (2004) suggest including in the Harris matrix the following spatial constraint relationships (Claramunt and Jiang 2000) (Figure 2.5).



Spatial Relations	**A**	**B**	**C**	**D**	**E**
A	Equals	Contact	Contact	Disjoint	Disjoint
B	Contact	Equal	Included	Contain	Contain
C	Contact	Included	Equal	Disjoint	Disjoint
D	Disjoint	Included	Disjoint	Equal	Contain
E	Disjoint	Included	Disjoint	Included	Equal

Figure 2.5. Schematic representation and associated table explaining spatial constratint relationships (*Modified after Claramunt and Jiang 2000*).

Unlike the stratigraphic relationships 'above' and 'below', these horizontal spatial relationships cannot be directly translated into a temporal arrangement. They can, however, be integrated into the Harris matrix, to represent more faithfully the temporality of the archaeological site formation processes.

Rodilla *et al*. (2016) define a stratigraphic unit as an entity made up of material or the trace of extracted material, arranged as a layer with respect to others, reflecting a specific order of deposition, construction, or destruction. They distinguish different subtypes:

- *Stratum:* a stratigraphic unit formed by a volume of material.
- *Stratum by Deposit*: a stratum comprising the material of a deposit.

- *Stratum by Object*: a stratum comprising the material of an object.
- *Interface*: stratigraphic unit consisting of a surface of material.
- *Stratigraphic sequence*: composed of a set of stratigraphic units that are physically interrelated.

They extend the basic stratigraphic overlay relationships by defining:

- *Stratigraphic relationship of Joining*: a three-dimensional stratigraphic relationship consisting of a source stratum horizontally touching the target stratigraphic unit without merging with it. This stratigraphic relationship is symmetrical; that is, if *A* joins *B*, this implies that *B* joins *A*.
- *Stratigraphic relationship of Abutment*: a three-dimensional stratigraphic relationship consisting of a source stratum that merges horizontally with the target stratigraphic unit. This stratigraphic relationship is symmetrical, i.e., if *A* abuts *B*, this implies that *B* abuts *A*.
- *Stratigraphic relationship of Support*: a three-dimensional stratigraphic relationship consisting of a source stratum touching vertically and from above the target stratigraphic unit and resting on it. This stratigraphic relationship is antisymmetric; that is, if *A* is supported by *B*, this implies that *B* cannot be supported by *A*.
- *Stratigraphic relationship of Coverage:* a three-dimensional stratigraphic relationship consisting of a source stratum that firmly adheres to the surface of the target stratigraphic unit, covering it. This stratigraphic relationship is antisymmetric; that is, if *A* covers *B*, this implies that *B* cannot cover *A*.
- *Stratigraphic relationship of Filling:* a three-dimensional stratigraphic relationship consisting of a source stratum filling a concavity of the target stratigraphic unit. This stratigraphic relationship is antisymmetric, i.e., if *A* fills *B*, this implies that *B* cannot fill *A*.
- *Stratigraphic relationship of Cutting*: a two-dimensional stratigraphic relationship consisting of a source interface that establishes a removal of matter from the target stratigraphic unit. This stratigraphic relationship is antisymmetric; that is, if *A* cuts *B*, this implies that *B* cannot cut *A*.
- *Stratigraphic relationship of Equivalence*: a non-physical stratigraphic relationship that indicates the material and interpretative equivalence of the

stratigraphic units involved. This stratigraphic relationship is symmetrical, i.e., if *A* is equivalent to *B*, this implies that *B* is equivalent to *A*.

The more complex and diverse the set of spatial relationships, vertical and/or horizontal, the greater the ambiguity and uncertainty of the ensuing ordination (Adams 1992; Aguirre 1997; Holst 2001; Desachy 2016). To deal with this degree of uncertainty, it has been proposed to distinguish between 'strict contemporaneity' and 'broad contemporaneity' (Sharon 1995).

Holst (2001) has introduced the terms *partial/full asynchronism* to deal more effectively with the uncertainty of basic temporal relationships (Figure 2.6).

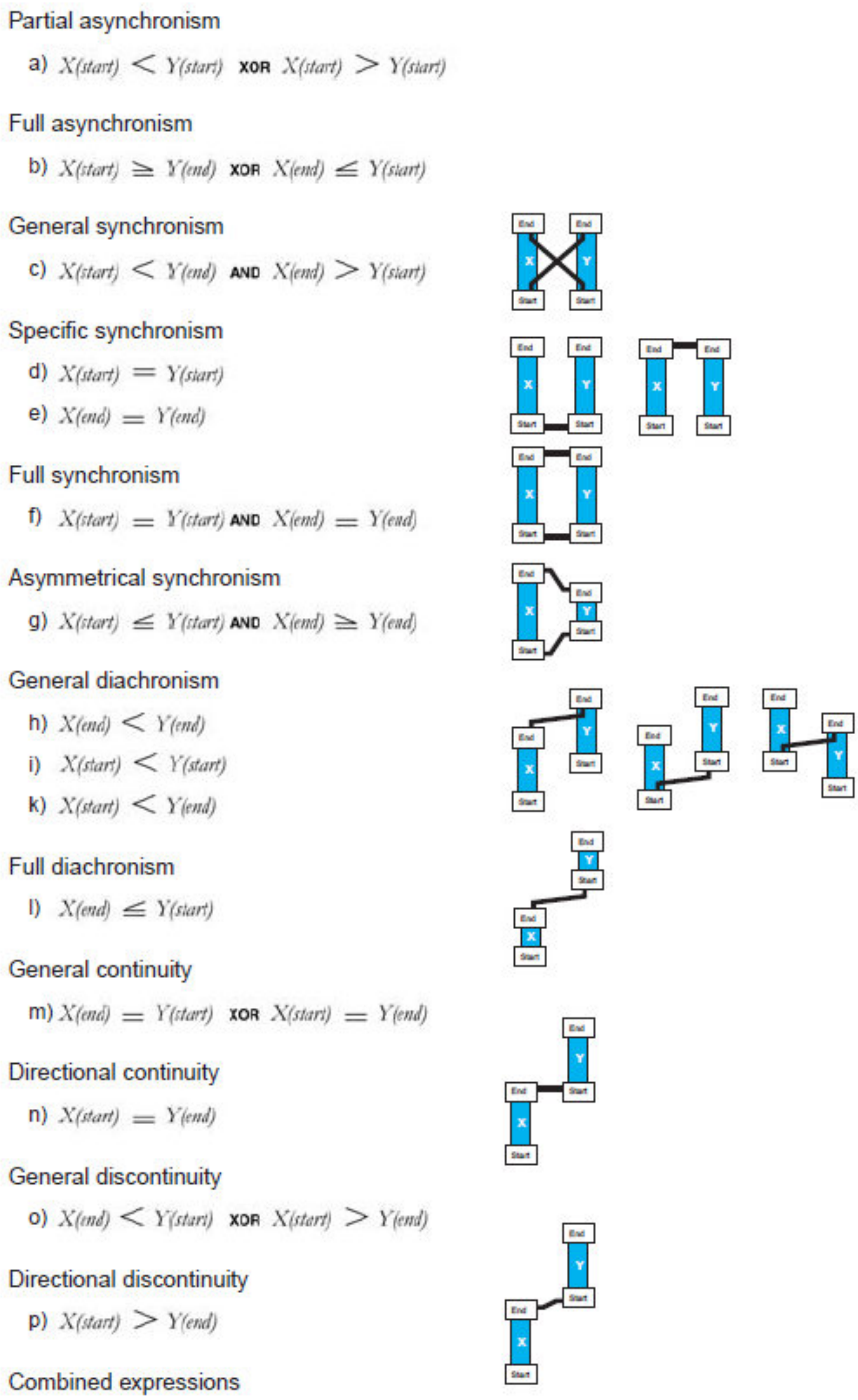
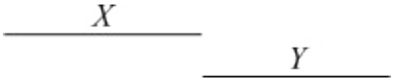
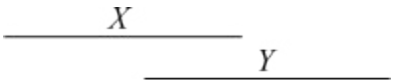
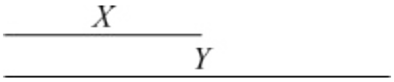
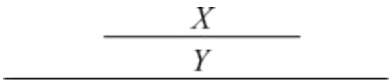
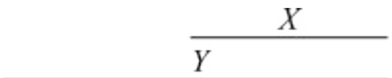
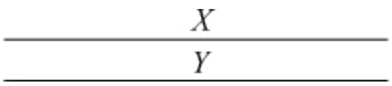


Figure 2.6. Classification of the temporal implications with graphical representation, where the implication is unambiguous (Holst 2001).

Another alternative would be to extend the inferred temporal relationships in a Harris matrix using Allen's interval algebra, which is a calculus of temporal reasoning introduced by James F. Allen in 1983 (Table 2.2).

Table 2.2. Table representing 13 possible Allen temporal relations (seven relations illustrated and their inverse ones) between *X* and *Y* and the chronological sequence of the start and end points of both intervals.

Illustration	Interpretation	Chronological Sequence
	*X* takes place before *Y*	$X_{start} < X_{end} < Y_{start} < Y_{end}$
	*X* meets *Y*	$X_{start} < X_{end} = Y_{start} < Y_{end}$
	*X* overlaps with *Y*	$X_{start} < Y_{start} < X_{end} < Y_{end}$
	*X* starts with *Y*	$X_{start} = Y_{start} < X_{end} < Y_{end}$
	*X* during *Y*	$X_{start} < Y_{start} < Y_{end} < X_{end}$
	*X* finishes with *Y*	$Y_{start} < X_{start} < X_{end} = Y_{end}$
	*X* is equal to *Y*	$X_{start} = Y_{start} < X_{end} = Y_{end}$

All except the relation 'is equal to' have their inverse, making a total of 13 basic relations. Compared to the basic temporal relationships of a Harris Matrix, Allen's algebra provides more temporal information, although it requires that the units whose relationship is established have a given temporal position and that their duration is equal to 0.

Although Allen's algebra is widely used in archaeology, its use to express the topology of temporal order in an archaeological site is still very limited (Drap *et al.* 2017; Dye and Buck 2015; Belussi and Migliorini 2017). The problem is that inferring Allen's temporality relationships directly from stratigraphic relationships between archaeological deposits and stratigraphic units is not straightforward, and often requires the subjectivity of archaeologists. Thus, stratigraphic relationship *A* is contemporaneous with *B*, can be translated into Allen's Algebra in several ways:

- *A* starts with *B*
- *A* is equal to *B*

- *A* overlaps with *B*
- *A* during *B*

Additional information is necessary to disambiguate the inferable temporal relations of the stratigraphic relation. The same happens in the case of the stratigraphic relation '*A* below *B*', which can be translated in Allen's Algebra by:

- *A* takes place before *B*
- *A* meets *B*

The only way to apply Allen's Algebra to infer temporal order from stratigraphic relationships would be to differentiate the beginning from the end of each stratigraphic unit (Drap *et al.* 2017). *A* and *B* denote time intervals that represent the time span of two depositional events. Each interval should be described by a set of temporal endpoints: A_{start}, A_{end}, B_{start} and B_{end}. The idea of continuity, and hence duration, would be formally expressed as $A_{start} < B_{end}$, which states that the beginning of the first event must occur before the end of the second event. For the sake of simplicity, from this point on, any reference to the time intervals *A* and *B* or to their endpoints will also refer to the instances of the corresponding events, unless explicitly stated otherwise. As a result, a reference to A_{start} establishes the starting point of the time interval representing the time extension of the first event. The determination of an end point that concludes the sequence of events constitutes the minimum information necessary to determine the continuity of the process. The logical linkage $A_{start} < B_{end}$ reflects a series of equivalent time relationships associating the occurrence of *A* and *B*.

The problem is therefore to distinguish empirically in a stratigraphic sequence the beginning from the end of the depositional event. If only the superposition or accumulation of certain deposits is recorded, it won't be possible to find out when the depositional event started on the time scale (Lucas 2012). This argumentation allows us to suggest that analytical decompositions of the archaeological site into stratigraphic units that do not consider the time interval that was necessary for their formation should be left aside (Lucas 2001). Instead, it would be useful to determine the beginning and end of each depositional event (Aubry 2009).

2.5. Establishing the onset of a depositional event

In the Harris Matrix, and its derivatives, the temporal interpretation of stratigraphic order relations rests on the basic assumption of the irreversibility of successive depositions and the sequence of soils being shaped as new actions occur at the same location. There are several criticisms of the blind application of the law of superposition in geology (Berthault 2013). Hence, modernly, instead of time units of indefinite and indefinable duration (equivalent to archaeological 'phases' and 'periods'), it is preferred to select a particular sequence of defined stratified rocks. This sequence should contain a physically localized stratigraphic point that serves as a reference location to define the boundary between units on the time scale (Catuneanu *et al.* 1998; Carver 1990; Carter 2007; Zalasiewicz *et al.* 2004; Dermitzakis 2010). Thus, this point will correspond to an instant of time at the boundary between the time intervals that make up the time scale (Aubry 2009). Therefore, instead of referring to packages of associated stratigraphic units as aggregate time units, the use of the Global Boundary Stratotype Section and Point (GSSP) is claimed in geology as an international reference point in a stratigraphic section that defines the starting time of a *period* in terms of the lower boundary of a particular stratigraphic unit.

To be used as a chronological marker in geology:

- *The lower boundary of a well-defined stratigraphic unit must be defined using a primary marker (usually the datum of the first occurrence of a fossil species).*
- *There must also be secondary markers (other fossils or detected geomagnetic reversals).*
- *The horizon in which the marker appears must have components that can be dated radiometrically.*
- *The marker must have regional and global correlation in outcrops of the same age.*
- *The marker must be facies*[12] *independent.*
- *The outcrop must be of sufficient thickness to be fully identifiable.*
- *Sedimentation must be continuous, with no changes in facies.*

[12] In geology, facies are a group of sedimentary or metamorphic rocks with specific characteristics, either paleontological (fossils) or lithological (mineral composition, sedimentary structures, geometry, etc.) that help to recognize the sedimentary or metamorphic environments, respectively, in which the rock was formed.

- *The outcrop must be unaffected by tectonic and sedimentary movements and metamorphism.*
- *The outcrop must be accessible for research and freely accessible.*

The archaeological equivalent of a stratotype section and global boundary point will be an *interface*, in the sense that Harris gives to the term (Harris 1989; Fedele 1984). However, not just any *interface* will provide evidence of the beginning of a depositional event, but only that discontinuity which permits to properly define the initial moment of a depositional event. *Interfaces* correspond to an instant without temporal duration (Perrin *et al.* 2011). Therefore, the archaeological equivalent of the GSPP, the boundary line or surface that marks the beginning of the depositional event, must have the same temporal position along its entire length. The category 'soil' meets these requirements.

In everyday speech, we refer to the 'ground' (soil, floor, etc) as the lower part of certain constructions or things on which all kinds of acts and actions take place. In geology, 'soil' is the biologically active, superficial part of the earth's crust that comes from the physical and chemical disintegration or alteration of rocks and the residues of the activities of living beings that settle on it (Crespo Villalaz 2004; Linderholm 2010; Salisbury 2012). Formally, a geological soil is defined as an accumulation of organic material and mineral by-products of weathering (Howard 2017). According to the SSS terminology (1999: 9) soil is described as:

'*a natural body composed of solids (minerals and organic matter), liquids and gases that occurs on the surface of the earth, occupies a space and is characterized either because it has horizons or layers that differ from the initial material as a result of additions, losses, 'translocations and transformations of energy and matter or because it is capable of supporting rooted plants in a natural environment*' (Restrepo 2007; p.276).

It is therefore formed by the accumulation of loose weathered material covering much of the earth's surface to a depth ranging from a fraction of a centimeter to many meters. In its upper part or *horizon*, which represents the boundary between soil and air, it is essentially a mixture, in varying proportions, of organic matter (largely plant matter), called humus, and inorganic particles (minerals) that come from the weathering of rocks. The inorganic part of a soil may have been transformed *in situ* or be the result of transport of debris from elsewhere.

Many processes can contribute to the creation of a particular soil, some of these are: wind deposition, sedimentation in watercourses, weathering, and deposition of organic material. The processes of mechanical alteration and chemical weathering of rocks lead to the formation of an alteration blanket or *eluvium*, which, when displaced from its original position by the action of slope transport mechanisms, is called *colluvium*. Soil is the result of the physical, chemical and biological dynamics of the disturbed materials of the colluvium, giving rise to a vertical differentiation into horizontal levels or horizons. In these processes, biological and biochemical agents become very important, either by the decomposition of plant products and their metabolism, or by micro-organisms and burrowing animals.

Anthropogenic soils, also known as artificial soils (Howard 2017), are soils that have been influenced, modified, or created by human activity, as opposed to natural or native soils, which are formed by natural processes. They are formed by three basic mechanisms:

(1) sealing of a natural soil under one or more layers of artificially manufactured impermeable material (*paving*),
(2) transformation of a natural soil by human action (*metagenetics*), or
(3) development of a new soil profile by human deposition of new sedimentary material (*anthrosediment*). Each type can be subsequently modified.

In archaeology, the term *"living floors"* refers to the identified surface on which a human population acted, and all remains and features observed on that surface. Among these features are the obvious human-made structures (e.g., hearths), as well as 'latent structures' indirectly interpreted, such as accumulations of remains at the boundaries of what was once a wall and which at the time of excavation has disappeared (Leroi-Gourhan and Brezillon 1972). It is precisely this 'occupation floors' that can serve as a key element to distinguish 'precise moments in past times' (Roe 1980). This is possible through the identification of the material remains of a floor, or surface conditioned by human action (Henry 2012). Ideally, then, each minimum spatial unit should be defined not only by its homogeneous archaeological content, but also by its association with specific pedogenetic horizons (Restrepo 2007). Distinguishable archaeological contexts and pedogenetic horizons represent distinct units of reference, with different principles and properties. The relationship between anthropogenic and natural remains will help to properly define the occurrence in each place and the specific temporal position of a depositional event.

In temporal terms, each occupation surface thus characterized will correspond to a time instant at the boundary between the time intervals that make up the duration of the depositional event. In spatial terms, this surface defines the lower limit of the accumulated deposit during a given time interval. In this way, by increasing the spatial resolution of the analysis, the temporal resolution of the human activities that have left evidence in the archaeological record is increased too. The occupation floor then becomes the minimum temporal unit of the archaeological site formation process. The main difference with the use of GSSP in geology is that the archaeological stratotype and boundary point will always be local, not regionally generalizable. This is because the relative chronology is an ordering of depositional events at a given location, and the soil characteristics resulting from the depositional event are only applicable to that event.

The original proposal of the concept of the 'occupation surface' or 'living floor' is largely based on ethnographic analogies, insofar as it implies that the activities that left depositional evidence at a particular site were contemporaneous (Leroi-Gourhan and Brézillon 1966; Malinsky-Buller *et al.* 2011). However, years ago Bordes (1975) (Bordes *et al.* 1972) questioned the validity of analogies between archaeological and ethnographic records, as well as the ability of archaeological methodology to achieve the resolution necessary to identify prehistoric analogues of ethnographic records of occupation floors. He argued that ethnographic analogues constituted an ephemeral surface with a uniquely human signature, whereas an archaeologically identified stratigraphic unit comprises different 'surfaces'. These were disturbed by synchronous or sequential natural and/ or anthropic factors.

To a certain extent, Bordes' criticism on the possibility of being able to precisely record the beginning of a depositional event is valid. In anthropogenic depositional environments, the contacts between major and minor sedimentary units are not always conformable, i.e., well defined. The identification of the original depositional plane is not straightforward, due to the action of natural processes on the exposed surfaces of archaeological sites. These could occur during periods of 'non-occupation' (Mallol and Mentzer 2017) and could have degraded the possible evidence of a given surface. The sedimentary substrate may have been mechanically modified or diagenetically altered by the addition of chemicals derived from human activity. As a result, almost all archaeological sites are, in some way, palimpsests: products of multiple depositional events or actions (Goldberg and Macphail 2006; Lucas 2012; Davies *et al.* 2016; Mallol and Metnzer 2017; Shahack-Gross 2017; Karkanas and Goldberg 2019).

In his discussion of the phenomenon of archaeological palimpsest, Bailey (2007) defines five varieties ranging from true palimpsest to those palimpsests involving the accumulation and transformation of successive depositions. In the former case, the differentiation between consecutive depositional events is almost completely blurry, while in the latter ones, there is the masking of some of the distinct depositional events of a given sequence. These are multiple, successive, stratified episodes that have been compressed into a single surface in which individual episodes are difficult to trace.

Malinsky-Buller *et al.* (2011) have distinguished between:

- *Rapid accumulation palimpsests*: a model that postulates that a series of occupation surfaces resulting from repeated and frequent human activities were rapidly buried and/or superimposed on one another. As a result, they merge into what, at first glance, appears to be a single horizon due to a combination of post-depositional mechanisms. In this scenario, accumulation would tend to be less discrete spatially. It is likely that the spatial distribution patterns of archaeological materials would have become less noticeable or even completely erased. Still, the assumption of a *rapid accumulation palimpsest* predicts a spatial distribution in which several anthropogenic concentrations of deposited material can still be observed. Such concentrations may occur at a single horizon but may not be contemporaneous. Alternatively, concentrations may overlap and clearly belong to different occupation periods.

- *Slow accumulation palimpsests*: In this scenario, the remains of many episodes of human activities accumulate over a stable surface, where low rates of natural deposition led to prolonged exposure of each occupation surface. This results in a slow mixing of the anthropogenic remains with the previous ones, as well as with the remains left by non-human agents (biological or geological). Due to the slow deposition, which need not be continuous, the likelihood increases that artefacts and other material elements will be deposited in that location. These could easily be removed after deposition. Due to the longer exposure time on the stable surface, it is expected that a higher proportion of weathered and worn (i.e., mechanically damaged) artefacts will be mixed with items in better condition. The model of a *slow accumulation palimpsest* predicts a homogeneous distribution of artefacts, with no discernible anthropogenic clusters, due to taphonomic effects.

2.5.1. Micromorphological analysis of sediments as a tool for the detection of depositional events

Micromorphological analysis is the method of observation of sediment structure under the microscope. It enters the realm of *microstratigraphy* as it reveals stratigraphic characteristics not visible to the naked eye. As it involves knowledge from more than one discipline (sedimentology, soil chemistry, geology, archaeology, mineralogy) and goes beyond the visual record, it has been referred to by Wiener as *Microarchaeology* (Weiner 2010). All the archaeological content of an excavation is often studied by different specialized disciplines, although under the microscope this record is studied as a whole, as part of the same sediment, soil, deposit. In order to obtain valid synthesis of the depositional processes forming an archaeological site the integration of the observations made on macro scale with the information obtained from the study of the microarchaeological record is essential.

By integrating the embedded information of the microscopic record to the macroscopic one, a better understanding of the archaeological record can be achieved (Weiner 2010). One of the tools used in earth sciences and only recently added in the toolkit of archaeologists is micromorphological analysis of sediments. This is a study of sediments and soils under the microscope, aiming to decipher the processes forming and deforming the archaeological record.

Given the problems of post-depositional integrity of occupation surfaces, the initiation of a depositional event cannot be identified by simple, usually subjective observation. On the contrary, the analysis of anthropogenic, geological and pedological processes that generated a real difference in depositional mechanisms is necessary. Among the analyses that could be carried out in order to distinguish between the processes forming an occupation surface is micromorphological analysis of soils and sediments.

The microstratigraphic approach is based on the detection of specific archaeological events spanning relatively short time intervals. Many anthropogenic activities, including food preparation, combustion structures, tool manufacture, etc. may have added element loads to soils and these loads can be studied microscopically. This approach therefore involves the study of the sequence of site formation, differentiating the causes of formation of the different stratigraphic contacts. Furthermore, it is possible to distinguish occupation surfaces (caused by anthropogenic factors) from those discontinuities resulting from geogenic, pedogenic or biogenic processes. Numerous sediment analysis techniques, mostly adapted from geosciences, chemistry, and botanical research, are used for this purpose. These techniques include micromorphology, elemental analysis, mineralogy, phytolith analysis and fat (lipid) content analysis.

The starting assumptions are: 1) different functional areas have characteristic geochemical signatures and these signatures are broadly consistent between sites; 2) the geochemistry of soils and soil layers can be related to the geochemistry of previous known inputs to these soils.

Microscopic evidence for assigning sedimentary surfaces to human activity includes microstructural features such as compaction, cracking and development of granular aggregates, as well as *in situ* breakage of brittle materials such as charcoal or bone, known as trampling. On the other hand, such analyses provide relevant information on the nature and degree of integrity of the geogenic, biogenic and anthropogenic components of archaeological deposits. They additionally help to determine whether differences in sediment composition, fabric or texture between individual units mark continuity or change in depositional mode (Goldberg and Macphail 2006; Wilson *et al.* 2008; Walkington 2010; Weiner 2010; Henry 2012; Díaz and Eraso 2010; Díaz *et al.*

2014; Barham and MacPhail 2016; Davies *et al.* 2016; Mallol and Mentzer 2017; Shahack-Gross 2017; Karkanas and Goldberg 2019).

2.5.2. Site formation and /or depositional processes

As it has been stated before, it is generally accepted that stratigraphy is the beginning and end of archaeological practice (McAnany and Hodder 2009). It occupies a three-dimensional body of physical space and is defined as the arrangement of depositional units in time and space (Karkanas and Goldberg 2019). The depositional units are the byproduct of the interplay between anthropic and natural processes. As a result, the study of the stratigraphic sequence provides the framework for reconstructing the biography of an archaeological site.

Starting from the assertion that the archaeological site is three-dimensional arrangement of deposits and artefacts, the activities and processes forming the stratigraphic sequence must be deciphered. The deposit is the unit that has to be analyzed as it bears the artefacts. In order to trace the artefacts position in the stratigraphic sequence the reference of the stratigraphic unit where artifacts belong is necessary. This is also necessary at the time of sampling artefacts for radiocarbon dating. Consequently, the artefacts cannot be separated from their sedimentary matrix; the archaeological container is conditioning and at the same time conditioned by the archaeological content.

By distinguishing the boundaries that separate one depositional event from another both in the field and under the microscope, better time resolution can be acquired as well. However, apart from the artefacts, an archaeological deposit contains mineralogical and chemical signals. These signals permit geoarchaeologists tracing the source of sediments but also the nature of post-depositional alteration (diagenesis) (Karkanas and Goldberg 2019). Given that anthropogenic activities are dynamic, they can leave signals similar to the ones of natural processes such as transport and deposition or redeposition. The most common of these activities are dumping, sweeping, trampling, brushing, kneading, etc. The fabric of the sediment under the microscope, which reflects the content and organization of sediments' components can help us figure out the nature of occupational surfaces.

Until recently, sediments were considered noise during excavation and the interest was turned on the artefacts instead. But without their associated deposits artefacts could be as well considered out of context. All discarded material in an archeological site bears equal social and symbolic importance and should not be undermined at the time of excavation.

However, in an archaeological site anthropogenic processes are usually interwoven with natural ones and *vice versa*. This means that even the natural processes taking control of the final abandonment of a settlement are still conditioned by human actions and decisions, thus currying cultural meaning. The present case of the lacustrine settlement of La Draga offers a great example of this concept. The topographic relief of the lake and its dynamic formation through time has a direct effect on the nature of natural deposits present in the settlement occupying the lakeshores. Topographic relief also affects subsequent deposition and anthropogenic activities. The contrary is also true; every anthropogenic activity or sedimentation affects equally subsequent depositions.

2.5.3. Other techniques for the detection of depositional events

High-resolution microspatial analysis, based on geostatistical techniques that investigate the higher or lower concentration of materials is another method that in combination with microstratigraphy can lead to the detection of depositional events. Since an occupation surface represents human activities that took place in a highly restricted space and at a delimited moment in time, it is assumed that the more clustered the deposited material is, the shorter the time that elapsed between the deposition of one material and another. Hence, the starting assumption of an occupation floor predicts discrete areas of activity, identified by specific spatial associations of various categories of artefacts (Villa 1976). If the material residues are distributed in a manner compatible with the concrete working mechanics that characterized the action, then the point cloud generated by the x,y,z distribution of artefacts of a given category should allow us to reconstruct the locus of the original deposition. In addition to this, insight can be gained on how the original surface conditioned that deposition. By means of different statistical and geometrical methods the variations in artefact density, shape and orientation of this point cloud can be studied. Furthermore, this study can include their possible spatial correlation with the original surface over which these materials were deposited.

Likewise, by applying geometrical criteria it is possible to join all the concentrations or dispersions of different types of material found on the same surface; in this way it is possible to reconstruct discontinuity planes (Hofman 1986; Bollong 1994; Beardah 1999; Beardah and Baxter 1999; Vaquero and Pastó 2001; Barceló 2002; Brantingham *et al*. 2007; Anderson and Burke 2008; Santoriello and Scelza 2008; Sullivan 2008; Wandsnider 2008; Crema *et al.* 2010; Cascalheira and Gonçalves 2011; Gallotti *et al.* 2012; Vaquero *et al.* 2012; Řídký *et al.* 2014; Gigli *et al.* 2016; Gopher *et al.* 2016; Martínez-Moreno *et al.* 2016; Davies *et al.* 2016; Clark 2017; Katsianis *et al.* 2017; Achino and Barceló 2018). Thus, variation in the vertical distribution of artefacts may be attributed to differences in the number of occupations, although the duration of each episode, while undoubtedly short, is not determinable.

For such an analysis to be valid, we need to know the precise causal relationship between the material remains observed archaeologically and the action that generated them in the past, not observable in the present of the excavation, but inferable by experimentation and replication. On the other hand, in most archaeological sites, few artefacts were abandoned on their occupation soil, but many of them ended up in purposefully excavated rubbish dumps. This makes many occupation floors appear 'empty' and the spatial density pattern of the material residues of the action cannot be analyzed. By increasing the resolution of the analysis, micro-rests of the productive activities can be discovered, hardly observable with the naked eye. Additionally, their differential spatial density (in three dimensions) could be analysed to determine the most probable location of the occupation surface corresponding to the production and/or space maintenance (cleaning) activities responsible for their deposition in a particular place (Banerjea *et al.* 2015) (Figure 2.7).

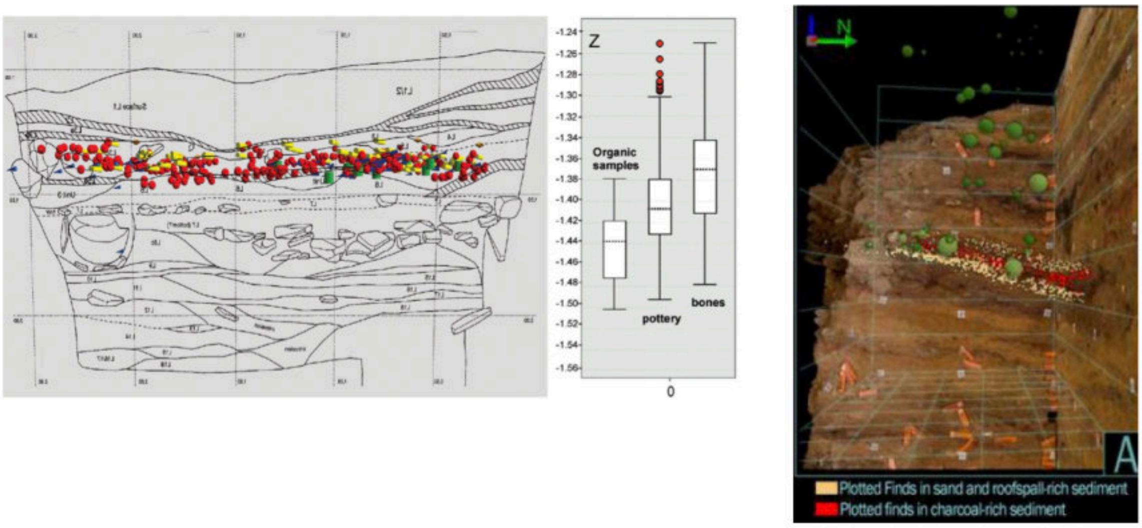


Figure 2.7. Examples of analyses of 3D material concentrations to determine the special location of the accommodation planes (Figures after Katsianis *et al.* 2017 on the left and Fisher *et al.* 2015 on the right).

Taphonomic analysis is also necessary to determine the degree of post-depositional alteration of deposited material. A common criticism of high-resolution intra-spatial spatial studies is that researchers are often too willing to view artefacts and associated evidence in the primary context and are therefore appropriate for tracing site structure (Schiffer 1976; Binford 1981; Dibble *et al.* 1997; LaMotta and Schiffer 1999; Banerjea *et al.* 2015; Shahack-Gross 2017). Therefore, the possibility of inferring the location of human activity (occupation surface) from observing the dispersion of archaeological remains in the present is affected by uncertainty. Research cannot guarantee that the abundance of material elements in a particular place fully reflects what took place there at a particular and restricted time in the past. Therefore, assume that these interpretative processes are stochastic, as they provide the reconstruction of probabilistic scenarios. This difficulty could be partly solved if post-depositional processes are considered as a source of disorganization and entropy increase. By measuring the degree of disorganization, each stratigraphic unit could be analyzed as a potentially biased sample taken from an earlier population, which is also a potentially biased sample. Given the probabilistic nature of causal relationships, we cannot claim that the materials deposited in an occupation surface are completely predictable if the destructive influences are known. However, the fact that the degree of post-depositional disturbance of an artefact assemblage cannot be predicted, does not mean that a series of archaeological observations cannot be analyzed. Afterall, these should be perceived as a by-product of a set of social actions altered by other processes (or the reproduction of the same actions in the same place) (Estevez and Vila 2000; Mameli *et al.* 2002; Achino 2016; Achino and Barceló 2018).

Ultimately, the distinction of depositional events is a much more complex problem than the distinction of 'discontinuities' or 'interfaces', in the traditional practice derived by E. Harris (1989). M. Wheeler (1964: 53) once noted that to excavate is

'to raise successive strata in conformity with their own lines of deposition, thus ensuring precise isolation of structural phases and relevant artefacts' (O'Brien and Lyman 1999; Ward *et al.* 2016).

The problem is that the distinction between the beginning and end of a depositional event is not observable to the naked eye, and often ends up being subjectively defined (Carandini 1991). In other words, the 'pages' into which an archaeological site is divided do not exist before archaeologists pretend to 'read' that book. They are constructed during the research process (Katsianis 2012; Lucas 2012), and there is no single way to define them (Fedele 1984; Wandsnider 1996; Vaquero and Pastó 2001; Bandini *et al.* 2005).

As a result, a depositional event can only be determined in terms of the occupation surface on which it took place, and that this surface is often determinable using high-resolution and/or microstratigraphic methods. Although in many other cases, the remains that may have existed of such a surface have disappeared, and possible apparent interfaces may be the result of post-depositional processes. The failure to distinguish the beginning of a depositional event prevents the reconstruction of the historical trajectory of a deposit, which becomes a whole with no possible temporal interpretation.

Michael Leyton (1992) has argued that a trajectory of change (a history) can be described as a discontinuous sequence composed of a minimum set of observable results of distinguishable actions. 'Discontinuity' is therefore the key word to distinguish between successive depositional events (Byers 1982; Mallol and Mentzer 2017). The perception and adequate description of such *discontinuity* is fundamental for the intelligibility of archaeological site formation processes.

2.6. Establishing the end of a depositional event

Evidently, there can be an indeterminate time interval between the beginning and the end of a depositional event. Thus, for example, the temporal position of a wall delimiting a certain spatial unit includes not only the duration of construction, but also the period of use of that wall, as part of an inhabited or used structure, until its destruction. If a wall was built, it can be reasoned that its temporal arc begins at the point of construction and continues not only through all floors adjoining it but also through its reuse. The temporal arc of the wall would finally end when it is physically sealed by demolition debris or the collapse of overlying structures. This would ultimately prevent it from being an 'active residual' part of that ground. In this case, the physical sealing of the wall marks the termination of the duration, as the wall ceases to exist actively at this point. In terms of 'changes of state' of a unit, and to re-use the example of a wall, the point at which the construction of the wall is finished must be defined. At this point a new event begins, as for example the use of the built structure, marked by the sealing of its construction cut off by a different depositional event. Or else the end of the wall's lifespan and the beginning of its final degradation (marked by the first abandonment, or demolition deposit sealing the last floor, or occupation deposit) (Taylor 2016).

Similarly, a floor may have been laid before a hearth or kiln was built on top of it, but the floor itself, as an active, used surface, may have lasted as long, if not longer, than the hearth. The stratigraphic sequence only shows the temporality of production, not the temporality of use of the built context.

In geology, the end of a geological period is often marked in terms of the beginning of the next, i.e., by recording the base of the next stratigraphic unit. Subsequently, this can be interpreted as the starting point of a new time block. This second GSSP[13] may be geographically distant from the first (Remane *et al.* 1996; Aubry *et al.* 1999; Cox and Richard 2005). In archaeology, such a strategy is often used, which, although not

[13] GSSP stands for Global Boundary Stratotype Section and Point. GSSPs are reference points on a stratigrahic section which define the lower boundaries of stages on the geologic timescale. More information is provided by the International Committee of Stratigraphy (ICS), in https://stratigraphy.org/gssps/.

erroneous, is imprecise, as it increases the imprecision of the end of an event. The end of a brief depositional event does not necessarily coincide with the beginning of another depositional event in the same place. Although in excavation practice there has been distinguished a certain interface as the 'roof' of a stratigraphic unit, it is not part of the initial depositional event, but of the one that follows it (Neubauer 2008a). Treating the upper interface of the stratigraphic unit as an integral part of the depositional event below it, ignores the possibility that it represents another chronostratigraphic unit. This can be the case either because the surface it represents was altered by erosion, exposing old deposits, or because the surface itself was exposed for some time (Dye and Buck 2015).

The end of an occupation surface is marked not so much by what happened in an indeterminate 'after', but by its immediate abandonment. When a community leaves the site, taking with them what may still be useful and leaving behind useless, cumbersome, and impracticable artefacts. In some cases, the material consequences of abandonment can be easily distinguished. For example, this could be the case of a sudden abandonment caused by natural episodes. When, on the other hand, people leave a place without haste, a clear understanding of each action in a more general chronological sequence is more complicated.

The abandonment of settlements triggers a series of processes involving the transformation of the occupation surface and the materials deposited on it. These are objects, installations and structures that are often still useful but nevertheless enter the archaeological context because they are left at the site of abandonment. Numerous factors influence the nature of *de facto* waste formation and preservation behaviors at any given site, including, among others, the rate of abandonment, the means of transport available, the distance to the next settlement, the formal characteristics of the items involved, and the perceived value of the items (Schiffer 1987). Indeed, waste deposition and differential preservation are two sides of the same coin: while the former represents a process of accumulation, the latter is a process of disposal. Therefore, an occupation floor empty of materials, or one in which all we find are broken fragments of objects, is likely to manifest that they have been abandoned (Murray 1980; Stevenson 1982; Nash and Petraglia 1987; Schiffer 1987; Cameron 1991; Cameron and Tomka 1993; Joyce and Johansen 1993; Kent 1993; LaMotta and Schiffer 1999; Allison 1999).

The problem is that even if we can determine the archaeological record of the social practice of abandonment or non-occupation - i.e., in terms of a particular pattern of fragmentation of deposited material - we cannot determine it stratigraphically. Since the fragmented and abandoned materials, probably because of their apparent 'uselessness', are deposited in contact with the occupation surface, they are not differentiated from it. In these circumstances, the beginning and the end of the phenomenon coincide stratigraphically, and the duration of the phenomenon cannot be defined in stratigraphic terms.

If the precise moment of the end of a depositional event is not stratigraphically determinable, this does not mean that a *terminus ante quem* cannot be established. In the same way that the formation of the occupation surface constitutes the *terminus post quem*, the sedimentary matrix or fill that separates that surface from the next one constitutes the *terminus ante quem* in discussion. It might be thought that the next surface to form already provides this information. Although, the sedimentary fill separating two successive surfaces or deposits is closer to the end time of the previous event than the start time of the next event in the historical trajectory of the stratigraphic deposit.

Between one soil and the next there is, by definition, an accumulated material that differentiates them. In geology, these are called *sedimentary facies*, and are defined based on the regularity (mineralogical, chemical, physical) of the material deposited between two successive interfaces or depositional planes. Microvariations in this material give rise to the differentiation of microfacies, whose existence is related to the rate of deposition and the specific mechanics of the formation process(es) involved (Goldberg and MacPhail 2017).

Sometimes this material is an intentionally deposited assemblage of artefacts. At other times, it is a post-depositional accumulation from the disorganization of a built structure, such as the degradation of an adobe or rammed earth wall, or the collapse of a stone wall. It may be that what separates one surface from the next is a sedimentary matrix accumulated by the action of the wind or another agent (anthropic or natural). Notwithstanding this, the basal surface of the next depositional event acts as the final moment of the event in which these materials have accumulated. By the action of gravity and the slope that is the result, in turn, of the prior accumulation, the edges that form the shape of the new surface will come into contact at some point with the previous surface.

In any case, it is essential to distinguish between the sedimentary infill of event *A*, and the soil thickness characteristic of surface *B*. Geologically speaking, soil is a natural body characterized by horizons (layers) that are distinguished from the initial parent material by additions, losses, transfers and transformations of energy and matter. The upper soil boundary is the boundary between soil and air, shallow water, living plants or plant materials that have not yet begun to decompose (Howard 2017). The base of that soil is defined by the material deposited by different processes, natural and anthropogenic, that formed the surface on which a particular social practice would take place. This base is part of the new depositional event and should be distinguished from the possible final ('sealed') moment of the previous event. This can be distinguished by means of micro-stratigraphic and sedimentary methods.

If the sedimentary matrix or fill accumulated just above an occupation surface provides the *terminus ante quem* of the depositional event, it is essential to study the specific nature and physical mechanics of the process (biogeological or anthropogenic) that generated that deposition. The most characteristic example of the end of an event is often the collapse of a wall or roof above the surface it once bounded (Milek 2012; Friesem *et al*. 2014a; 2014b). If this wall or roof was made of a soluble material, it will degrade to form a layer of varying thickness on top of the initial surface. Depending on the geological and physical nature of the soil, its outer surface will act as an accommodation plane for this new accumulated material, distinguishing itself and constituting an interface. Sometimes, however, the nature of the soil is also soluble or degradable, and then the disappearance of what was once its outer surface generates an indistinguishable palimpsest. As a matter of fact, the collapse of the wall or roof constitutes a new depositional event. However, the sediment that covers the materials deposited in the past is rarely differentiated from the soil on which they were deposited. It is 'soil', and archaeology has always been defined as 'excavation', that is, digging up hidden things. The truth is that this soil contains as much or more information than the materials archaeology seeks to 'unearth' (Hassan 1978; Schiffer 1987; Nash and

Petraglia 1987; Gé *et al.* 1993; Matthews *et al.* 1997; Weiner *et al.* 2002; Lenoble and Bertran 2004; Davidson *et al.* 2010; Barham and MacPhail 2016; Villagran *et al*. 2017).

2.7. Chronology of a depositional event

2.7.1. Dating a depositional event

It is generally assumed that the most likely position of a depositional event on the time scale should be close to the temporal position of most of the isotopic events it contains (Barceló and Bogdanovic 2020). Van der Plicht et al. (1999: 434) referred to ^{14}C events, defining them as *"the separation of a certain substance containing carbon from the source from which the carbon was obtained"*. Generalizing to any kind of isotopic clock, we refer to an isotopic event (See also, Lanos and Philippe 2017; 2018; 2020).

Since the temporal position of each isotopic event on the time scale is necessarily uncertain, a series of isotopic events is necessary (the larger, the better), and a combination of their respective confidence intervals, to estimate the temporal position of the depositional event. The rationale for this chronological inference is that the material consequences of activities performed at the same time should be closer spatially to each other than to those materials that were deposited farthest in time. Synchronicity of depositional processes suggests that all things being equal, activities occurring at the same time will tend to increase the joint frequency of their effects. Therefore, this can be further observed in the spatial density of such effects.

Nevertheless, this assumption is not always correct. Not only must we keep in mind the possible time lag between the isotopic event and the depositional event, but we must also know in detail the content-container relationship that may exist between the dated sample and the minimum spatial unit of reference in which it has been found (Roskams 1992; Berry 2008; Thorpe 2012).

A depositional event may contain one isotopic event, while an archaeological event is a palimpsest of various depositional events. Instead, an archeological phase is defined by a set of archeological events mostly contemporaneous. On the contrary, a set of events and phases not necessarily contemporaneous but relatively near in time and space, characterize a historical sequence (Barceló and Bogdanovic 2020).

Still, we must bear in mind that in order to detect the temporal position of an isotopic event, the archaeological material inference must be sampled. This should lead to the date of the depositional event, although not necessarily of the process of deposition. Consequently, dating is inevitably affected by the principle of included fragments, where artefacts found in the same layer may be older that the filling of sediments covering them. Although, depending on the depositional processes, artefacts may have been penecontemporaneous with the sediment (Karkanas and Goldeberg 2019). Post depositional processes are another factor with serious implications on the artefacts selected for dating. Artefacts included in more recent deposits or older ones can move and alter position after deposition due to diagenesis of some kind, such as bioturbation. Therefore, it is important to define the place and context of isotopic event.

The same is intended by distinguishing between immediate and related context (Barceló *et al.* 2012; 2013; Capuzzo et al. 2014; Morell 2019; Barceló and Bogdanovic 2020). On one hand, the immediate context includes refers to artefacts and dated sample that share the same depositional event, that is the minimum spatial unit of reference. On the other hand, artefacts belonging to different depositional events, even though contemporaneous, are part of a related context. The contemporaneity is defined stratigraphically, by connecting depositional events belonging in the same 'phase'.

That is the reason why some authors suggest distinguishing between 'strict contemporaneity' and 'broad contemporaneity' (Sharon 1995; Holst 2001; Desachy 2008a). Two elements are strictly contemporaneous if they were deposited at the same time; 'broad' contemporaneity expresses those two depositional events that may have occurred within the same temporal interval, but not necessarily simultaneously. The duration of the depositional process, its continuity, and the longitude of the temporal gap between the start and the end of the deposition also introduce strong and weak synchronisms. This distinction is important, because weak synchronisms or broad 'contemporaneities' would not allow us to establish temporally ordered relationships: if *A* is later than *B*, and if *B* is possibly contemporaneous with *C* (but we do not know with certainty), then we cannot affirm that *A* is later than *C*, although the degree of certainty can be expressed in probabilistic terms.

The slower the depositional event, and the longer time it needed to end, the more difficult it can be to fix its temporal position on the calendar scale. On one hand, the statistical combination of estimated dates for isotopic events in the same depositional event is more difficult. This is because the precision of radiocarbon estimate is often 'lost' in the calibration to calendar time scale (Blaauw *et al.* 2005). On the other hand, if the depositional event is assumed to have occurred along a relatively large time span (it was 'slow'), the contemporaneity of constituting isotopic events is 'broad'. Or else the different depositional events seem to be functionally related in some way. In this case scenario, chronological units can be built and defined as phases.

As it was previously described, a phase is an aggregation of broadly contemporary depositional events, or a single depositional event whose formation process has been extremely slow. Martín-Rodilla et al. (2016) qualify the supposed contemporaneity of events belonging to the same phase as a circumstance occurring over a long-time interval, during which no changes appear in the associated entities. It is the interval of the calendar scale fulfilling the condition: "there is a non-zero and calculable probability that any depositional event included within its limits contains at least one of the isotopic events to which it refers" (Barceló 2009). Furthermore, phases are groups of functionally linked archaeological units, in the sense expressed by E. Harris (1989): they are the result of a structural combination of structural archaeological spatial reference units, and not necessarily of temporal (chronostratigraphic) units (see also Cox 2001, Traxler and Neubauer 2008).

Although different, both uses of the term "phase" have similar explanations when used to reconstruct the "biography" of an archaeological site. They can be viewed as individual steps in the temporal trajectory of the site occupation and formation. In both cases, a single scalar –calendar date- for positioning such steps is not enough. However, the start and end of the activity or processes responsible for the formation of the individual event or the functionally connected set of events, can be defined.

2.7.2. Studying the duration of depositional events

The logic of the intervals *Terminus Post Quem* (occupation surface) - *Terminus Ante Quem* (sedimentary matrix or fill in contact with that surface) will help us to define more accurately the duration of each depositional event and to calculate more precisely the temporal relationships between them. Allen's algebra allows using more specific temporal relationships than the usual anterior-posteriority and contemporaneity. According to Allen's theory, a time interval is considered as an ordered set of points representing a discrete partition of the time scale. Each time interval is continuous and is formalized by a pair of endpoints indicating its beginning and end. It is worth noting that a time interval is identified as valid if it conforms to a basic temporal constraint. This means that the interval cannot have a duration of zero, i.e., its starting point must always be before the end point. Temporal constraints are considered as rules describing the consequent temporal order; in particular, they associate the end points of related intervals. Allen's theory introduces a set of temporal operators, known as Allen's operators, which describe the possible relationships between time intervals (Table 2.2). The operators are formalized using a set of temporal constraints that associate all possible pairs of corresponding intervals. As discussed in previous pages of this chapter, the use of temporal Allen operators in archaeology are hampered because they are limited to the requirement of complete temporal knowledge (Papadakis and Doerr 2015; Drap *et al.* 2017). This knowledge could be acquired by dating occupation surfaces, sedimentary matrices and fills, and materials deposited at different locations in the stratigraphic sequence.

The *Terminus Post Quem* (*TPQ*) is usually estimated through the dating of objects or features whose deposition defines the occupation surface, which will be used as a reference unit. In fact, the most recent of these features (provided it is not intrusive) allows to approximate the time position after which the event must have occurred with the highest probability. When it comes to an artefact, what we are estimating is the temporal position of the act related to its production (action before which the object should not exist). This means that the interval of imprecision of the Terminus *Post Quem* is at least as long as the duration of the use of the object in question. It is important to keep in mind that all these estimates refer to the final limit of the depositional event and not so much to its origin. For example, in the case of a landfill or dump in use for several years, the *TPQ* comes from a dated artefact, produced at a given time, and discarded in the last year of use of the dump. Consequently, its end corresponds to the time of deposition of the artefact, but the beginning of the dump is much earlier (Desachy 2012).

The *Terminus Ante Quem (TAQ),* the time position after which the event could not have taken place, can be estimated based on non-stratigraphic information. For example, this could be when the time position of the formation of the sedimentary fill (volcanic eruption, earthquake, military destruction) that seals the original occupation surface has been determined. The uncertainty interval can then be very long; in particular, the time interval separating the *TPQ* from the undetermined temporal position of the event (its last occurrence) can be very long. This is especially true when the element that allows us to link it to the time scale is not in primary position, but removed and re-deposited because of post-depositional processes.

It is therefore necessary to bear in mind that the end of a depositional event (*TAQ*) will always be more imprecise than its initial moment (*TPQ*). This uncertainty is related to the fixing of the end of the depositional event. This leads to the differentiation between the time interval within which the depositional event took place and the confidence interval with which the time position of its beginning and end can be fixed. In most cases, the only thing that can be done in archaeology is to establish limits that define approximately the temporal position of any event.

The *TPQ-TAQ* pair forms an interval of inaccuracy, delimiting a specific, but unknown, temporal position, even though it is sometimes the only chronological reference available for some depositional events. This interval provides a good framework for inferring the final instant of a certain depositional event. Although, it is not enough for estimating the duration of the event - during what time interval materials have been deposited on a certain surface - nor the onset of the event. Therefore, when speaking of 'dating' a stratigraphic unit, we refer to this final moment of a particular formation process (Desachy 2016).

Strict rules can be applied to combine these relative time positions with the stratigraphic anterio-posteriority order: a *TPQ* can be applied to each subsequent stratigraphic unit (if it does not have a subsequent *TPQ*), and a *TAQ* can be applied to each earlier unit (if it does not have an earlier *TAQ*). This is the traditional way of integrating stratigraphic constraints into the dating of objects or structures. For example, software such as ChronoModel and OxCal rely on the use of the *TPQ* endpoint to reduce the probabilistic imprecision of radiometric dating. However, the use of this interval [*TPQ,* *TAQ*] poses some problems, which have been well stated by Desachy (2016): the *TPQ* is sometimes confused with the actual chronological position of the site, in statements such as 'the ditch fill contains a shard of Roman pottery, so the ditch is Roman'. This is a simplification, because the sedimentary fill may be much more recent than the object it contains. It is recognized that the *TPQ* is at least a boundary for the temporal position of the depositional event; but what exactly does it mark: the beginning or the end of the formation of the unit? The most recent object found on a well-specified occupation deposit (usual definition of the *TPQ*, as stated above) corresponds to the earliest date of the end of its formation process. Although, it does not specify the beginning of its formation (because an object made after the beginning of the formation of a unit can be deposited in this unit, if the duration of the formation is long enough). However, in another form of simplification, the *TPQ* can be interpreted as an absolute date indicating an intended 'not before', relevant also for the beginning of the formation of the deposit. In short, the interval [*TPQ, TAQ*] limits a moment (the final moment) of the unit, not its duration. So, a reasoning based only on the [*TPQ, TAQ*] tends to intellectually reduce the unitary temporality to a simple date - only a moment in time without duration.

2.8. The formal analysis of a stratigraphic-temporal order

As discussed in the previous section, the temporal logic of a stratigraphically superimposed sequence of depositional events is much more complex than the mere statement 'the deeper, the older'. On the one hand, not just any stratigraphic order represents a temporal order, given the complexity of human action and the diversity of depositional events it can generate. On the other hand, a Harris matrix does not necessarily reflect the stratigraphic formation processes of an archaeological site if we do not specify the beginning and end of each of the events in the sequence (Herzog 1995). Therefore, drawing the possible relationships of temporal anteriority, posteriority, or contemporaneity on a graph should not be limited. Instead, the type of arrangement that emerges from the combination of the stratigraphic (vertical) relationships should be calculated. Furthermore, it should be evaluated whether it coincides with a possible temporal arrangement, which basically consists of a strict logical order, with very specific formal properties.

If we start from the relation of contemporaneity between depositional events whose initial moments coincide, we will define a relation of equivalence (transitive, symmetrical and reflexive) (Desachy 2005; 2008a), since:

- ✓ every event is contemporary to itself (reflexive properties),
- ✓ if one event is contemporary with another, the latter is contemporary with the former (symmetric), and
- ✓ if one event is contemporary with another, which in turn is contemporary with the second, the first will necessarily be contemporary with the third (transitive property).

Conversely, if the onset of the different depositional events does not coincide, then we must define a partially ordered set (or poset) because the relations between these initial moments fulfil the non-reflexive, anti-symmetric, and transitive properties (Orton 1980; Salin 1985; Desachy and Djindjian 1990; Herzog 1993; Sharon 1995; Desachy 2005; 2008a; Dye and Buck 2015; De Roo *et al.* 2016; Taylor 2016). That is, for any stratigraphic units *a, b*, and *c* in *X*, the following applies:

- *a* is not stratigraphically below itself (non-reflexivity).
- If *a* is stratigraphically below *b*, then *b* is not stratigraphically below *a* (antisymmetry).
- If *a* is stratigraphically below *b*, and *b* is stratigraphically below *c*, then *a* is stratigraphically below *c* (transitivity).

Such an order does not necessarily have to be total, i.e., it is not necessary that all depositional events are related to all others. Although it would be an interesting condition, enough reliable stratigraphic information is not always available to order all the depositional events that may have occurred in the archaeological site along its formation trajectory. Total order is a particular case of partial order.

2.8.1. Directed Acyclic Graphs (DAG) and Marcov Chain Monte Carlo (MCMC) algorithms

The stratigraphic order thus induces an ordering that has the same properties as an ordering of events according to their temporal position. This isomorphism becomes apparent when we represent the observed order by means of a directed acyclic graph (*DAG*). Formally, a directed acyclic graph can also be represented in the form of an adjacency matrix (De Roo *et al.* 2016).

Alternatively, a graphical representation can be employed, in which a set of vertices or nodes represent occupation floors, sedimentary matrices, or deposited artefacts. These are linked by edges or arcs, representing binary relationships between the recorded archaeological entities. The most recently formed element - the most 'modern' - is by convention designated the starting node of the arc and the entity that formed first - the 'oldest' - the end node. It is customary to represent arcs on a directed graph as arrows, with an arrowhead at the end of each arc to indicate direction (Salin 1985; Ryan 1988; Herzog 1993; 1995; Desachy 2005; 2008a; Dye and Buck 2015; De Roo *et al.* 2016; Belussi and Migliorini 2017) (Figure 2.8).

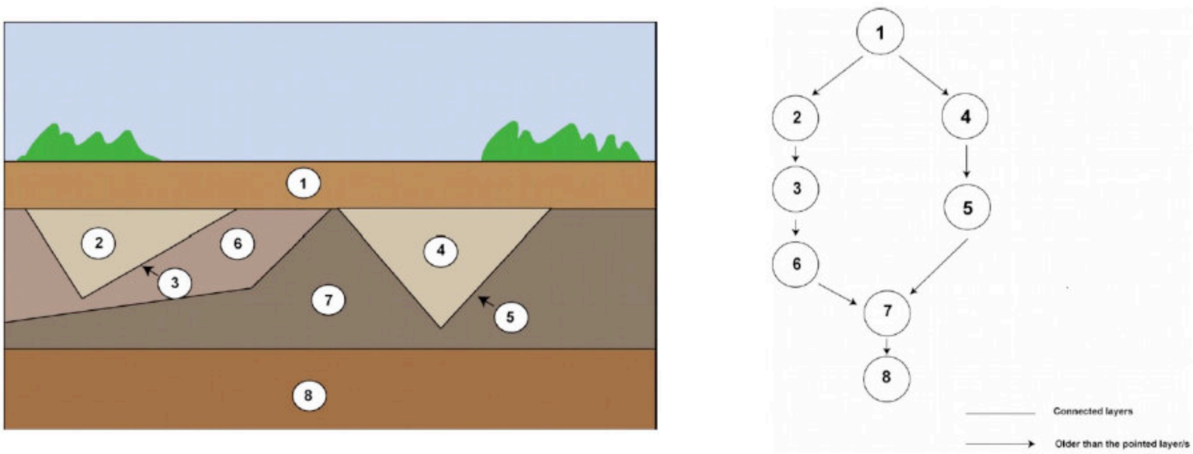


Figure 2.8. Stratigraphic section and directed acyclic graph (*DAG*) representing the temporal order of deposition.

The drawing of a graph should not be confused with the graph itself: the same graph can have different paths that express the same relationship[14] (Sharon 1995; Herzog 1995).

[14] Alternative conventions to node-link diagrams include: (a) spatial adjacency representations where vertices are represented by disjoint regions in the plane and edges are represented by contacts between regions; (b) intersection representations where vertices are represented by non-disjoint geometric objects and edges are represented by their intersections; (c) visibility representations where vertices are represented by regions in the plane and edges are represented by regions that have an unobstructed line of sight to each other; (d) confluent patterns, where edges are represented as smooth curves; e) lattices, where nodes are represented as horizontal lines and edges as vertical lines (Tamassia 2013).

In any case, the greatest difficulty in expressing stratigraphic relationships in the form of a temporally directed graph lies in the expression of contemporaneity relationships, when the events involved are not in stratigraphic contact.

To formally represent the duration of a depositional event in an acyclic directed graph a distinction must be made between (Taylor 2016; Drap *et al.* 2017):

- An 'initial t-node'; is a point in the sequence that will have a *TPQ* based on the lower stratigraphic relationship of the occupation surface within the sequence.

- A 'terminal t-node'; is a point in the sequence that will have a *TAQ* based on the stratigraphic relationship above the reference occupation surface, since it is a new physical relationship, which marks a boundary.

Furthermore, the temporal arc of a stratigraphic unit must be subject to a change in its interpretive state (what was deposited, how), marked by a 't-node of transformation' (which may have occurred at any time after the starting t-node). This must be also defined temporally by either a stratigraphic relationship, or a 'significant' physical relationship with another stratigraphic unit.

In the same acyclic directed graph that generates the stratigraphic relationships, now the nodes are specified in greater detail. They correspond to occupation floors, i.e., bases of the stratigraphic units themselves, and constitute a temporal referential unit, and can have a geometric realization on the time scale as an instant (Belussi and Migliorini 2017). An arrow in such a graph represents a relationship between two successive depositional events, whose temporality is established in terms of their starting instants. There is, strictly speaking, no terminal node. It is the next event that concludes the previous depositional event. Therefore, this graph does not, by itself, establish the duration of the depositional event, but only the general direction of the formation process (Figure 2.9).

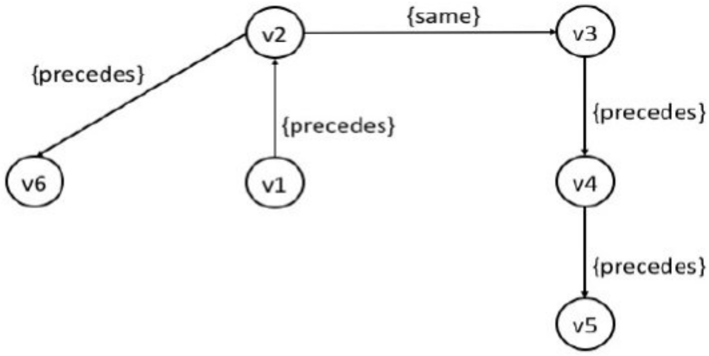


Figure 2.9. Graph in which depositional events are connected by arrows representing the direction of the formation process.

In other words, if the spatial location of occupation deposit *A*, defined by its minimum and maximum topographic elevation, is below the elevation of another deposit *B*, then deposit *A* will most likely have an earlier start date than *B*. If the entire extent of *A* is below *B*, then the temporal relationship of antero-posteriority between the two will be more likely than if the two deposits are partially overlapping. This probability will decrease based on the percentage of overlap. If at some point both deposits come into contact, the probability of an antero-posterior temporal relationship will be equal to 0. In other words, the more the topographic elevation of the two occupation deposits coincide, the more likely the contemporaneity between them will be.

Additionally, it can be argued that a stratigraphic sequence constitutes a Markov chain, or a random series of transitions between discrete states. The transition probabilities from one state to another are calculable. The order number of an event specifies the number of states in the process, i.e., a first-order process will calculate the probability of a state transitioning to another state. In the case of a second-order chain, the probability of transition to one state could be calculated from a defined sequence of two states. This approach has been widely applied in the geological literature to search for non-random sequential patterns in stratigraphy (Krumbein and Dacey 1969; Carle and Fogg 1997; Carver 2013).

This indicates that the formation of a deposit and/or surface or the deposition of a certain material on that surface will be independent of the state of any other deposition to which it is not stratigraphically related. This property is called a causal Markov condition (Cartwright 1999; Hausman and Woodward 1999; Spirtes *et al.* 2000; Steel 2005; Koller and Friedman 2009; Marazopoulou *et al.* 2015; Murray-Watters and Glymour 2015; Pearl 2009; 2010; 2014; Pearl *et al*. 2016; Bechlivanidis and Lagnado 2016; Schurz 2017; Dafoe 2018).

An additional advantage of the Markov condition of an acyclic directed graph representing a series of stratigraphic sequences is that the stratigraphic relationships, and thus also the temporal order, are probabilistically predictable. That is, local stratigraphic sequences (profiles, sections, boreholes) can be used to predict the continuity of a depositional event in an unexcavated area, or its main sedimentary and/or archaeological features. There are several ways of doing this, involving the inversion of the stratigraphic model, i.e., inverting the acyclic directed graph, so that the dates do not go from the previous event to the next, i.e., from cause to effect, but the other way round. Such a graph is converted into a Bayesian belief network by assigning probability tables to the various possible connections between units, based on known stratigraphic sequences. The Bayesian network will allow calculations to be made that will provide us with the probability that in the unexcavated area a surface stratigraphic unit (observed) is in connection with an earlier depositional event (unobservable). Partially used in geology (Charvin *et al.* 2009; Martinelli *et al.* 2011), this technology has not yet been applied to stratigraphic research in archaeology.

Since the aim is to find out whether a stratigraphic arrangement expresses a possible temporal order, what the topological validity of the temporal relationships derived from the observed stratigraphic order should be tested (De Roo *et al.* 2016).

In our case, topology refers to the properties of the acyclic directed graph expressing the chronostratigraphic ordering that hold under continuous deformation, such as adjacency, overlapping or separation (Thiele *et al*. 2016). It is possible to define three different orders in such a topology:

- a first-order topology describing depositional events in stratigraphic contact,
- a second-order topology defined by relationships between soils and stratigraphic fills, expressed in terms of the arcs or links in the graph, and

- a third-order topology representing continuity relationships between events that are not in stratigraphic contact but can be defined in terms of contemporaneity relationships (defined by related nodes).

Using this notation, the first-order topology describes stratigraphic contact relationships regardless of the spatial dimensions used to represent them geologically. Higher-order topologies become available as more degrees of freedom are allowed. This is possible by introducing new variables or new temporal information (the idea of contemporaneity, established by comparison of materials and not by stratigraphic location).

A point in time occupies a position in a temporal reference system and can be connected to other points through relationships. Therefore, topological structures can be used to explicitly describe relationships between time points. This is possible even when they cannot be derived directly, as the exact position of time points is unknown (Thiele *et al.* 2016; Belussi and Migliorini 2017).

The most important aspect investigated in topology is the notion of continuity. In the field of archaeology, the topology of a depositional sequence refers to a set of connected depositional events, represented as elements of a series of variously related sets. In this sense, only if a sequence of depositional events is expressible as an acyclic directed graph will it retain the topological information contained in the stratigraphic sequence (Salin 1985; Adams 1992; Thiele *et al.* 2016). That is, the diagram (as a topological model) will describe the possible temporal continuity or discontinuity between events. This will happen without considering distortions due to features such as stratigraphic depth, convexity or curvature of depositional planes, temporal and spatial distance between topologically continuous events.

Suppose a set of depositional events linked by contemporaneity relationships has been identified. They thus constitute a *'phase'*, in the traditional sense of the term. These depositional events (contexts, deposits, features, assemblages, structures, sedimentary fills) may intersect each other, may be disjunct, may include the whole phase (which is a part of itself), etc. To be defined topologically, the *'phase'* must satisfy certain simple properties. Among these properties that of a topologically open set is included. This will also apply to that set of related events in which each one of its members is surrounded by depositional events that also belong to the set.

One of the most interesting aspects of the topological analysis of a stratigraphic sequence is the possibility of applying the axioms of set separation. In topology, separation axioms are properties that a topological space can satisfy in terms of the degree to which different chronostratigraphic units grouped in closed sets can be separated by means of open sets. They are fundamental in translating stratigraphic overlap relations into temporal ordering relations. However, topological separation analysis does not provide information on the duration of the depositional event. This requires the use of absolute dating.

Stratigraphic order is not the same as stratigraphic depth. The latter is rather defined as the linear distance between the location of the ground over which the depositional event occurred in the past and the present ground level of the observer. Stratigraphic order has been defined as a topology, and it has been proved to be isomorphic to the topology of temporal order. The question is whether that relationship is measurable. In mathematics, a metric or distance function is a function that defines a distance between each pair of elements of a set. In our case, this is the temporal distance - measured by an isotopic clock, for example - and the vertical distance between the current ground and the ground generated in the past - measured by a theodolite, for example. In principle, the assumption that the archaeological space is a metric space is made. Afterwards, the question how the metric of space is related to the metric of time is asked.

2.9. The relationship between stratigraphic depth and the temporal position of depositional events

In 1958, H.E. Wheeler[15] developed a way to visualize the temporality of a stratification process, proposing a chronostratigraphic section, in which the vertical dimension is

[15] Simultaneously to the definition of the "Wheeler plots" and the definition of chronostratigraphic sections in geology by the North American Harry Eugene Wheeler (1907-1987), the Englishman Mortimer Wheeler (1890-1976) was one of the first archaeologists to propose stratigraphic excavation, in which archaeological materials are documented by referencing them to the different regular grids into which the excavation area is divided, and by establishing the chronological sequences. It is a

drawn with a time scale instead of a depth scale (Wheeler 1958; 1964) (Figure 2.10). The *y*-axis represents a relative geological time (*RGT*) scale, expressed in terms of stratigraphic depth, and the *x*-axis represents a measure of spatial distance between two points. In these graphs, a contact surface or depositional plane is considered as a time boundary separating older strata from younger strata, defining a relative time scale. In this way, temporal phases and discontinuities are easily visualized and the nature of the correlation between stratigraphic depth and temporal order can be accurately indicated (Posamentier *et al.* 1993; Miall and Miall 2004; Stark 2005; De Bruin *et al.* 2007; Monsen *et al*. 2007; Qayyum *et al.* 2012; 2014; 2015; Smith *et al.* 2015; Amosu and Sun 2017). The problem is that through the transformation of stratigraphic depth to a relative time scale, the thickness and volume of the depositional unit is lost, and the duration of each deposition is left undefined. This approach does not allow the study of the possible metric relationship between depth and temporality.

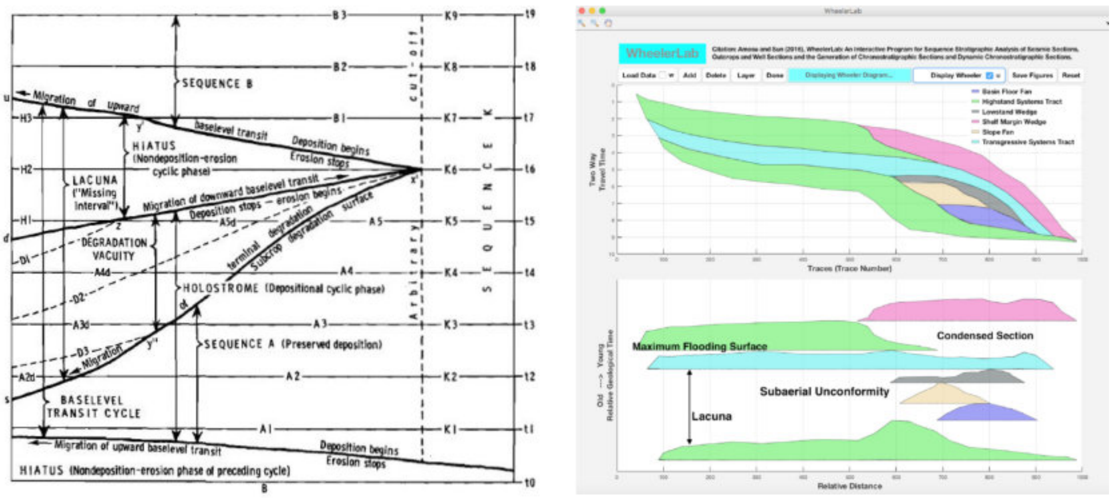


Figure 2.10. Original Wheeler (1964) diagram and modern counterpart using the open access WheelerLab software (Amosu and Sun 2017).

The alternatives for the archaeological analysis of the metric (not topological) relationship between depth and temporality are mostly based on the visualization of the stratigraphic units in a three-dimensional geometric model that reproduces the archaeological space. As in Wheeler diagrams, the *z*-axis becomes a way of expressing the axis of temporality. In the present analysis, no further details of three-dimensional approaches will be discussed.

curious coincidence that two researchers from different disciplines, but with the same surname, are related by their mutual interest in stratigraphy and chronostratigraphy.

However, the duration of the depositional events is completely lost in a Harris matrix, making these visualizations useless for understanding whether there is a metric relationship between stratigraphic depth and temporality. More efficient would be to represent in a 3D visualization the initial moment of each of the depositional events in the sequence. If we define this initial moment in terms of the formation of an occupation floor, the result will be a 3D correlation of successive depositional surfaces or planes.

2.9.1. Depth-age modelling

Studies that focus on the metric relationship between stratigraphic depth of a depositional event and the temporal position of that event on the calendrical scale are not common in archaeology but are of great importance in geology for estimates of the possible duration in calendar years of each *phase* or *period* (Bronk Ramsey 2008; Blaauw 2010; Blaauw *et al.* 2012; Bennett and Buck 2016; Telford *et al.* 2004; Trachsel and Telford 2017). The reasoning involved in constructing such models is complex, subtle, and scientifically demanding. Therefore, there is a lack of knowledge of the processes that control the rate of accumulation of material over time, which is responsible for the depth at which the dated sample was located.

For this reason, a choice between several types of alternative models must be made. In the so-called 'classical' model, a curve or line is fitted to a series of points defined by two coordinates, 'depth' and 'absolute time position'. This is realized without prior assumptions about the rate of sediment accumulation or the monotonicity of the time positions of the dated samples obtained (Blaauw 2010). If the time position has been determined using radiometric dating, these dates may or may not be calibrated. Any calibration is performed before curve fitting, and outliers are rejected, either before analysis or after producing the model. Common classical algorithms include linear interpolation, linear or polynomial regression, and various forms of spline calculations[16]. Different types of models will require different minimum amounts of dates or radiometric dating, for example, a smooth spline needs at least four data points, and linear interpolation or regression at least two. Hiatuses, or possible breaks in the sequence, should be included in the model by providing their depths (Blaauw *et al.* 2018). Slow depositional events, which involve long-lived events, can be modelled by

[16] Among the classic age-depth modelling software is Clam 2.2 (Blaaw 2010). http://chrono.qub.ac.uk/blaauw/clam.html.

providing their upper and lower depths. If there are multiple such events, we will have to provide a list of all their upper and lower depths. Unfortunately, different models provide very different answers, both for the inferred time position at a particular depth and for the uncertainty associated with that estimate, and it is difficult to determine which model is closest to reality.

Telford *et al.* (2004) compared different modelling techniques and found that uncertainty is often underestimated, and errors are surprisingly large, especially when there are few layers with precise dating. Considerable advances in depth-age modelling have been made in the last decade (Trachsel and Telford 2017), all based on the principle that the stratigraphic depth-temporality relationship is only meaningful and useful when calculated using calibrated radiocarbon dating. Otherwise, if such dating is not calibrated, variations in sedimentation rate are obscured by oscillations in the calibration curve. The use of a central point (arithmetic mean, median) of the resulting confidence interval is common practice, but not entirely appropriate, especially when the inferred calendar date falls on one of the plateaus of the calibration curve. In this case, broad, multi-modal probability distributions cannot be meaningfully characterized by means of a single central value, and large errors can result if this is done.

For this reason, Bayesian statistical models for relating temporal position and stratigraphic depth have gained popularity in recent years. These models attempt to reproduce the processes that explain sediment deposition in an analytical way, so that different parameters must be set, which strongly affect the suitability of the model.

Programs implementing Bayesian age models include Bacon[17] (Blaauw and Christen 2011), OxCal (Bronk Ramsey 2008), BChron (Haslett and Parnell 2008), CSciBox (Bradley *et al.* 2018), ChronoModel (Lanos and Dufresne 2019) and ChronoLog (Levy *et al.* 2022). The latter provides the possibility of using Algebra-based relationships and synchronisms between two dated units. Another advantage involves the introduction of *TAQ* and *TPQ* bounds, thus leading to the creation of chronological networks (Levy *et al.* 2022).

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[17] It is a library in R, a statistical language. http://chrono.qub.ac.uk/blaauw/bacon.html.

The need for volume genesis modelling is highlighted, where it is not only the sediment deposited that matters, but also the manner in which it was deposited. The formation of the stratigraphic volume in process; its decomposition into various depositional events for analysis and reconstruction according to sedimentation through time (use of radiometric dates).

2.10. Conclusions

'Analysis' is understood as the decomposition of a whole into its constituent elements in order to proceed to its comprehension and rearticulation. It is evident that all analysis requires its complement: re-composition or synthesis. When decomposing -analyzing- reality, it is deconstructed, which is why it is necessary to re-construct it based on synthesis (Echevarría *et al.* 2010). Analytical stratigraphy is, therefore, an inferential and interpretative mechanism, rather than the simple verification of visual differences (Fedele 1984; Sáenz de Buruaga 1999; Katsianis 2012; Quintana and Sáenz de Buruaga 2015). Andrea Carandini (1991) stated that excavation presupposes the articulation of the subsoil into discretionary parts and its re-composition into a model that restores its original unitary sense but transformed by its 'interpretation'. Without reconstruction we would be lost in the chaos of the superposition of stratigraphic units (Carandini 1991: 82-88).

Spatially, a depositional event was defined -in the present research- as the smallest determinable spatial unit, which proves to be internally homogeneous and whose discernible material characteristics are the result of a single action or set of closely related actions. Temporally, it is assumed that every human or natural process took place on a solid natural surface or on a surface formed because of a previous action or series of activities. This surface constitutes the *post quem term* that may allow us to define the beginning of the depositional event itself.

Through chronological modelling of depositional events what is proposed in this case is not so much a visualization of the structures buried in the site. Instead, the visualization of the relationship between the stratigraphic formation of the depositional events and their temporal position on a given scale of measurement is intended. In a way, the idea is to reconstruct the site's biography; the depositional processes that formed the archaeological site in the past. It is essential to keep in mind that archaeological stratification is the result of a series of actions (deposition, sedimentary accommodation, transport, accumulation) and therefore, all stratigraphy is immobilized movement. That is, a heterogeneous, complex, contradictory movement: with differentiated intensities and rhythms that determine transformations and qualitative changes in the individual and general conformation of deposits and sequences. Stratigraphy is thus movement (and movements) of diversity in unity, materialized in the form of an organized, articulated, and interrelated nucleus of situations. Stratigraphic situations must be analyzed according to an organic whole in which each one of them forms a dynamic structure organized in relation to itself and to the whole sequence (Quintana and Sáenz de Buruaga 2015).

As it has been described in the preceding sections, in archaeology, as in geology, stratigraphic temporality is defined based on the distinction between two types of reference unit. On one hand, the chronostratigraphic unit, which is nothing more than the distinction of visually or analytically distinguishable deposits, and on the other hand, temporal units ('geochronological', in the broadest sense of the word), which are defined as discrete partitions on the time scale. The basis of the Harris Matrix diagrams lies precisely in the definition of time units based on the topological continuity between stratigraphic units.

The stratigraphic units in archaeology are small and extraordinarily diverse, because they express depositional events of a great diversity, when compared to geological units. There are many sedimentary and depositional processes involved and each of them may have a different rate. Ultimately, even if there could be a relationship, it is not a linear one; the stratigraphic depth (z) is related in a very irregular way to the different chronological phases into which the stratigraphy of the site has been divided. Therefore, it cannot be assumed that the greater the depth at which a depositional event is located in a stratigraphic sequence, the greater the age of the event.

However, the fact that this relationship is complex does not mean that it does not exist or that it cannot be studied. The difficulties are essentially technical. On the one hand, we must increase the number of dated samples to calculate a relationship that is characteristically irregular. These dates must be properly associated with both the time of the beginning of the event (surface) and its end (sedimentary fill). Since the isotopic event does not usually coincide with the depositional event, many short-lived samples of different nature (seeds, bones of juvenile-aged animals, etc.) are necessary. This will permit the closer matching of the sample with the beginning or the end of the event. If the classical radiometric models of depth-temporality already require many dates, their archaeological application requires many more, given the extreme diversity of depositional mechanisms at work.

The aim is to reconstruct the process of formation of a sequence of deposits, and this implies knowing how they are related. More specifically, how a more recent deposit and /or surface cuts through a deposit and/ or surface that was formed earlier, or simply has a contact (the more recent one 'breaks through' the older one). The procedure is simple. The 'basal surface' assignable to each stratigraphic unit or depositional event represents the *TAQ* of that unit. The 'basal surface' of the subsequent overlying unit is then used as the *TPQ* of the first unit. Once all the basal surfaces are combined and presented together, the areas of overlap between them are calculated. These overlap areas represent the stratigraphic breaks and discontinuities. Similarly, the volume representing the sedimentary fill expresses an *ante quem* term.

In any case, and as Desachy (2016) has argued: the temporality of stratigraphy is not the same as the temporality of historical events. Stratigraphic time, discussed so far, is strictly related to the formation of those partitions of physical space that have been identified throughout the archaeological excavation. In order to approach the historical time of the social agents who lived there and left material evidence of their behavior, various factors must be considered. It is important to take into consideration not only the time of formation of the material remains, but also their whole 'cultural life'. This took place in a systemic context longer than the duration of the formation of the space in which the action took place. Stratigraphic time, limited to the duration of the process of physical space formation in which social agents acted, does not take into account the temporality of the systemic context in which social behavior must be understood. Recognizing that systemic context, the historical entities themselves, from a set of stratigraphic units cannot be inferred through a simple grouping of 'spaces' based on elementary relationships of subsets. There is a more complex relationship between stratigraphic units and related historical material entities, so these two temporalities - stratigraphic and historical - should not be confused.

3. FORMATION PROCESSES IN LAKESIDE SETTLEMENTS

3.1. The privilege of water: Living on the wetlands

Life nearby water bodies has been attractive to humans dating back to hominine evolution (Nicholas 2007) through Holocene times until nowadays for various reasons related to their valuable source. The common characteristics of different wetlands (swamp, marsh, bog, fen, wet meadow, shallow water) refer to their location in the interface between terrestrial and aquatic systems and usually share characteristics of both (Keddy 2010). They are associated to fluctuating water levels and their interaction both with the lake and the terrestrial system is constant (Figure 3.1). Nevertheless, the characteristics that make them differ from terrestrial and deep-water aquatic systems are either intermittent or permanent flooding and vegetation that survives saturated conditions (Mitsch and Gosselink 2015). The attraction of these environments during the past has been linked to various needs such as subsistence practices, defense systems, socio-economic reasons and rituals, all associated with the element of water (Menotti and O' Sullivan 2013).

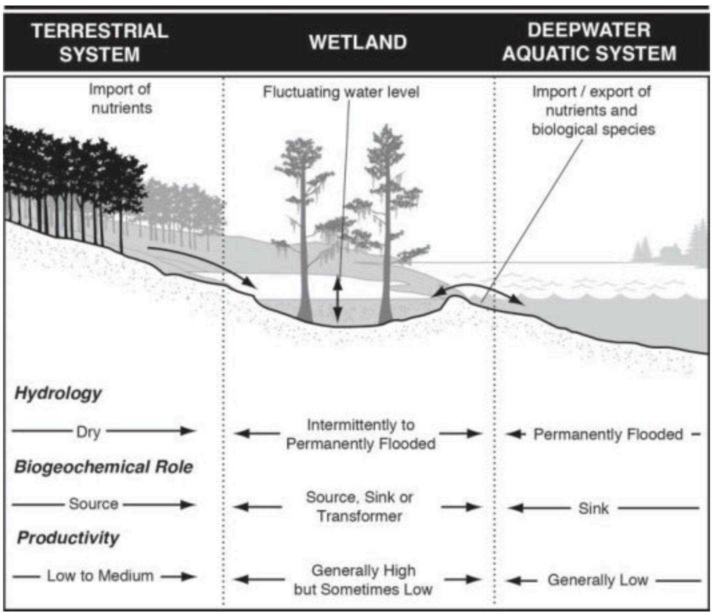


Figure 3.1. The location of wetlands in the interface between terrestrial and (deep water) aquatic systems and their interaction with both (Mitch and Gosselink 2015).

Especially during the Mesolithic and Neolithic times in the northern part of Europe the deglaciation during the Early Holocene led to the formation of water bodies throughout the Scandinavian (Larsson 2001) regions and the Baltic Sea. The understanding of human selection strategies through their connection with water has been crucial to the understanding of the neolithization process as well in the rest of Europe (Menotti 2012). Furthermore, the importance of wetlands in the development of agricultural practices has made them preferential for occupation (Gopal and Junk 2000). Even when drylands were preferred, wetlands in close distance were still exploited, as for instance in the British Isles (Coles *et al.* 1973; Raftery 1996; Carew *et al.* 2009). Apart from the preservation of the organic material, lakeside settlements, bogs, marshes and crannogs offered information on the construction of wooden pile-dwellings and trackways (O'Sullivan and Van de Noort 2007b) during the settlement's life span (Coles 1984; 2001).

Van de Noort (2016) and Van de Noort and O'Sullivan (2006b) have discussed that to fully integrate wetlands into a broader landscape perspective, they must be theoretically and geographically contextualized. That means their integration to the landscape outside of the wetlands. That is already feasible through the enhancement of pollen data both on regional scale and on-site, enabling this way a better understanding of the natural-cultural interactions, as the surrounding landscape also interacts with the wetlands (Walsh *et al*. 2003). In the next sections, the type of wetlands discussed is mainly lakeside settlements and the formation and deformation processes linked to them.

3.1.1. The "lake-dwelling phenomenon"

Special in the research of wetlands is the case of the '*lake-dwelling phenomenon'*, a type of settlement characterized by pile-dwellings found around several lakes. The best known are in the Circum-Alpine region, in Switzerland (Keller, 1866; Pétrequin 1986; Pétrequin and Pétrequin 1988; Pétrequin and Bailly 2004; Menotti 2001a; 2004; 2012a; Hafner 2004; Marzatico 2004; Ruoff 2004; Ruttkay *et al.* 2004) although this phenomenon has the earliest evidence in the Mediterranean region. However, the construction practices do not only include pile-dwellings over the water level, but also ground surface structures.

In the beginning of the last decade, 111 prehistoric pile-dwellings in the Circum - Alpine region have been declared as UNESCO World Heritage, with the purpose to address their conservation problems and help maintaining them, while enabling public access. The lacustrine sites in the peri-alpine region are dated in the Early Neolithic, Bronze and Early Iron Age. Above the Alps, lacustrine sites date since the 5th millennium BC (Hafner 2013; Hafner *et al.* 2014). Some of them are *Egolzwill 3* (Wauwilermoos, Lucerne Canton) and *Zurich-Kleiner Hafner* (Lake Zurich) in Switzerland (Vogt 1951; Suter 1987; Stöckli *et al.* 2013; Gibaja *et al.* 2017). Settlements like *Saint-Aubin* and *Bevaix* in Lake Neuchâtel are also dated in this period (Wüthrich 2003). In Italy, some of the settlements dated in the Early Neolithic are *Isolino Virginia* (Lake Varese) and *Palù di Livenza* (Friullian foothills) (Banchieri 2017; Antolín *et al.* 2022; Visentini; Pini 2004). The number of identified pile-dwellings in the peri alpine region is big, with the most populated lakes being in Switzerland (Lake Zürich, Lakes Bierne, Morat and Neûchatel), Germany and France (Lake Geneva, Lake Constance), Northern Italy (Lake Garda) and Slovenia (Ljubljansko Barje). In the last, the oldest settlement is Resnikov prekop (*ca.* 4600 BC) (Čufar *et al.* 2013; Velušček 2006).

Outside the peri-alpine region (Austria, Switzerland, Italy, France, Germany, Slovenia), other lakeside settlements with shared characteristics were discovered throughout the Balkans (Prendi 1966; 2018; Naumov 2018; 2020) in Macedonia, Greece, Belarus, Albania, Estonia to the western Mediterranean coast in the northeastern part of the Iberian Peninsula, in Spain and Italy. The first sites are dated into the 6th millennium BC in Greece, Italy and Spain. Some of the lacustrine sites (among others) presenting similar characteristics have been gathered in Table 3.1. Apart from Europe, past life around water was also spread in Russia, China (Liu *et al.* 2011), Anatolia (Roberts and Rosen 2009), Malaysia, Polynesia (Kirch 1989; Nunn 2005; Nagaoka 2011) and Mesopotamia (Pournelle 2003). Less Neolithic pile-dwellings are available for Great Britain (Coles 2004; Van de Noort and O' Sullivan 2006; Crone and Clarke 2007; Fletcher and van de Noort 2007; Henderson 2007). The pile-dwelling phenomenon seems to have come to an end around 800 BC.

Table 3.1. Table including some of the lacustrine sites discovered outside of the peri-alpine region mentioned in the bibliography considered for this chapter.

Lacustrine sites	**References**
Lake Ochrid* (Macedonia)** ***Lake Prespa	Naumov 2016a, Kuzman 2009, Zdravkovski and Kanzurova 2016
Lake Djoran	Albrecht and Wilke 2008, Hoffmann *et al.* 2010

Dispilio* (Greece)** ***Amindeon basin ***Anarghiri IXB*** ***Limnochori II***	Hourmouziadis 1996; 2002, Touloumis and Hourmouziadi 2003, Theodoulou 2011, Karkanas *et al*. 2011, Facorellis *et al*. 2014 Chrysostomou *et al*. 2015, Arabatzis 2016 Giagkoulis 2020 Chrysostomou and Giagkoulis 2018
***Kryvina* peat bog (Belarus)**	Charniauski 2020
Lake Maliq* (Albania)** ***Sovjan	Prendi 1966; 2018, Korkuti 1993 Lera and Touchais 2002, Fouache *et al.* 2010
***Lake Valgjärv of Koorküla* (Estonia)**	Roio 2020
Serteya II,* Lovat-Dvina basin (Russia)** ***Dubokray*, *Lake Sennitsa ***Veksa site***	Mazurkevich *et al.* 2020a Mazurkevich *et al*. 2020b Piezonka *et al.* 2020
***La Draga, Lake Banyoles* (Spain)**	Bosch et al. 2000; 2006; 2011, Palomo *et al*. 2014, Bogdanovic *et al.* 2015, Terradas *et al.* 2020
***La Marmotta, Lake Bracciano* (Italy)**	Fugazzola-Delpino and Mineo 1995, Fugazzola-Delpino 2002
Great Britain	Coles 2004, Van de Noort and O' Sullivan 2006, Crone and Clarke 2007, Fletcher and van de Noort 2007, Henderson 2007)
China	Liu *et al.* 2011
Malaysia **Polynesia**	Kirch 1989, Nunn 2005, Nagaoka 2011
Mesopotamia	Pournelle 2003
Anatolia	Roberts and Rosen 2009

While research increased the last decades applying interdisciplinary methods in archaeology, most of the sites have yet to be excavated (Figure 3.2). One of the main contributions of archaeological research on pile-dwellings was the insight on a household level of the prehistoric settlements, thus increasing our aspects on everyday life of the dwellers. Not only that, but under permanent water table conditions, sediments and soils get saturated by water and while reducing conditions prevail, the organic material is better preserved due to the deceleration of the humification process (Van de Noort and O'Sullivan 2006). As the preservation of the organic material offers insight on cultural levels not studied easily in drylands, not only were settlement patterns better defined, but also various aspects of the economy have been revealed in a household scale. The recovered material gave place to sciences such as micromorphology, palynology, archaeobotany, archaeozoology and others to further develop the knowledge around wetlands economy and subsistence practices (Antolín *et al.* 2017; Revelles *et al.* 2018; Piqué *et al.* 2021a). Furthermore, by studying the aquatic invertebrate assemblages, only recently, the potential of identifying occupation over dry land or above water during the Neolithic was gained (Tóth *et al.* 2019).

Further implementation of chronological techniques, such as dendrochronological analysis helped determining the life span of occupations associated to wetlands, in addition to already spread radiocarbon dating (Coles 1988; Gassmann 1989; Gassmann and Pillonel 1993; Billamboz 2003; O' Sullivan and Van de Noort 2007a; Brown and Baillie 2007; Bleicher and Harb 2018; Andreaki *et al*. 2020; Hafner *et al.* 2021 among others). That added to a better comprehension of the dynamics of cultural changes and adaptations to the environment of lakeside settlements. Furthermore, due to the quantity of information that can be retrieved from the preserved material on wetlands, a variety of everyday tasks can be defined (Crone 2000; Coles 2001). Not only this, but further implications on population density, gender, etc. can be acquired. That led Van de Noort (2016) into suggesting further research into wetlands as taskscapes, while this notion has already been adopted in some sites from the Alpine region (Arnold 1986; Magny 1993; Menotti 2003), Scotland (Crone 2000) and Ireland (O' Sullivan 2000).

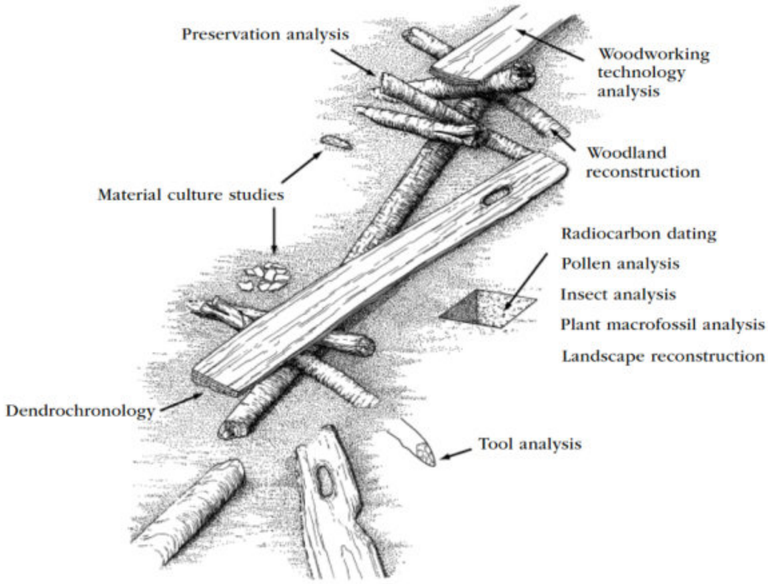


Figure 3.2. Representation of some of the interdisciplinary analyses employed in wetlands (Van de Noort 2006).

3.2. Sedimentation and depositional milieux in lakeside settlements

Lakes are great archives of local and regional change, given the fact that they integrate climate variations and environmental change. They are also influenced by their catchment area, for example tectonics may affect the basin morphology and the sedimentology of a lake, as well as induce lake-level changes. Annual changes in lakes can be acquired from sediments in the profundal zone, where varves record annual depositions, constituting them as great archives of palaeolimnology. As a result, the hydrological system of a lake has an interactive relationship with geomorphological and climatic variables, present in the environmental setting (Mitsch and Gosselink 2015). These features not only affect the physiochemical properties of a lake, such as soil chemistry and the availability of oxygen in soils, but also the living organisms such as vegetation and animals (biota). Lacustrine sedimentation includes chemical precipitation of minerals such as carbonate, as in the case of Lake Banyoles (*Chapter 4*), biogenic and organic sedimentation due to biological productivity and clastic input usually from water and wind related forces. The latter is also associated to transport, erosion and depositional processes into the lake, reflecting landscape changes.

Water is the most important conductive factor of sedimentation in wetlands as it can trigger various formation processes. The timing and flow of water into an archaeological site can be better understood in terms of flooding processes. During drier conditions, flood pulses are present in the form of rainfall or snow melt (Keddy 2010). The effects of flooding processes on the depositional processes of peats in lakeside settlements are further discussed by Ismail-Meyer *et al.* (2013). Wave and current activity in lakes is affected mostly by the wind, while the water influx into the lake is not as strong as it loses force getting into the water.

Furthermore, a lake is divided into different zones according to their depth and distance from the shoreline (Figure 3.3). The water in the littoral zone is shallow with presence of emerged plants, whereas the profundal is the aphotic, deep-water zone of the lake, receiving no sunlight. Wave activity influences, also the depositional milieu of the littoral zone as sediments get reworked from wave action and erosion (Wiemann and Rentzel 2015). Apart from the dynamic depositional milieu of the littoral zone, usually causing erosion, other characteristics of this zone include high rate of sedimentation and very strong anthropogenic signals being the one closest to the settlements.

Normally, the sedimentation rate in this zone tends not be destructive or abrupt, rather than slow and gradual, leading to a better preservation of the archaeological record. Nevertheless, in dry periods, the low lake level would expose part of the littoral zone, leading the shoreline further into the lake, under subaerial conditions. Under subaerial conditions, a hard compact carbonate surface with high amounts of micrite would have been created. It would represent the transition from limnic sediments to an occupational surface by humans (Ismail-Meyer *et al.* 2013).

On the contrary, in the profundal zone of the lake, the depositional milieu is calmer with lower rate of sedimentation resulting in laminated deposits (Wiemann and Rentzel 2015). In general, the sediments tend to be coarser near the shoreline, while finer sediments are found in greater water depth. Moreover, the vegetation patterns are indicative of the water table and evidence seasonality.

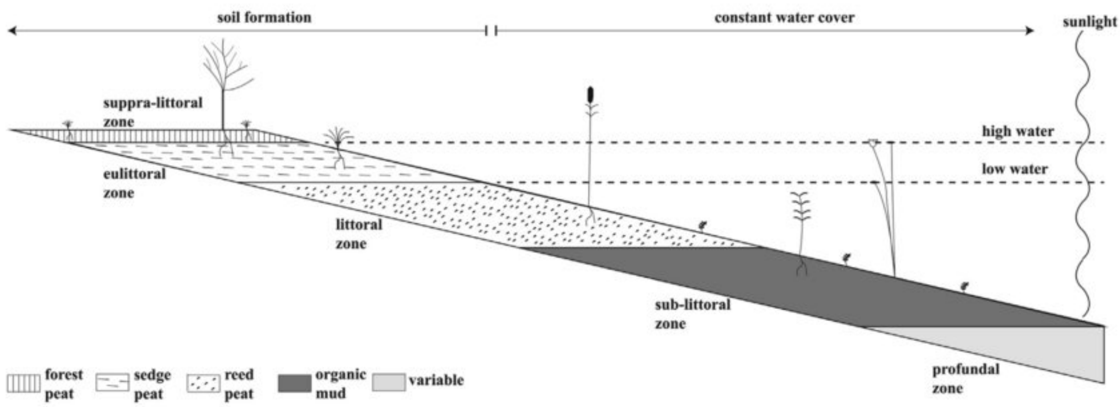


Figure 3.3. Schematic representation of the depositional milieu found in wetlands, including the littoral and profundal zones, as well as the water cover in every zone (figure after Overbeck [1950:15], following nomenclature of Wright [1990], in Stahlschmidt *et al.* 2015).

3.3. The site biography: Formation and deformation processes in lakeside settlements

Depending on the depositional milieu and the influence of water level and sedimentation rate discussed briefly above, environments ranging from limnic to terrestrial may arise. Apart from the transition from underwater to subaerial conditions, other transitional processes include the successive transport, depositional and erosional processes that may have an impact on the preservation of the archaeological record (Feibel 2001; Gkouma 2017). In addition to that, the constant change from anoxic to oxic conditions and the contrary reflects chemical processes acting at the same time, resulting in syn and/or post-depositional alterations on the archaeological record.

The archaeological record is here perceived as a palimpsest of both the deposits and the artifacts included in them. In order to unveil the activities affecting the record, formation and deformation processes must be analyzed. To that end the most common site formation processes occurring in lakeside settlements are discussed in the context of a site's biography since the first moment of installation to the final abandonment of the settlement. The analysis should not exclude post-depositional processes taking place after the abandonment of lacustrine settlements altering the archaeological record.

3.3.1. Installation

As discussed before, in most of the cases under study the installation horizon is usually described by a lake marl surface when the settlements are placed on the shore of the lake, although other substrate cannot be discarded. It is possible that the lake marl substrate may have been hardened and suitable for construction by humans, as it is consisted by carbonate muds. Nonetheless, when wet it would have been easily penetrated by wooden timber logs. Afterwards, the inflation of wood inside the lake marl substrate would consolidate the timber logs, functioning as a natural cement for the bases of the risen wooden platforms. This process would be repeated for subsequent repairs aiming to maintain the original constructions or adding new ones into the substrate by just wetting (if not already wet) the ground surface (Menotti 2012). In the case of lakeside villages, the accumulation of mostly organic matter yields the first cultural deposits on a previously naturally formed surface (lake marl surface or other kind of occupational surface). These include remnants from food processing and cooking (animal bones, seeds, fruits, cereals, charcoals and ashes), fuel (roots, wood, twigs, bark, leaves), wood working and mineral working material, animal stabling, pollen, as well as remnants of insulation against humidity (bark residues, twigs, mosses, clay) (Ismail-Meyer *et al.* 2013).

According to pollen data, the first installation and construction of pile-dwellings during the Neolithic period is usually associated to deforestation and environmental changes on one side, and increased Cerealia pollen associated to crop cultivation on the other side (Kouli and Dermitzakis 2008; Kouli 2015; Sadori *et al.* 2016; Revelles *et al.* 2018). Deforestation could cause soil erosion and enable input of terrigenous sediment into the settlement as well as facilitating inundation as a result of flooding processes.

3.3.2. Construction

The construction choices also reflect the environmental setting and the conditions of the ground surface, either dry or wet. Whereas, on the shoreline, pile-dwellings would have been raised over the lake level, the alternate use of these and ground structures would have been applied further inland at a greater distance from the lake. However, the construction practices in lakeside settlements could easily change during the life of a settlement most importantly influenced by lake-level fluctuations.

Wooden platforms with dwellings above them were preferred in Lake Zurich, probably to prevent a water level increase and avoid inundation (Menotti 2001a). Outside the Circum -Alpine region, the construction of ground surface dwellings seems to have been the case for many Neolithic settlements such as La Draga in Lake Banyoles (Spain) (Bosch *et al.* 2006; Palomo *et al.* 2014) and La Marmotta in Lake Bracciano (Italy) (Fugazzola-Delpino and Mineo 1995; Fugazzola-Delpino 2002). In the former case, more than a thousand piles were recovered from the lake marl substrate, evidencing the use of this technique to avoid water inundations. However, ground dwellings would have been also preferred by creating a foundation made of various strata of roundwood, twigs, bark and plaster, where the dwelling would rely on (Menotti 2012). So, the effect of water changes would be avoided in both cases. As a result, planification and prevention strategies are reflected on the choice of building techniques.

During the life of a pile-dwellings settlement, consecutive repairs of the constructive materials would have been necessary for the maintenance of the dwellings, as in this case in the lakeside settlement of La Draga (*Chapter 8*). High-resolution micromorphological analysis is often applied in these cases to decipher the formation processes in combination with other remains from the excavated sites (*Chapter 7*; Ismail-Meyer *et al.* 2014; Karkanas *et al.* 2011).

3.3.3. Occupation and Use

The occupational surfaces or else living floors were the stage of anthropogenic activities. By reconstructing these, an insight on everyday life practices can be gained. Food processing (preparation, consumption and discard), manufacture of tools, artefacts and everyday utensils, maintenance of activity areas, livestock and crop storage are only some of the activities that could take place during occupation. The deposition of the material remnants of these activities could occur through various processes; First, through discard or deposition at their primary space of production and/or use (Schiffer 1972; 1996) either intentionally or by accident, as *in situ* artifacts. Of course, that depends on the location of the living surfaces; if raised above water then a lot of the material may be found either *on* the wooden platforms of the dwellings or on the lake marl surface *below* them. In many lacustrine settlements with elevated surfaces, the daily discard was deposited underneath the elevated floor (Jacomet et al. 2004; Leuzinger 2000), while elsewhere the discarded waste would be accumulated inside or around the dwellings (Menotti 2012). The secondary deposition of material refers to the relocation or refuse process of cleaning up process from the living floors. As a result, these artefacts usually related to hearths cleaning, include ash, fragmented bones and charcoal fragments used for fire. After use they would get cleaned up and discarded elsewhere (Jacomet and Brombacher 2005), subsequently not reflecting *in situ* occupational surfaces. Most of the times, proper pits or dumps would be created for waste discard, i.e., in Lucone (Baioni *et al.* 2006), Lake Constance and Chalain station 3 (Lundström-Baudais *et al.* 1997).

Fireplace cleaning is one of the main activities observed in the sediments leading to the accumulation of ashes and charcoal fragments. Areas with dung layers have been interpreted as animal stables inside the settlements, while leaves would have been part of animals' diet (Ismail-Meyer 2017; Brönnimann *et al.* 2017).

A high number of both natural and cultural transforms (Wiemann and Rentzel 2015) would have taken place in parallel with the occupation forming and deforming the archaeological record. These syn-depositional processes include fire episodes, either natural or anthropogenic as well as flooding episodes. Flooding because of rainfall or snow melt could have triggered erosional processes on anthropogenic deposits (Jacomet *et al.* 2004). The effects of flooding must be calibrated depending on the rate of water input and its velocity in the settlement. Slow water rise could have erosional effects, while rapid inundation of the settlement wouldn't be this destructive for the archaeological record (Goldberg and Macphail 2006). The problem of conflagrations especially during dry periods was also common.

These were natural processes that affected cultural choices and leaded the settlers either to adaptation or abandonment of lakeside settlements. Adaptation was reflected in the repair and reformation of wooden structures either to reinforce the already existing dwelling or to construct new ones. In addition to that, insulation techniques would have been also applied to prevent flooding.

Lake level fluctuations could have been the cause for major rearrangement of deposits, further reflected in changes on sediment texture and carbonate content. Also important are the changes on vegetation remains indicating different water conditions. We shouldn't forget that major climate variations in the Swiss Plateau and Jura mountains have been responsible for alternations on lake level during the Holocene (Magny 2001).

3.3.4. Abandonment

When abandonment of the settlement was preferred by the settlers, a number of deformation processes would start taking place to transform the archaeological record. Both spatial and temporal factors must be taken into account before examining the post-depositional processes. The spatial abandonment range varies from the minimum spatial unit such as an activity area (i.e., a hearth) to a part or dwelling of the settlement to finally the whole settlement, followed by subsequent displacement of the dwellers to another area. The temporal factor ranged from short-term to long-term and definitive abandonment.

Periods of occupational hiatus and/ or abandonment in lakeside settlements have been related both to natural and cultural reasons. Even if literature agrees with lake shore occupation during favorable climate conditions (Magny 1993), that is not always the case. Climatic deterioration was not always linked with abandonment of the lakeshores during the Neolithic period, while human occupation was also absent during favorable climate conditions (Pétrequin and Bailly 2004; Arbogast *et al.* 2006). Therefore, the cultural factors are crucial to the interpretation of the human-nature interactions during the past. Some of the possible culturally induced explanations for the temporal or permanent abandonment of lake shore occupations may be associated to failure of crops during both dry and humid periods as well as demographic reasons and overexploitation of the local resources (Pétrequin *et al.* 2005; Menotti 2009).

Climate variability would have affected the hydrological systems of lakes often causing lake level fluctuations and thus creating an impact on human occupations in the proximity of lakes. Inundation events in lands of agricultural practices and animal husbandry would have led to economic crises associated to subsistence and food production (Menotti 2001b). The subsequent loss of economic sustainability (Arbogast et al. 2006; Jennings 2014) would have led to displacement and diversification practices. The study of the formation processes focuses on deciphering the human responses to climate variations, which are reflected on their immediate surroundings. Rapid burial of the archaeological record by a sudden lake level rise for example, would have prevented the decay of organic material. On the other hand, slow lake level rise after abandonment could result in peat deposits ranging from oxic to anoxic conditions under shallow water conditions, in a swamped state.

According to Menotti (2001b), a cultural abandonment phenomenon initially triggered by climatic change seems to have been the case for the Middle Bronze Age settlements in the northern alpine region. In the same line of reasoning, demographic expansion due to environmental overexploitation would be the case for the Neolithic settlement of lake-dwellings at Chalain in France (Arbogast *et al.* 2006).

On the other hand, in Terramare culture settlements, humidity was considered favorable across the Po plain and abandonment was rather linked with drier conditions during the Bronze Age (Magny *et al.* 2009). This phenomenon led scholars to speculate over social and political reorganization being the cause behind the abandonment of the Terramare region (Cardarelli 2010; Cremaschi 2010). In the case of the Neolithic settlement of La Draga (Lake Banyoles, Spain), climatic factor would not have been the decisive force for abandonment after the first occupation, as adaptation and construction with new material despite humidity was preferred (C*hapter 9*).

Finally, definite abandonment of lakeside settlements during the Iron Age was not directly related to higher lake levels either. However, the abandonment must have been inaugurated by a new culture preferring occupation over open and upland territories, probably associated to other needs during the Late Bronze and Iron Age (Jennings 2014).

Post-depositional processes and associated disturbances of the archaeological record are common after the abandonment of a settlement. On an artefact scale, an attempt to predict accumulation patterns after abandonment has been proposed through intra-site spatial distribution patterns of the artefacts (Achino *et al.* 2016).

3.3.5. Post-abandonment

The organic material is better preserved under anaerobic conditions, where the constant humidity and the high sedimentation rate would lead to the rapid coverage of the material and its preservation in a waterlogged state. Under waterlogged conditions the archaeological record is kept safe from weathering effects, such as oxidation and bioturbation (Wallace 1999; Menotti 2012). However, this grade of preservation does not exclude the effect of natural processes modifying the original deposition of the anthropogenic deposits (Karkanas *et al.* 2011). Despite waterlogged conditions artefact preservation may vary according to other factors, such as pH, soil chemical composition, and saturation (Menotti 2012). More specifically, in the case of pile-dwellings where the platforms may be higher than the ground surface material discarded by anthropogenic activities *on* the platforms can get mixed with the material *below* them. In addition to that, if water level is higher the materials are moved from their original place of deposition and the sediments get graded and sorted by wave activity and /or lake level fluctuations. Afterwards they are transported and redeposited elsewhere as a result either of erosion and lake regression or post- depositional bioturbation in the littoral zone (Wallace 2003). Another post-depositional disturbance that can confuse the primary depositional signals is the mixing of sediments and material caused by the penetration of the wooden piles into the lake marl surface.

Nevertheless, larger scale stratigraphical and sedimentological analyses have also been in use to better define the effect of taphonomy on the artifacts (Bleicher *et al.* 2018). Understanding the distribution patterns of the artefacts is crucial not only for understanding the processes affecting the preservation but also reconstructing the depositional milieu (Figure 3.4).

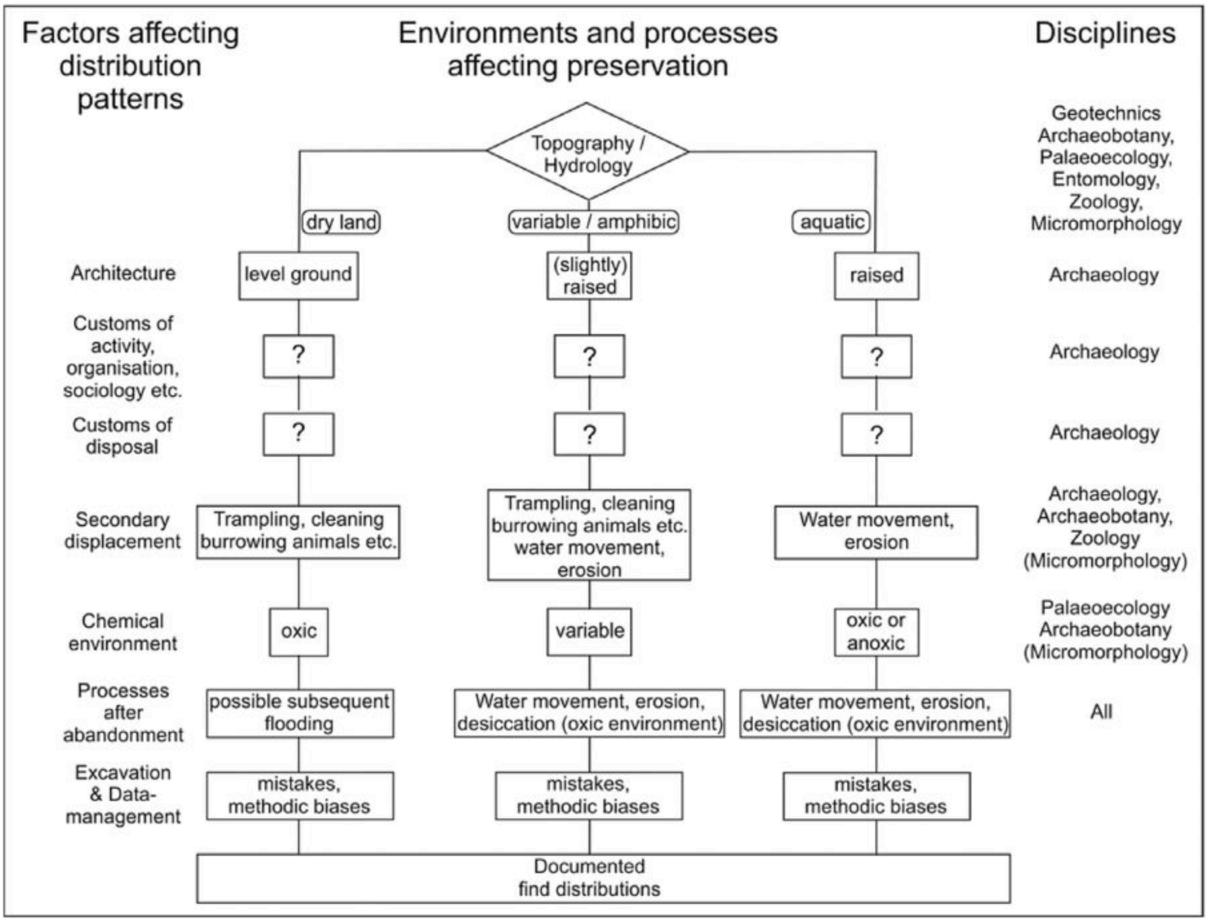


Figure 3.4. Environments and processes affecting the preservation and the respective distribution patterns in lakeside settlements, as well as the disciplines applied for their analysis (Bleicher *et al*. 2018).

Furthermore, ground structures are also affected by post-depositional processes, as they are constructed directly on the lake marl surface. Organic accumulations of anthropogenic material could eventually form a peaty sediment caused by lake level fluctuations (Ismail-Meyer *et al.* 2013). The subsequent flooding processes that can affect the peat deposits can result into the erosion of the upper part and its redeposition elsewhere while the bottom part of these deposits can get compacted because of the water retention (Ismail-Meyer *et al.* 2013). In addition to that, bioturbation may cause disturbance of the peat and redistribution of the archaeological material. However, if the deposition after burial of the archaeological record is the result of high-energy sedimentation caused by rapid lake level rise, then the good preservation of the archaeological material is the most possible scenario (Mallol 2006).

Trampling is an anthropogenic process both synchronous and posterior to the abandonment of the settlement that also reflects living conditions (Bleicher 2013). However, trampling consists part of the syn-depositional processes building up the deposit (Karkanas and Goldberg 2019). Human and animal traffic is reflected on modifications of the artefacts' structure such as fragmentation, transport to other place outside its context of deposition and redeposition elsewhere.

Some of the natural post-depositional processes taking place after abandonment include changes in the spatial arrangement of the artefacts. These may be caused by flooding episodes, such as wave activity and fluctuations. Surface flow from the hinterland may result in erosion of the anthropogenic sediments. On the contrary, lake flooding is more often associated with the deposition of micrite on sediments (Ismail-Meyer *et al*. 2013). Reworked sediments include micrite deposition, sand component and organic detritus in contrast to *in situ* deposits.

Nevertheless, most disturbances in the archaeological record are due to human activities: husbandry, agriculture, forestry. Furthermore, the construction of channels in recent ages and drainage would lead to erosion. Ploughing and modern agricultural practices as well as scavenging by animals and humans in posterior periods would disturb the archaeological record. In the case of Lake Banyoles, preparatory works on the soils around the lake, had a major effect on the rearrangement of some artefacts from the Neolithic lakeside settlement of La Draga as well as the invasion of modern material in the prehistoric deposits, during the Olympics of 1992 (Palomo *et al.* 2014).

3.4. Wetlands at risk

During the last decade, special value has been put into wetlands as natural and cultural archives based not only on the information they offer on past societies, but also on the prominent climate change affecting their preservation. More specifically, post-depositional processes taking place after the abandonment of waterlogged sites may disturb the preservation of cultural layers. Additionally, periods of erosion and/or desiccation associated to the hydrology of lakes affect the integrity of the cultural record (Hafner 2008; Banchieri *et al.* 2015a). Apart from natural processes, human impact - especially in modern periods- has not been sustainable for wetlands, directly affected by urban planning, industrial uses and tourism. Nevertheless, various actions have been taken the last few years in an attempt to preserve waterlogged archaeological sites[18], as for instance the declaration of 111 pile-dwellings as UNESCO cultural heritage in the Circum-Alpine region (Hafner 2013). At present, many archaeological projects especially in Europe start to gain conscience on the matter and integrate the preservation of waterlogged excavated sites and their material in their goals.

[18] "Archaeological Wooden Pile-Dwelling in Mediterranean European lakes: strategies for their exploitation, monitoring and conservation" in which also La Draga archaeological site participates (JPICH Conservation and Protection Call).

4. MATERIALS

4.1. Lake Banyoles

4.1.1. Geological and geomorphological setting

Lake Banyoles (42º1'N; 2º4'E, 173 m above sea level), with a surface area of 1.12 km^2 is located at the northeastern part of the Iberian Peninsula between the Pyrenees and the Mediterranean (approximately 30 km from the coastline) (Casamitjana *et al.* 2006). It is a multi-basin lake of mixed tectonic-karstic origin, remnant of the greater Banyoles-Besalú complex developed during Pliocene-Quaternary times (Julià 1980; Canals *et al.* 1990).

The geological context of Lake Banyoles could be described generally as the accumulation of quaternary lacustrine materials over previous formed (Neogene or Eocene formations) substrate (Brusi *et al.* 1987). The stratigraphy of the substrate consists -from the bottom up- of a 100-200 m dolomite (Perafita formation), overlain by 200 to 300m of massive gypsum (Beuda Formation) found under organic and pyritic-rich Eocene marls and mudstones (Banyoles Formation) (Bischoff *et al.* 1994). The contact between the last two formations and the subsequent gypsum dissolution has caused a 'de-dolomitization' process of the bedrock, inducing karstification responsible for the basin depressions of Lake Banyoles (Bischoff *et al.* 1994).

The geological map (Figure 4.1) shows that Lutetian age marls and blue clays (ELb_1) are deposited in the northern part rich in fossiliferous content (nummulites, oysters, echinoderms, bivalves, myriolids and plant remains). At the eastern shore, travertine limestones (*Qtvb*) attributed to the Upper Pleistocene occasionally intercalated with calcareous sands are the product of the surplus water of the lake. The approximate depth of the travertines reaches 10 meters, and they occupy the area where the city of Banyoles is currently situated. Low Pleistocene-Holocene lacustrine deposits of Lake Banyoles (*QIId*) are formed by carbonate precipitation and their thickness can exceed 30 meters. They are consisted by laminated carbonated clays, silts and fine sands with intercalated coarser material. They emerge around the lake where they are intersected by Low Pleistocene- Holocene alluvial and colluvial deposits (Qac_2). The latter are mainly developed in the valley of Sant Miquel Campmajor and around the lake of Banyoles, reach up to 7 meters and are interpreted as the result of fluvio-torrential sedimentation by the stream. They contain sludge and fine sands with intercalations of pebbles, often cemented by calcium carbonate.

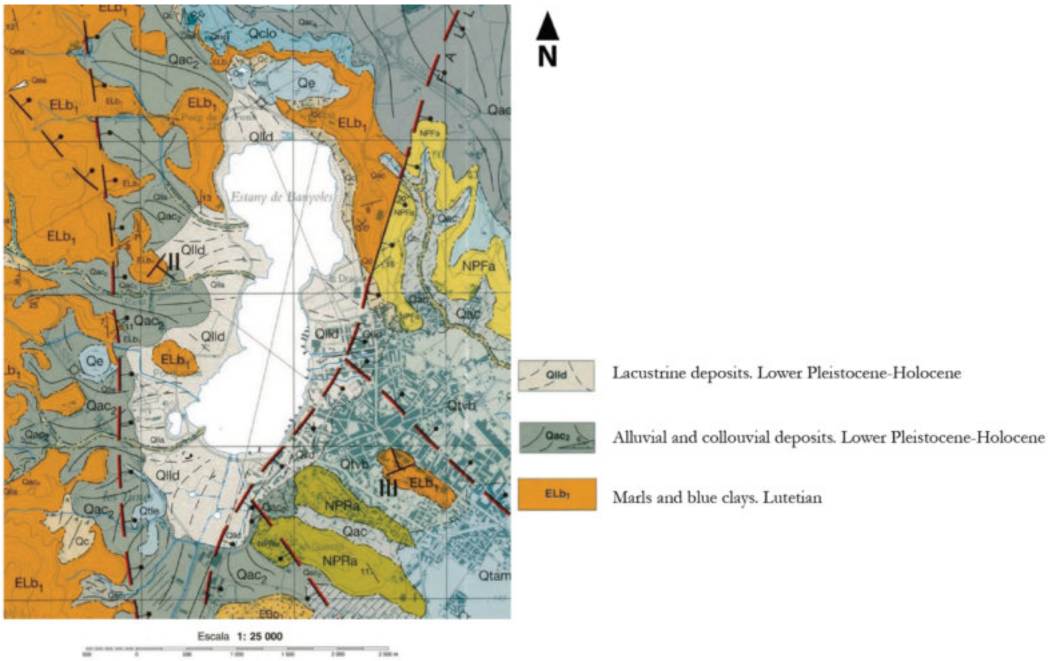


Figure 4.1. Geological map of the close area surrounding Lake Banyoles with major depositional facies (Figure modified after *Institut Cartografic i Geologic de Catalunya, icgc.cat*). Scale 1:25.000.

The dominant process throughout the substrate is the development of karstic dissolution forms, constituting a phenomenon of active karst with travertine formation, as it is evidenced by the last large collapse, that took place in 1978, creating a new basin named Estanyol Nou in the western shore. This Geological heritage is especially unique in terms of current dynamism of karst processes coexisting with evidence of a lacustrine presence and travertine formation since the Lower Pleistocene to the present day (Julià and Bischoff 1991). Travertine formations are relevant in the area such as those of Can Po, Lió, Les Estunes and other quarries of the Pla de Mata. These travertine formations constitute an exceptional source for the record of the Quaternary vertebrate fauna and botanical remains. Among these findings, the Neanderthal mandible of Banyoles -found in a quarry located in Pla de la Formiga- stands out (Grün *et al*. 2006).

Travertines are the most common sedimentary deposits in the Lake Banyoles Basin. In general, travertine is formed by the chemical precipitation of calcium carbonate from fresh water (surface and groundwater). In the case of the Banyoles lacustrine area, the main control factors of travertine precipitation are the high salinity of the lake water in combination with the release of CO^2 (Pallí *et al.* 2005). Further research from previous authors (Julià 1980; Brusi 1993; 1996) has already shed light on the distribution and variety of travertine formations in the extensive area surrounding Lake Banyoles. In total, six types of travertine sedimentation environments have been characterised according to their hydrodynamic regime into a synthetic model (Figure 4.2) (Brusi 1993; Brusi *et al.* 1997). The travertine formations observed include stromatolitic and oncolytic structures, pisolitic and macrophyte facies, as well as calcarenite and breccia travertines (Pallí *et al.* 2005).

An additional sedimentary type of carbonate muds is present near the lakeshore, in La Draga. These muds have a greyish white color, result of the micrite crystals and they are often found in the form of cemented carbonate deposits. Their origin is caused by intense calcite precipitation by the groundwater and are related to the sediments filling the depressions (sinkholes) underwater. More research about lacustrine carbonates and their depositional environments in karst lakes of the Iberian Peninsula is presented from Valero-Garcés *et al.* 2014. The littoral zone of the modern lake (0–3mwater depth) is covered by a thin macrophyte vegetation belt of *Phragmites*, *Schoenoplectus* and *Myriophyllum*. Sediments range from travertines and calcareous sands in the littoral areas, to carbonate-rich silts and clays in the distal areas (Morellón *et al.* 2014).

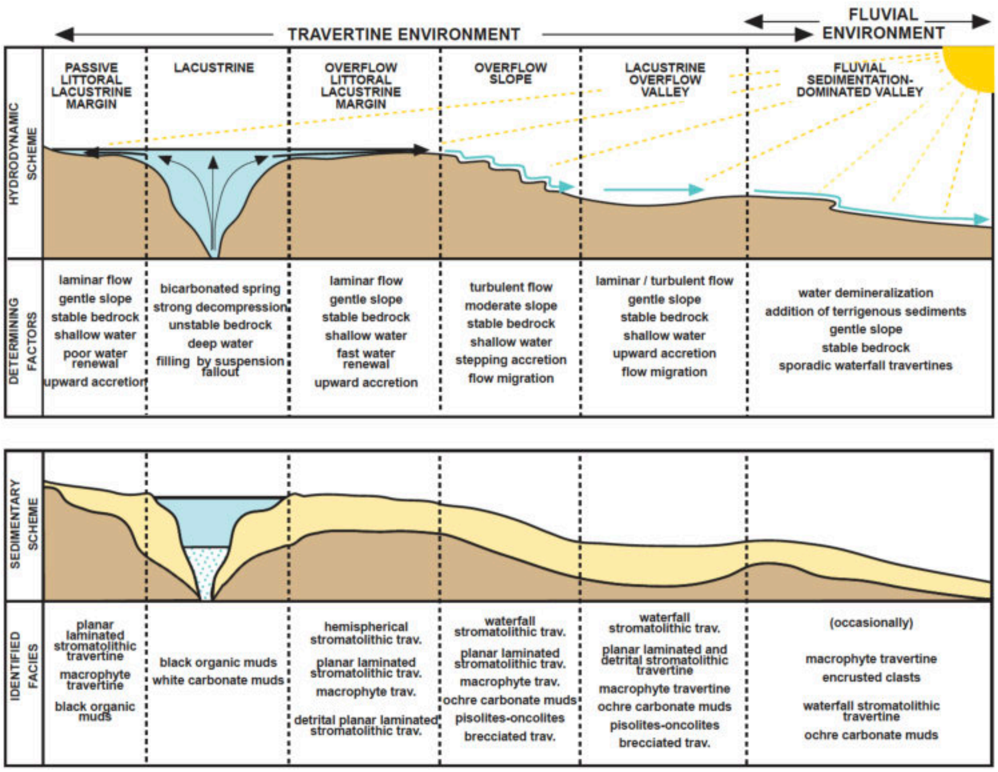


Figure 4.2. Sedimentary-depositional model of the travertine deposits in the Banyoles depression (Pallí *et al.* 2005; *Modified after Brusi et al. 1997*).

The hydrogeological system of Banyoles is a characterized karst complex by a remote feeding zone in the Alta Garrotxa massif with marked pluviometric influence (rainwater), and one discharge area conditioned by tectonics, through a fault with a NW-SE development. The difference in dimensions between both areas is sufficient to give the aquifers the necessary pressure to maintain the karstification process. The hydrogeological system (Figure 4.3) has been first explained by Julià (1980) and Sanz (1985) and have been further adjusted by Brusi *et al*. 1999 and is accepted until today. The starting points are located in four large areas staggered in height, which may have a continuous operation according to pressure. These areas of water emergence are the Pla de Martís - Usall, the Vall de Sant Miquel de Campmajor, the depression of Banyoles and the Fluvià river valley.

The water infiltrated in the Alta Garrotxa massif (700-900m of altitude) feeds an aquifer flowing southwards through the karstification of limestone levels. Wherever tectonic features appear, the upward discharge of the flow is possible (e.g., Fluvià river). The confined flow runs through low permeability layers until it finds a new upraise area or creates new flow paths, at the expense of the dissolution of Eocene evaporitic formations. Gravitational instability processes trigger the subsidence of the topographic surface caused by the dissolution of the underlying Eocene gypsum and the sinkholes are formed, that may turn into ponds (or lagoons) (Brusi *et al*. 1987; 1999). The fusion of various of these ponds constitutes the basin of Lake Banyoles. Collapse phenomena have a dynamic effect on the lake system as well, apart from determining the upwelling lagoons. They have an impact not only on the flow and position of the active upwellings, but they can also affect the geological materials of the substrate and/or remobilize the lacustrine sediments (Brusi *et al.* 1987; Gutiérrez *et al*. 2016).

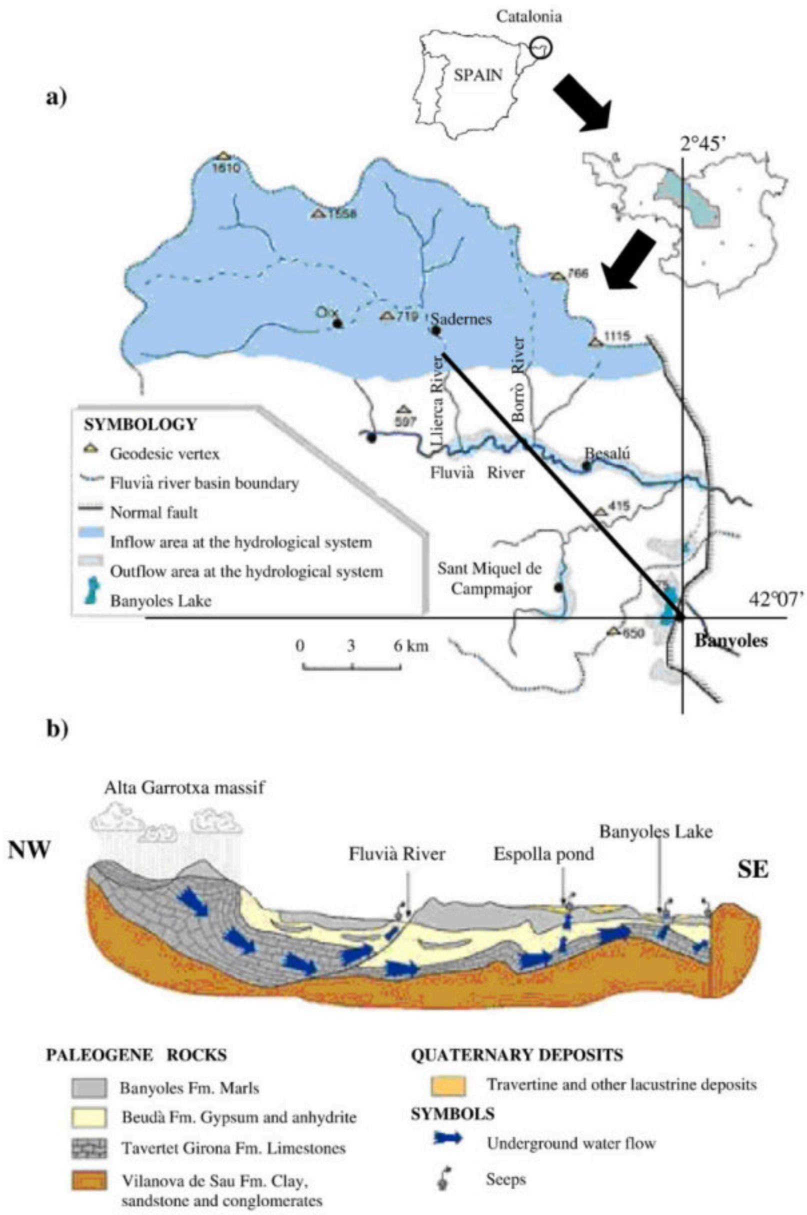


Figure 4.3. a) Location map of the hydrogeological system of lake Banyoles with the cross-section represented in b) marked in black. b) Cross-section of the route of the system from Alta Garrotxa to the Banyoles lake and the stratigraphy of the deposits (Soler *et al.* 2009; *Modified after Sanz 1985*).

4.1.2. Physical characteristics of the lake

The length of the lake is 2,150 m, with a maximum width of 775 m and a minimum of 235 m. Its shape has a N-S elongated form of an 8, and its basin is consisted by six karstic cone-shaped depressions (dolines or sinkholes), formed by different episodes of collapse (Figure 4.4) (Julià 1980). The six sub-basins (B1-B6) have a varying depth between 7.5 and 44 meters, while they are connected by shallower platforms. The medium maximum depth of the lake is 12 meters. The lake is divided into two basins - the northern and the southern - by a narrow sill (<500m) in the center (Morellón *et al.* 2014).

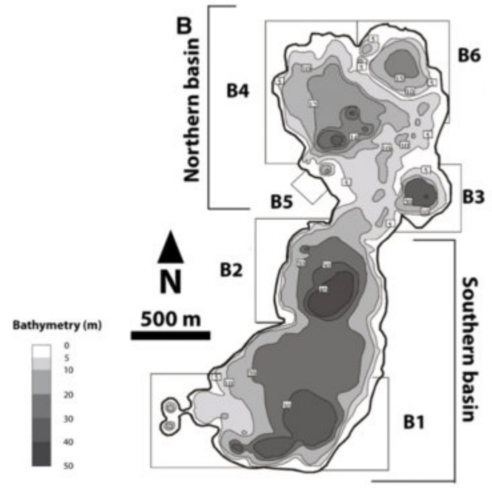


Figure 4.4. Bathymetric map of Lake Banyoles (Morellón *et al.* 2014; *Modified after Moreno-Amich and Garcia-Berthou 1989*).

It's a hydrologically open karst lake. Its basin is endorreic with no natural outflow. It is mainly groundwater-fed through the subterranean springs located in the sub-basins of the southern lobe (B1-B2). The groundwater input is about 40,000 m^3 a day, accounting for more than 85% of the total inflow to the lake (Casamitjana *et al.* 2006). Water incoming through the sub-basins from up to 13 subterranean springs fed by a recharge area in the volcanic field of Olot (20km NW of Banyoles), maintains basement marl and clay sediments into suspension, forming a distinct layer. The temperature of the water is affected constantly by the incoming groundwater (18-19^o C degrees).

The outflow of the lake is in the east side, where five channels were constructed during the Middle Ages in order to channel the excessive water into nearby marshes. The lake is also used as a source of water for the city of Banyoles in the east side, as well. The sub-basins differ between them in physical conditions and water-sediment mixing dynamics. Sub-basins B3 and B5 are meromictic, whereas B1, B2 and B6 are holomictic. Different periods of anoxia ranging from 1 to 12 months per year are presented in the hypolimnions of the six sub-basins which are isolated from the epilimnetic waters that connect them to each other (Prat and Rieradevall 1995; Morellón *et al*. 2014).

All of them have only one period of stratification during summer, while in late summer, the bottom water in the basins of Northern lobe becomes completely anoxic and accumulates sulphide due to sulphate reduction related to excess use of fertilizers near the catchment area. Therefore, the hardness of the lake water is considerably high due to carbonates and sulphates loaded from the groundwater (ILEC data). The water's pH values between 7 and 8.1 while the water temperature ranges from 8 to 25 ºC degrees depending on the depth and season (Rieradevall and Roca 1995).

The processes of sedimentation and groundwater influx between the sub-basins of the northern and the southern lobe of the lake have quite different effects on the type of sediments and processes involved in their stratification. Given that the higher percentage of groundwater input comes from the southern lobe, sub-basins B1 and B2 are affected by hydrothermal plumes which are created due to temperature shifts in the lutocline and the hypolimnetic waters respectively. That may cause turbidity currents that lead to the rearrangement of the particles in suspension, shifting this way the sedimentation of the sub-basins (Casamitjana *et al*. 2006). However, that is mostly restricted to the southern lobe, as the sedimentation in the northern lobe doesn't seem to be affected by re-suspended material as it is mostly consisted of carbonated silts and sands rich in charophytes stems and biogenic clasts such as ostracods and gastropods (Serra *et al.* 2005; Morellón *et al*. 2014).

According to research results based on seismic activity and sedimentological characterization of lithotypes recognised in cores retrieved from Lake Banyoles, these fluidization events of re-suspended material have been proven to be responsible for the formation of homogenites in the southern lobe (Morellón *et al.* 2014). Homogenites are associated to higher input of groundwater in sub basin B2, probably due to increased rainfall at the recharge area in Alta Garrotxa. Carbonate rich massive fine-grained silts are characterized as homogenites occurring as mm or cm thick homogenous layers in the sedimentary record. In the 7.600 cal BP sedimentary sequence from Lake Banyoles, homogenites are not present until 2.800 cal BP and they are connected to a lake level change, suggesting an increase of the water table (Morellón *et al.* 2014). The alteration of shallow lake sediments interbedded by the archaeological layers is also evident in the Early Neolithic lacustrine site of La Draga. That is further supported by the existence of the lacustrine settlement of La Draga in the eastern shore of the lake, dated during the Neolithic period, implying a lake water level up to 1.5 meter lower than the current level. Probably, a wetland, marshy area used to extend east to the present eastern shoreline (Banyoles-La Draga area) before the Christian colonization of the catchment during the 9th century. It seems that at the time of the establishment of a monastery in Banyoles, drainage channels were dug, still present in the urban areas of the town and easily identified in aerial photographs by their regular shape. These channels were built to become natural overflows of the wetlands of the lake, often avoiding their overflow and favoring a natural drainage that allowed the use of water and its strength for civil and industrial uses.

4.1.3. Climate and vegetation

The mean annual temperature in the broader area of Lake Banyoles is 15^{o} C, with an average maximum of 23^{o} C during the summer months (warm and dry) and a minimum average of 7^{o} C during winter (wet). The climate is characterized as humid Mediterranean, with an annual precipitation of 750 mm.

The current vegetation around Lake Banyoles is distributed in concentric lines around the lake, although it is highly affected by human activity since the city of Banyoles is located on its southeastern coast and on the western coast there are currently cultivated fields. Most common vegetation on the shores of the lake is riparian forests and reeds. The riverbank forest that is conserved in the emerged areas closest to the lake is made up of *Alnus*) and in it small communities of *Laurus nobilis* are conserved. There are also grass thickets of reeds on the eastern side of the lake. On the western shore are fields and orchards and forests of oak and white pine. The mixed forest of holm oaks and oaks (*Quercus ilex* and *Q. pubescens*) extends along the northern slopes, while in the flatter areas there is the typical holm oak (*Quercetum ilicis galloprovinciale subass. Pistacietosum*).

Given that lacustrine deposits offer a great record of climatic oscillations, they are often used for paleoclimatic reconstructions, also human impact are recorded in lake deposits. In the Lake of Banyoles, various pollen studies have been undertaken (Pérez-Obiol and Julià, 1994; Revelles *et al*. 2014; 2015). Through the last years coring strategies attempt to record the paleoclimate since the Early Holocene (Magny 2004; Höbig *et al.* 2012; Revelles *et al*. 2015).

The palynological record of Lake Banyoles from a 31-ka core from alongside U/Th and ^{14}C dating inform us that the last glacial sequence registered the Younger Dryas between 11.5 and 12.7 ka, a cold event around 11 ka and a tree cover maximum around 6 cal ka BP (Pérez-Obiol and Julià 1994). Regarding the vegetation changes during the Holocene, these must have been from the alternation between arid and humid phases. More specifically, shifts in vegetation cover seem to occur during six aridification phases dated by data from SE France to SE Spain around 9.5-9 ka, 7.5-7 ka, 4.5-4 ka, 3.7-3.3 ka, 2.6-1.9 ka, and 1.3-1 ka BP (Jalut *et al*. 2000).

Further research by Perez-Obiol *et al*. 2011 confirmed an aridification phase from 5.5 ka until today, a humid phase between 12 and 7 ka BP and a transitional phase between 7 and 5.5 ka BP (marked by a decreasing pollen concentration between 6.7 and 6 ka BP at Banyoles) (Hobig *et al.* 2012). According to Revelles (2017) Middle- Holocene is bounded by the cooling episode of 8.2 cal ka BP (Cacho *et al.* 2001; Frigola *et al.* 2007; Pérez-Sanz *et al*. 2013; Peyron *et al.* 2011 among others) and the aridification process registered around 4.2 cal ka BP (Mayewski *et al.* 2004; Staubwasser and Weiss 2006; Wanner *et al.* 2011; Renssen *et al*. 2012; Walker *et al.* 2012; Innes *et al.* 2014). Arid phases have been further identified around 7.5-7.0 ka BP in Iberian lacustrine sediments (Vegas *et al.* 2010; Pérez-Sanz *et al.* 2013).

According to Magny, climate instability during the Holocene is directly connected to the solar activity and the precipitation rates, determining this way lake level changes (Magny 2004; Mayewski *et al.* 2004). However, the direct mechanisms causing climate variability remain unknown (Frigola *et al.* 2007). That is the reason why paleoclimatic reconstructions are closely related to lake level changes as well as changes in the sedimentary record.

Nevertheless, environmental changes and human impact are both reflected on the vegetation history of the region. Data gathered from the sedimentary sequence of SB2 core at the western part of Lake Banyoles shore alongside with further characterization of the sedimentary facies and geochemical data was carried out in parallel with pollen analysis (Revelles *et al.* 2015). Before the occupation of the lacustrine settlement of La Draga, there is an attested change in the sedimentological record from shallow water lacustrine Charophyte-rich carbonate facies to palustrine peaty wetland colonized by lakeshore vegetation, such as *Cladium mariscus* (Revelles *et al*. 2015). That is consistent with a lake water level regression, resulting in lowering of the lake level. This change is further associated by an attested cooling event creating drier conditions caused by reduced rainfall and decreasing fluvial activity in the Mediterranean around 8.9 cal ka BP (Magny *et al.* 2002). These same processes could probably be behind the discovery of a newly exposed lake marl surface in the eastern shore of Lake Banyoles by the first settlers of the Neolithic village of La Draga *ca*. 7.3 cal ka BP. Either that being the result of a lake water lever regression or the deposition of carbonate facies due to exceeding rate of groundwater influx, such sedimentary and hydrological changes suggest evidence of arid conditions (Revelles 2017).

The hypothesis of colder environmental conditions at the time of settlement foundation is reinforced by $\delta^{18}O$ values obtained from archaeological wooden remains of Phase I of La Draga (Aguilera *et al.* 2011). Differences between sub-fossil and extant samples in $\delta^{13}C$ and $\delta^{18}O$ records suggest slightly lower temperatures and higher plant water availability than at present during the establishment of agricultural practices at the site. These environmental conditions at the time of the first settlement foundation could possibly explain the exposure of the shoreline of Lake Banyoles allowing its occupation by the settlers. The exposed lake marl platform would be attractive for Neolithic communities to settle in a place devoid of vegetation. This would be a highly valued space in the context of a densely forested landscape.

The vegetation around Lake Banyoles at the time of the Neolithic occupation of La Draga was densely forested, with predominant broadleaf deciduous forests (*Quercus* and *Corylus*) and conifers (*Pinus* and *Abies*) in the surrounding mountains and the presence of evergreen sclerophyllous taxa (*Quercus ilex-coccifera, Olea* and *Phillyrea*) at a regional scale. Riparian forests (*Ulmus, Fraxinus and Salix*) predominate along the lakeshore, while there is presence of hygrophyte and aquatic plants in areas with higher water availability (Revelles 2017). A fall in *Quercus deciduous* values (Pérez-Obiol 1994; Burjachs 2000; Revelles 2017) attested around the time of the occupation of La Draga is not only related to a cooling event but also to anthropogenic activities such as deforestation practices, for firewood and for the construction of wooden habitats (Piqué 2000; Caruso-Fermé and Piqué 2014; López-Bultó and Piqué 2018). Subsequent lack of plant cover in La Draga from 7.16 to 6.75 cal ka BP due to deforestation and farming activities has been linked to soil erosion processes, responsible for changes in the hydrological regime and the higher input of terrigenous sediments. Finally, the fast recovery of oak forests is consistent with the end of the Early Neolithic period around 5.5 cal ka BP.

4.2. The lacustrine site of La Draga (Girona, NE Iberian Peninsula)

4.2.1. Historical and cultural background to the site of La Draga

The lacustrine settlement of La Draga is often studied in the context of the '*neolithization*' process of the Northeastern Iberian Peninsula as it is usually called the transition from a hunter-gatherer way of life present until the Early Holocene to farming practices present since the Early-Mid Holocene onwards (Piqué *et al.* 2021). Of course, that is not absolute, as evidence -where present- of the Mesolithic period suggests a smoother transition that maintains a lot of the previous ways of subsistence into the Early Neolithic period, rather than an abrupt change. In the case of the Northeastern part of the Iberian Peninsula, evidence prior to the Neolithic occupation of La Draga is scarce (Oms *et al*. 2018; Piqué *et al*. 2021). Nevertheless, even when evidence of previous Mesolithic occupation is available, as in the case of Bauma del Serrat (Alcalde *et al*. 2009; Alcalde and Saña 2017), that has a chronological gap of more than 500 years from the subsequent Neolithic occupation.

On one hand, there is the lack of Mesolithic period sites at the Northeastern part of the Iberian Peninsula and on the other hand the gap of available radiocarbon dates for that period. Only attested sites with Mesolithic presence in the area apart from Bauma del Serrat are Font del Ros, and Can Sadurní, and further south, already in the framework of the Ebro Bassin, Cova del Vidre and Coves del Fem. Unavoidably, the data leads the research onto the hypothesis of settlement at La Draga in a previously unoccupied territory (Piqué *et al*. 2021b).

The chronological hiatus concerning the hunter-gatherer presence prior to the occupation of La Draga is often interpreted as the result of an abrupt cooling episode around *ca*. 7.3 cal ka BP associated to temporally reduced precipitation (Jalut *et al.* 2000; Frigola *et al.* 2007; Vegas *et al.* 2010; Pérez-Sanz *et al*. 2013). For that period, immediately before the foundation of La Draga settlement, there is some indirect evidence of human occupation on the shores of Lake Banyoles, although it has not produced any archaeological record until now. Based on the thickness variability of oak trunks used as vertical piles in the construction of the wooden platforms at La Draga, the number of tree-rings and their estimated age spread, dendrochronologists suggest that timber came from already cleared different forest stands. According to the known growth rate of Mediterranean oaks, this period of area exploration before full sedentary settlement can be estimated in *ca.* 150 years (López-Bultó *et al. in press*).

The occupation that started in La Draga *ca.* 5310 cal BC is characterized by Cardial Pottery impressed ware tecnique: the techniques are similar to those from Bauma del Serrat del Pont and Cova del Toll older occupations (Oms *et al*. 2014). This is also a period of technological advance. In the Iberian Peninsula harvesting tools bearing whole, parallel-hafted blades first appear after 5300 cal BC, in both coastal (e.g., Sant Pau del Camp) and inland areas, and become more frequent, gradually replacing serrated sickles, at least in some geographical zones (Mazzucco *et al.* 2020; Palomo *et al*. 2021b; Terradas *et al.* 2021).

No other remains of contemporaneous human occupations have been found in the rest of the Empordà plain (Revelles *et al*. 2018). La Draga, at the shores of Banyoles Lake constitutes the largest known settlement in the area, and it appears to be more carefully planned in its construction and organization than others from the Northeastern region. This gives an image of very dispersed small groups occupying a mostly depopulated area, and concentrating the settlements in rationally selected points that had the best conditions for their initial and still partial farming economy.

La Draga's second occupation, 5100-4900 cal BC is contemporaneous with farming societies spread across the whole Northeastern Iberian Peninsula, from the coast following water courses upriver, as far as the Pyrenean valleys (Antolín *et al.* 2018; Palomo *et al.* 2021a), and show some minor changes in economic life –new cultigens- and in material culture. This is the period of the recovery of Neolithic occupations, well attested in statistical graphs of summed radiocarbon probability distributions, in which the number of dated archaeological contexts arrive to a value never attained before (Oms *et al*. 2016). Sites that were also occupied during the first period, and experimented short interruptions during the interval 5150-5000 cal BC, are reoccupied now. This scenario of human expansion in the area explains the increase in the number of contemporaneous archaeological sites around the Banyoles Lake.

Very few remains dated after 4700 cal BC are known for the La Draga site. Post-depositional activity and erosion of the upper layers at the site cannot allow explaining the possible abandonment of the site nor its connection with higher scale depopulation trends in temperate Europe, like those analyzed by Shennan *et al.* (2013) among many others. Balsera *et al.* (2015), Bernabeu (2017*)*, García-Puchol *et al.* (2017 ; 2018*)*, Drake *et al.* (2017), Fyfe *et al.* (2019), Pardo-Gordó and Barceló (2020) have argued about a probable decline in accumulated probability of dating archaeological sites after 4700 cal BC. The causes of this sudden decrease following the demographic boom of the earlier Neolithic expansion period remain unclear, but it should be related with the rapid fission within early farming communities, fission in turn caused by competing centrifugal and centripetal economic forces within small-scale egalitarian groups (Leppard 2021). Internal (Shennan et *al.* 2013; Bernabeu *et al.* 2015; 2017) and externals drivers (Gronenborn 2009; Walsh *et al*. 2019) have been proposed to explain this phenomenon. Although, no specific evidence has been presented until now to support the reasons behind the abandonment of the settlement of La Draga.

4.2.2. History of research

The site of La Draga was first discovered in 1990 and since the next year (1991) several excavation campaigns took place and they are still ongoing (Bosch *et al*. 2000; 2006; 2011; Palomo *et al.* 2014). While evaluation fieldwork of the site was made during 1990, the three basic sectors of the settlement were partially excavated during the period 1991-2005. Sector A is the one found at a furthest distance from the shoreline inland, in a higher elevation from the others. In sector B-D the archaeological units are found under the current phreatic level, while sector C is the one currently submerged under the water table, in the Banyoles Lake. The excavation methods had to adjust to the particularity of different conservation contexts of the archaeological record. All the excavated sectors were initially introduced to a general grid system, based on Cartesian coordinates, while excavations both in land and underwater were taking place at the same time.

The first underwater surveys in the lake under the coordination of the Catalan Center of Underwater Archaeology (CASC) brought to light a stratigraphic sequence of approximately two meters deep and a well-preserved organic layer under it, while the drilling holes made in 1996 determined an extension of 1500 m^2 for this submerged sector of the settlement (Bosch *et al*. 2012). The first excavations were carried out between 1991 and 2005 (Bosch *et al.* 2000; 2006; 2011) discovering an area of 328 m^2 in Sector A (1991-1995), and 132 m^2 in sector B (1997-2005). In the underwater sector (Sector C), exposed in prehistoric times, 310 m^2 were also excavated (1994-2005) (Bosch *et al.* 2000).

In addition to that, 17 drilling holes were made along two perpendicular axes (10 drilling holes along the North-South axis and 7 along the East-West axis) crossing through the site and extending until the shoreline in order to define the outer limits of the settlement.

A research program under new direction was initiated since 2008 and is still running until nowadays (Terradas *et al*. 2020). After a five-year hiatus (2005-2010) archaeological excavations resumed in 2010. A new excavation area of 55.5 m^2 was opened, adjacent to sector B, which was named sector D, and another new area of 178 m^2, adjacent to sector A, was also investigated (Palomo *et al*. 2014). Apart from intra-site excavation, systematic surveying around the Lake Banyoles (2008-2009) aimed to acquire more data related to the lake. More specifically, 97 cores (Figures 4.8, 4.9) were retrieved from the perimeter of the lake (one every 50 meters when possible) to both detect other evidence of occupations in the proximities of La Draga and put insight into the sedimentary dynamics that could have formed the lake landscape since prehistoric times in Banyoles (Bosch *et al*. 2010; Terradas *et al.* 2013a). Excavations in sector D were carried out during the 2010-2013 period whereas new excavations in the northern part of sector A were carried out since 2013 to date in order to detect settlement patterns and clarify stratigraphic connections between the two sectors (Palomo *et al*. 2014; Terradas *et al*. 2020). At the same time, another set of cores, was made in 2013 to reconstruct the geomorphology intra site (Iriarte *et al.* 2014).

Since 2014 until nowadays the excavations cover mostly extensions at the northern part of sector A and underwater surveys and excavations in sector C (2017, 2019). The extension of the settlement is currently estimated in approximately 15,000 m^2 .

Cores 2008-2009

During the years 2008-2009 a survey took place around the perimeter of Lake Banyoles in order to determine on one hand the presence of human activities during past periods near the lakeshore and on the other hand to establish the limits of ancient lakeshores (Bosch *et al.* 2010). That would permit to reconstruct the anthropic and natural factors affecting the formation processes around the lake. For this purpose, 97 cores were realised around the perimeter of the lake (Figure 4.5). After their georeferentiation and geomorphological description, they were sampled for various kinds of analysis related to environmental indicators (pollen, sedimentological, malacological, plant macroremains, etc.) as well as to chronological evidence (^{14}C dating). Although the results of the abovementioned analysis do not evidence human traces prior to the settlement of La Draga, the data corresponding to posterior periods are numerous dating from the fifth until the second millennium cal BC. The recovered materials that indicate the human presence are mostly wooden remains and charcoal fragments. The presence of introduced species is indirect evidence for human presence in the surrounding lake environment, although no human activities can be specified.

Figure 4.5. Map of the distribution of the drillings made around Lake Banyoles during 2008-2009 (Bosch *et al.* 2010; Terradas *et al.* 2013a).

The first 3-4 meters of sedimentation –corresponding to Holocene sequence- were characterised around the lake Banyoles and their stratigraphic sequence was described (Figures 4.7, 4.8). In general terms, the predominant type of sediment in most of the cases is clay, with stratigraphic depth of 4 meters in most of the zones such as D, F, G, I, and K (Figure 4.6). Although the cores retrieved from these zones contain no archaeological material, they may have been deposited during historical times, as it is attested by a charcoal fragment dated in 161 cal BC – 128 cal AD (core 13, 180 cm deep). Zone C is characterised by 3 meters of clay sediment, containing archaeological material (150-270 cm deep) such as pottery and fauna remains probably associated to the Iberian roman occupations in the area. In the zones J, H, I and L, long sequences of peaty sediments were attested. This is organic sediment with high presence of charcoal fragments. The recovered charcoals were radiocarbon-dated and gave insight on the human impact on the lake surroundings between the second and the fifth millennium cal BC (core 26, 1267-1040 cal BC, core 76, 3615- 3612 cal BC and core 96, 4248-4196 cal BC) (Terradas *et al.* 2013a). Based on these results, several cores were repeated in the following years in zones that have been proved to be of special archaeological interest, in the same way that new areas were explored based on the results of previous surveys.

Such an example is core SB2, at the western shore of the lake, where a series of analysis were realised in order to decipher the sedimentation around the lake and the climatic conditions during the Holocene (Revelles *et al.* 2015).

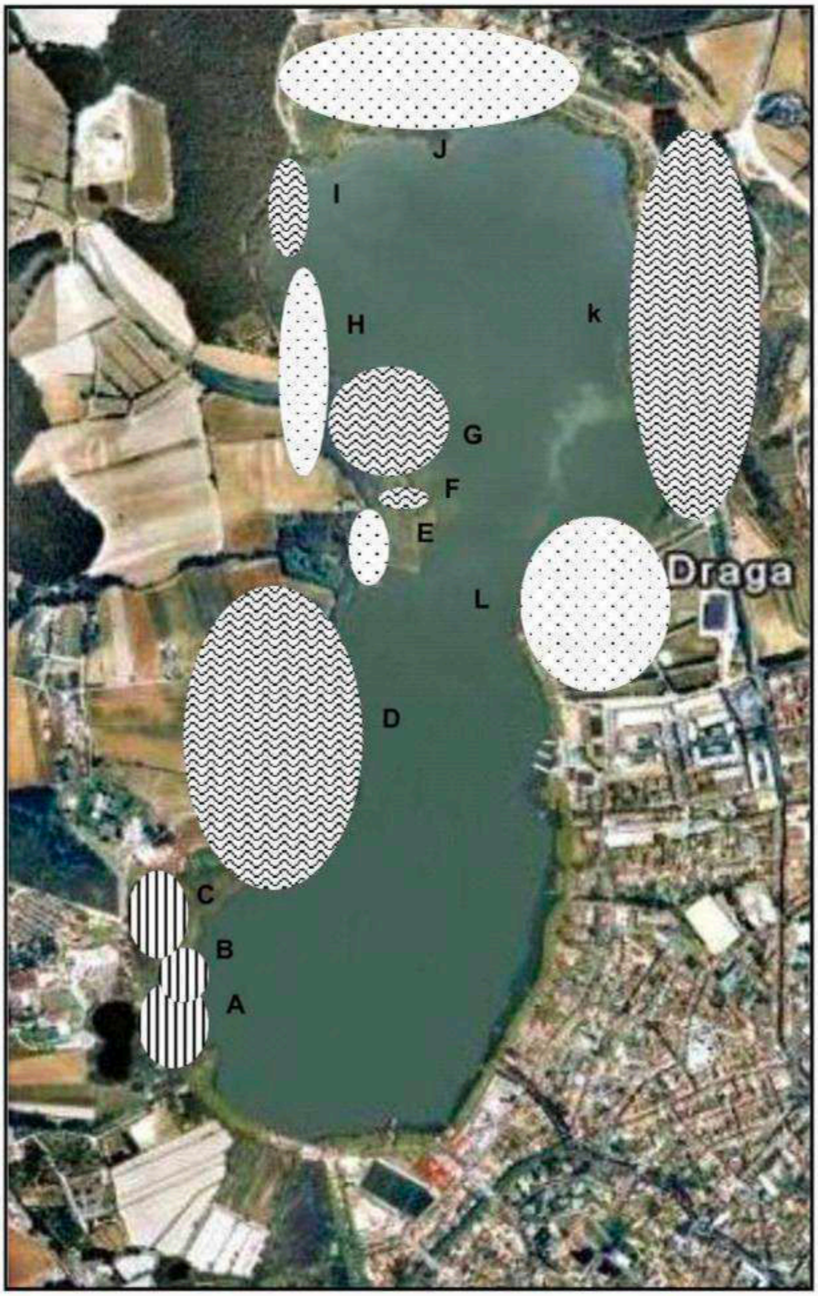


Figure 4.6. Map of the sedimentary zones characterized by the cores surrounding Lake Banyoles (Bosch *et al*. 2010; Terradas *et al*. 2013a).

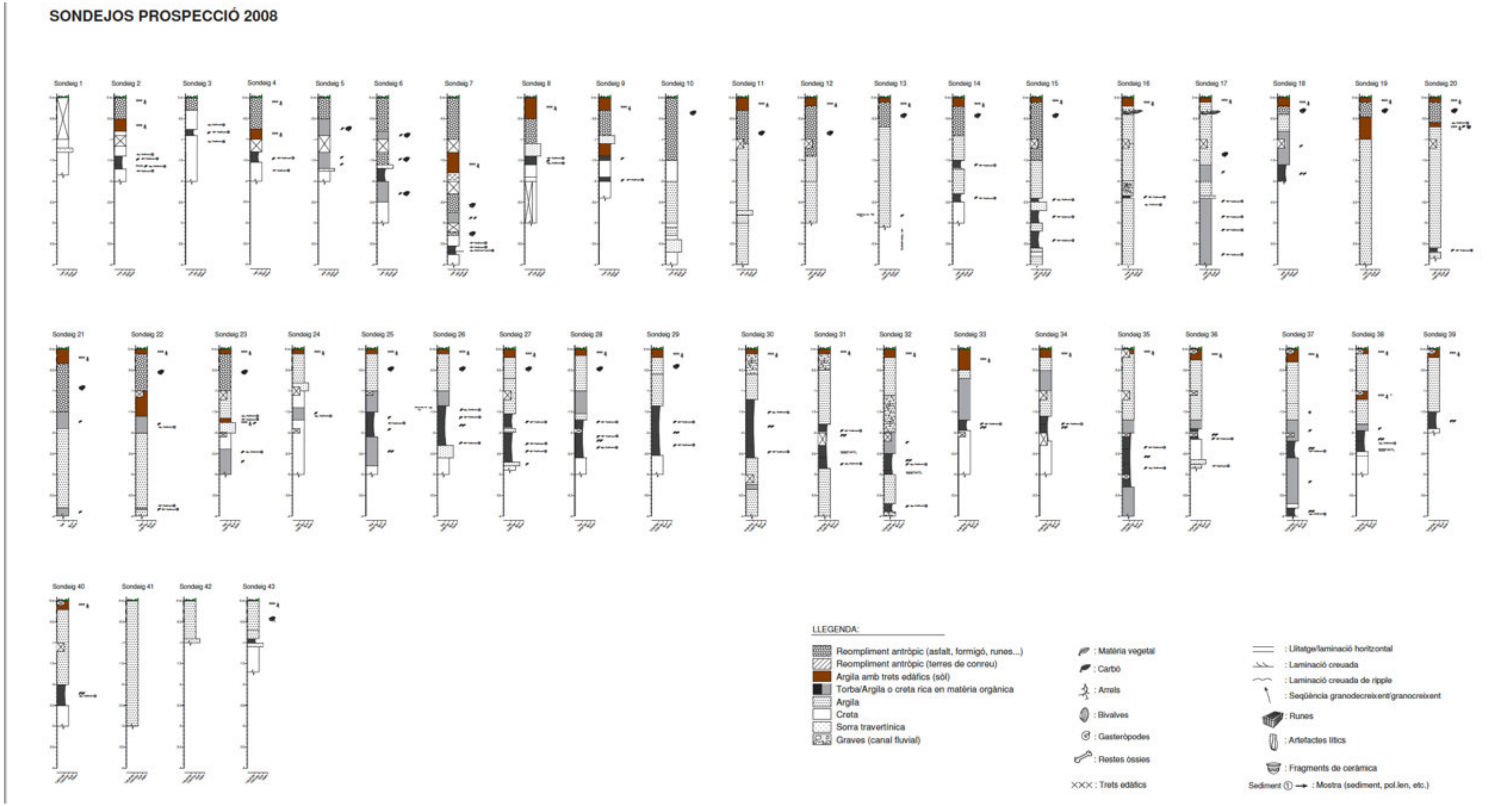


Figure 4.7. Diagram of representation of the cores 1 to 43 realized in the perimeter of Lake Banyoles as shown in the map (Figure 4.6), revealing their stratigraphic sequence.

SONDEJOS PROSPECCIÓ 2009

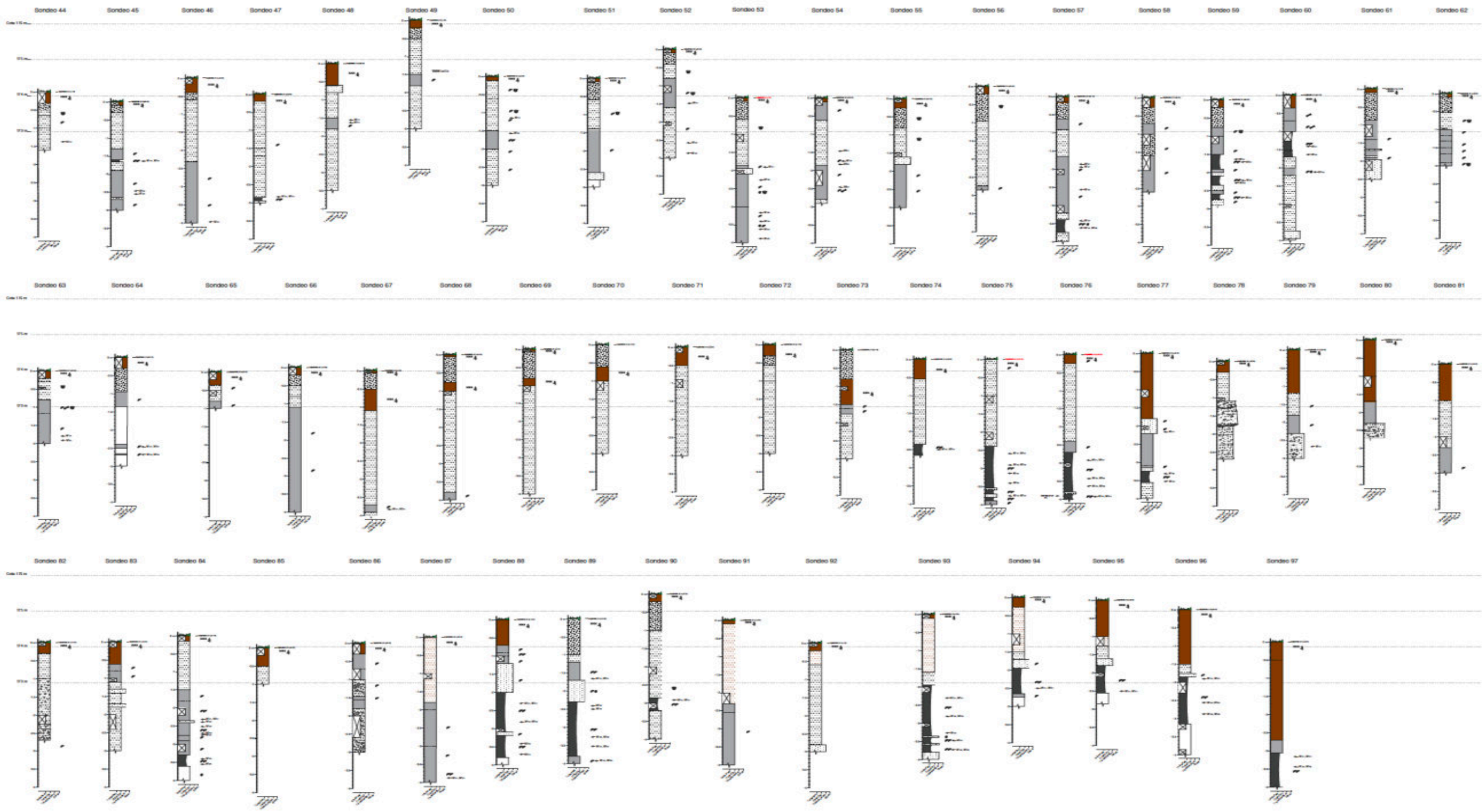


Figure 4.8. Diagram of representation of the cores 44 to 97 realized in the perimeter of Lake Banyoles as shown in the map (Figure 4.6), revealing their stratigraphic sequence.

Cores 1996, 2013

A method that was applied during the course of two excavation campaigns at La Draga, was to realize series of cores in order to answer questions, such as the extension of the lacustrine settlement (1996 cores), the reconstruction of the stratigraphic sequence as well as the depositional processes (2013 cores) that may have affected the distribution of the material record and may be relevant to the Neolithic occupations at La Draga.

In 1996, 17 cores were realized in the terrestrial part of the settlement with the purpose to define its limits and orientation in relation to the lake. These were distributed along two perpendicular axes, one from the northern to the southern part of the settlement and another from the western to the eastern part (Figure 4.9). The results from the stratigraphic reconstruction revealed a continuous inclination from the eastern inland part towards the western shore of the lake. Furthermore, according to data retrieved from bathymetric analysis, the location of the shoreline during Neolithic times was estimated to be at 15 meters further into the lake than the actual shoreline (Bosch *et al*. 2000; Andreaki 2016).

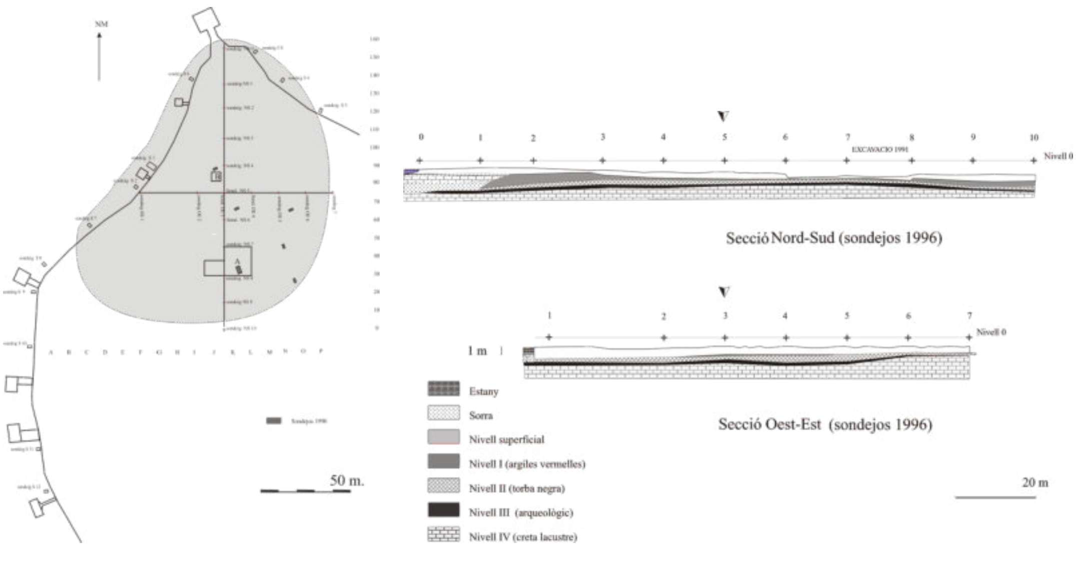


Figure 4.9. Map of distribution of the 1996 cores marked in two perpendicular axes on the left and the reconstruction of the stratigraphic sequence alongside each axis on the right. The North-south axis above and the west-east axis below (Bosch *et al.* 2000).

In 2013, 12 additional cores were realized in various points of the settlement (Figure 4.10) in between the excavated sectors with the objective to reconstruct the major depositional processes affecting the archaeological record. Based on the sedimentary sequence of the cores stratigraphic correlation between the excavated sectors A and B-D were possible and a three-dimensional stratigraphic model was realized (Andreaki 2016). Although further edaphological and geochemical analyses were realized by Iriarte (Iriarte *et al.* 2014) arguing the reconstructed sequence of the cores, the results are yet to be published. In the meantime, the results of the stratigraphic correlation between sectors were informative about the existence of a ground subsidence located in the limits of sectors B-D (Andreaki 2016).

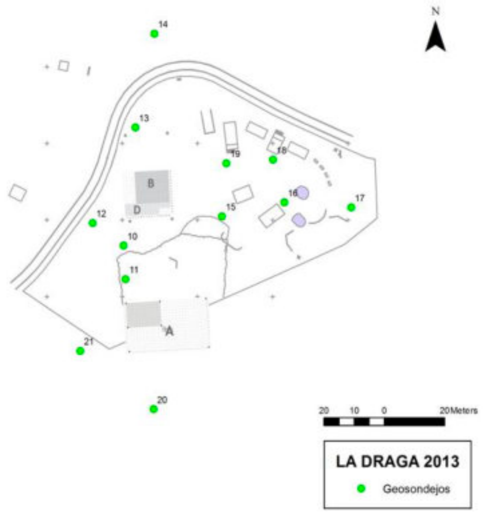


Figure 4.10. Map of the distribution of twelve cores realized during the 2013 excavation campaign at La Draga site. The cores are marked as green dots (Iriarte *et al.* 2014).

4.2.3. Stratigraphy and chronology

The total extension of the Neolithic settlement is currently calculated at over 15,000 square meters, 1,500 of which are currently underwater. Three different areas have been excavated so far achieving almost 1,000 square meters out of the estimated total extension. They were excavated since 1991 until nowadays (Bosch *et al.* 2000; Bosch *et al.* 2011). Those include sector A, actually emerged found in relatively dry conditions, sector B-D where the archaeological layers are located at a similar depth to that of the water table and last but not least, sector C, the one found completely underwater (Figure 4.11) (Palomo *et al.* 2017; Terradas *et al.* 2013b).

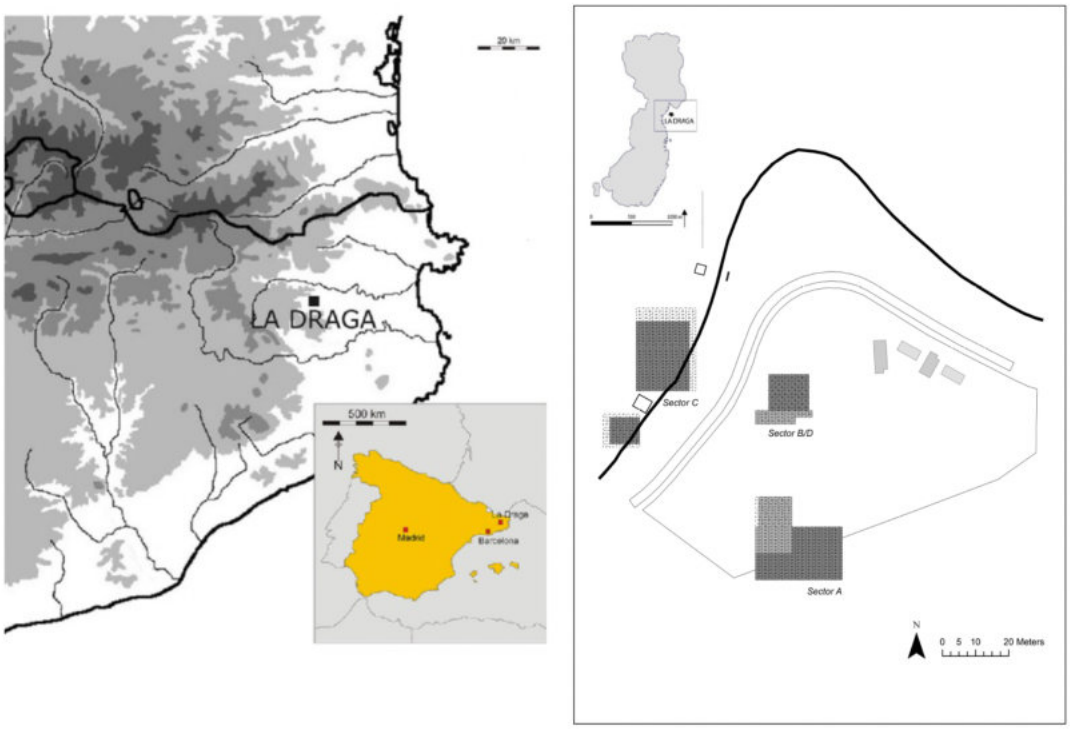


Figure 4.11. Geographical position of La Draga site in the map on the left and general view of the excavated sectors in the lakeshore of Lake Banyoles on the right (*Plan modified after Núria Morera*). Dark grey color represents the square meters excavated under old direction in sector A (1991-1995), sector B (1997-2005) and sector C (1995-2005). Instead, in light grey, the square meters excavated since 2010 until 2021 are represented. The black line represents the lake shoreline.

Sector A alone has been excavated during various campaigns firstly during the years 1990-1995 and later since 2013 until 2020. Its total extension comes up to 506m^2. Sector A is situated at the southern and more remote distance part from the lakeshore, where the archaeological layer reaches the highest level from the water table. Due to that, only the tips of the wooden piles, found inside the lake marl substrate and attributable to the oldest occupation, were preserved. On the other hand, the structures[19] constructed during the most recent phase were found directly on the lake marl surface, which was covered from travertine slabs (Palomo *et al*. 2014; Terradas *et al*. 2020).

As a result, the stratigraphic sequence of this drier part of the settlement is partially preserved. During the oldest construction phase of the settlement, wooden timber logs were inserted in vertical position into the lake marl substrate in order to support the

[19] The characterization of the accumulation of travertine slabs across the excavated surface as *structures*, is used here as a convention. The identified borders in the case of various accumulations and the intentional deposition of the travertine slabs have led the excavators to call them *structures*. Although, the definition *structure* refers more to an archaeologically defined context.

wooden structures. The lake marl deposits were formed underwater, before the early Neolithic occupation of La Draga and as a result, correspond to the base of the installation horizon, as called in some literature (Wiemann and Rentzel 2015). Going on upwards, the covering layer includes several travertine structures encountered directly over the lake marl surface (See *Chapter 6*) (Figure 4.12).

In sector A these structures are in the form of pits, while all over Sector B-D appear as wider paved surface consisted by travertine slabs, covering the previous occupation phase (Figure 4.12).

Figure 4.12. Plan of two different uses of materials in sector B-D. On the left side, view of the oldest occupation with the presence of wooden material for the construction of the platforms over the exposed white lake marl surface. On the right, view of the same space with travertine slabs covering the previous occupation in the form of paved surface. Two separate structures corresponding to fireplaces were marked with red squares (*Modified after Piqué et al. 2021a*).

Apart from the relative chronological order retrieved from the stratigraphy documented in the field, various samples were taken through the years from different archaeological layers from all excavated sectors, for radiocarbon dating (Andreaki *et al. in press*).

Based on the results, the total duration of occupation at La Draga comes up to 400 years approximately and belongs to the Early Neolithic period in the Iberian Peninsula. Two different kinds of use of space documented in both sectors are corresponding to the occupational horizon of the settlement (Palomo *et al.* 2014; Bogdanovic *et al*. 2015). The oldest occupational phase (5300-5085 cal BC) is characterized by the construction of dwellings on wooden platforms, attested by the wooden timber logs extracted from the lake marl substrate, as well as from the collapse layer documented in sector B-D, preserving the organic material under waterlogged conditions. On the other hand, during the more recent occupational phase (5100-4700 cal BC), it seems that travertine is the new material used to construct structures (sectors A and B- D) and a paved area (sector B-D), over the collapse wooden structures, at the excavated parts of the settlement. As it is evidenced from radiocarbon data, there is no chronological interruption between the two occupational phases, suggesting parallel adaptation to the water table changes and different use of space.

Although, recent Bayesian analysis included almost the totality of radiocarbon dates (40 ^{14}C dates) at the site of La Draga and suggested chronological differentiation between the occupational phases connected to depositional processes (Andreaki *et al*. 2020). According to the latter, two phases associated with the wooden platforms were distinguished into the first construction, use and further repairs of platforms ca 5300-5230 cal BC and another phase posterior to wooden platforms ca 5200-5085 cal BC. That could probably be associated with a temporary cease of human activities in certain areas of the settlement. The reappearance of archaeological material linked to travertine use in the arrangement of spaces takes place in two subsequent periods of time between *ca* 5100-4900 cal BC and 4950-4700 cal BC (Andreaki *et al*. 2020).

In the present research a total of 62 radiocarbon dates were taken into further research and presented in Chapter 8. In addition, stratigraphical order of depositional events (Chapter 6) and micromorphological results (Chapter 7) were taken into account for the analysis. As a result, a more detailed evaluation of the contemporaneity of chronological events associated to the dendrochronological data retrieved from the timber logs, is possible (See *Chapter 8*).

4.2.4. Subsistence strategies and human practices during the Neolithic period at La Draga

The arrival of the first farming communities in the Northeastern Iberian Peninsula coincides with the cooling event dated ca. 7.5- 7.0 cal ka BP, and as a result creates confusion among recent research for the climatic and human interaction and its impact on the environment during the Early to Mid-Holocene. In the case of La Draga, first occupation took place in the eastern shore of Lake Banyoles as early as in 7.3 cal ka BP due to the exposure of a lake marl surface suitable for settling on the shore (See *Chapter 4.1.3*).

Pollen rates and archaeobotanical data show evidence for deforestation coinciding with the Early Neolithic occupation at the site of La Draga ca. 7.3-6.7 cal ka BP (Revelles *et al.* 2015). That is also consistent with archaeobotanical data recovered intra site and used to provide a complete picture on the exploitation of animal and plant resources surrounding La Draga. Deciduous oak and pine forests were the common plant resources for providing the settlers with firewood, timber, raw wood, and plant fibers (Piqué *et al.* 2021a). These were subsequently used for various purposes in the context of a farming community: timber for the construction and repair of the wooden platforms during the first occupation at La Draga (López- Bultó and Piqué 2018; López-Bultó *et al.* 2020), raw wood material for the creation of tools necessary for the agricultural tasks of such a community, such as adzes, axes, planes and chisels (Palomo *et al.* 2013; Piqué *et al.* 2021a), as well as bows (Piqué *et al.* 2015) and for hunting. Furthermore, plant fibers were used for basketry and cordage (Piqué *et al.* 2018; Romero *et al*. 2021), and firewood was considered to be more long lasting for cooking practices, etc. In addition, the charred state of some fungi at La Draga suggests them were used for tinder (Piqué *et al.* 2020).

Well-preserved fruit and seed remains from the lacustrine settlement of La Draga inform us about the cultivation of specific types of crops (Antolín 2016). These are mainly represented by cereals like naked wheat, barley, emmer, einkorn and new glume wheat (*Triticum durum/turgidum*, *Triticum dicoccum, Triticum monococcum and Triticum sp./*new type) (Antolín 2016). Other gathered plants include opium poppy, hazelnuts, wild grape, acorns, etc.

Apart from agricultural practices, the subsistence of La Draga inhabitants was also based on livestock and husbandry practices, while fishing and hunting remained although marginally. The predominant species represented in the animal record are cattle, ovicaprids and pigs (*Bos taurus, Capra hircus, Ovis aries* and *Sus domesticus*). They would have been used both for meat, milk, leather and by products (Saña 2011). Based on the pollen rates of coprophilous fungi (Revelles *et al*. 2016) the flocks were kept in the settlement, whereas there is limited impact caused by grazing pressure out of site. In addition to agriculture and livestock, production processes involved also ornaments and instruments made of bone, shell and minerals, as well as pottery, completing the image of artisanal production in La Draga (Terradas *et al*. 2021).

All that in the context of socioeconomical changes characterizing the first half of the Holocene, well documented around Europe (Harris 1996; Mercuri *et al.* 2019; García-Puchol and Salazar- García 2017), including not only technological innovations for the management of resources and food production, plant and animal domestication processes but also, land use and its subsequent changes in settlement patterns and social organization.

After the rapid decrease of *Quercus* pollen in the site and in lakeshore peat deposits (Burjachs 2000; Revelles *et al.* 2016) following the occupation of settlers at La Draga, the surrounded vegetation was colonized by shrubs like *Buxus sempervirens*, herbs and other secondary trees (*Pinus, Tilia* and *Corylus*). The most used species from the riparian vegetation was laurel (*Laurus nobilis*). Some species were even used for specific purposes in each occupational phase according to anthracological data (Caruso-Fermé and Piqué 2014; Piqué *et al.* 2021b).

The absence of sedimentary charcoal in the core SB2 suggests no fire episode involved in the deforestation process, although cutting was the means to felling trees for raw material and firewood. In parallel with this evidence, no crop fields have been identified in the site of La Draga, suggesting their implantation in the close surroundings, probably further upland to avoid the swampy deposits of the lakeshore settlement, which were unsuitable for cultivation (Revelles *et al.* 2015). However, high concentrations of *Cerealia-t* pollen in the settlements should be linked to storage and by-products.

5. METHODS

The materials of the present research include the stratigraphic sequences of all the excavated sectors in La Draga (A, B-D, C), as well as the data obtained from cores realized in 2006 and 2013 (See *Chapter 4.2.2*) and undisturbed samples used for micromorphological analysis. The sedimentological description of the depositional sequences of the distinct sectors at La Draga, alongside micro-stratigraphical observations permit the reconstruction of the formation processes throughout the settlement. Moreover, a selection of radiocarbon dates across the site was made in relation to recent dendrochronological data in order to reconstruct the absolute chronology of La Draga (Chapter 8; Andreaki *et al. forthcoming*). All radiocarbon and tree-ring data were further organized into depositional events, according to their archaeological context and micro-stratigraphical information. Ultimately, the correlation of the respective sedimentary environments in the same site is attempted through the reconstruction of the stratigraphic data.

5.1. Micromorphological analysis of sediments

Although micromorphological analysis has more traction in archaeology in recent years, that wasn´t the case for older excavations. This is also true in the case of La Draga, as samples for micromorphological analysis were taken for the first time during the 2010 excavation campaign and were not part of a systematic sampling strategy, although they set the base for future studies. Sector B-D was sampled during the excavation campaigns of years 2010 (Balbo and Antolín 2013) and 2014 (Eneko Iriarte), Sector A was sampled during the years 2013-2014, while underwater sector C was never sampled. All samples during the period 2010-2014 were selected according to criteria considered pertinent during the excavation.

Since 2017, sampling of sediments for micromorphological analysis became an integral part of the excavation procedures and as a result sectors A and C were further studied under the author´s supervision. Sector B-D could no longer be sampled as it was covered after the completion of its excavation in 2014.

The samples for micromorphological analysis were retrieved in the form of undisturbed deposits either in the form of Kubiena boxes (Kubiena 1970), as for instance in the case of the interior of combustion features, or in the form of larger hard plastic boxes (36 x 8cm) from already exposed profiles. The monoliths were registered, photographed and described in detail at the time of their extraction. Thin sections were produced by external professional laboratories. A petrographic polarizing microscope (Leica DM2500 P) was used to study the thin sections, under a magnification range from 1.25 x to 40x. Microscope photos were taken during the study of each thin section and its components were observed both under plane polarized light (PPL) and crossed polarized light (XPL). The thin section description was made according to Stoops (2003) and Macphail and Goldberg (2018), by distinguishing between microfacies types (MFTs). Additional guides (Nicosia and Stoops 2017; Stoops *et al.* 2018) were also used for the recognition of anthropogenic remains, such as ash, bone, and mineral components.

Artefacts are conditioned further by the sedimentation, so both artefacts and deposits bearing them have been deposited penecontemporaneously. However, this is not always the case because materials may have been deposited and then sediments covered them, so it is hard to separate them during excavation (Karkanas and Goldberg 2019). That is not the case for structural entities, such as dwellings or travertine pavements devoid of sediment. Nevertheless, they must be included in the depositional dynamics of the rest of archaeological record, in order to be correlated. Separate architectonical features, such as the travertine pavement in Sector D of La Draga, are permanent construction features devoid of sediment and are conceived as separate units.

Deposits may be geogenic, anthropogenic or both in the lakeside settlement of La Draga. Most of the archaeological deposits are a mixture of geogenic and anthropogenic sediments being deposited by natural processes (Karkanas and Goldberg 2019). The micromorphological analysis of sediments was primarily realized with the scope to define the start and end of the depositional events. The depositional events were afterwards ordered in a sequence through Harris Matrix Composer as a guide for the chronological models (See *Chapter 6*).

By implementing facies analysis in the stratigraphic sequence then the correlation of deposits is possible between various parts of the same site. Furthermore, facies analysis provides the context for accurate sampling for dating in an archaeological site (Courty 2001; Karkanas and Goldberg 2019). Microfacies refer to these differences observed under the microscope and divide further sedimentary facies described in the field. In the present analysis, the special characteristics separating one microfacies type (MFTs) from another are the fine fabric, the coarse components and the pedofeatures observed (Macphail and Goldberg 2018). Pedofeatures such as weathering, infillings, etc. reflect the effect of post-depositional alterations (diagenesis).

In addition to that, each layer under the microscope was separated from the next by a change in physical attributes and the contacts bear crucial information at the time of deciphering periods of occupational hiatus. Difference between gradational and abrupt changes from one layer to another bears information regarding the change in depositional regime. A gradational change means rather gradual change in the conditions forming the sediments, so the contact between two successive units is diffuse. On the other hand, abrupt contacts mean clear lines that could probably be associated with non-deposition periods or erosional episodes. In the last case, these changes are translated to temporal stratigraphic gaps implying temporal hiatus (Karkanas and Goldberg 2019).

In this context, syn and post-depositional alterations that affect the stratigraphic sequence actively forming and deforming the archaeological site are studied. Nevertheless, a distinction has been made between those events leading to deposition and those taking place after the final deposition.

In this research, the microstructure of sediments was to further distinguish specific activities that may have happened *in situ* or not and conditioned the use of space. These include discard of material, accumulation, burning, cleaning, trampling etc. (See *Chapter 7*), mostly associated to occupational debris and living floors. It is the combination of these actions that would lead to the interpretation of human activities.

Overall, micromorphological analysis of sediments at the lacustrine settlement of La Draga serves as a tool for understanding the formation and deformation processes taking place and affecting the archaeological record. These would have conditioned not only the social action, but also the reasons behind the occupation and abandonment of the settlement during the Neolithic period.

5.1.1. Sampling Strategy

The scope of the sampling strategy was to retrieve samples from all the excavated sectors of the site, including the underwater sector C. It was important that all the samples would contain anthropogenic sediments related to the identified occupational surfaces of the settlement, as well as their contact and transition from the lake marl substrate. That would offer information about the water table at the time of installation, as the lake marl is the substrate all over the extension of the settlement. Samples coming from the submerged sector C also offer valuable insight on the depositional sequence affected by the lake water table before and after the occupation of the settlement.

The post-depositional processes taking place after the end of the Neolithic occupation are also sampled and studied in order to gain a complete picture of the formation processes at all moments throughout the stratigraphical sequence.

The spatial axis was also considered during sampling in order to resolve specific questions, as for example in the case of the travertine features appearing mostly in sectors A and B-D. For that reason, and to trace any kind of correlation between both sectors and the use of space in each one the samples presented in Table 5.1 were retrieved.

Various methods were employed according to the questions being posed on the field. Systematic sampling was employed in the case of sector C, where the whole vertical profile was sampled for micromorphology, while selective sampling was the most appropriate way for sectors A and B-D. In sector A, where there are numerous combustion features associated to travertine slabs, sampling included both the interior of the features (*E258*, *E261*, *E263*) and the lateral variations by sampling a transversal section passing through these features (*MP307*). Additionally, the eastern profile of the sector was also sampled entirely (overlapping sampling, Courty *et al.* 1989) in order to include the whole stratigraphic sequence (*MP318*).

In sector D, the samples taken during older excavations were focused on capturing the whole stratigraphic sequence, as they were retrieved from uncovered vertical sections (*MP124-128*, *MP2*, *MP3*). Samples for thin sections in sector D were recovered by Eneko Iriarte (MP124-128) and Ferrán Antolín and Andrea Balbo (MP2, MP3). The former were not studied, while for the latter a preliminary microstratigraphic analysis was made by Andrea Balbo (Balbo and Antolín 2013) being a pioneer study in the site that settled the bases of the future works.

In parallel with sampling for micromorphological analysis samples for palynology and micro fauna were also recollected from the archaeologists on the field, although results from mentioned analyses are not the objective of this thesis.

Table 5.1. Archeological structures and stratigraphic profiles and sections sampled for micromorphological analysis. The samples come from all excavated sectors at La Draga.

SECTORS	STRUCTURES	PROFILES
A	E258 (MP65, MP66)	MP307 (SOUTH SECTION)
	E261 (MP291)	MP318 (EAST PROFILE)
	E263 (MP292)	
B-D	–	M1-M5 (MP124-MP128, WEST PROFILE)
		MP2, MP3 (SOUTH PROFILE)
C	–	DRAGA_SECTOR C (C1-C11)

5.1.2. XRF core scanning of sediments

XRF scanning for chemical components was applied in the case of the core extracted from the underwater sector C. The XRF scanning of the core from La Draga was realized at the XRF Core Scanner Laboratory, in the University of Barcelona (Barcelona, Spain). As part of the underwater stratigraphic record, with a stratigraphic sequence including lacustrine deposits before and after the Neolithic occupation at La Draga, this core was considered as the right tool to examine the quantitative relationship of organic matter and carbonate content in the sediments. Micromorphological analysis of the sediments was implemented in the totality of the core. In the same core, samples for ^{14}C dates were taken from the archaeological strata and the peat deposits, while samples for U/th chronology were taken from the lacustrine ones.

5.2. Stratigraphic ordering of depositional events

5.2.1. Harris Matrix Diagrams

Before proceeding to the recollection of any kind of samples in the site, all the stratigraphic sequences of all excavated sectors were described geomorphologically. However, the methods of excavation and stratigraphy record have changed importantly from the beginning of the excavation in 1991 until recent years. Since 2010 different methods for the register of stratigraphy were implemented. Excavation sheets including name and characteristics of each stratigraphic unit were accompanied by a sedimentological description of the deposits. This description was based on general manuals used by archaeologists for determining the colour (Munsell soil colour charts), texture (clay, silt, sand, gravel) and consistency of the sediment or soil. In addition to that, the limits of each stratigraphic unit were explained in the form of a review at the end of the excavation of each stratigraphic unit. Any significant archaeological material included in the unit would be mentioned as well.

Closed contexts determined during excavations were registered as separate stratigraphic contexts (pits, combustion feature, hearths, structures, buildings, etc.). The stratigraphic sections were drawn and digitalized while photos of the plans and stratigraphic sections were taken at every step of the excavation. The aim has been to reconstruct the stratigraphy through photogrammetry, although that is not the object of the present research.

However, given that stratigraphy is a three-dimensional body extending in space and time, stratigraphic units represent only part of the archaeological record, and do not coincide with depositional events. Furthermore, it is necessary to separate the stratigraphic units defined on the field during excavation from the identification of depositional units (Karkanas and Goldberg 2019).

In the present research the stratigraphic relationships between the excavated units were considered alongside the microscopic observations made. Based on the results of the micromorphologcial analysis of sediments stratigraphic units were redefined and depositional events were determined. Surfaces were distinguished from the deposits, in order to better reconstruct the sequence of depositional events.

These were later organized into Harris Matrix diagrams for each excavated sector separately. The use of the diagrams in the present research is for the purpose of representation and organization of depositional events, whose temporal range corresponds to the isotopic events defined by the radiocarbon processing of the ^{14}C dates.

Although, as Karkanas and Goldberg (2019) pointed out, if Harris Matrix diagrams were drawn without previous knowledge of depositional processes, then the result would be another 'automated procedure' that lists sequential events. Subsequently this would affect our interpretation of the data as well. Major changes in stratigraphic sequence are normally observed through the detection of interfaces (discontinuities or unconformities). These mark the lower part or else accommodation plane of the deposit above (See *Chapter 2.3*).

Contemporaneity of depositional events was based on relative chronology like stratigraphic position and / or absolute chronology. The microfacies types of sediments (*MFTs*) were also considered in an attempt to correlate depositional units sharing the same attributes between separate sectors of the settlement. To reconstruct the stratigraphic sequence the depositional processes were considered.

In addition, by introducing isotopic data the stratigraphical relationships between the depositional events were further transformed into temporal relationships based on Allen´s Algebra (see Chapter 2). The chronological models were constructed integrating tree-ring data and ^{14}C dates in the OxCal and ChronoModel software (See *Chapter 8*).

5.3. Chronological modelling of depositional events

All radiocarbon samples and tree-ring data have been organized into depositional events, using archaeological contexts and micro-stratigraphic information. In so doing, we have followed the general approach by Barceló and Andreaki (2020), Barceló and Bogdanovic (2020). A depositional event is the material expression of an archaeological event: something happened at a specific place during an interval of time and modified the physical appearance of the ground surface where the action took place, differentiating specific areas from their neighbors. Therefore, a depositional event will correspond to the smallest differentiable spatial unit, that is, a particular closed area where the values of some particular spatial variable(s) are homogenous and statistically different from the values the same spatial variable(s) had at neighboring closed areas. It is important to consider that social action alone is not the only cause for a depositional event to occur. That´s because an archaeological site is not only the place where human action took place at a certain time, but also, where numerous post-depositional processes (geological, chemical, physical, mechanical, biological, etc.) modified or altered that initial human deposition (*Chapter 2*).

A depositional event is thus, the smallest spatial referential archaeological unit of observation showing some degree of homogeneity, and it should be defined according to the modification of the surface generated by the activity at that place: the accumulation –ordered or random- of materials on the surface, and/or the excavation of the same ground surface. In so doing, depositional events should be defined according to:

- the archaeological material they contain (what has been deposited),
- the microstratigraphical information revealing the formation processes *in situ* (the way the ground was altered as a result of deposition),
- the relative (stratigraphic order) and absolute chronological information (dendrochronological and radiocarbon data) for each one of them (the particular order in which different depositions occurred, and the position of each deposition in the calendar scale) (Barceló and Andreaki 2020).

To solve the question whether all the materials found at a referential spatial unit were deposited at the same time, we can calculate the significance of the differences in the estimated ^{14}C age using the classical Ward and Wilson test (1978*).* This is a statistical test that assesses the degree of consistency of the determinations, which if not found significantly different, can be combined. Otherwise, if these determinations are different, outliers should be examined.

If the result is positive for all the isotopic events within the same depositional event, we can conclude that the duration of the deposition was short, and the position in the calendar scale of the depositional event will be calculated in terms of the statistical combination (average) of the uncalibrated ^{14}C ages of the samples contained in the spatial unit.

In the case that the combination of isotopic events from the same depositional event fails the Ward and Wilson statistical test, the estimation of the temporal position of the depositional event will be compromised. The samples either were deposited because of different depositional actions, or the time lag between different effects of the same action is too great to be effectively detected in terms of a chi-square statistical distribution. Depositional events can be fast–a day, a week, less than a year-, medium slow –less than 20 years- or slow –more than 20 years.

OxCal 4.4. (Bronk Ramsey 1994; 2001a; 2019) and ChronoModel 2.0.18 (Lanos *et al.* 2016; Lanos and Dufresne 2019) software tools were used to integrate isotopic events that were depositionally associated with a single depositional event. In addition to that, depositional events were ordered according to stratigraphic constraints. The term 'phase' is used here in the same way as Bronk Ramsey (2015) and Lanos and Philippe (2018; 2020): as a group of events –isotopic and/or depositional- that are related in some way but for which there is no information on the internal ordering, and no (prior) chronological distinctions or temporal ordering can be assumed. That means, that *phases* are undetermined temporal intervals and the only way of estimating their temporal position depends on the probability of fixing the temporality of their start and end events (Andreaki *et al.* 2020).

The modeling approach is very different between OxCal and ChronoModel, although in both cases the temporal duration of *phases* is estimated in terms of the difference between a start and an end event. The idea is to reduce the uncertainty of calendar date estimates using hypothesis of starts and ends based on stratigraphic relationships, or the number of tree-rings between different radiocarbon samples of the same tree-ring sequence. Both computer programs apply Bayesian probability reasoning to define the proper limits of their assumed broad contemporaneity in terms of the spread of the dates, and the interphases or boundary temporal limits of the phase. In ChronoModel, the radiometric date of an event is assumed to be affected by an unknown error sigma, which will be estimated *a posteriori*. If this error is too large, compared to the error of other dates, we will be dealing with an 'outlier'. In this case, OxCal would have displayed an A_i lower than 60%. On the other side, in ChronoModel, there is no need to remove this date: it will be automatically discounted because of this high individual posterior error (Lanos and Philippe 2018; 2020). Consequently, in ChronoModel, there is no sorting of dates according to outlier elimination steps: all dates are considered, but some of them are later discounted. As a result, they do not affect the phase temporal range when they diverge from the other dates (Lanos, personal communication).

In the remaining of the research, a *phase* is thus, an aggregation of broadly contemporary depositional events, or a single depositional event whose formation process has been extremely slow. Martín-Rodilla *et al.* (2016) qualify the supposed contemporaneity of events belonging to the same phase by saying that it is a circumstance occurring over a long-time interval, during which no changes appear in the associated entities. It is the interval of the calendar scale fulfilling the condition:

'there is a non-zero and calculable probability that any depositional event included within its limits contains at least one of the isotopic events to which it refers' (Barceló 2009a).

Furthermore, *phases* are groups of functionally linked archaeological units, in the sense expressed by E. Harris (1989): they are the result of a structural combination of structural archaeological spatial reference units, and not necessarily of temporal (chronostratigraphic) units (see also Cox 2001; Traxler and Neubauer 2008). Although different, both uses of the term *phase* have similar explanations when used to reconstruct the 'biography' of an archaeological site. They can be viewed as individual steps in the temporal trajectory of the site occupation and formation. In both cases, a single scalar –calendar date for positioning such steps is not enough. However, the start and end of the activity or processes responsible for the formation of the individual event or the functionally connected set of events could be defined in some way.

A variety of radiocarbon dates has been recovered during the old and new excavations in La Draga, but they were never studied systematically until now. 62 ^{14}C dates have been gathered and analysed from all the excavated sectors of the settlement, including

12 wooden piles. The rest of the dated samples correspond to fauna remains, charcoal, cereal grains, bones, and wooden material retrieved during excavation. Sectors A and B-D are the best dated, with 29 dated samples coming from sector A, 15 from sector B and 12 from sector D. There are only 6 radiocarbon dated samples from the underwater sector C. The integration of the isotopic events corresponding to 33 depositional events was made by the softwares OxCal 4.4. (Bronk Ramsey 1999) and ChronoModel 2.0.18 (Lanos *et al.* 2016), using the IntCAL 2020 calibration curve (Reimer *et al.* 2020).

5.3.1. OxCal 4.4.

The use of OxCal offers both the calculation of probable age ranges for scientifically dated samples (by radiocarbon calibration, dendrochronological estimations) and the analysis of clusters of events that are related either generically or through stratigraphic relationships (Medina and Capuzzo 2020). In the present case of study, OxCal 4.4. was additionally used to calculate the Ward and Wilson (1978) test of contemporaneity (χ^2 test)- not yet available in ChronoModel 2.0 – in order to test the statistical contemporaneity of stratigraphically contemporaneous events. This test consists in calculating the estimated average of a series of dates and the comparison of the dates with the estimated average. In addition to that, it also generates a total error estimate resulting from the standard deviations of the dates (Medina and Capuzzo 2020). In the present study (*See Chapter 8*), the χ^2 test was especially used to test the contemporaneity of two or more events, archaeologically related to each other. If one or more events did not pass the test, then they would not be perceived as contemporaneous.

For the interpretation of series of dates, Bayesian statistics are applied in the case of both OxCal and ChronoModel. This means that analysis through OxCal allows the combination of dates with other kind of information offered by the archaeologists. This is mainly the stratigraphic sequence, as in this case the sequence constructed in OxCal is based on the Harris Matrix diagrams of the excavated sectors at La Draga.

To translate the deposits from the archaeological site into ordered units in the Harris Matrix Diagrams, the *Chronological Query Language (CQL)* is used in OxCal. The *CQL* includes the meanings of events, phases, sequences and boundaries among others. As these concepts come with special temporal significance, their use in the present

analysis is already explained previously. In order to construct the chronological model in OxCal each date corresponds to an event. The *phase* refers to the grouping of various dates, while the *sequence* represents the temporal order of the dates belonging to events and /or phases. A probability distribution for each calibrated dated was generated in OxCal based on the Marcov Chain Monte Carlo (MCMC) algorithm. The duration of phases and sequences, as well as the hiatuses between them were calculated. Furthermore, the dates marked as outliers could be excluded from the analysis, without eliminating them from the chronological model (Medina and Capuzzo 2020).
At the time of grouping the events into a chronological model, there were two options, either as part of the same phase or sequence. In contrast with a phase model, where there is no necessary connection between the events, the sequence model includes dates that follow a determinate temporal order. The sequence models were used in OxCal for the present analysis (See *Chapter 8*).

5.3.2. ChronoModel 2.0.18.

ChronoModel permits the construction of chronological models based on the *a priori* information coming from archaeology as well as the radiometric dates on the material recovered on archaeological excavations (Vibet *et al.* 2016).

In the context of *a priori* information, the year of felling of the oak trees for construction of the pile-dwellings has been determined by dendrochronological analysis. In fact, two temporally distinct felling moments have been defined *a priori* based on tree-ring analysis of the recovered wooden piles. The first corresponds to the timber logs used for construction, whereas the second includes the ones used for repair and maintenance of the dwellings on a later date. For the moment, the time span between these moments based on tree-ring data is of 28 years. So, until now the information of the felling date is equal to all recovered piles and has been introduced in ChronoModel as the tree-felling date. This marks further construction and repair phases afterwards. In addition to that, the time span of 28 years including the construction and last registered repair has been considered at the time of constructing the chronological model in ChronoModel. That is useful, especially in the case Of La Draga, where tree-ring data are available, as dendrochronologically-based boundaries can be determined as *terminus post/ante quem* both on the events and phases board.

At the time of constructing the chronological model of La Draga, depositional events previously determined through stratigraphic and micromorphological analysis have been considered. These are the main constituents of the model. For each depositional event one or more dates were added and the corresponding event in ChronoModel was created (Andreaki *et al.* 2020; *Chapter 8*).

At the time of organizing the depositional events and their associated dates, ChronoModel offers the possibility of either calculating the temporal ranges of the events into program-generated phases or using the *a priori* stratigraphical constraints to fix the phases based on relative chronological data. For that purpose, the stratigraphic sequence of depositional events in the form of Harris Matrix diagrams was translated into the same sequence in ChronoModel. Stratigraphic constraints in the form of arrows were used to direct the temporal order of the sequence. The same rationale has been applied to phases.

The software permits the simulation of Marcov chains for the calculation of the *a posteriori* distribution. This is represented as the average temporal interval for each date, event or phase. In ChronoModel phases have been defined based on groups of events archaeologically relevant. These events were first tested in OxCal through the chi-square test (Ward and Wilson 1978) and if they resulted contemporaneous, then they were included in the same phase.

ChronoModel 2.0 (www.chronomodel.fr) has a different way to calculate the *a posteriori* temporal interval. It is based on the concept of *Event*. An *Event* is a point in time for which a hierarchical Bayesian statistical model can be defined (Lanos and Philippe 2019). In our case, it corresponds to what we have defined as depositional event, when the temporal duration can be argued as less than the lab error of the isotopic date. A *Phase* is a group of *Events*, and it is here defined as a series of related depositional events, whose joint temporal duration exceeds 30-40 years. We have used exactly the same number and definition of phases in the models implemented in OxCal and ChronoModel. ChronoModel differs from the OxCal model in the way depositional events and their stratigraphic anterior/posterior constraints have been included. Unlike *Event* model, the *Phase* does not respond to a statistical model: indeed, we do not know how events can be *a priori* distributed in a phase. However, we may question the

beginning, end or duration of a phase from the *Events* that are observed there (query). A level of *a priori* information can be added: the Events from one phase may be constrained by a known duration and a hiatus between two phases can be inserted (this imposes a temporal order between two groups of Events). In ChronoModel, constraints link events and not calibrated dates. (Lanos *et al.* 2016; Lanos and Philippe 2017).
The idea is to estimate the unknown date of phases based on dated samples associated to Events, which in their turn, are associated to Phases. The event model, implemented in ChronoModel, combines contemporary dates, $t_1 \dots t_n$, with individual errors, $\sigma_1 \dots \sigma_n$ in order to estimate the unknown calendar date θ. The following equation shows the stochastic relationship between t_i and θ:

$$t_i = \theta + \sigma_i + \epsilon_i^{CM}$$

where $\epsilon_i^{CM} \sim N(0,1)$ for $i=1$ to n and $\epsilon_i^{CM}, \dots, \epsilon_n^{CM}$ are independent. θ is the unknown parameter of interest and $\sigma_1 \dots \sigma_n$ are the unknown standard deviation parameters. That means that each parameter t_i can be affected by errors σ_i coming from different sources (Lanos and Philippe 2017).

The temporal position of each phase on the calendar scale is estimated according to the events included in it. The following information are given for each phase:

- The beginning of a phase, α, reflects the minimum of the *r* events included in the phase:
  $\alpha = min\ (\theta j, j=1 \dots r)$
- The end of a phase, β, reflects the maximum of the *r* events included in the phase:

$\beta = max\ (\theta j, j=1 \dots r)$

- The duration, τ, is the time between the beginning and the end of a phase:

$\tau = \beta - \alpha$

The posterior distribution of all these elements may be approximated by MCMC methods and statistical results such as the median, the standard deviation and so on, may be estimated (Lanos and Dufresne 2019).

5.3.3. ^{14}C Wiggle-Matching

The excavations carried out to date at the site of La Draga, have made it possible to recover more than a thousand wooden piles from all the excavated sectors. The dendrochronological analysis of the piles is still in progress (Piqué *et al.* 2021b; López-Bultó *et al*. *in press*). However, tree-rings from 136 piles and horizontal timber logs have been described and measured, providing a floating dendrochronological sequence that covers an interval of 265 years. The dendrochronological sequence could not be correlated with any other, because of the lack of a fixed dendrochronological sequence covering from the Neolithic period up to the present for the North-eastern part of the Iberian Peninsula.

Wiggle matching in the case of La Draga only allowed estimating the temporal range of the use and repair of the wooden piles, based on the ^{14}C dates and their association to the last growth ring of the piles defined dendrochronologically. Furthermore, more accurate time spans were achieved for the construction and repair events associated to the first phase of occupation at La Draga.

A cross-dating process was carried out between the dendrochronological data available derived from the wooden piles and their radiocarbon dates at La Draga (13 wooden piles were cross-dated and used in the present research) (Andreaki *et al. forthcoming*: López-Bultó *et al*. in press). By radiocarbon dating wooden piles with visible tree rings, matching them to the 'wiggles' of the calibration curve was possible. The program (OxCal) then calculates ages for these rings using the defined gaps.

The cross-dating technique of ^{14}C dates and dendrochronological data retrieved from an archaeological site is known as wiggle-matching. Wiggles are called the abnormal lines observed in the calibration curve. ^{14}C wiggle-match dating refers to the matching of several ^{14}C dates from a constrained sequence of unknown calendrical age (e.g., tree ring sequence) to a calibration curve (Bronk Ramsey *et al.* 2001b). Thus, these data are matched to the wiggles in the curve, thus improving the calibration precision (Bronk Ramsey *et al*. 2001b). These offsets, either geographic or systemic, between the sampled data and the calibration curve can usually produce inaccuracies in wiggle-match dating (Bronk Ramsey 2009). The influence of offsets can be remedied by using a calibration curve based on local chronology (e.g., dendrochronology).

Wiggle-matching is also used to resolve the appearance of plateaus in the ^{14}C calibration curve, in the parts of the world where this is possible. The plateaus of the calibration curve are the result of scattered or scarce calibration dated over certain time intervals or different regions (Galimberti *et al.* 2004).

According to the Bayesian probabilistic approach the more the data archaeologists can offer the shorter the possible calibration range for a set of radiocarbon dates under study. In the case of archaeological data, ^{14}C wiggle-match dating from a local tree-ring sequence can enhance the calibration range. Furthermore, additional information coming from relative chronological data such as the stratigraphic sequence can further increase the possibility of shorter chronological time intervals.

Three different methods have been discussed by Ramsey *et al.* (2001b) for the matching of ^{14}C dates to the wiggles of the calibration curve. The first consists on realizing a classical chi-square test (χ^2 test) of the ^{14}C data to the calibration curve, although only one answer can be produced. This is the date where the data fit best and allows fit tests. However, this method is not suitable for measuring the uncertainty of the date. The second method applies Monte Carlo techniques, through which a range of possible ^{14}C values can be produced for the measured samples as well as possible points on the calibration curve. Afterwards, by applying the chi-square test discussed above, an optimal fit can be acquired. All ^{14}C measurements are *a priori* assumed to be equally likely during the Monte Carlo simulation. During the χ^2 test all calendar dates are assumed to be equally likely. Thus, the overall dating uncertainty can be derived from this technique.

The third method is based on Bayesian statistics and considers the probability distributions produced by the calibration of single ^{14}C dates. Based on these, a range of most likely dates can be calculated. The *a priori* assumption in this case is that all possible calendar ages are equally likely, although not all ^{14}C measurements are assumed to be equally likely. This one is used in OxCal (Bronk Ramsey 1994; 1995; 1998). The first two methods are based on Classical Statistics, while the third one on the Bayesian probabilistic theory. All of them can give consistent results, although the use of each one of these methods should depend on the scientific questions asked (Bronk Ramsey *et al.* 2001b).

In the case of a local tree ring sequence, usual in some archaeological sites, the implementation of wiggle-matching can add precision to the chronological sequence. By measuring the radiocarbon content in a sequence of ring groups in an undated sample, the generated ^{14}C dates are matched with the calibration curve. The by-products of this method are dates more accurate than a single ^{14}C date (Leavitt and Bannister 2009). When the data of local chronology are available, wiggle-matching analysis helps reduce the calibrated time ranges. When multiple radiocarbon dates with known temporal relationships are available for a single calendar date, they can significantly enhance the chronological resolution (Galimberti *et al.* 2004).

Dates coming from dendrochronology are presented in calendar years based on a local tree-ring sequence, while radiocarbon dates are presented as probability distributions for time intervals. The correspondence between both kind of dates is valid if the dendrochronological date falls into the 95% probability interval of the calibrated ^{14}C date (Matskovsky 2016).

Because of the availability of a local tree-ring sequence, although not yet complete, it was possible to proceed to ^{14}C wiggle-matching of the wooden posts at La Draga. Bayesian analysis and radiocarbon dating of the wooden posts are usually implemented with the goal to confirm the precision of tree-ring analysis and radiocarbon dating independently (Hamilton *et al.* 2007). In the case of La Draga, there is only one radiocarbon date coming from each wooden post, thus, it would be difficult to confirm accurate tree-ring sequences. However, there is an ongoing analysis of the tree ring sequence based on a big amount of recovered wooden logs and more data will be available in the future. Although, the accuracy of calendar years cannot yet be acquired, the chronological range of occupation of the site can be defined with greater precision. A Bayesian approach to chronological modelling was used for the radiocarbon dated samples in this case. By using this probabilistic approach, parts of the probability distributions of dates were highlighted as more likely given the tree-ring information. As a result, a reduced date range, known as *posterior density estimate* is acquired. All models were ultimately realized with OxCal 4.4. The information acquired by wiggle-matching was afterwards used in the determination of construction and repair phases of the lakeside settlement in ChronoModel (See *Chapter 8*).

6. STRATIGRAPHIC SEQUENCE OF THE DEPOSITIONAL EVENTS AT LA DRAGA

The different preservation of the archaeological record at the three excavated areas of the site and the complex and distinct post-depositional dynamics at each one due to the water dynamics generates additional problems when correlating the structures and sequences of the different sectors, which can only be partially related. Sector A is the one located further inland at a greater distance from the lakeshore and the one less affected by the water lake level, in drier condition. That means poor preservation of the organic materials that would have been encountered over the lake marl surface. However, water presence is expressed by the groundwater input through the lake marl substrate, as well as affected by the annual precipitation in the lake. In sector B-D, the image is completely different as the organic remains were preserved in very good condition, due to the anoxic conditions created by the water presence over the archaeological layers. The creation of a peat after the abandonment of the settlement would have also contributed to the conditions preserving the organic materials of La Draga, at this part of the settlement. Similar conditions of preservation are also present in Sector C, given the fact that it is found under the water lake level.

The stratigraphic relationships between excavated units of all sectors were described and further organized into Harris Matrix diagrams. In addition to the stratigraphical order of the units, these were translated into a sequence of depositional events, whose temporal range depend on the isotopic events identified at each minimum spatial unit of reference (See *Chapter 5*).

6.1. Sector A

In the area of the site located further inland and at a higher altitude respecting the lake level (Sector A), the stratigraphy shows a more complex deposition of sediments. The horizontal logs signalling the level of the original wooden constructions have not been preserved given the fact that the organic remains were found above the actual phreatic level and as a result were not preserved. Most travertine slabs marking the probable second occupational surface are in close contact with the original lake marl surface, making it very hard to distinguish between the two occupational surfaces. However, in some cases the bottom of the piles and/or the totality of the pile have been preserved-the part stuck into the lake marl- and the negative imprint of the pile belonging to the first occupational surface can be detected.

In the corresponding Harris Matrix (Figure 6.1) the lake marl surface and all detected individual piles (*CRETA, PV089, PV151, PV1441, PV153, PV106, PV1450, PV1300, PV1311, PV1399*) have been integrated into the same first stratigraphic phase (*Phase 1*). These are clearly associated to the remnants of surfaces and building materials related to the occupation in wooden platforms.

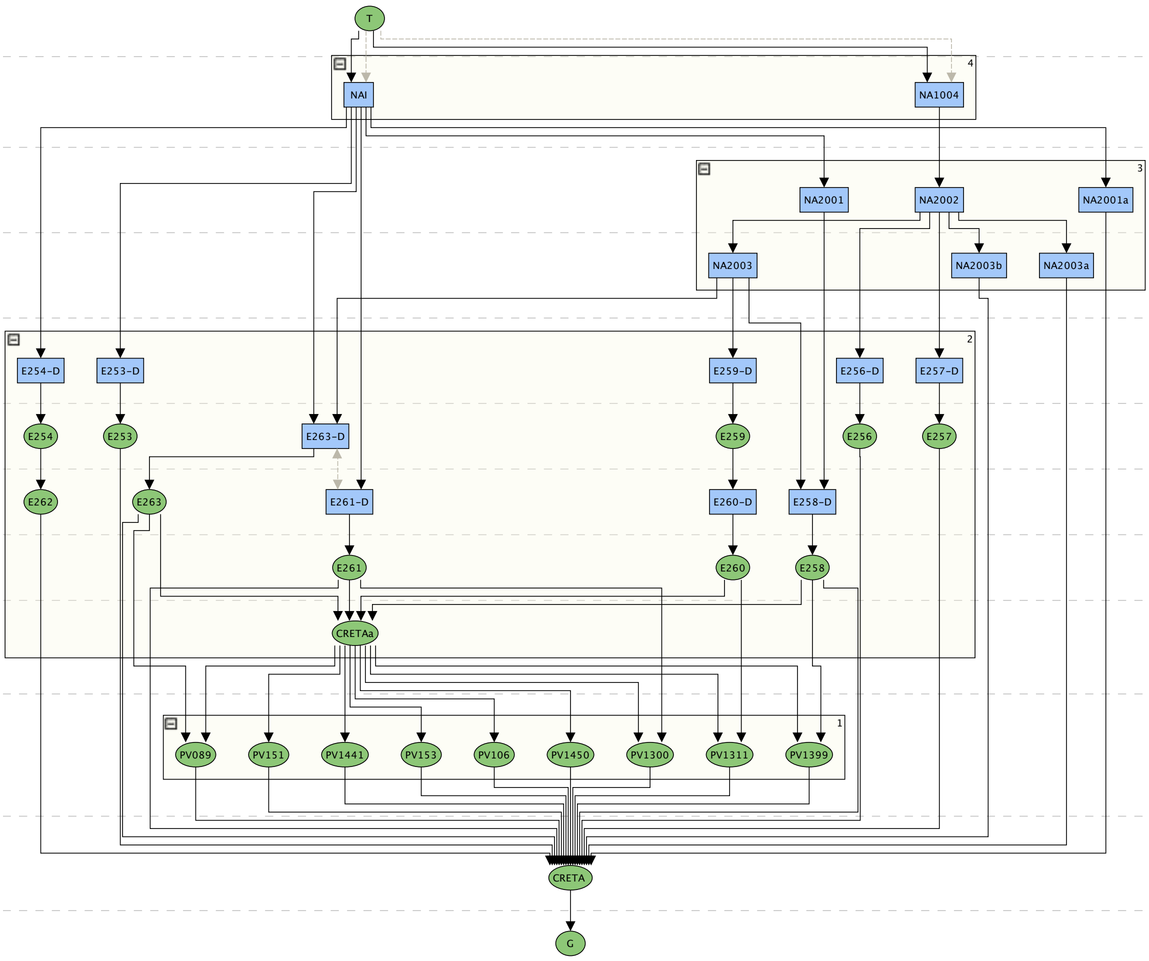


Figure 6.1. Harris Matrix diagram of sector A of the settlement of La Draga (edited with Harris Matrix Composer). The stratigraphic units are separated by grouped in four phases (HM diagram by *V. Andreaki*).

The second phase (*Phase 2*) in the diagram includes all stratigraphic units associated with the distribution of features or accumulations arranged with travertine slabs. Combustion features (hearths) are abundant in this stratigraphic phase, where about forty of them have been identified and present different morphologies. They are arranged with travertine slabs, sandstones or burnt pebbles, and preserve abundant charcoal, remains of the firewood used, and other remains such as bones. Furthermore, several negative constructions, defined by spatial arrangements of travertine slabs, with irregular forms and different dimensions have been identified. These differentiated structures are filled with large quantities of diverse archaeological material such as charred seeds, charcoal, animal bones, fragments of pottery, quartz, flint and bone tools, pieces of ornaments and grinding instruments.

Structures *E258*, *E261* and *E263* were studied in the present case and sampled for micromorphological analysis (Figures 6.2, 6.3, 6.4) (See *7.1*). These are located over former wooden postholes, confirming their arrangement and use after the original wooden constructions have been abandoned.

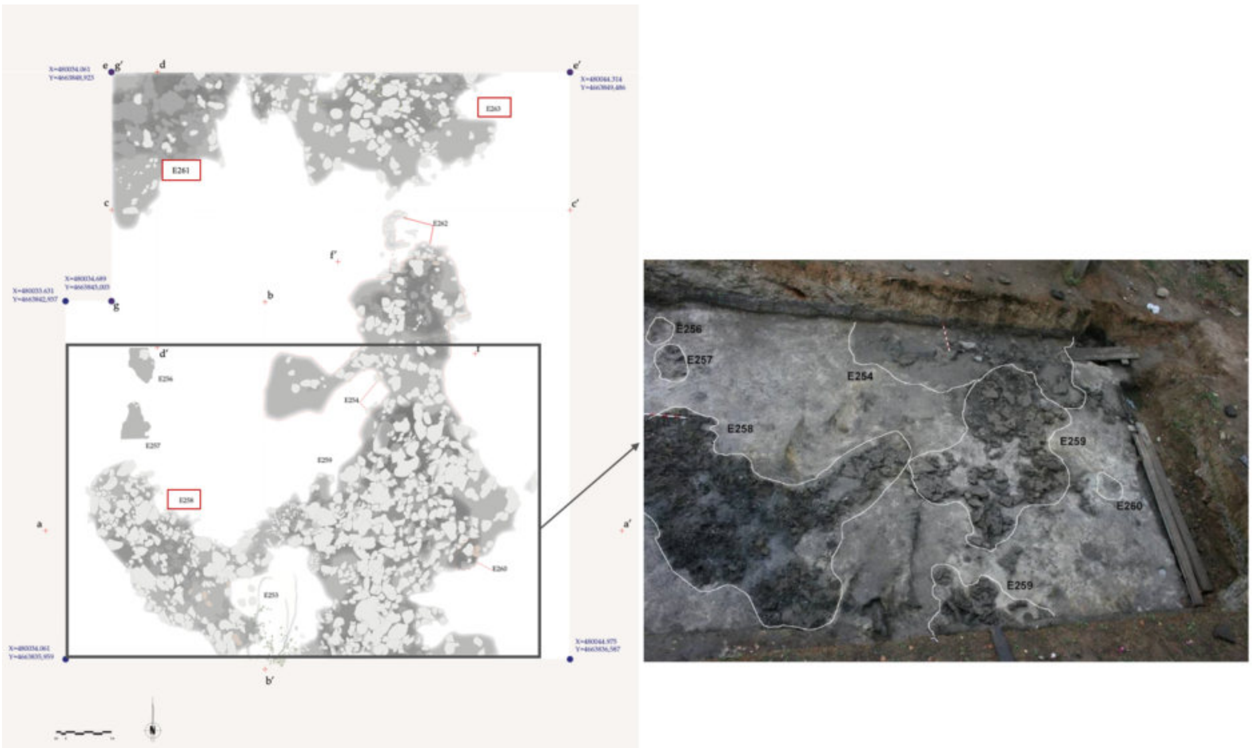


Figure 6.2. Vertical and horizontal view of the same plan of the combustion features *E254*, *E256*, *E257*, *E258*, *E259* and *E260*. *E261* and *E263* are only shown in the left plan (*Modified after Morera and Terradas 2017*). The alphabetical letters a-a´, b-b´, c-c´, d-d´, e-e´, f-f´and g-g´correspond to the drawn stratigraphic sections cutting through the features and represented in Figures 6.3. and 6.4.

The stratigraphic sequence from the bottom up is the following at this part of the settlement (Figure 6.4):

- ***E254:*** an irregularly shaped pit filled with a brownish grey sediment of clayey texture (total extension: 5.20 x 3.80m) and containing abundant archaeological material such ornamental objects. Among them, many representative remains of different stages within the manufacturing process of specific types of ornament –circular beads and, mainly, pendant-bead made of shell- have been attested.
- ***E260:*** small oval shaped arrangement of travertine slabs (75x54 cm), with a maximum thickness of 17 cm, found over the lake marl substrate. It is filled with a greyish clayey sediment and contains travertine slabs of different measurements between 5 and 30cm. The material recovered apart from the slabs, is characterized by an accumulation of faunal remains anatomically connected.
- ***E261:*** a big distinctive spatial unit (5.40x2.95m), with a basal depression dug into the lake marl substrate and a filling sediment and content like E258. The differentiated sedimentary sublayers have been distinguished depositionally (Figure 6.3). At its eastern side is in contact with structure E263, while inside the travertine enclosure there have been evidenced various concentrations of charcoal, giving the sediment its darkish color.

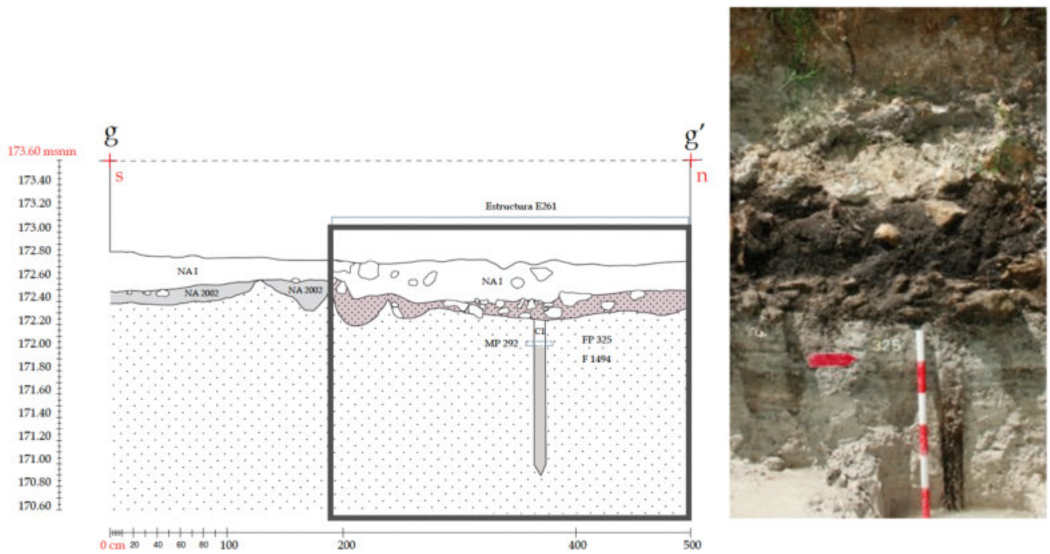


Figure 6.3. Stratigraphic sequence of structure E261(grey window) represented both in section (left) and in field (right) in Sector A. The sequence includes the posthole (FP325) and the wooden pile (F1494) found stuck in the lake marl substrate (*Modified after Rafa Rosillo;* Palomo *et al.* 2018).

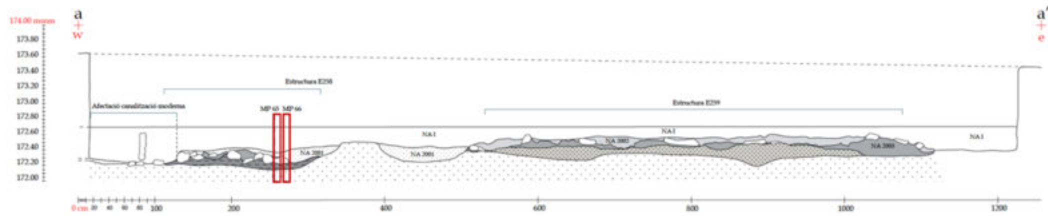
- ***E263**:* arrangement of travertine slabs, whose bottom part was dug into the lake marl substrate. Its sediment is organic of darkish colour, containing charcoals and a large amount of archaeological material, especially faunal remains. At its western side, meets with E261.
- ***E258**:* irregular oval shaped arrangement (5.10 x1.30 m) of different sized travertine slabs between 5 and 50cm. Although the structure is filled with a homogenous dark clayey sediment containing a big number of charcoals, sedimentary differentiation between the bottom and the top allows distinguishing two different moments in its construction and filling.
- ***E253, E259, E256*** and ***E257**:* The first two are travertine accumulations of irregular shape, including a clayey darkish sediment and charcoal remains. The remaining two are negative features, in the form of small pits found over the lake marl surface and covered by stratigraphic unit NA2002.

Stratigraphic *Phase 3* in Sector A is defined by travertine slabs covering the spatial units described in *Phase 2* (stratigraphic unit 2003 (*NA2003*)), and a clayey terrigenous sediment, containing a lot of clasts found in between the travertine slabs and over them (Stratigraphic unit 2002 (*NA2002*). These units can be explained as syn- and /or post-depositional of the travertine arranged features of *Phase 2*.

- ***2003- 2003b**:* travertine slabs covering the spatial units characterized as combustion features, pits, hearths and travertine accumulations below.
- ***2002**:* clayey terrigenous sediment, containing a lot of clasts found both in between the travertine slabs and over them. This layer bears scarce archaeological remains.

Phase 4 is consisted by a darkish brown sediment with some modern archaeological material, extending all over sector A (*NAI, NA1004*).

- ***1**:* a darkish brown sediment characterized by the intrusion of modern archaeological material, extending all over sector A.
- ***1004**:* a variation of the stratigraphic unit *NAI,* although more compact and less disturbed by modern archaeological remains.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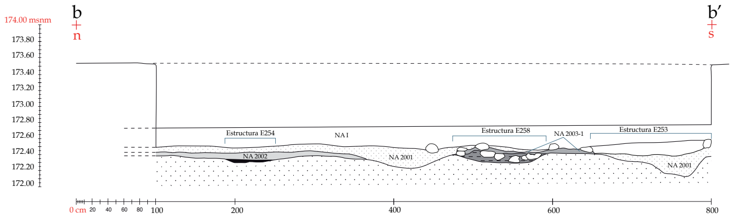
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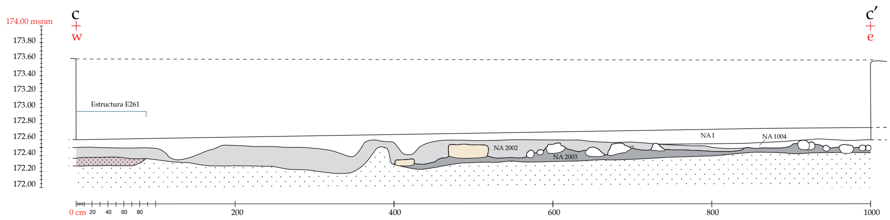
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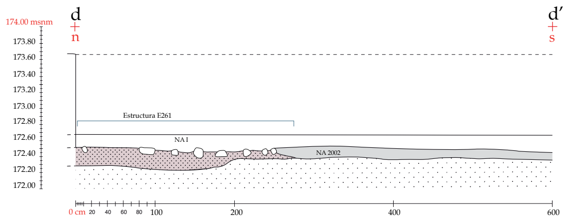
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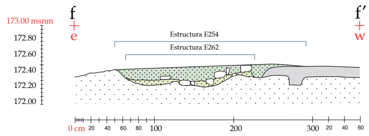
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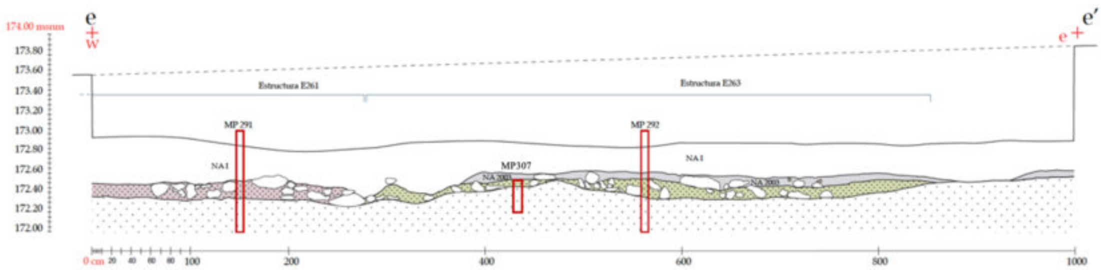
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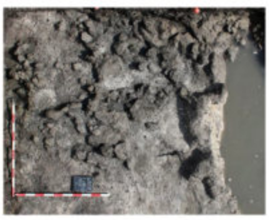

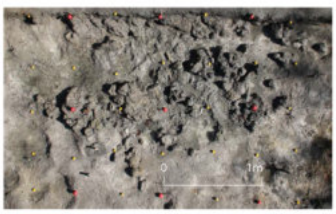
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Figure 6.4. Stratigraphic sections from sector A (plan view in Figure 6.2), with the stratigraphic units and structures in black (E258, E261, E263) and the columns of sediment sampled for micromorphological analysis in red (*MP65, MP66, MP291, MP292, MP307*) (*Modified after Rafa Rosillo*; Palomo *et al.* 2018).

Stratigraphic sequence A (1990-1995):

However, as it was mentioned previously the stratigraphic record at La Draga is not homogeneous. The general stratigraphic sequences of sectors A and B described before 2005 (Bosch *et al*. 2000; Bosch *et al*. 2006) are the following:

- ***Level I****:* A superficial layer consisted of compact brown soil, formed at a dry period when the water table of the lake would be lower. This layer has a capacity of approximately 30-40 cm. The post depositional processes of the settlement result really informative for the formation of this layer between wet and dry periods. Probably, this part of La Draga remained dry till the Benedictins' arrival at the 9th century AC, who by constructing the dock between the fields at southeastern zone of the lake, provoked the uplifting of the water table. Later, on 1850 when a new road was constructed surrounding the lake, a process of drying took place in order to keep away the water from the asphalt.
- ***Level II:*** a layer of compact peaty sediment consisted of vegetal remains result of a probable removal of the waters. This layer corresponds to the abandonment of the settlement during the earlier Neolithic period.
- ***Level III:*** stratigraphic unit with archaeological remain with a capacity of (15-20 cm) that was divided into two sublayers; ***IIIa*** corresponding to the abandonment layer and ***IIIb*** to the base layer of the archaeological level. These layers appear in both sectors A and B. In sector A, sublayer *IIIa* consists of darkish brown sediment, partially covered by travertine slabs. Aggregates from the peaty sediment of *level II* are also present. Layer *IIIb* consists of sandy greyish sediment characterized by the presence of numerous structures either negative (e.g., pits) or superposed directly over the lake marl surface.
- ***Level IV:*** lake marl substrate.

Layer *IIIa* corresponds to *NA2003-2003b,* while *IIIb* would be correlated with the identified hearths and negative features of later excavations (*E253-E259, E260, E261, E263*.

6.2. Stratigraphic sequence of Sector B-D

Sector B-D is closer to the lake. This is the sector found in the phreatic level, where water has helped maintaining anoxic conditions necessary for the preservation of the organic material. A more complete archaeological sequence of Sector D (Figures 6.6, 6.7), excavated more recently, is available than the contiguous Sector B, where archaeological excavations began in 1991. However, both sectors are studied as a unity due to their similarities in preservation conditions regarding the archaeological record. In this area of the site, below the actual phreatic level, the well preserved wooden vertical piles have been found stuck in the lake marl substrate (Figure 4.12). The stratigraphic sequence from the bottom up in sector D is presented below (Bosch *et al.* 2012; Terradas *et al.* 2013a; Palomo *et al.* 2014):

- ***VIII***: dark organic sediment found in some parts of the excavated sector over the lake marl surface. It is characterized by the presence of non-transformed non-carbonized organic material and contains a lot of leaves.
- ***VII***: dark grey sediment -with abundant and well-preserved wooden elements (tools, branches, twigs, leaves, horizontal wooden boards), associated to charcoals. *VII* is associated to the occupational debris of the wooden structures and at some parts of the sectors gets 30 cm thick. This sediment seems to be the consequence of little grade swamping due to constant seasonal lake level fluctuations and/or rise of the groundwater, which would have led to the precipitation of carbonate in the sediments and chemical alteration in situ during and /or after the occupation (See *Chapter 7.1*).
- ***7001***: accumulations of cereal grains found in between the wooden elements.

Layer *II* in sector B is called the stratigraphic unit used in older excavation campaigns (1997-2005) to describe the occupational debris found in sector D. It is characterized by two sublayers: a) a dark organic sediment 30 cm thick containing an accumulation of superposed wooden remains in contact with the lake marl surface and b) a dark greyish sediment full of organic remains containing various wooden structural remains (mostly horizontal boards). In general, layer II from sector B is correlated with *VII* in sector D.

In the corresponding Harris matrix diagram of this sector (Figure 6.5), the *in situ* preserved remains of wooden vertical piles (*PV600, PV605, PV738, PV607, PV986, PV584, PV582*) and the abovementioned stratigraphy units (*VIII, VII, 7001*) have been integrated into a structural stratigraphic *Phase 1*.

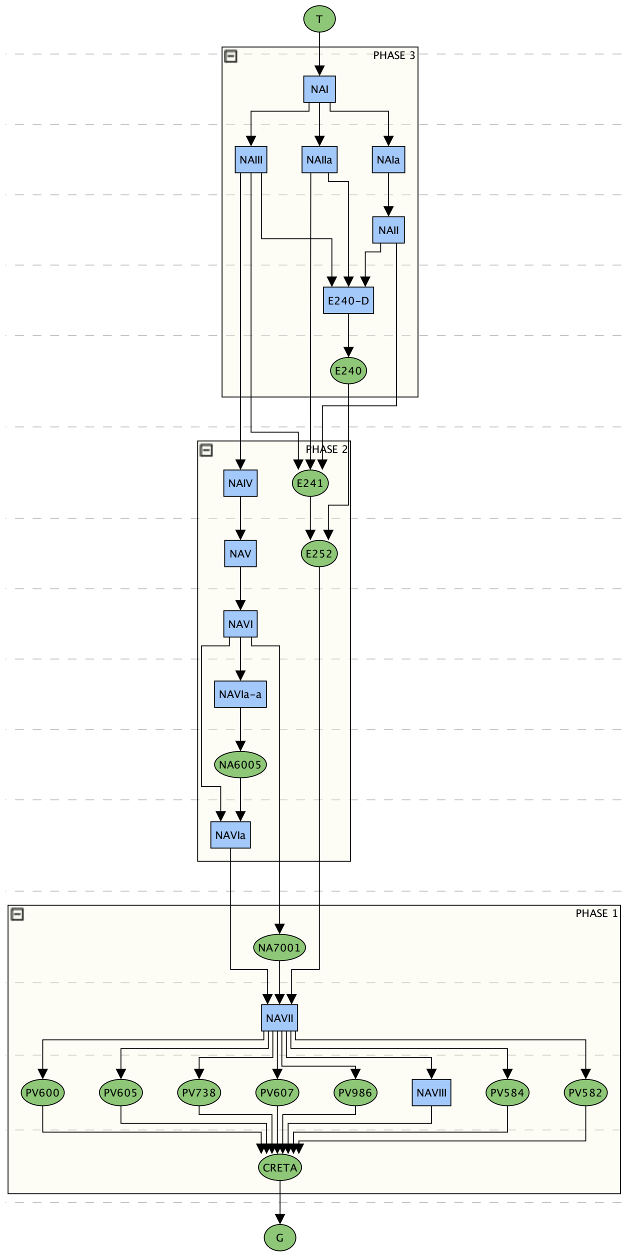


Figure 6.5. Harris Matrix diagram of sectors B-D of the settlement of La Draga (edited with Harris Matrix Composer). The stratigraphic units are separated by grouped in three phases. (HM diagram *by V. Andreaki*).

Phase 2 in the same diagram includes stratigraphic units characterized as pre-depositional/and or syn-depositional with the paved surface made from travertine slabs of various sizes. *VI-IV* are mostly composed by a sequence of clayey levels that include a layer of travertine blocks all over the excavated sector D (structure *E252*) with identified combustion structures over it (*E240*, *E249*).

- ***VI***: a clayey greyish sediment with anthropogenic organic remains, that extends all over the excavated sector immediately below the paved surface of travertine slabs (*E252*) and just above the preserved wooden elements from previous *Phase 1* (*VII*).
- ***VIa***: greyish clayey sediment containing some organic remains, covering the occupation debris of *VII*. It is found only in the southern part of this sector.
- ***6005***: Dark clayey sediment characterized by the presence of charcoal and charred seeds. Detected only in some parts of this sector.
- ***V***: greyish clayey sediment found right below the travertine slabs (*E252*). Ti contains no archaeological remains.
- ***E252*****:** corresponds to the travertine slabs defining an apparently paved surface.
- ***IV***: Greyish clayey sediment devoid of archaeological remains. It is found above and laterally of the travertine slabs. *IV* has the same consistency as *V*.

These sediments are of terrestrial origin, either from fluvial transport or from accumulation after torrential rains, and they deposited in a very short time interval covering the trenches and basins caused by ground surface subsidence. Those layers are composed mainly of clays, and they are very poor in archaeological material.

On the other side, at sector B the sublevel IIIa was representing various timber logs, situated right into the peat and some 20 cm above the great accumulation of timber logs of the sublevel IIIb. The former one, was situated into a stratum of dark crumbly soil containing a big number (30 cm of capacity) of timber logs superposed till the lacustrine chalk soil level.

Phase 3 includes the stratigraphic units characterized as syn-depositional and /or post-depositional of the paved surface. These are stratigraphic units *III, II* and ***I*.** The last two are mostly characterized by dark clay sediment with some light clay episodes among them. They also present surface disturbances caused by modern material and agricultural works (until 1989). *II* and *I* are clearly post-depositional events.

- ***III***: sandy greyish sediment containing fragmented travertine slabs and coinciding with the upper part of the paved surface (*E252*).
- ***II*** and ***I***: darkish sediment with decayed organic matter and scarce mixed archaeological material.
- ***IIa****:* a restricted area characterized by a peaty sediment of dark colour, with little presence of archaeological material and mostly consisted of decayed organic matter, whose inferior part is in contact with the travertine paved area.

The fact that the plant remains have only been preserved by carbonization, suggest that these more recent layers remained above the water table for most of their post-depositional history.

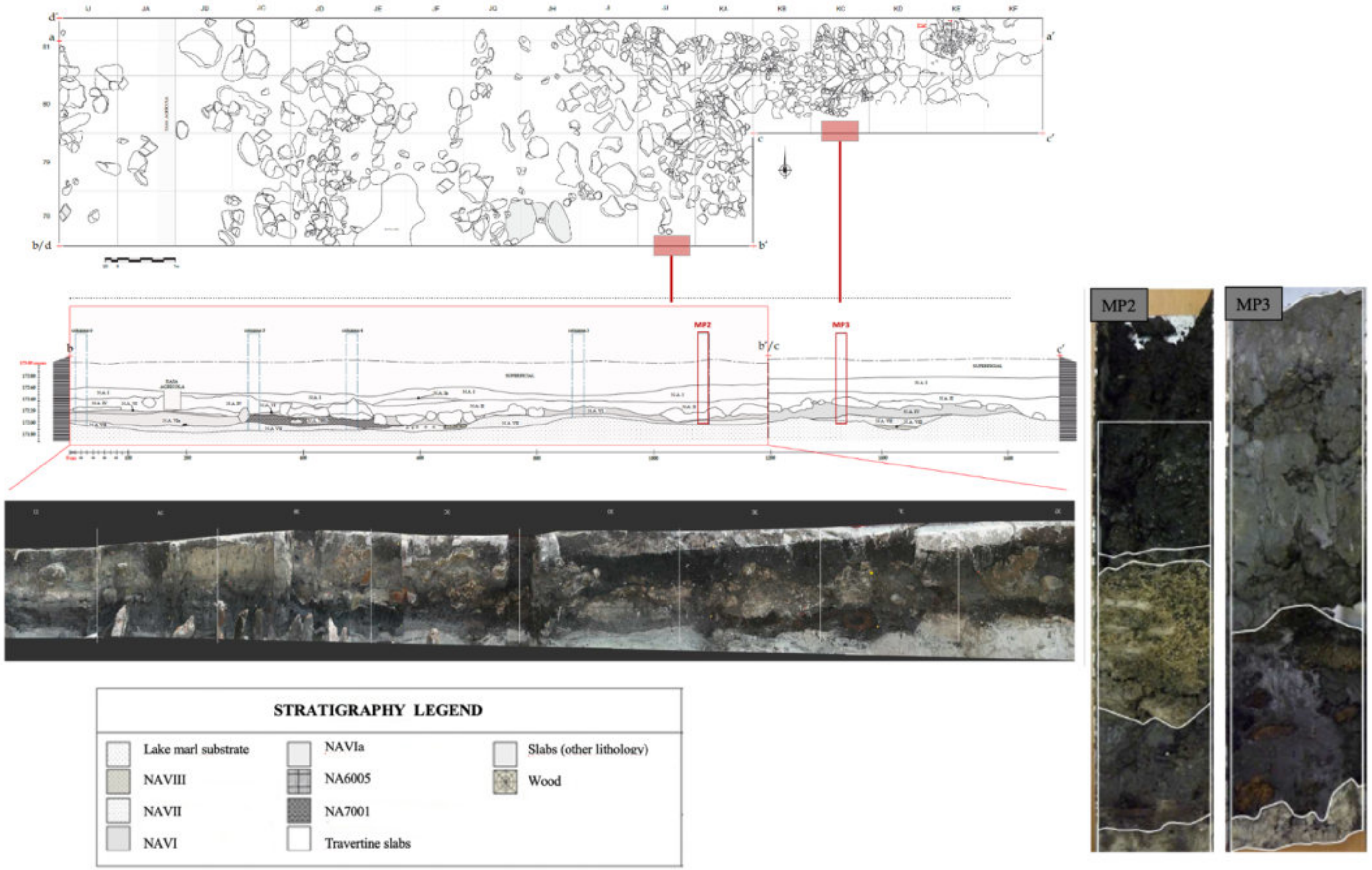


Figure 6.6. Southern section of sector D with the position of micromorphology samples in red color (*MP2, MP3; Modified after Balbo and Antolín 2013*) with stratigraphy legend on the bottom right (*Modified after Rafa Rosillo*; Terradas *et al.* 2013c).

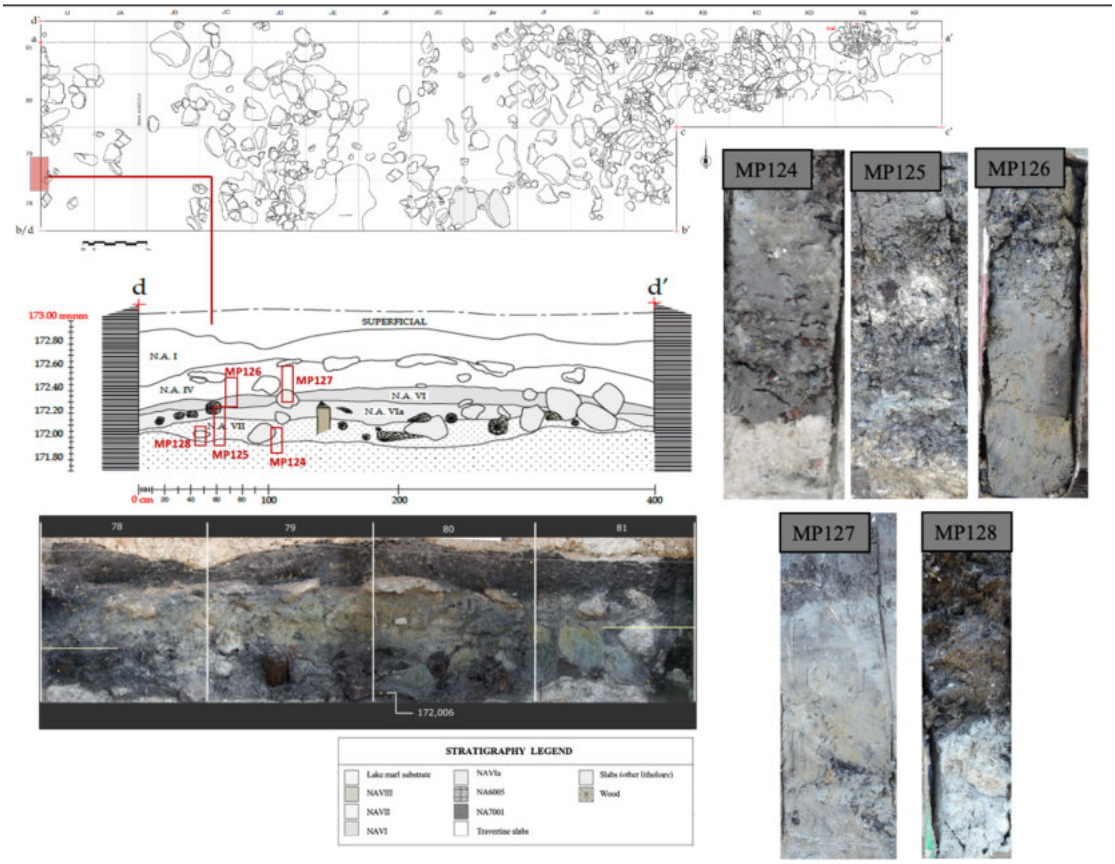


Figure 6.7. West stratigraphic section of sector D with the position of the samples for micromorphological analysis in red color (*MP124-MP128; Modified after Eneko Iriarte*) with stratigraphy legend on the bottom right (*Modified after Rafa Rosillo*; Terradas *et al.* 2013c).

6.3. Underwater Sector C

Sector C is found underwater in the limit of the actual lake shoreline, and as a result the stratigraphy may be affected by subsequent lake marl depositions, preceding and following the archaeological layers. The alteration between depositions of peat, carbonate sandy sediments and lake marl silt is usual in wetland sites (See *Chapter 3*). The stratigraphic sequence described during excavation is presented by the following units (Figure 6.8):

- ***12b***: sandy carbonated sediment.
- ***11b***: lake marl.
- ***10b***: in close contact with the lake marl surface (*11b*) approximately 15cm thick, including anthropogenic remains such as charcoals, fauna, charred seeds,

pottery and flint. Wooden remains in the form of branches, sticks and bark are also present.

- ***9b***: fragments of travertine slabs embedded in a compact sandy deposit, alongside with non-anthropically transformed vegetal remains and other archaeological material. This deposit has an approximate thickness of 30 cm.
- ***8b***: peaty aggregates in a greyish sandy carbonated sediment.
- ***7b***: silty sediment of lake marl containing organic matter.
- ***6b***: sandy carbonated sediment.
- ***5b***: peaty sediment.
- ***4b***: sandy carbonated sediment.
- ***3b***: peaty sediment.
- ***2b***: creta/arrels. Sandy carbonated sediment including a lot of snails.

The anthropically affected sediments are concentrated at the bottom part of the section, represented by units 10b and 9b in the stratigraphic section (Figure 6.8). These would correspond to the occupational phases detected in the rest of the settlement. Further micromorphological analysis has been implemented to enhance the reliability of stratigraphic observations (See *Chapter 7*).

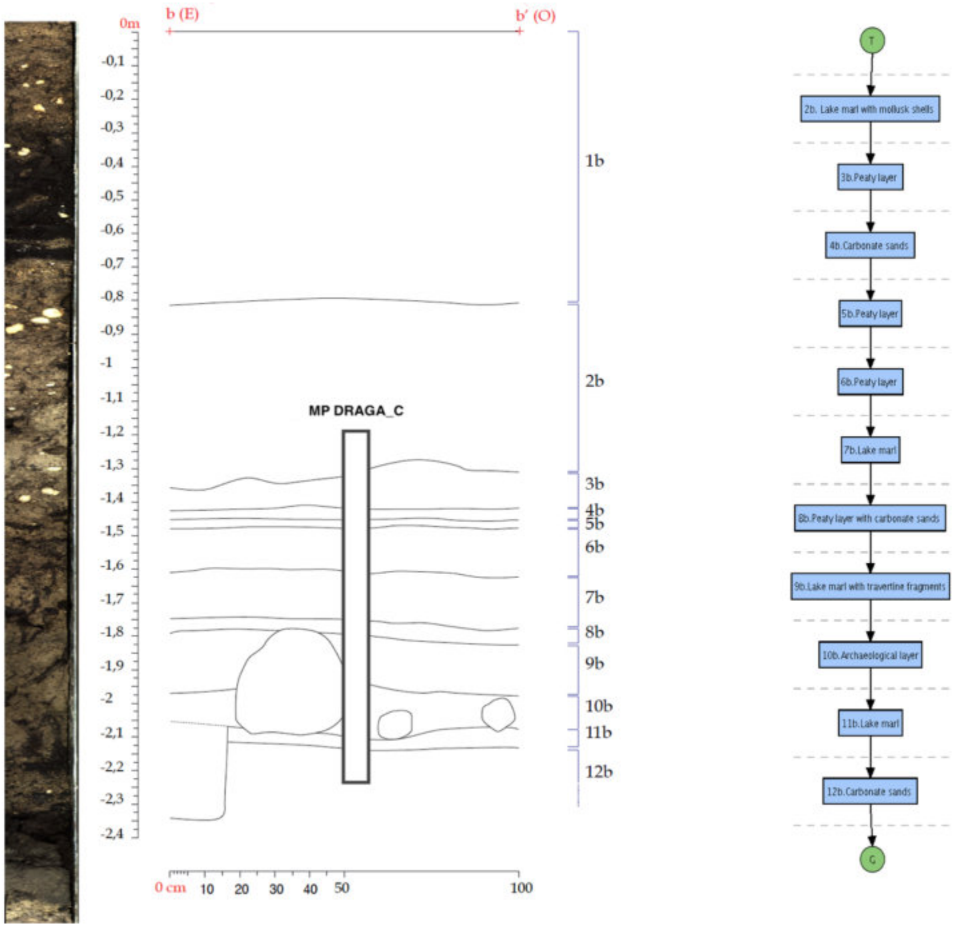


Figure 6.8. Stratigraphic section from the underwater sector C. On the left, the core of sediments MP DRAGA_C, extracted in 2017 for micromorphological analysis (See *Chapter 7*) (Stratigraphic section modifies after *Rafa Rosillo*). On the right, the Harris Matrix diagram (edited in Harris Matrix Composer) of the identified units in sector C (HM diagram *by V. Andreaki*).

7. MICROMORPHOLOGICAL ANALYSIS OF SOILS AND SEDIMENTS AT LA DRAGA

In this chapter the results of the micromorphological analysis of the excavated sectors A, D and C of the lacustrine settlement of La Draga are presented.

The data from sectors A and D are integrated in the presentation while sector C is presented separately for the purposes of this analysis. Nonetheless, all three sectors share common microfacies types and conclusions as well as interpretation were based on the correlation between all of them. Sectors A and D share almost the same amount of microfacies types and their repetition is informative on possible use of space and detection of anthropogenic activity surfaces. Furthermore, they are both affected by lake-level fluctuations, although they are located further inland from the actual shoreline.

Regarding sector C, separate presentation of the results of micromorphological analysis was based on various factors. First, the sampling strategy although scarce for all sectors, has been comparatively more intensive on sectors A and D than in sector C. Given the underwater condition of the stratigraphic sequence of the latter, samples of sediments for micromorphological analysis were never taken before. As a result, sector C is underrepresented in comparison with the other sectors. Moreover, given that it is found under the water table the sequence is mostly affected by alternating lake marl depositions. Water table fluctuations and minor wave activity also affect syn-depositionally the sequence. Consequently, the input gained on lacustrine sedimentation is greater in this sector.

7.1. Sectors A and D under the microscope

From sector A, travertine associated features *E258* (MP65, MP66), *E261* (MP291) and *E263* (MP292) have been sampled (Figures 6.2, 6.3, 6.4), as well as sediments below these features (MP307; Figure 6.4). A column from the eastern section of this sector (MP318) was also sampled in order to give an idea of the depositional processes outside of the structures in sector A (Figure 7.1). In sector D, samples were retrieved by the western (MP124-MP128) and southern sections (MP2, MP3) of the sector (Figures 6.6, 6.7). Sampling strategy is further explained in *Chapter 5.1.1*, while all sediment samples for micromorphological analysis are gathered in Table 5.1.

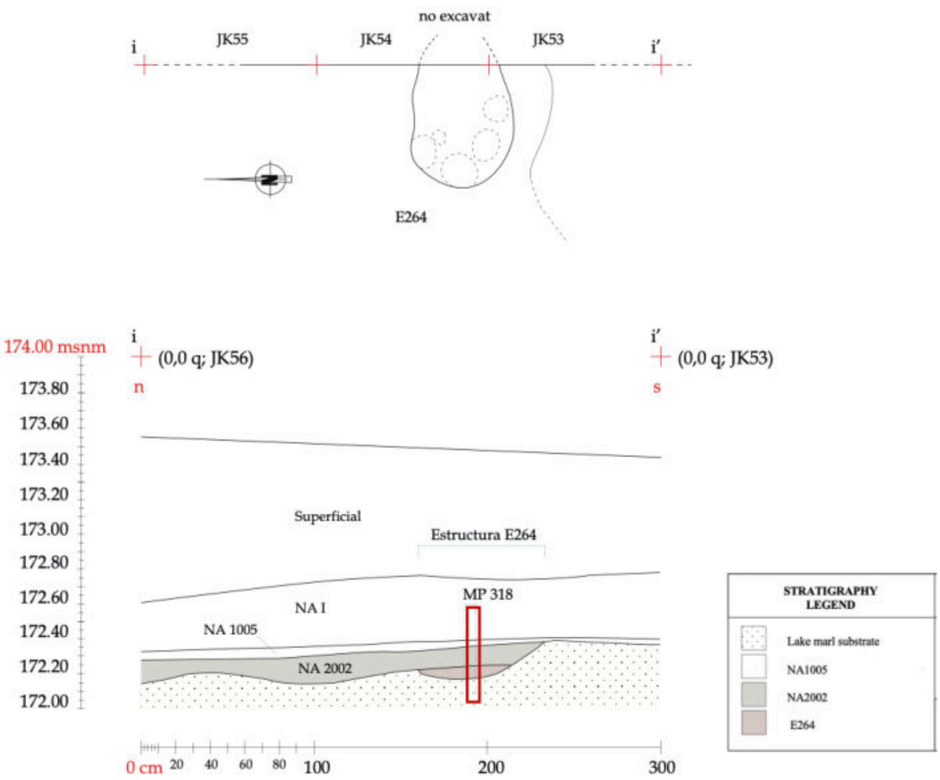


Figure 7.1. Stratigraphic section respresenting the column MP318 sampled for micromorphological analysis in sector A (*Modified after Rafa Rosillo*).

Following the stratigraphic analysis of the excavated sectors at the settlement (*Chapter 6*), microfacies types were defined for each unit according to its constituents on a microscopic level, in order to distinguish it from the rest. Macroscopic units identified during excavation were used as guidelines for the preliminary observation of the microfacies under the microscope. Each microfacies type is distinct from the rest based on a series of features observed under the microscope, such as the microstructure of the sediment and /or soil, the coarse mineral, and coarse organic and anthropogenic materials, as well as any noticeable pedofeatures. To sum up, a brief sedimentary description based on the micromorphological observations and the columns sampled in each sector are cross-referenced with the stratigraphic units identified on the field (Tables 7.1, 7.2). The sequence of thin sections used for these table comes from samples MP318 (sector A) and MP2 (sector D).

Table 7.1. Thin sections retrieved from sample MP318 (sector A) showing the microstratigraphy and its correspondence to the occupational phases and the archaeological layers recognized in the field. Sample MP318 is just an example of the correlation between macroscopic units and their view under the microscope.

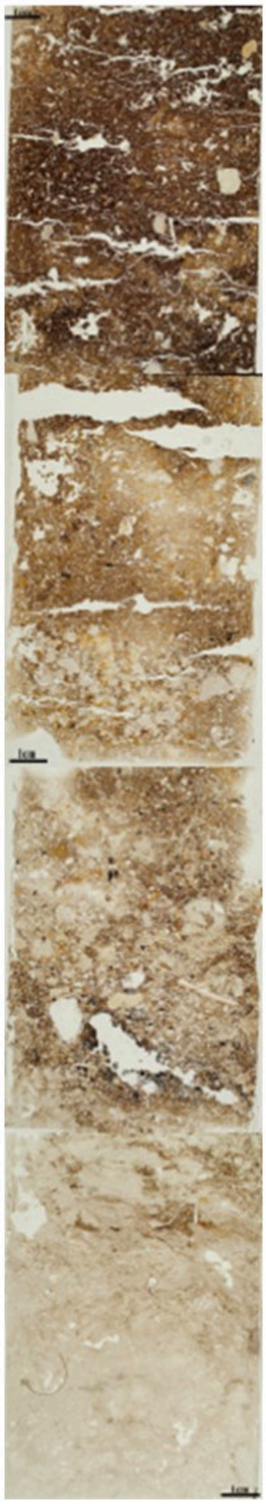
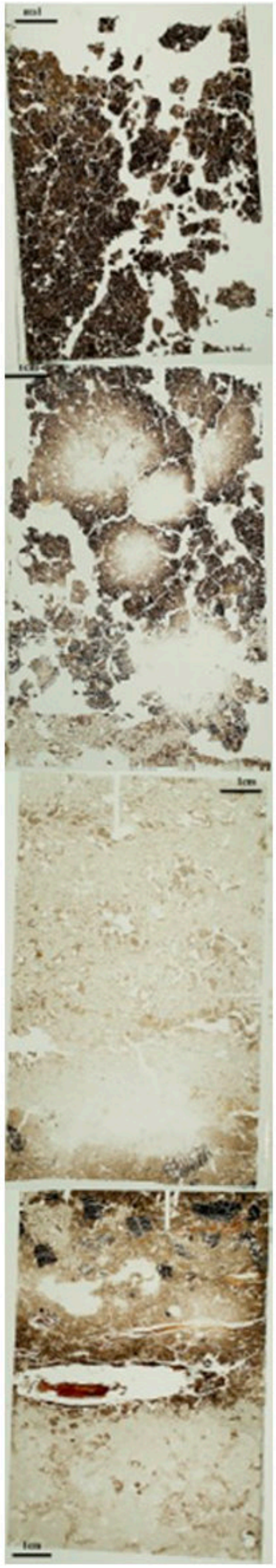
Stratigraphic Unit	Macroscopic Description	Sector	Sample (MP)	Phase	Micro-Stratigraphic Section
I	Peaty sediment with mixed modern archaeological material	A	MP318	Post-Occupational	
2001	Green clayey organic-rich sediment with terrigenous input	A	MP318	Post-Occupational	
2002	Green clayey sediment of terrigenous origin with little archaeological material covering the travertine structures	A	MP318	Synchronic or /and posterior of the Neolithic occupation	
2003	Extended travertine emplacement with embedded terrigenous sediment	A	MP318	Synchronic or/and posterior of the Neolithic occupation	
E258	Darkish clayey sediment mixed with travertine flagstone remains	A	MP65 MP66	Neolithic occupation- 2nd occupational phase	
E261	Darkish clayey sediment and travertine flagstone remains	A	MP291	Neolithic occupation- 2nd occupational phase	
E263	Darkish clayey sediment and travertine flagstones	A	MP292	Neolithic occupation- 2nd occupational phase	
IX	Lake marl substrate	A	MP65 MP307 MP318 MP291 MP292	Pre-occupational	

Table 7.2. Same as Table 7.1. for sample MP2 (sector D) (*Photo of thin sections modified after Andrea Balbo*).

Stratigraphic Unit	Macroscopic Description	Sector	Sample (MP)	Phase	Micro-Stratigraphic Section
I	Peaty layer formed by decomposed organic matter	D	MP2	Post-Occupational	
II	Compact peaty layer of darkish color. Base of peaty layer I	D	MP2	Post-Occupational	
III	Grey organic-rich sandy sediment with embedded travertine slabs	D	MP2 MP3	Post-Occupational	
IV	Greyish organic-rich terrigenous clay with no archaeological remains covering the travertine pavement	D	MP3	Neolithic occupation- 2nd occupational phase	
VI	Travertine pavement with greyish organic-rich terrigenous clay infillings	D	MP2 MP3	Neolithic occupation- 2nd occupational phase	
7001	Assemblage of charcoal and charred seeds	D	MP3	Neolithic occupation- 1st occupational phase	
VIa	Dark grey clay rich with charred matter over collapsed wooden structures	D	MP2 MP3	Neolithic occupation- 1st occupational phase	
VII	Organic-rich clayey sediment with waterlogged wooden elements	D	MP2 MP3	Neolithic occupation – 1st occupational phase	
IX	Lake marl substrate	D	MP2 MP3	Pre-occupational	

7.1.1. Sedimentary Microfacies Description

The sequence of microfacies types[20] (*MFTs*) present in both sectors is presented below:

Microfacies A

This type of microfacies refers to the limnic sediments that served as ground for the construction of the wooden platforms and is visible in the field as the lake marl substrate (Figure 7.2.a). It has the typical white color due to concentration of calcium carbonate and a rather compact nature. Its groundmass is rather homogeneous and voidless, although some occasional vughs and voids are present. Under the microscope, it has a greyish color and a massive microstructure. It has a calcitic crystallitic b-fabric which is cloudy due to the high amount of micritic calcite crystals. The presence of oogonia and charophyte algae as well as framboidal pyrite are characteristic features (Figure 7.3.a-d).

In sector D, clean lacustrine deposits include fragmented shells as well as shells in living position. The microstructure is massive to locally almost spongy due to bioturbation (Figure 7.6.a), which moves sediment downwards (Figure 7.2.e). Pelletal biogenic excrements are most probably originated by charophyte algae (Figure 7.6.a). This microfacies is the common ground for all the samples retrieved from the settlement of La Draga. Neoformed material such as gypsum crystal intergrowths is present in the contact of microfacies *A* with microfacies *C* (Figure 7.3.i, j).

Microfacies A_1

A local variation of microfacies *A* is A_1. This is represented by a layer of lake marl with signs of exposure and embedded anthropogenic material, found between the lake marl substrate and the occupational levels of structure E258 (Figure 7.3. e, f). However, microfacies A_1 is only visible in the case of structure E258 (Appendix I). In the rest of the excavated sectors, the transition from the lake marl to the occupational level is sharp, without intermediate transition layer.

Microfacies B

[20] Microfacies types may be also present in text by the acronym MFT followed by a capital letter of the alphabet corresponding to the microfacies type (e.g., *MFT-A* is the same as *Microfacies A*).

This microfacies describes lake marl with evidence of exposure and influence by terrigenous sediments input (Figure 7.2.b). Under the microscope, they are detected in the form of root burrowing and yellow clay staining with embedded micro-contrasted particles of charcoal. It maintains the calcitic crystallitic b-fabric of lake marl, but it presents some yellowish-brown staining in the gray groundmass, due to moderate iron content and probably some humus. These features are associated with the input of sand silt grains of rounded quartz. The groundmass of the terrigenous clastic sediment is heterogeneous with typical massive microstructure and porphyric related distribution. In the sample MP318-2 (Appendix I), the clastic component presents characteristic laminations (Figure 7.3.g, h), showing this fluctuation zone movement under a low water table.

Microfacies C

This microfacies is characteristic of what is called the occupational level in all sectors (Figure 7.2.c, d). It is differentiated from previous microfacies types due to the accumulation of anthropogenic and organic material (Figure 7.4.a-d). Macroscopically, it appears as the filling of the travertine structures in sector A (MP65, MP291, MP292, Appendix I) and includes concentrations of charcoal, ash (Figure 7.4.g, h), burnt and unburnt fauna remains and associated archaeological artefacts (MP307, MP318, Appendix I). The sediment's color is yellowish brown due to moderate iron and humus content, and the groundmass is heterogeneous, including mixed material such as charcoal, roots and bones, as well as a lot of sandy mineral grains and a silt component. It has a massive microstructure, probably caused by trampling effects. In MP318-5 (Appendix I), microfacies *C* consists of terrigenous sediment with mixed anthropogenic and organic material. There is a significant input of clasts and alongside with the sediment orientation, it seems like a sheet wash episode, introducing allochthonous material. The input of clay is also higher with signs of human trampling. It probably represents a transition layer related to the abandonment of the area, in sector A.

Microfacies C_1

A local variation of Microfacies *C* is C_1. This is characterized by deformed lenses of laminated terrigenous sediment and a sediment with a high carbonate content due to the presence of ashes. C_1 has the same microstructure and crystallitic fabric as Microfacies *C*, although it is found only in one sample from structure *E258*. It's still part of the occupation level but seems to have been pushed downwards perhaps by trampling or poaching under wet conditions (Figure 7.4.i, j).

Microfacies C_2

Microfacies type *C_2*, corresponds to the occupational level associated with wooden structures (wooden bark lying directly on the lake marl) and is preserved in waterlogged conditions, only in sector D (Figure 7.2.e, Figure 7.6.c, d). It maintains a very compacted massive microstructure with few voids and vughs and the sediment is of darker brownish color due to the decay of organic matter. Collapsed structure of the sediment attests for exposure to moisture and slaking conditions due to deposition under water.

In MP3-8 (Appendix II), stratigraphic unit *VIII* is characterized by a dark clay sediment with three distinct layers of waterlogged wooden elements, mostly twigs and branches in horizontal position. A pottery fragment is resting directly on the lake marl (MP3-8, Appendix II), while embedded in wooden remains of unit *VIII*. The pottery sherd is consisted by coarse semi-angular and angular clasts with very little quantity of clay. Sediment from the *VIII* unit (*MFT-C_2*) is embedded into the lake marl (*MFT-A*) and shows evidence of downwards pressure (Figure 7.6.b).

Microfacies D

Massive carbonate with signs of *in situ* chemical formation probably from running water or lake precipitation and /or groundwater springs. Upward and lateral movements of groundwaters rich in dissolved calcium carbonate are known to induce the precipitation of sparite that cements plants, sediments or soils. It is associated with terrigenous clastic sediment and anthropogenic material (Figure 7.5.a).

This microfacies type is macroscopically identified by the arrangement of travertine slabs in the studied structures in sector A and the travertine paved surface in sector D (Figure 7.2.f). They are identified as the construction material of these structures, while on the other side, microfacies *C* is representing the sediment filling them. However, both *C* and *D* microfacies are identified as part of the same occupation level. Travertine is a local stone in La Draga, and in the samples recovered from sector A seems to be in association with little or no sediment and the characteristic plant-pseudomorphic shape of their voids. Calcite/carbonate hypocoatings reveal the travertine slabs have been exposed. Overall, the microstructure is massive and vesicular, consisted by close vughy vesicles and compound packing voids. The fine fabric of the sediment is brownish gray (PPL) with some fine and coarse inclusions of charcoal while the coarse anthropogenic material includes charcoal, burnt plant fibers and roots. The presence of ashes under XPL is associated to a calcitic crystallitic b-fabric. Some of the pedofeatures observed, include humic staining from the sediments under the travertine blocks, organic staining from the charcoal as well as depletion and regrowth of some root voids.

Microfacies D_1 is a variation of this microfacies found in the samples from structures E258 and E263. It is consisted by fine travertine sand fragments organized in a slightly inclined horizontal direction, usually with no associated sediment or anthropogenic material embedded (MP65-2, MP292-M, Appendix I).

Microfacies E

It is consistent with a layer of mixed material covering the travertine structures throughout all the excavated sectors in La Draga (Figure 7.2.g). Under plane polarized light (PPL) the groundmass is dark brown (humus), while under oblique incident light (OIL) its color is dark reddish brown (iron content). Its birefringence is dusty, speckled and dotted with very fine, fine and coarse inclusions and the fabric is crystallitic. It is heterogeneous with massive microstructure with a few voids, fissures (vertical and horizontal), planes and channels and open porphyric related distribution. The finer mineral material dominates the sediment, including clayey sand, micrite fragments and fragmented quartz grains. The coarser organic and anthropogenic materials consist mainly of charcoal, shells, bone and roots. The whole sediment is full of organic matter and is characterized by strong compaction (Figure 7.5.e). Nonetheless, the sediment seems to be of natural origin and posteriorly deformed by human or animal trampling. Aggregates of calcium carbonate associated with iron staining of the groundmass indicate the occasional water presence during the gradual formation of this sediment in sector A (Figure 7.5.c). The creation of layering due to the separation of coarser sand grains from finer material that is later deformed by trampling is usually common in water-saturated sediments according to Karkanas (Karkanas 2018). Other pedofeatures present include clay coatings and weathered quartz grains.

So far, the described microfacies are observed in Sector A and are the result of anthropogenic deformation of naturally transported materials. The following microfacies are observed in sector D.

Microfacies E_1

In sector D, a grey yellow sediment is formed naturally under seasonally dry and /or exposed conditions (cracking features indicate exposure). The transition is clear between a layer of carbonized material including charcoal and seeds (*MFT-F*) and the sediment associated to microfacies type E_1 (Figure 7.2.j). Segregation of calcite near the top of the layer is evidence of weathering and seasonal exposure under dry conditions. Nonetheless, the grey, yellow sediment with moderately separated angular blocky microstructure is formed in a palustrine environment, as the sediment is coarser grained mixed with travertine fragments, indicating the influence of running water.

Microfacies F

This type is present in sector D and corresponds to a charcoal layer (*Quercus sp. deciduous*) with little sediment embedded (Figure 7.2.k). It is found over the travertine pavement and can be associated with burning in a dry environment (Figure 7.7.a-f).

Microfacies G

Darkish sediment with decayed organic matter and *in situ* embedded oogonia (Figure 7.2.i). Corresponds to a peaty sediment of strong compaction, formed gradually under wet conditions in sector D. Compaction of the originally soft organic peat material is probably due to the overburden material that is usually observed in similar sediment in lacustrine environments.

Signs of inwash of terrigenous deposit into the peaty layer are present, while embedded, slightly fractured molluscs are associated with the transportation of mineral clasts into the peat (Figure 7.6.h).

When lake levels are high for a long period of time, anoxia is providing the right conditions for the peat deposit to grow thicker. On the contrary, in the case of Sector D the peaty deposit is formed gradually under seasonally changing water levels and, as a result, occasional exposure to oxygen (Bleicher and Schubert 2015).

Microfacies H

This microfacies describes a hummus rich groundmass with inclusions of charcoal in sector D (Figure 7.2.h, MP2-2, Appendix II). It is a compacted sediment of darkish brown color, poorly mixed locally with the peaty layer above it (Figure 7.6.g).

Microfacies I

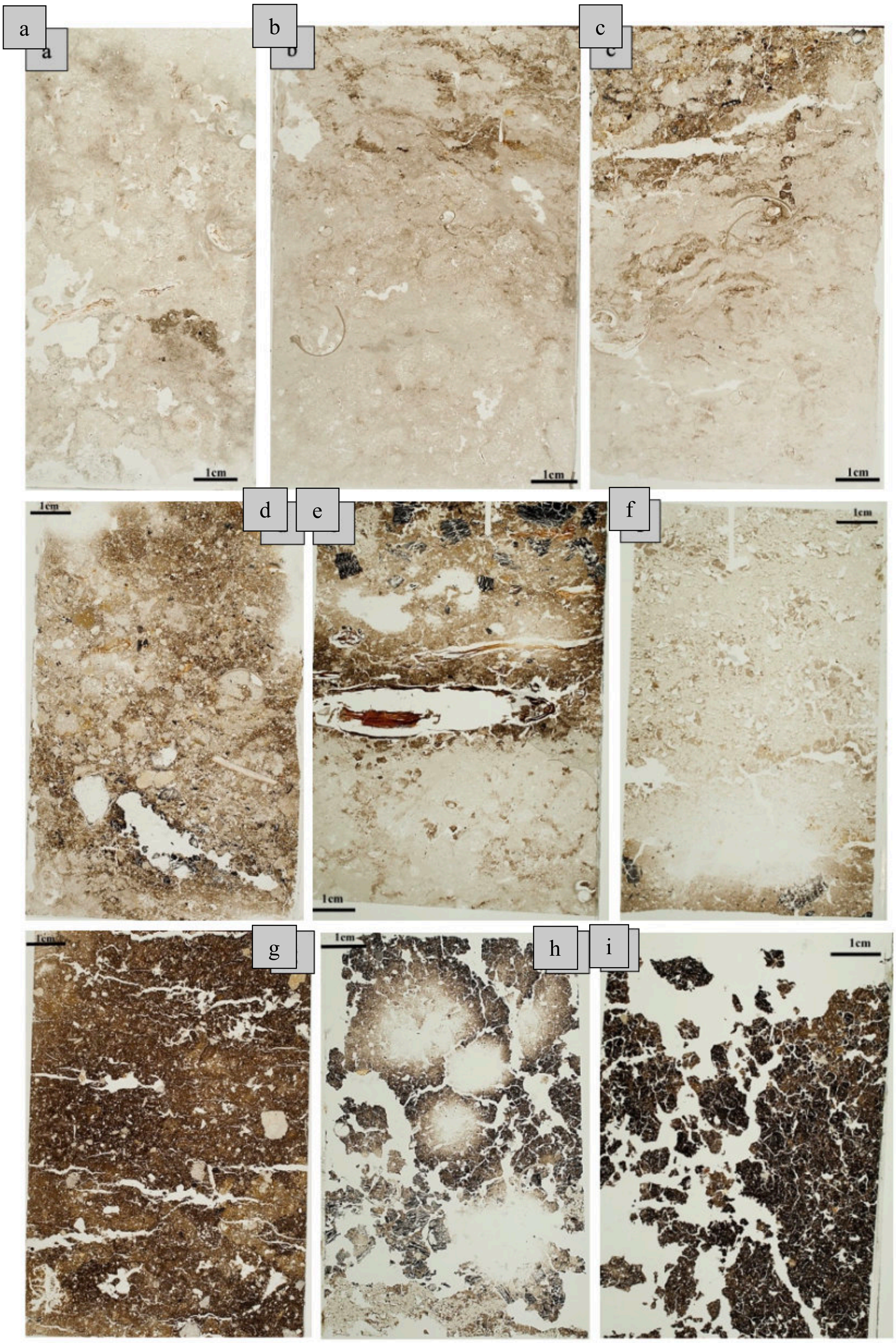
That corresponds to a dark grey sediment consisted by aggregates of ash and clay found on the upper part of MP3-5/6 (Appendix II), in sector D.

A table was made based on the summarized description of the microfacies present in sectors A and D resulting from the micromorphological analysis of sediments as well as a brief interpretation of the microfeatures of each microfacies (Table 7.3).

Table 7.3. Micromorphological description of microfacies types at Sectors A and D, La Draga.

Microfacies	Micromorphological description	Interpretation
A	Lake marl sediment with massive microstructure and high carbonate content. *In situ* underwater bioturbation. Presence of charophyte algae and framboidal pyrite. Calcitic crystallitic b-fabric.	Natural lake marl
A_1	Lake marl, same as above. More embedded anthropogenic material in the form of mollusk shells, roots, charcoal and rounded quartz grains. Excrement as infilling of root and presence of calcite crystals.	Fluctuation zone. Shallow water
B	Heterogeneous sediment of terrigenous origin with massive microstructure and porphyric related distribution. Mollusks and roots. Clay staining related to aerial exposure or decay effects. Yellow brown color due to humus content. Crystallitic b-fabric.	Gradual emersion. Terrigenous sediment embedded in lake marl
C	Heterogeneous sediment with massive microstructure and open porphyric related distribution. Anthropogenic and organic material and quartz grains. Humic-iron staining and some secondary carbonate around voids. Crystallitic b-fabric.	Sediment filling the structures. Occupation level, affected and compacted by direct or indirect trampling
C_1	Laminated terrigenous sediment with ashy remains. Presence of organic matter and micro-contrasted particles of charcoal. Crystallitic b-fabric.	Aggregate of sediment coming from the occupation level with downward inclination maybe by trampling under wet conditions (Sector A)
C_2	Terrigenous sediment of brownish color with decayed organic matter and charcoal inclusions. Massive microstructure with few vughs and voids. Signs of trampling and slaking.	Occupation level associated with the construction of wooden structures. Deposition under water (Sectors D, C)
D	Travertine fragments of calcium carbonate in various sizes with massive microstructure and plant- pseudomorphic voids. Little or no sediment associated. Crystallitic b-fabric.	Travertine fragments covering or surrounding the layers of occupation
D_1	Travertine sand horizontally arranged. Crystallitic b-fabric.	Layer of finer travertine sand intentionally deposited
E	Dark brownish sediment of humic content with large quantities of organic matter. Undifferentiated b-fabric.	Mudflat. Sedimentation because of naturally transported material under occasional water influence. Contains mixed anthropogenic material (Sector A)
E_1	Grey, yellow heterogenous sediment with moderately separated angular blocky microstructure with coarse mineral and anthropogenic material. Travertine fragments embedded. Crystallitic b-fabric with medium to low interference colors due to obscuration by organic matter or charcoal.	Mudflat. Palustrine environment. Segregation of calcite because of weathering under seasonally dry conditions. Water influence near the top of the sediment (Sector D)
F	Charcoal-rich layer with little or no sediment associated	Burning or fire episode over the travertine pavement (sector D)
G	Bioturbated peaty sediment with decayed organic matter and terrigenous sediment embedded	Peat formation under wet conditions
H	Compacted brownish sediment with clay input and clasts from hinterland. Characteristic laminations of sheet wash origin	Sheet wash transporting allochthonous sediment (sector A)

H_1	High humus content in darkish brown humus-rich sediment	Abandonment layer (sector D)
I	Dark grey sediment with embedded ash and clay aggregates	Layer of possible insulation under the travertine pavement. Under wet conditions (Sector D)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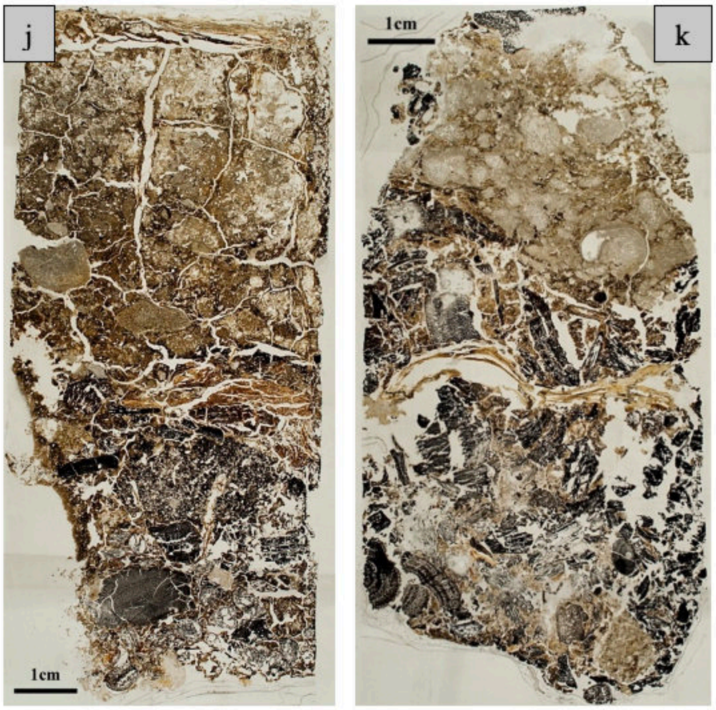


Figure 7.2. Microfacies types in thin sections from sectors A (Appendix I) and D (Appendix II). **a)** MFT-*A*, silty carbonate muds (lake marl) above the structures. MP307-1, sector A. **b)** Transition from lake marl (MFT-*A*) to lake marl with terrigenous sediment embedded (MFT-*B*). Note the laminations at the upper right part of the thin section. MP318-3, sector A**. c)** Transition from MFT-*B* to the heterogeneous sediment associated to occupation (MFT-*C*) at the upper part of the TS. MP318-2, sector A**. d)** MFT-*C* .MP318-4, sector A. **e)** Transition from MFT-*A* to the first archaeological layer associated to wooden platforms (MFT-*C2*), MP2-4, sector D. **f)** Carbonate groundmass of a travertine paved surface (MFT-*D*), MP2-3, sector D. **g)** Heterogeneous peaty sediment including clasts and organic material (MFT-*E*), MP318-6, sector A. **h)** Heterogeneous humus-rich sediment (MFT-*H*), MP2-2, sector D. **i)** Peaty sediment with decayed organic matter (MFT-*G*), MP2-1, sector D. **j)** Heterogeneous grey yellow sediment with angular blocky microstructure (MFT- *E1*) at the middle upper part of the thin section, MP125, sector D. **k)** MFT-*F* including charred material (*Quercus sp. deciduous*) at the middle bottom part of the thin section, MP126-2, sector D.

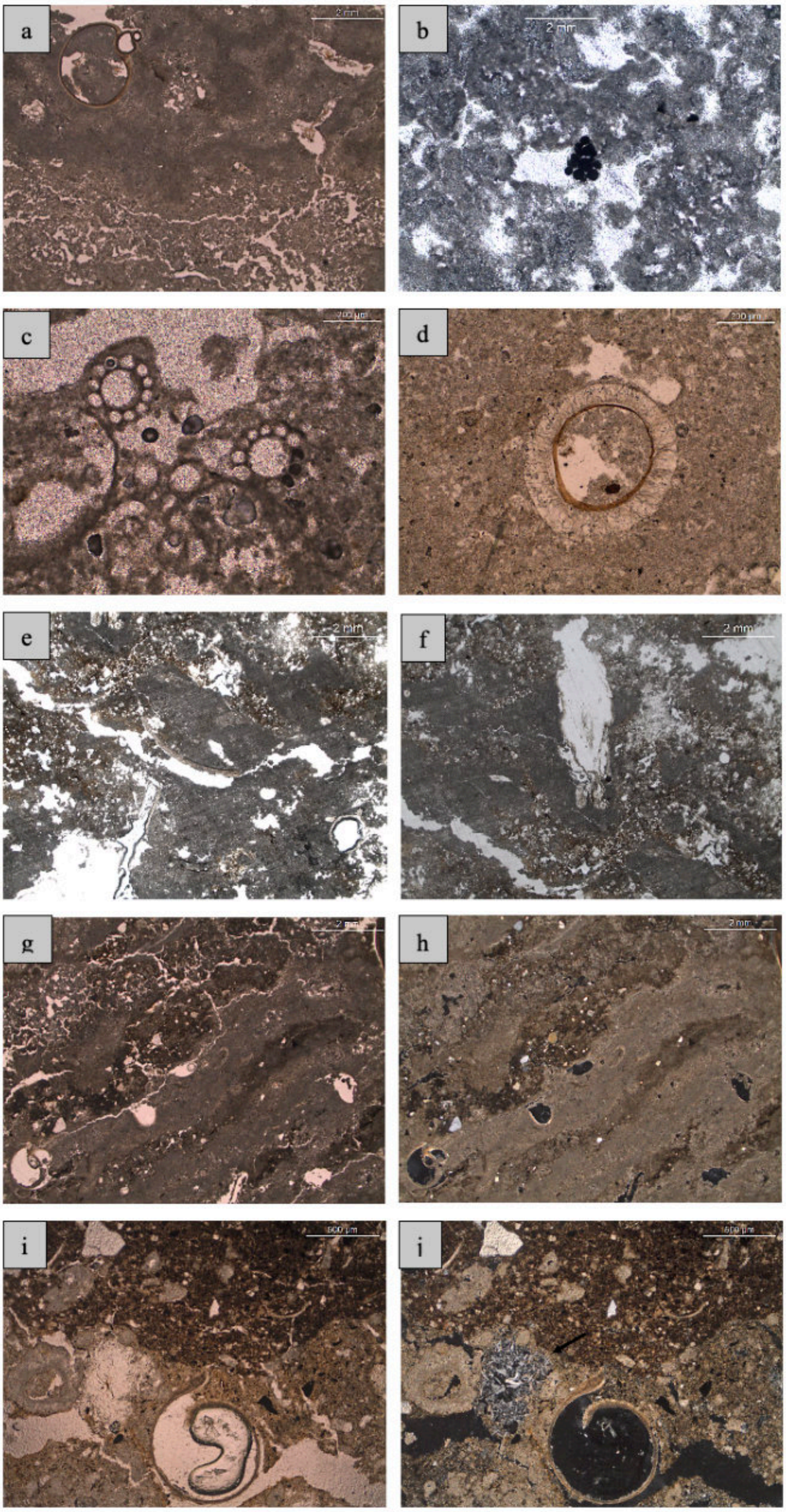


Figure 7.3. Microphotographs of Microfacies *A, A1* and *B,* sector A. **a)** Massive, carbonate rich lake marl with *in situ* mollusk shell. MP318, PPL**. b)** Example of framboidal pyrite. MP65, PPL**. c)** Cross sections of charophyte algae, MP318, PPL, **d)** and oogonia *Trichoderma*. MP307, PPL. **e)** Lake marl with terrigenous yellow brown

sediment in the form of sand silt grains and subrounded quartz, including mollusk shells and **f)** root remnant evidencing gradual exposure of lake marl. MP65, PPL. **g)** Characteristic laminations of lake marl and terrigenous sediment, suggesting a water fluctuation zone. MP318, PPL. **h)** Same as g, XPL. **i)** Lake marl surface with some charcoal pieces. Note the sharp transition to the overlying occupational level with abundant anthropogenic material. MP307, PPL**. j)** Same as i, XPL. Note the transition from a crystallitic to an undifferentiated b-fabric and the random gypsum crystal intergrowths (arrow).

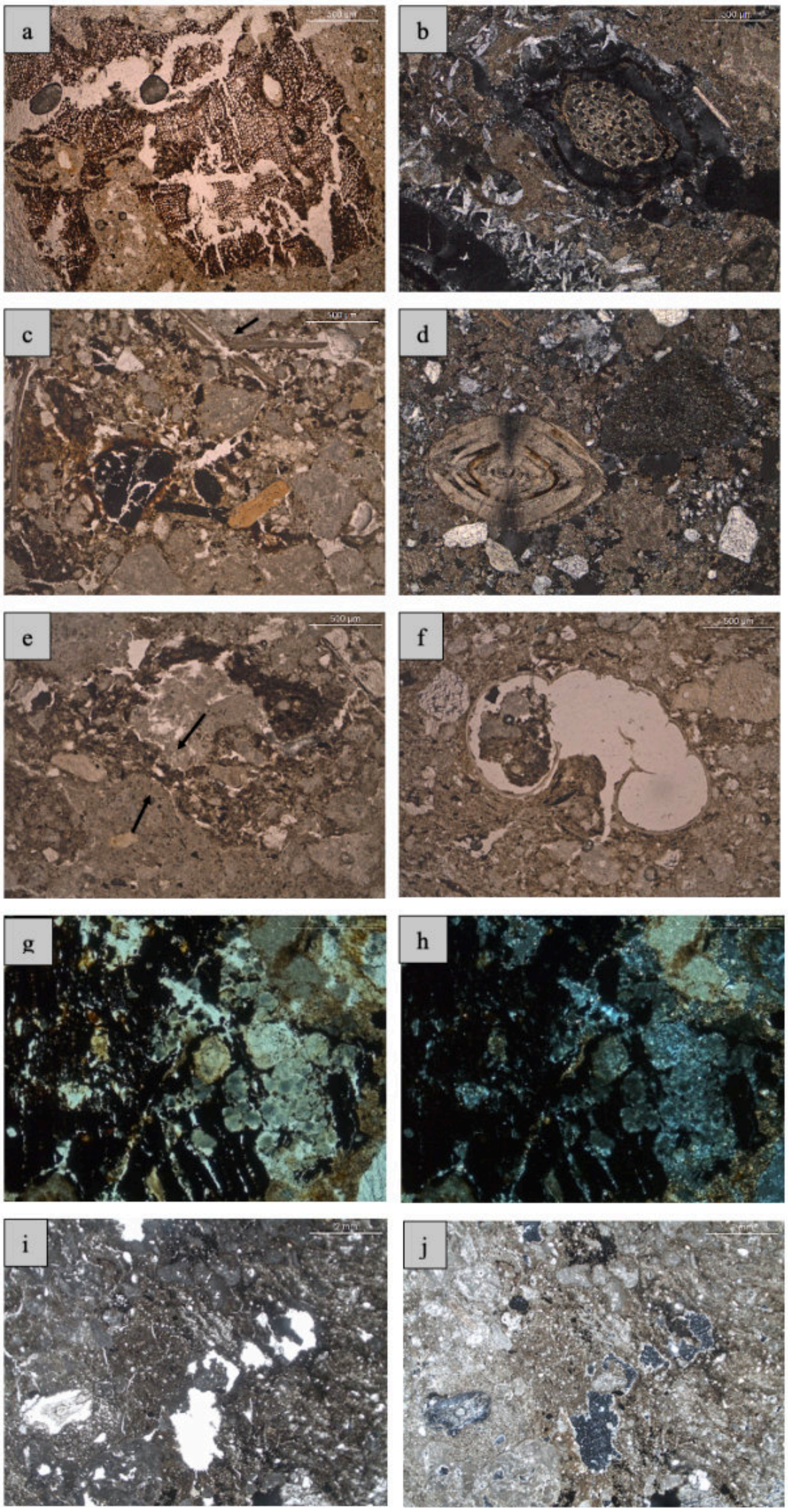


Figure 7.4. Microphotographs of Microfacies *C,* sector A. **a)** Transversal section of a wooden fragment (coniferous species). MP307, PPL**. b)** gypsum crystals surrounding a root in transversal section. MP307, XPL**. c)** Charcoal and bones in a heterogenous groundmass consisted by travertine sand and terrigenous sediment. Note the cracking effect of trampling on the shell (arrow). MP318, PPL. **d)** *Nummulite foraminifer*, part of the larger group of benthic foraminifera, incorporated in the occupational debris. Its size attests for low hydrodynamic regime. Probably transported by water into the settlement. MP318, XPL. **e)** Squeezing/poaching of the groundmass. MP318, PPL. **f)** Deformations around mollusk shell, MP318, PPL. **g)** Ash presence MP291-D, PPL. **h)** Same as g, XPL. **i)** MFT-*C1*, inclined laminations probably due to trampling MP65-2, PPL. **j)** Same as i in XPL. Note the carbonate thin laminations alternating with more heterogeneous sediment.

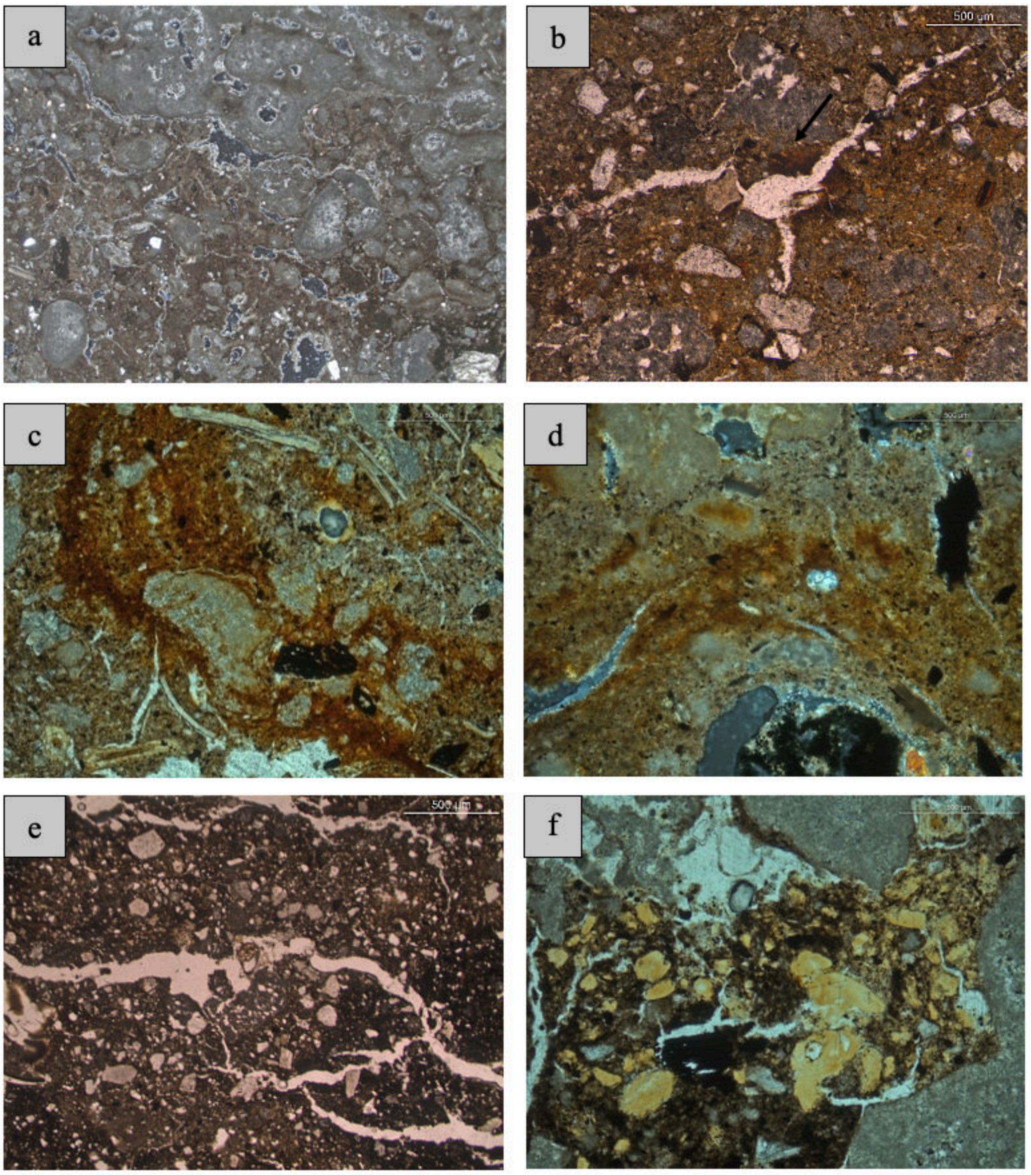


Figure 7.5. Microphotographs of microfacies and associated features in sector A (Appendix I). **a)** Gradual change from microfacies *C* to *D.* MP65, Sector A, XPL. **b)** Microfacies *D*. Brownish oxidation feature (arrow) due to exposure and weathering, MP318, PPL. **c)** Microfacies *E.* Clay coatings and iron staining of a heterogeneous groundmass in MP291-M, PPL. **d)** Microfacies *D*. Iron staining on anthropogenic sediment associated to travertine slabs in MP291-D, XPL. It could be associated with occasional water saturation. **e)** Microfacies *E.* Massive

microstructure of mixed terrigenous sediment with a lot of minerogenic clasts and amorphous organic matter, MP318-6, PPL. **f)** Fragmented bone embedded in terrigenous sediment. Probably trampled by the indirect pressure of the surrounding travertine fragments (MFT-*D*). MP291-D, PPL.

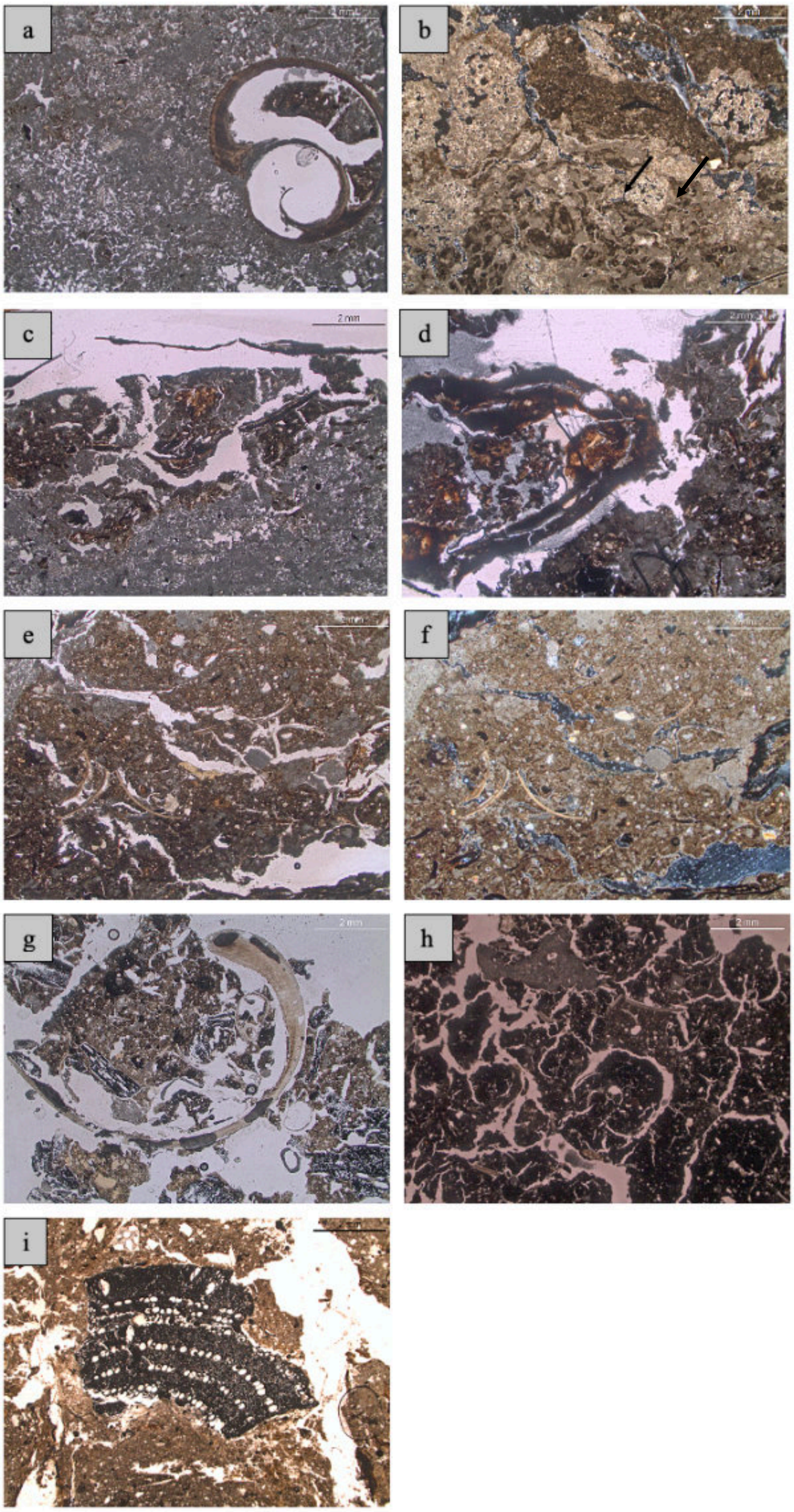


Figure 7.6. Microphotographs of microfacies types in sector D**. a)** Lake marl with massive to almost spongy microstructure due to bioturbation. Snail in living, primary position. Microfacies *A*, MP2-4, PPL. **b)** Trampled lentoid forms of brownish terrigenous sediment pushed downwards into the lake marl (*MFT-A* in contact with *MFT-*

C2), MP3-6, Sector D, XPL. Note the convolutions attesting for poaching conditions (arrow). **c)** Microfacies *A* in contact with Microfacies *C2*, MP2-4, PPL. **d)** The tip of a wooden log in contact with sediment associated to microfacies *C2* in MP2-4, PPL. **e)** Heterogeneous groundmass consisted of a mixture of carbonate and terrigenous sediment comprising MFT-*C2* in MP2-4, PPL**. f)** same as e, in XPL. Note the compacted microstructure. **g)** Aggregate of sediment with embedded charcoals, shells and some travertine fragments, probably coming from the travertine pavement. Part of Microfacies *F*, MP2-2, PPL. **h)** Peaty sediment with decayed organic matter and other mixed material formed under seasonally waterlogged conditions. Microfacies *G*, MP2-1, PPL**. i)** Charcoal fragment embedded in microfacies *C2* associated to wooden remains (*Quercus sp. deciduous*). Note the growth rings. MP3-7, PPL.

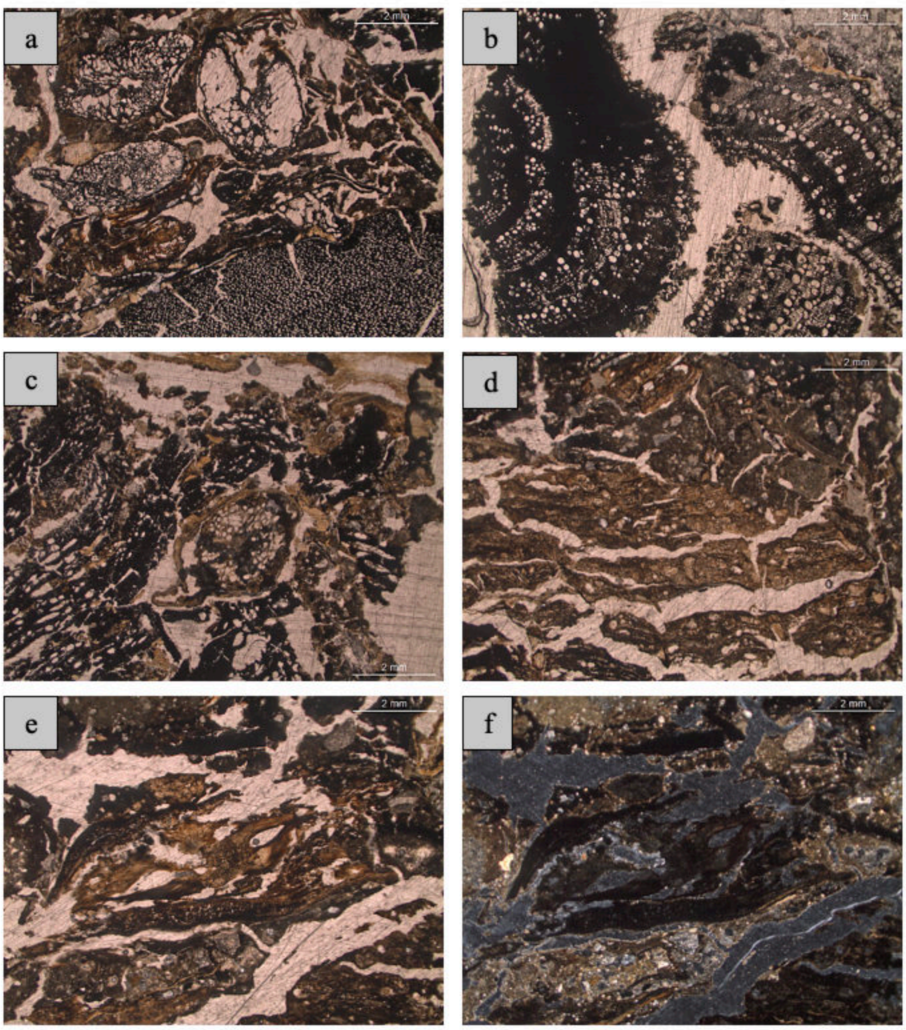


Figure 7.7. Microphotographs of Microfacies *F* in Sector D (Appendix II). **a)** Charred seeds associated to some roots and other organic material in MP125, PPL. **b)** Charred charcoal fragments (*Quercus sp. deciduous*) devoid of sediment, probably burnt on a dry environment in MP126-3, PPL. Note the growth rings. **c)** Charred charcoal fragment with embedded seed conserving the cellular structure in the middle. MP126-3, PPL. **d)** Horizontally laminated roots overlain by travertine fragments in MP125, PPL. **e)** Leaf and wooden remains in a not entirely burnt state, MP125, PPL. **f)** Same as e, in XPL.

7.1.2. Interpretation of the Microfacies types: Formation processes and the anthropic use of space in sectors A and D

An attempt to correlate the data acquired through the micromorphological analysis in both sectors A and D has been made, in order to reconstruct the dynamics of both anthropogenic and geogenic formation processes. These include the construction of occupational features by humans (travertine structures, travertine pavement, wooden dwellings and platforms) and the casual or intentional deposition of anthropogenic material during the Neolithic occupation, as well as natural processes of transportation and sedimentation of such material. In the study of formation processes, the dynamic interplay between these and their integration into the environmental setting must be considered. These are discussed below in comparison with relevant observations originated by pollen and non- pollen palynomorphs analysis realized at La Draga (Revelles *et al.* 2014; Revelles *et al.* 2016).

A summarized view of the microfacies sequence for each sample in sectors A and D is presented in the following tables (Tables 7.4, 7.5). These tables serve as a reference guide for the possible correlation between different samples from the same sector based on the identified microfacies types. Stratigraphic correlation is also possible between different sectors. An example table was created for the sequence of microfacies types in samples MP2 and MP3 and their respective correspondence to stratigraphic units identified in the field (Figure 7.7).

Table 7.4. Microfacies sequence of the structures and sections sampled for micromorphological analysis at sector A. Microfacies are described in a sequential manner from bottom up starting by MFT-A. The thin sections made from the samples in sector A are presented in detail in Appendix I.

E258 **(MP65-66)**	**E261** **(MP291)**	**E263** **(MP292)**	**MP307** **(Transversal section, under travertine features)**	**MP318** **(Eastern section)**
MFT-D		MFT-D		
MFT-C1		MFT-C		MFT-E
MFT-C	MFT-E	MFT-D		MFT-H1
MFT-D1	MFT-D	MFT-C		MFT-C
MFT-C	MFT-C	MFT-D1	MFT-C	MFT-D
MFT-A1	MFT-D	MFT-D	MFT-A	MFT-C
MFT-B	MFT-C	MFT-C	MFT-B	MFT-B
MFT-A	MFT-A	MFT-A	MFT-A	MFT-A

Table 7.5. Microfacies sequence of sampled columns for micromorphological analysis from the southern (MP2, MP3) and western section in sector D (Figures 6.6, 6.7) divided into two groups according to their common characteristics (MP124-MP128). Microfacies are described in a sequential manner from the bottom up starting from MFT-A. Thin sections made from samples in sector D are presented in detail in Appendix II.

MP2	MP3	MP128-MP125-MP126	MP128-MP124-MP127
MFT-G			MFT-F
MFT-H	MFT-I		MFT-C
MFT-F	MFT-C	MFT-D	MFT-D
MFT-D	MFT-F	MFT-F	-
MFT-C	MFT-C	MFT-E1	MFT-E1
MFT-C2	MFT-C2	MFT-F	MFT-C
MFT-A	MFT-A	MFT-A	MFT-A

Table 7.6. Microfacies sequence of sampled columns for micromorphological analysis from the southern section (MP2, MP3; Balbo and Antolín 2013) of sector D (Figure 6.6). Microfacies are described in a sequential manner from the bottom up in correlation with the stratigraphic sequence of each column.

STRATIGRAPHY MP2	MICROFACIES TYPES
II	MFT-G
IIa	MFT-H MFT-F
III	MFT-D
VI VII VIII	MFT-C MFT-C2
IX	MFT-A

STRATIGRAPHY MP3	MICROFACIES TYPES
VI	MFT-I MFT-C
VII	MFT-F MFT-C
VIII	MFT-C2
IX	MFT-A

Pre-Occupation Phase:

◊ ***Microfacies A***

Sector A

Microfacies *A* is located at the base of all samples in both sectors representing the lake marl substrate of the settlement with characteristics of a high-water table present before the Neolithic installation. This is consistent with high values of arboreal pollen with the most representative types of oak deciduous *Quercus* type, *Corylus cf. avellana* and *Pinus spp.* before the Neolithic occupation (Revelles *et al.* 2014). *In situ* underwater bioturbation of mollusks suggests relatively deep-water deposition of the marl, below the influence of waves. The presence of aquatic plants, such as charophyte algae is characteristic and indicative of high carbonate content and anoxic conditions of deposition. Framboidal pyrite (Figure 7.3.b) is also formed under anaerobic conditions. Common in waterlogged sites and intertidal ripening sediments, framboid formation is linked to the transition interface between the sediment and the water column from oxic to anoxic environment (Wilkin *et al.* 1996). Indicators of soil erosion like algae and fungi are present just before the occupation signals at sector A at La Draga, probably meaning a shift in the lake water table.

The upper surface of the lake marl substrate is identified as the installation horizon at both sectors and is either represented as the sharp contact with microfacies *C* (Figure 7.3.i, j), or in the case of structure E258 (sector A) with the presence of microfacies *A1*, indicating fluctuations of the lake level (Figure 7.3.e, f). In this case, it can be described as the result of a fluctuation zone with shallow waters and signs of the first occupation, but without signs of systematic deposition of anthropogenic material yet.

Sector D

However, in the case of sector D, being the better preserved under water conditions, the lake marl substrate is present all over the settlement and is the surface above which the first occupation associated with wooden structures (*MFT-*C_2) begins. In this sector, *MFT-A* is represented in the form of mostly limnic carbonates with seldom quartz grains (little terrigenous import). Low grade swamping and seasonal lake-level fluctuations would have been the conditions of formation of the lake marl which corresponds to stratigraphic unit *IX* (Table 7.2). The presence of charophyte algae, mollusk shells and snails indicate *in situ* bioturbation under water conditions as well (MP3-8, MP128, Appendix II).

◊ ***Microfacies B***

Sector A

Microfacies *B* shows local integration of terrigenous input into the lake marl marking at the same time a gradual drop of the water table. Subsequent exposure and emersion of the lake marl are present, but without signs of occupation yet. It probably represents a drier environment detected in all the samples (MP307-2, MP318-2, MP65-1&2, Appendix I) apart from the structures *E261* and *E263*. This is of special importance as those two structures are located at the northwestern corner of sector A and were distinguished from the rest because of their characteristic shape. They have been excavated in the form of pits instead of just being located over the lake marl surface. The swamp conditions show a lowering in lake level making possible the occupation on the lake marl surface, while there are signs of gradual emersion, reinforced by weathering, decay effects and aerial exposure associated with root burrowing and yellow clay staining. At the same time, pollen data register a fall of deciduous oak in the immediate surroundings of La Draga, while *Cerealia-t* pollen is present associated to the occupation of the settlement and the human impact further evidenced by the oak wood deforestation (Revelles 2017).

Occupation Phase:

Sector A

◊ ***Microfacies C***

At the contact of the transitional zones described above, the lake marl surface presents a series of characteristics, associated with trampling of water-saturated sediments or else called poaching (Figure 7.4.c, e, f, i, j) (Rentzel *et al.* 2017). This would mark the presence of water saturated environment in a fluctuating water zone, where the occupation took place. Anthropogenic material is embedded in this surface, but the human impact is still low. As a result, the first evidence of occupation (*MFT-C*) appears to have occurred under humid conditions, in an almost water saturated surface (MP307-3, upper part, Appendix I). That is consistent with stratigraphic unit *2002*, where pollen data record an erosion in a subaerial context (low values of freshwater algae), favoring the occupation at this part of the settlement (Revelles 2019). *MFT-C* associated to the space outside of the travertine structures (overrepresentation of herbs) (MP318-2 upper part, MP318-4, Appendix I) supports the existence of an environment conditioned by grasslands and oak deforestation. Furthermore, the presence of hydrophyte plants indicates an intentionally cleared environment for occupation and/or subsistence (Revelles 2019).

During excavations in sector A, numerous postholes were excavated over the lake marl surface. The vast majority of the extracted wooden timber logs that are associated with these postholes belong to the oldest occupation phase of wooden habitats. Their preservation was facilitated by the presence of anoxic conditions inside the lake marl. The travertine structures studied in this case, were located right over these former postholes of the oldest occupational phase, confirming in this way the abandonment of wooden habitat in this part of the settlement and the subsequent distinct use of space later on (Figure 7.8).

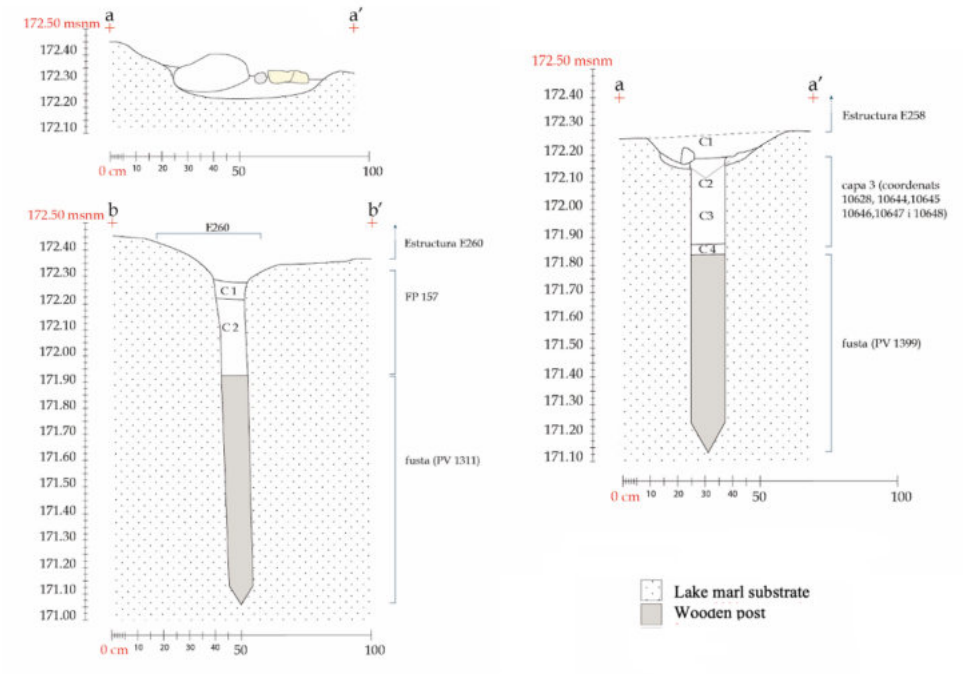


Figure 7.8. Structures E260 on the left and E258 on the right from sector A at La Draga. Examples of the stratigraphic sequence of structures from recent phase overlapping postholes and wooden vertical piles from the oldest phase of occupation at the site of La Draga (*Modified after Rafa Rosillo*; Palomo *et al.* 2018).

In order to decipher the use of travertine structures in sector A as well as their integration into the formation processes at the emerged part of the settlement, it is important to understand the sequences of microfacies detected. On one hand, the recurrent sequence of microfacies across all studied structures, indicates similarities in their functional dynamics, while on the other hand, their comparison to samples outside the structures helps to better represent the dynamics of formation processes in sector A in general.

Wherever the evidence of constructed floors is not detectable during excavation, non-constructed floors are detected micromorphologically as trampled minerogenic deposits (Rentzel *et al.* 2017). Microfacies *C* is the clear evidence of occupation debris consisting by a combination of organic material, but also bones, roots and burned wood. Further characteristics of this microfacies are the presence of ash and a mix of diverse material transported there and burned *in situ*. Deposits presenting the accumulation of this material in combination with trampling indicators, are elsewhere characterized as *'installation horizons'* (Ismail-Meyer *et al.* 2013; Wiemann and Rentzel 2015).

◊ ***Microfacies D***

It is necessary to remark that the above occupation layer was covered by travertine slabs covering it. This is described as microfacies *D*, consisting by travertine slabs, with little or no embedded sediment, while ash presence is higher, when in contact with the travertine slabs. Anthropogenic and organic material is found associated with the travertine slabs either below or above them. Calcite/carbonate hypocoatings reveal the travertine slabs have been exposed in sector A. Organic material was transported there intentionally and subsequently got burnt, or it was transported there already burnt. Ash remains are present although, pseudomorphs after plant structures are not preserved (Figure 7.4.g, h). That could be indication either of burning and subsequent sweeping or discard activities of already burnt material, in these features. The travertine slabs apart from surrounding the combustion and /or discard features, were also used to cover dumped material (*MFT-C*). The distribution of travertine slabs in the excavated sectors at La Draga is characterized by various orientations based on the algal growth of the travertine. Consequently, slabs were fragmented and transported to the settlement for constructive and other purposes. They do not correspond to natural travertine formations.

The alternate sequence of microfacies *C* and *D* occurs at least once in all samples and twice in all three travertine structures (*E258*, *E261*, *E263*). This indicates a repetitive use of these structures as enclosures and/or hearths including their subsequent clearance and covering with slabs and then again new burning activity over the previously deposited travertine slabs. According to Courty and Fedoroff (2002), this is indicative of continuous succession of activity surfaces. The repetition of the same microfacies in all the studied structures justifies a pattern of activities of clearing the burning remains in this place of this settlement during the most recent occupation of this sector after the oldest occupational phase of wooden structures. However, we should underline the significance of fauna found in anatomical connection *in situ* alongside with other special artefacts (such as polished adze blades, ornamental elements, flint and bone utensils and a rare double ring made of bone) in the structure *E263*, in contact with the lake marl surface, suggesting intentional deposition. Although, the filling of this structure and the recovered material may as well constitute a set of special significance, yet, they must be further interpreted by the archaeologists as the excavation proceeds.

Outside the enclosed travertine features, in MP318-5 (Appendix I), microfacies *C* appears in the form of compacted brownish sediment with clay input and clasts from hinterland, while the characteristic laminations of sheetwash origin could be considered evidence for sheetwash transporting allochthonous sediment in an outdoors space in sector A. This is found both underlying and overlying an accumulation of travertine fragments (*MFT-D*) with embedded terrigenous sediment. Both microfacies (*MFT-C* and *MFT-D*) are here associated with a wetter environment than the previous layer as attested by high values of ferns and freshwater algae in the pollen record (Revelles 2019). This evidence could mean an inundation event related to soil erosion and transportation of terrigenous sediment. This is in accordance with the micromorphological results of the presence of clasts, as well as mixed anthropogenic and organic material transported naturally probably by rainwash.

This is considered a transition layer before the abandonment of space in sector A.

On the other hand, the dynamics of use of the travertine sequences in sector A, must be seen in the context of the dynamics of sedimentation due to water presence seasonally and considering the data recovered from sector D.

Sector D

◊ ***Microfacies C_2***

The lake marl surface is overlain by a dark grey clayish sediment with waterlogged wooden elements and charcoal lenses (*MFT-C_2*). In MP2-4 (Appendix II) a piece of wood in fallen horizontal position is in direct contact with the lake marl surface (Figure 7.2.e, Figure 7.6.d). This suggests that terrigenous sediment was not present when the wooden dwellings collapsed, implying that at least this side of the settlement was under water influence. Sediment covering the wooden remains shows abundant quartz (terrigenous or anthropic origin). Organic matter with little or no charcoal lying directly over the lake marl corresponds to stratigraphic unit *VIII* from sector D (Table 7.2). *MFT-C_2* is a homogeneous naturally deposited sediment with grading of clast sizes from coarse to fine (MP3-8, Appendix II). The coarser grain sizes indicate probably rain-wash sedimentation, while slower deposition would have taken place later, under a standing water body (shallow waters, swamping).

The oldest occupation took place on a lake marl surface with evidence of swamping and seasonal lake-level fluctuations in sector D, where wooden platforms must have been constructed to avoid the occasional water rise. This is evident by the wooden bark found directly on the lake marl surface with signs of trampling either by humans or animal traffic. The latter is further attested by the presence of coprophilous fungi consistent with animal dung at this layer (Revelles *et al.* 2016). Furthermore, the occupational remains include also abundant charcoal, deposited in a wet environment, with no signs of grand emersion yet.

◊ ***Microfacies C***

Sharp transition to occupation level is observed from *MFT-A* to *MFT-C*, where malacofauna is less abundant and less fragmented than *MFT-A*. Grain sizes are similar, while clasts of quartz and limestone are more abundant. The material here is mostly burned with well-preserved large charcoal fragments in suspension (MP2-4, Appendix II). This suggests that they fell into the water and slowly sunk rather than transported and redeposited. There is little or no organic matter present. Microfacies *C* corresponds to stratigraphic unit *VII* (Table 7.2). Units *VIII* and *VII* may be the result of selected deposition in water as waterlogged organic matter is deposited first and lighter charcoal fragments later. There is a thin mineral layer between the two units, possibly indicating two different accumulation events (MP2-4, Appendix II).

Overlying *VII*, there is a light grey clayish sediment with apparently laminated organic matter and charcoal lenses that corresponds to the unit *VIa* which is found under the travertine paved surface (Table 7.2). *MFT-C* includes more mixed material near the top (MP3-7, Appendix II), although not discernible in the available thin sections. The microfacies has is of darker color and contains greter clay input upwards, while bioturbation near the top of the sediment suggests deposition under fluctuating water table, probably during the emersion stage (MP3-7, Appendix II).

◊ ***Microfacies I***

A darker gray clayish sediment follows with a concentration of charcoal fragments mixed with terrigenous sediment, probably suggesting burning. This is observed at the bottom of the thin section (MP3-5/6, Appendix II). Towards the top of the sediment, the occurrence of more clasts and coarser grains suggests a greater emersion. The mineral component is higher near the bottom of the sediment, while ash and clay increase upwards (*MFT-I*). Evidence of oxidation is present near the top. This deposit which consists of ash and clay may have been intentionally deposited either to support and cement the overlying travertine slabs or to insulate the surface from water rise (*MFT-I*).

After the oldest occupation, dry conditions and signs of exposure have been detected microscopically in sector D, right before the construction of a travertine pavement. This implies abandonment of the wooden platforms and after some period of exposure their covering by travertine slabs.

In MP2-2 (bottom part) (Appendix II), going upwards above unit *VI*, there is less mineral component and less charcoal, while malacofauna is present (Balbo and Antolín 2013). There is a drop of the lake level and lack of water transport as attested by terrigenous deposits. These are originated by pedofeatures from different soil types and/or soil horizons that could have been embedded as the result of transport and deposition and/or bioturbation within the deposit. Clear, abrupt transition to the travertine pavement could probably mean some temporarily dry conditions probably due to erosion before the placing of travertine slabs.

◊ ***Microfacies D***

The travertine structure (*MFT-D*) has some voids typical of gas bubble (MP2-3, Appendix II), while travertine slabs are found in secondary deposition, supporting anthropogenic origin. These were forming some kind of pavement, perhaps as a kind of insulation platform in order to reduce the rise of groundwater and isolate the occupation floor from the mud substrate (Figure 7.2.f). Pollen data retrieved from this layer confirm a deforested area in local level and shallow water presence (Revelles *et al.* 2016).

◊ ***Microfacies F***

A sediment with charcoal fragments (*MFT-F*) follows *MFT-D* through clear contact. This microfacies corresponds to stratigraphic unit *IIa* (Table 7.2). It contains more malacofauna than units *VII* and *VIII*. Concentration of large charcoal fragments at the bottom of the layer and decreasing upwards with little associated sediment suggest burning in dry conditions, over the travertine surface (MP2-2, Appendix II).

Across the western section of sector D, two thin sections were sampled alongside the same stratigraphic sequence (MP125, MP124, Appendix II), and present the same sequence of microfacies (Figure 7.7.a-f, Table 7.5). However, the microstructure is better preserved in the first case (MP125, Appendix II). Above the lake marl surface (*MFT-A*), a concentration of charred material (charcoal, seeds) (*MFT-F*) appears with some embedded terrigenous sediment. That is indication of a burning event on a relatively dry environment.

Post-Occupation Phase:

Sector A

◊ ***Microfacies E***

Microfacies *E* coincides with the abandonment of the travertine structures in sector A. Sedimentation seems to be the result of naturally transported anthropogenic material probably caused by a sheet wash episode (MP318-6 and MP291-M, Appendix I). It mainly consists of allochthonous terrigenous sediments and organic matter, as well as some embedded carbonates (Figure 7.5.c). These mudflat sediments are high in organic matter and are characterized by high compaction, caused by more recent animal or/ and human trampling on the area. The iron staining of the groundmass could be the result of water stagnation, while the clay coatings are evidence of transportation of allochthonous material (MP291-M, Appendix I). In MP318-6 (Appendix I), the altered form of some aggregates (squeezing) may have been the result of trampling after a rain-wash episode. Pollen records suggest the formation of this sediment under subaerial conditions with high presence of organic matter (Revelles 2019).

Sector D

Western section

◊ ***Microfacies E1***

In MP125 and MP124 (western section, Appendix II), the transition from *MFT-F* to *MFT- E1* is sharp and the microfacies indicate palustrine environment and seasonal exposure under dry conditions. The sediment includes travertine fragments that in the case of MP124 (Appendix II) lie directly on the carbonized wood (horizontally). The microstructure is massive while fresh humus is present. Broken charcoal fragments could indicate indirect pressure from the travertines above. There is more running water towards the top with the presence of coarse-grained sediment.

Also, at the western section of sector D, overlying *MFT-E1*, there is another concentration of charred material devoid of sediment (charcoal and seeds) (*MFT-F*) with evidence of *in situ* burning under dry conditions. After a sharp transition, there is a travertine layer (*MFT-D*) included within some terrigenous sediment. The travertine fragments are covered by mud deposited under dry conditions (MP126-2/3, Appendix II).

Overlying the travertine layer (*MFT-D*) in MP127 (Appendix II), a heterogeneous terrigenous sediment was probably deposited during an inwash episode. This heterogeneous sediment contained a lot of clasts and charcoal fragments and was deposited under semiterrestrial conditions, in a standing water body. There are some dispersed travertine fragments, while there is inverse grain size grading from coarse grained sediment at the top to fine grained at the bottom of the deposit. Another sharp transition above *MFT-D* leads to a concentration of charcoal fragments (*MFT-F)* without any sediment, probably deposited under dry conditions as well.

Southern section

◊ ***Microfacies H***

In sector D, a sediment rich in humic material and mixed archaeological remains indicates the abandonment of Neolithic occupation (Figure 7.2.h). Above the charcoal concentration, a sediment is deposited showing a humus-rich blackish matrix in some areas or a light brownish poorly or intensively mixed matrix in other areas (*MFT-H*). This mixing is probably related to the overlying peat formation (Figure 7.2.i, MP2-1, Appendix II). The coarse organic and anthropogenic components of microfacies *H* include mollusks, bone fragments, charcoal, and root fragments (Figure 7.6.g). The compacted soil microstructure is associated with vughs related to slaking, suggesting that the sediment was formed under seasonally wet conditions.

◊ ***Microfacies G***

MFT-H is covered by peat (*MFT-G*), which corresponds to stratigraphic unit *II* (Table 7.2). The peat is mostly composed of amorphous organic matter including plant tissues, while there are few malacological remains (Figure 7.2.i). Abundant bioturbation and highly decayed organic matter are some of the main characteristics of the peat. This natural formation of peat formed under water presence (*MFT-G*).

During occupation, the levels of *Quercus* pollen decreased indicating the general human influence on forest management, while after the settlement's abandonment those levels show increased values. The increase of *Quercus* pollen is also evident in the peat formation, suggesting recovery of the forest surrounding La Draga (Revelles *et al.* 2016; Revelles *et al.* 2014).

7.2. Sector C under the lenses

From the core sampled from sector C (MP-DRAGA_C, Figure 6.8), eleven thin sections were manufactured in order to cover the whole sedimentary sequence for further micromorphological analysis (C1-C11, Appendix III).

7.2.1. Microfacies Description

Because of the underwater location of the core, into the lake, the sediment may have been affected by modern lacustrine processes and water activity, and therefore, it has been studied separately from the rest of the samples. Some of the microfacies types are present in sectors A and D, although some additional microfacies are present in the core from sector C. Microfacies *A, C, C2* and *D* are already described in detail in *7.1.1*.

Table 7.7. Micromorphological description of microfacies types at underwater sector C, La Draga. Most of them are already described in Table 7.3.

Microfacies	Micromorphological description	Interpretation
A	Lake marl sediment with massive microstructure and high carbonate content. It has some terrigenous sediment embedded as well as some marl nodules. *In situ* underwater bioturbation. Presence of charophyte algae and framboidal pyrite. Calcitic crystallitic b-fabric	Natural lake marl

C	Heterogenous sediment with massive microstructure and open porphyric related distribution. Anthropogenic and organic material and quartz grains. Humic-iron staining and some secondary carbonate around voids. Crystallitic b-fabric	Sediment filling the structures. Occupation level, affected and compacted by direct or indirect trampling
C_2	Terrigenous sediment of brownish color with decayed organic matter and charcoal inclusions. Massive microstructure with few vughs and voids. Signs of trampling and slaking	Occupation level associated with the construction of wooden structures. Deposition under water
C_3	Carbonate thin layer not deposited by lake marl. Contains anthropogenic material such as decayed roots and ashes. Crystallitic b-fabric	Anthropogenic event related to burning episode under wet conditions
D	Travertine fragments of calcium carbonate in various sizes with massive microstructure and plant- pseudomorphic voids. Little or no sediment associated. Crystallitic b-fabric	Travertine fragments covering or surrounding the layers of occupation
P	Dark peaty sediment with decayed organic matter. Undifferentiated b-fabric	Peat formation. Low water lake level

Microfacies A

MFT-A is the common ground for human activities all over the settlement of La Draga and it has already been described in *Chapter 7.1.1*. Although the general microfacies description is the same, some local variations associated to the deposition of lake marl are present in the thin section from underwater sector C. More specifically, terrigenous sediment seems to have been embedded in the lake marl probably pushed downwards by trampling. Furthermore, the presence of lake marl aggregates with infillings of organic matter in the voids indicate bioturbation. In addition to this, their position indicates transportation from elsewhere and deposition there. These are relevant in this case, as the present lake level is in direct contact with the sampled core. As a result, the package of limnic sediments is crucial to decipher whether the post-Neolithic lake level changes have affected the occupation at La Draga. The variations in *MFT-A* are associated to lower and higher lake levels determined through biogenic and bioturbation signs (Thin sections C1, C3, C4, C5, C6, C7, C8, C10, C11, Appendix III). These are described in the microfacies sequence below in the order they appear (*Chapter 7.2.2*).

Microfacies C_3

It is a variation of the occupation level *MFT-C* present in all analyzed sectors; however, the groundmass of MFT- *C3* is different. *MFT-C3* describes a sediment with carbonate content, but not deposited as lake marl. It contains anthropogenic material such as decayed and charred roots, as well as ash remains (Figure 7.10.a, b). This material is arranged in an inclined thin laminated layer (Figure 7.9.a). *MFT-C3* is also present in the aggregate overlying the abovementioned layer. It has the same characteristics, but it is the result of different deposition processes. Whereas the carbonate thin layer seems to have been deposited *in situ*, the overlying aggregate seems to be redeposited from another area in a similar environment, since they share the same microfacies (Figure 7.10.c, d).

Microfacies P

Microfacies type *P* describes a dark peaty sediment with decayed organic matter and undifferentiated b- fabric (Figure 7.9.c, Figure 7.10.m, n).

7.2.2. Interpretation of the sedimentary microfacies: Water lake-level changes and associated formation processes

The microfacies sequence from the MP-DRAGA-C core described from the bottom up is the following (Appendix III):

Pre-Occupation Phase:

◊ Lake marl (*MFT-A*) with some input of terrigenous sediment. The semiplastic form of the marl nodules and the lack of bioturbation or trampling effects indicate formation under water (Appendix III, C1). However, the origin of the heterogenous terrigenous input in the sediment seems to be due to anthropogenic transport.

Occupation Phase:

◊ Carbonate thin layer not related to lake marl deposition (MFT-C_3) with horizontal roots, ash remains and micro-contrasted particles of charcoal (C1, Appendix III). Most of the roots are decayed, but not burned. Wet conditions may have prevented complete burning. That is the first anthropogenic event and it may be associated with burning of roots and other, probably naturally transported organic material in order to clear the surface for occupation (Figure 7.9.a, Figure 7.10.a, b).

◊ A carbonate aggregate similar to the previous microfacies overlies the abovementioned carbonate thin layer (Figure 7.10.c, d). The aggregate seems to have been transported from somewhere else in the same environment probably by trampling.

◊ Overlying the previous sedimentation, a travertine formation (MFT-*D*) with an abrupt contact with the abovementioned layers is found (C1, Appendix III). The travertine is not naturally formed *in situ*, but rather seems to be transported from elsewhere and deposited intentionally (anthropogenic origin).

◊ Above the travertine, there is clear occupation debris (MFT-*C*) at sector C. In this layer (C2, Appendix III) there is an alternation of anthropogenic material (MFT-*C*) and travertine fragments (MFT-*D*) associated with the occupation (Figure 7.9.b). At the bottom of the layer there are some large fragments of charcoal and a piece of wood, while at the upper part there are travertine fragments mixed with charred material. There is also some indication of burnt leaves (Figure 7.10. g, h, i). The inclusions of anthropogenic material are finer towards the upper part of the layer.

Post-Occupation Phase:

◊ Above the deposits associated with the occupation of the settlement at the submerged sector C, a package of lake marl deposition follows. A lot of charophyte algae and eroded foraminifera from Eocene limestones are present in the first few centimeters of lake marl deposition (C3, Appendix III) forming a pelleted microstructure produced by biogenic excrements (Figure 7.10.j) These are typical of the lake marl sediments found at the distal part of the lake and they are characteristic of deepening of the lake in this area. Vertical roots are observed starting some centimeters above the previous sediment and reaching into the bottom of the layer (C4, Appendix III). They could indicate seasonal shallowing (decrease of water level) which would have favored the growth of roots.

◊ Following the lake marl deposition (C5, Appendix III), in addition to the root formation, there is also presence of bioturbation which could imply a continuation of the water level decrease, perhaps as a result of seasonal fluctuation of the lake level (Figure 7.10.k, l). At the upper part of the same layer (C5, Appendix III) and in a sharp transition with the previous one, there are no longer roots (Figure 7.9.d). Therefore, the lake level increases again.

◊ In thin sections C6 and C7 (Appendix III) a dark greyish marl (MFT-*A*) includes more clay input and higher presence of bioturbation. The inclined laminations in the middle of the thin section C7, could indicate deposition of sediment by currents or gentle wave action in the area of the lakeshore (Figure 7.9.f, C7, Appendix III). A lighter silty carbonate sediment (C8, Appendix III) is found above C7 with *in situ* (living condition) shells (MFT-*A*) and less bioturbation. Here the waters get shallower (water level decrease) and this process continues through the subsequent deposition with evidence of exposure of the lake marl (C9, Appendix III) (MFT-*A*) until reaching the first peaty sediment (MFT-*P*) (upper part of C9, Appendix III, Figure 7.10.m).

◊ Peat formation (MFT-*P*) over the lake marl is present in the form of decayed organic matter and indicates formation under low water lake level (Figure 7.10.n). Between this and the following peaty formation there is a layer of lake marl (MFT-*A*), while some marl deposit is also included in the second peaty formation (MFT-*P*) (C9), perhaps as a result of downwards pressure from the overlying layer (inclined layer at the top right of C9, Appendix III).

◊ The overlying lake marl (C10, Appendix III) includes terrigenous sediment, roots and some organic matter (MFT-*A*). Water activity is indicated in the bottom part, while a gradual submersion (lake level increase) is taking place upwards. The organic matter decreases upwards (upper part of C10, Appendix III), giving place to a clearer marl (MFT-*A*) with shells, less roots and some secondary carbonates.

◊ This continues at the bottom part of C11 (Appendix III) (MFT-*A*), where calcified encrustations are observed around former aquatic plants due to precipitation of micrite. On the other hand, the upper part has the form of pelleted calcite with some identifiable laminations (Figure 7.9.e). These could be the result of current influence or wave action in the lakeshore.

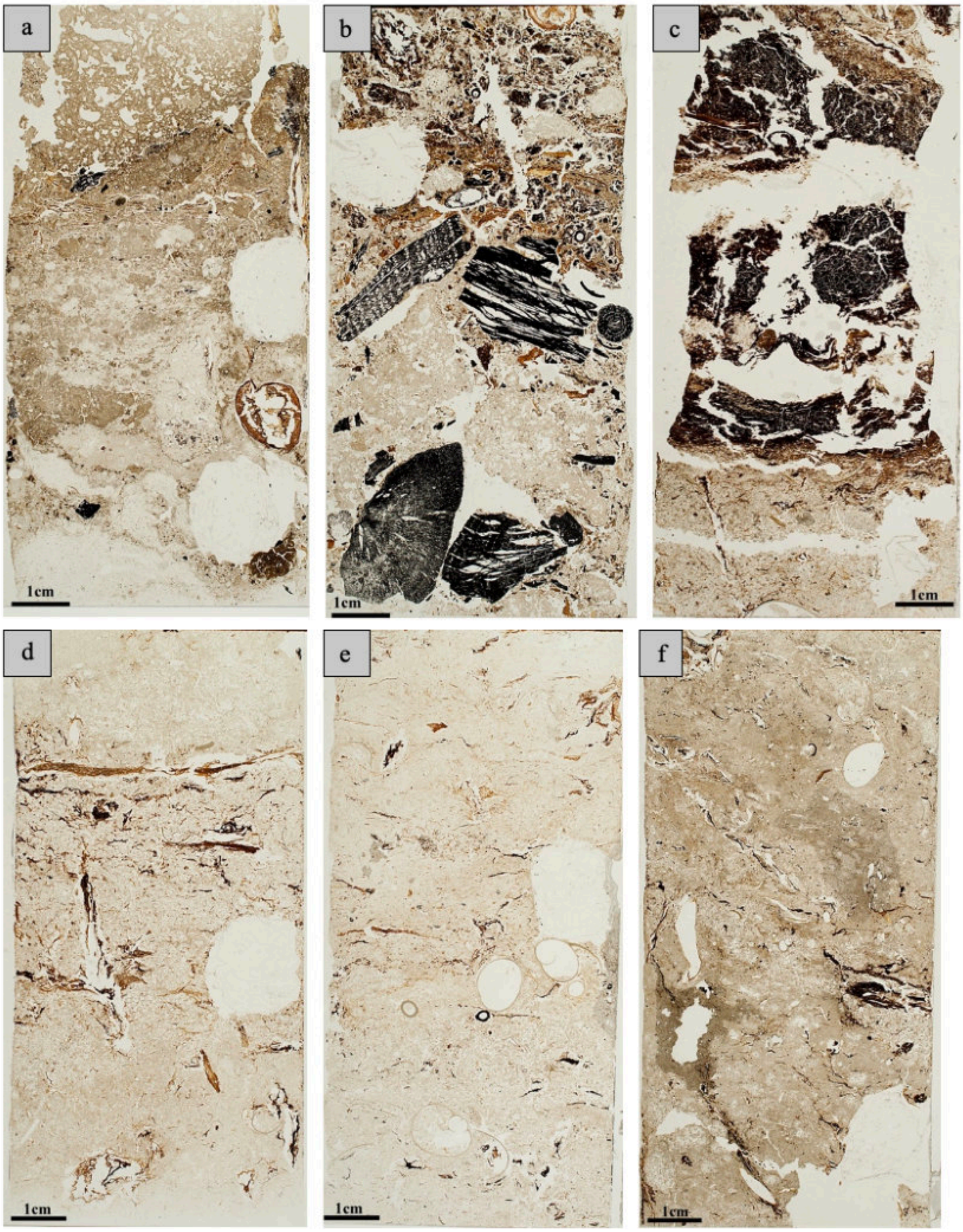
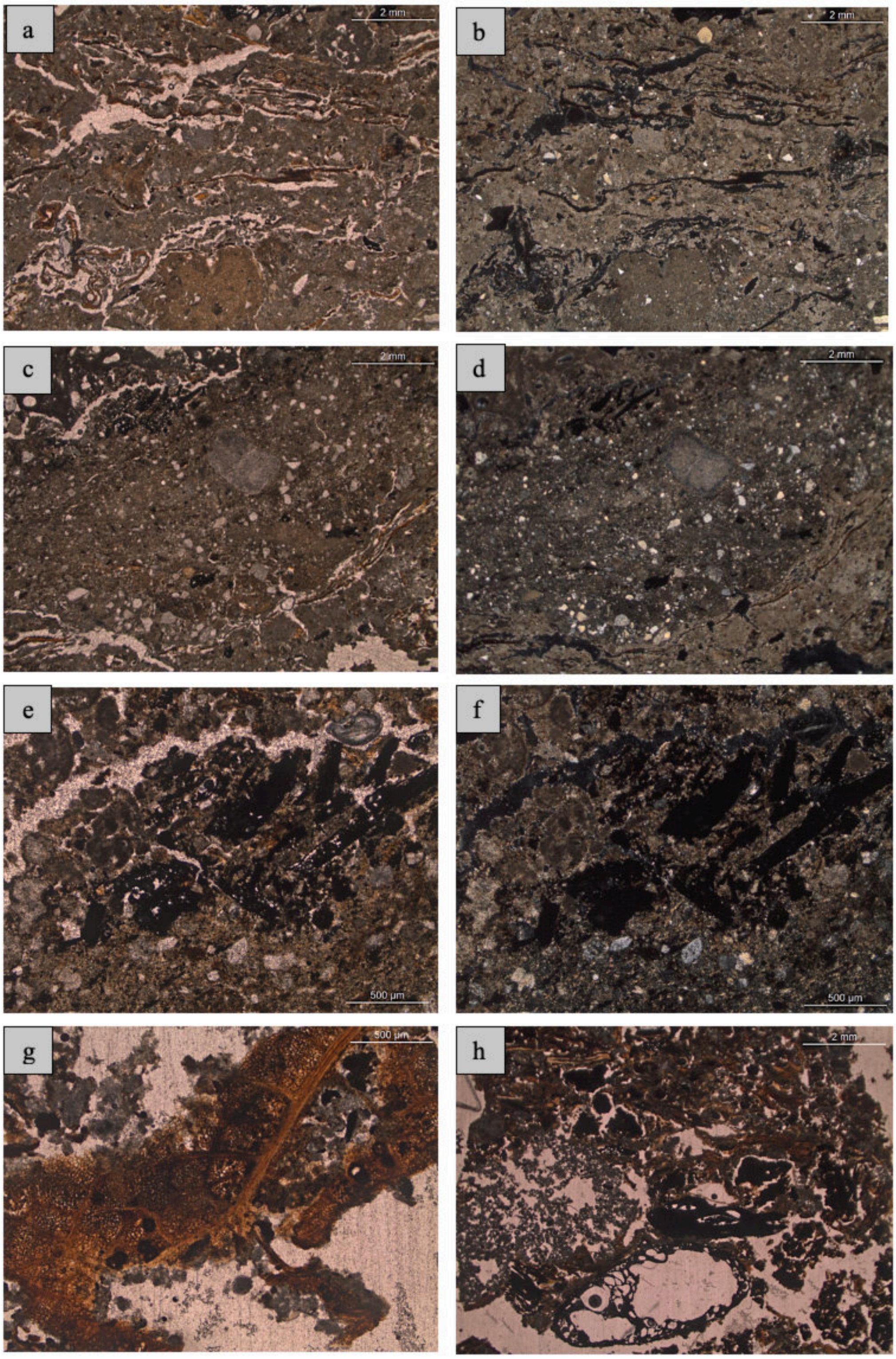


Figure 7.9. Microfacies *C, D* and *P* and variations of MFT-*A* at sector C (Appendix III). **a)** Lake marl with terrigenous sediment and semiplastic forms of the carbonate silts (C1). These are overlain by a thin carbonate layer

MFT-*C3* and a travertine slab MFT-*D*. Wet conditions. **b)** Heterogeneous sediment associated to the occupation remains, mostly charred material (*Quercus sp. deciduous*) and travertine fragments MFT-*C* (C2). **c)** Natural peat formation MFT-*P*, with compacted decayed organic matter (C9). **d)** MFT-*A* lake marl variation with presence of roots and bioturbation. Shallow waters (C5). **e)** MFT-*A* variation with calcite encrustations around former algae and precipitation of micrite mostly from the bottom until the middle of the thin section. Lake level increase (C11). **f)** MFT-*A* variation with inclined parallel laminations, probably affected by wave activity (C7).



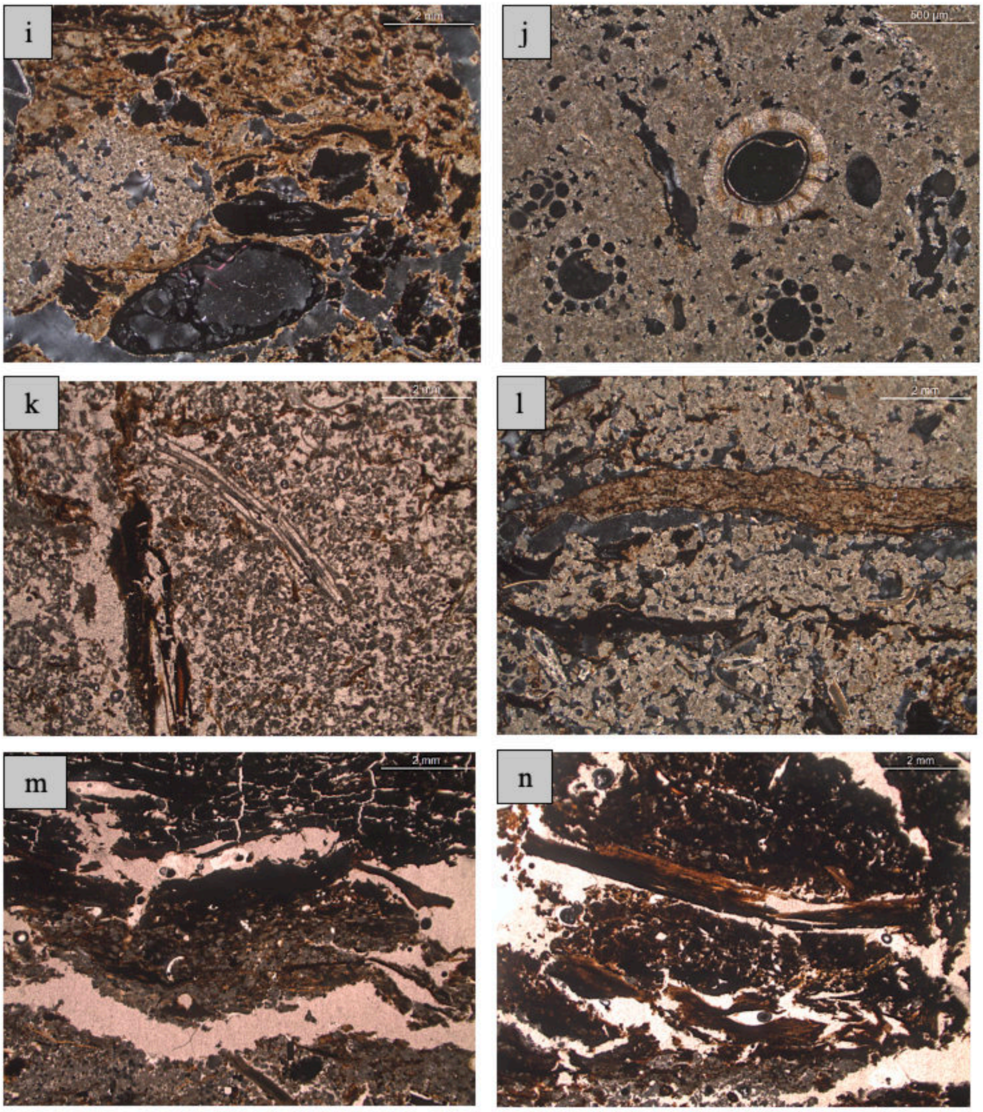
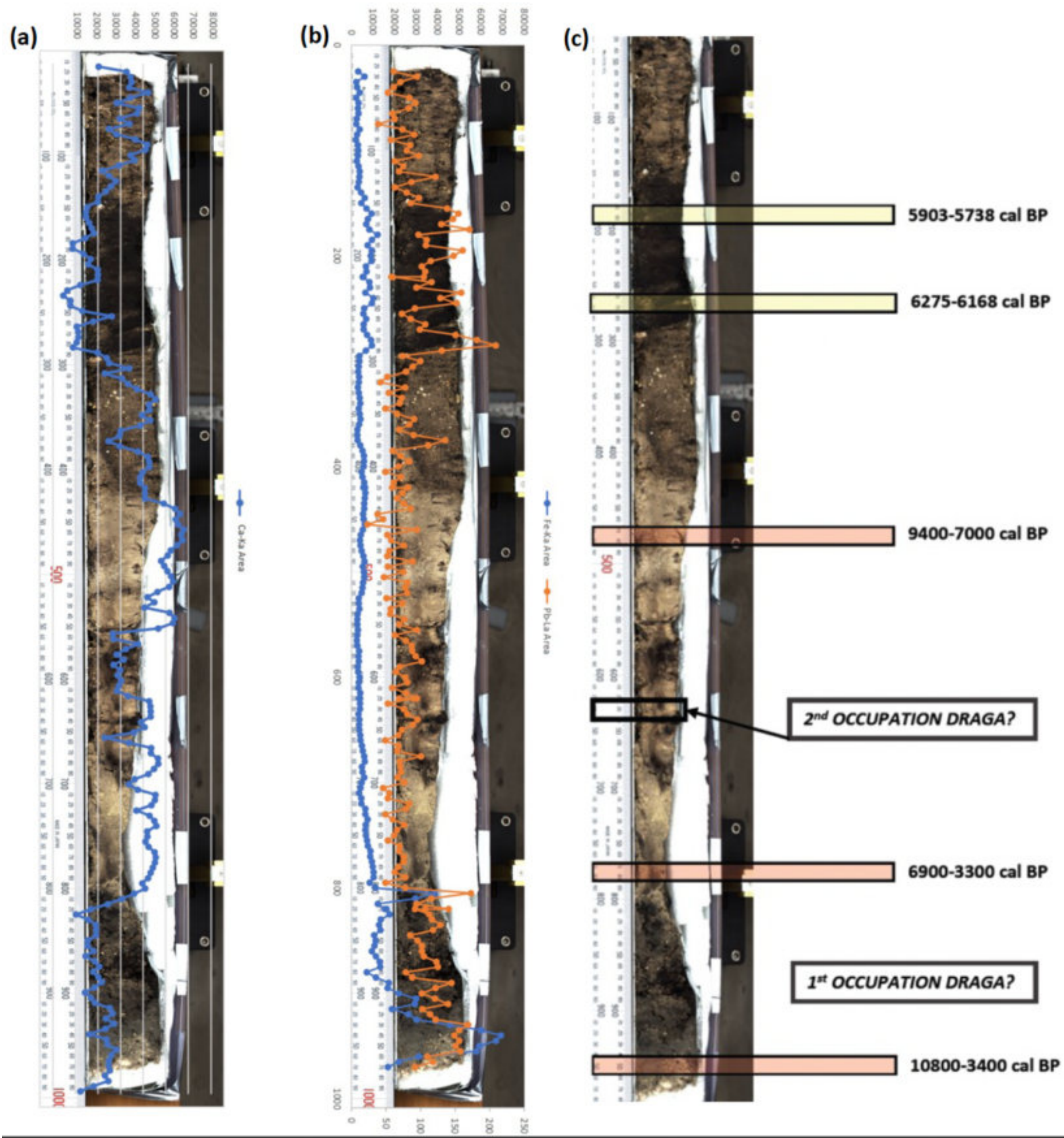


Figure 7.10. Microphotographs of Microfacies types in sector C (Appendix III). **a)** Thin carbonate layer with horizontally aligned root remnants (MFT-*C3*), C1, PPL**. b)** same as a) in XPL. **c)** Large aggregate (MFT-*C3*) between the thin layer (MFT-*C3*) below and sharp contact with the travertine (MFT-*D*) above, C1, PPL. **d)** Same as c, in XPL. **e)** Upper part of carbonate aggregate (MFT- *C3*) with charcoal fragments and ash remains under the overlying travertine slab, PPL and **f)** same as e, in XPL, C1. **g)** MFT-*C*. Leaf preserving its cellular structure due to wet conditions, surrounded by carbonate groundmass, C2, PPL. **h)** MFT-*C*. Roots and plant material in a carbonate groundmass; some appear charred and are probably associated with occupational remains, C2, PPL**. i)** Same as h. Note the presence of ash under XPL. **j)** *In situ charophyta* and a caracean gyrogonite in the center indicating natural deepening of the lake, C3, XPL. **k)** Highly bioturbated groundmass with pelletal microstructure including a vertical root and mollusk shells (MFT-*A*), C5, PPL**. i)** Horizontal roots associated with bioturbation, embedded in a pelletal microstructure of lake marl (MFT-*A*), C5, XPL. **m)** MFT-*P*. Peaty sediment and horizontal laminations; contact between lake marl and overlying peat, C9, PPL. **n)** Peaty sediment with embedded decayed organic material and massive microstructure, C9, XPL.

7.2.3. XRF core scanning of sediments

The core of sedimentary sequence extracted from sector C (Figure 6.8) was described and sampled for micromorphological, as well as radiocarbon and U/Th (Uranium/Thorium) dating. XRF (X-Ray fluorescence) scanning was implemented on the core of sediments extracted from sector C to study the composition of chemical elements of the sediments. The aim of this analysis was to complement further micromorphological observations in the distinction between sediments affected by organic input and those altered by carbonate content. As a result, that distinction would help to define better depositional environments and further alteration of the deposits before, during and after the occupations of the lacustrine site of La Draga. This analysis was complemented by chronological data regarding the periods of Neolithic occupation at La Draga (Figure 7.11).

The K-alpha (Kα) shown in association with the chemical elements (Figure 7.11) reflects the spectral line, that is, the characteristic energy/wavelength of the emitted photon when an electron vacancy in the K shell is filled by an electron from the L shell. The iron (Fe) values distributed all over the core are probably affected by periods of higher erosion or prolonged anoxia. This can create an oxidation environment further influenced by humic matter input and diagenesis (Makri *et al.* 2021). In fact, the Fe rates seem to be slightly higher in periods of peat formation and organic matter decay, first during the first occupation of La Draga and secondly, post-depositionally after the abandonment of the settlement *ca.* 6275-5738 cal BP. However, the highest rates of Fe are observed in the periods before and after the first occupation of La Draga. Before the first occupation of the settlement a possible regression of the lake level would have left the shore exposed for occupation, while immediately after the first occupation, a period linked with erosion processes and a chronological gap would have been the case before the beginning of the second occupation (See *Chapter 8*). In both cases, it could be associated with surface preparation and input of terrigenous material before each occupation (See *Chapter 7*). On the other hand, Pb (lead) signatures are consistent with human perturbations of the local environment and as a result they are present in periods of higher organic matter presence, during both occupations at La Draga.



Figure

Figure 7.11. XRF scanning of the *Core Draga 2017_ Sector C*. View of the core with **(a)** distribution of Ca-Ka (calcium) in comparison with **(b)** Fe-Ka (iron) and Pb-La (lead) areas. **(c)** Distribution of the dates over the *Core Draga 2017_ Sector C* obtained through radiocarbon dating (yellow color) and Uranium/Thorium (red color). From the bottom up, the 1st occupation at La Draga is found between the first two estimated dates, while signs of the 2nd occupation should be found between the second and the third date.

7.3. Overview: Anthropogenic and natural formation processes at La Draga

La Draga is a settlement situated in the interface between limnic and terrestrial conditions, as most of the lakeside settlements found in Europe (Menotti 2012). Various researchers have arrived at the conclusion that lacustrine settlements were both built directly on dry land and on wooden platforms risen above the water table (Leuzinger 2000; Menotti 2001). The data acquired by dendrochronological analyses have helped the archaeologists determine the settlement phases and the construction timelines, where they are available. The occupational patterns are differentiated constantly, adapting to the natural conditions and the depositional environment. This implies that the occupation is dynamic and not homogeneous for the whole site (Ismael-Meyer *et al.* 2013). The interplay between anthropogenic and geogenic formation processes is the key to reveal the dynamics behind lacustrine settlements alongside their depositional environment. All are means to the same objective that is to decipher past behavior. But past behavior cannot be deduced directly from the archaeological material, especially in prehistoric sites. The archeological material found on the field during excavation was gradually discarded and abandoned outside of its use context (Bernbeck 1997; Wiemann and Rentzel 2015). Therefore, it is important to reconstruct the formation and deformation processes that affected the archaeological features, in order to decipher the biography of a site.

The lake-dwelling deposits in La Draga were affected by alteration both during and after their abandonment. The application of micromorphological analysis of archeological sediments at the site of La Draga helps to understand the sedimentary dynamics before, during and after the Neolithic occupation. In every wetland environment water plays a significant role in the formation processes and the depositional dynamics. These affect the conservation and spatial distribution of archaeological artefacts. Both littoral and limnic processes have affected the deposits throughout the excavated sectors of the settlement. Furthermore, the analysis of pollen data and non-pollen palynomorphs provided valuable information about the environmental setting of occupation and the reconstruction of past vegetation along with anthracological and carpological analysis of macro remains (Revelles *et al.* 2014; Antolín 2016; Caruso and Piqué 2014).

The sediments identified through micromorphological analysis are both of natural and anthropic origin. Limnic sediments dominate the natural sedimentation at La Draga. The most common form created in lakes by carbonate precipitation is lake marl, which generally consists of silty carbonate muds. These have a high carbonate content and are mostly made of micrite. Micromorphological analysis of the limnic carbonates in La Draga (MFT-*A*) provided information on their depositional environment, as in the case of sector C. The lake marl was formed as homogeneous layers with fragmented mollusk shells as a result of reworking because of wave and current action on the lakeshore.

Anthropogenic sediments found in the case of la Draga and in lacustrine settlements in general are usually described as *installation horizons* (Ismael-Meyer *et al.* 2013; Wiemann and Rentzel 2015) or occupation surfaces. That is, the surface of lake marl in contact with the first accumulation of anthropogenic material. The transition from natural to anthropogenic sedimentation is abrupt and the contact between the two sediments is sharp. The sharp upper boundary suggests that the first installation of the inhabitants took place on a dry environment, where the lake marl surface would have been exposed and become dry and as a result hardened and compacted. In some cases, the lake marl surface has been exposed for a short time before the settlement was founded as suggested by the well-preserved pollen and mollusc shells (Magny 1978; Wallace 1999; Ismail-Meyer *et al.* 2013).

The site formation processes are either anthropogenic or natural and took place before, during and after the occupation of the settlement. Before the settlement foundation, the formation processes are mostly natural, in our case linked to sedimentation either from the lake or from the hinterland. In consequence, they reflect the environmental conditions and the climate at the time of installation. The depositional environment for the occupation layers (MFT-*C*) at La Draga is rather paludal. Nevertheless, during the occupation both natural and anthropogenic processes were forming and deforming the archaeological record. This is about both syn-sedimentary and post-sedimentary formation processes as described in literature (Wiemann and Rentzel 2015).

During or after the deposition of anthropogenic material various natural processes can take place and lead to alterations and modifications on the deposited material and sediments. These are mainly dependent on the water influence. Periodical water level decrease due to lake-level fluctuations can lead to the exposure of deposits and subsequent weathering. This is usually observed in the microstructure (cracking, blocky microstructure) (Figure 7.2.j), as well as in the organic material affected by microorganisms (e.g., mites who leave droppings made of organic remnants) (Wiemann and Rentzel 2015). Further depletion or humification of organic material is observed, while iron staining (Figure 7.5.b-d) and neoformed material such as gypsum crystals (Figure 7.3.j, Figure 7.4.b, MP292, Appendix I) are present mostly in voids associated with former roots and travertine slabs in sector A. Compaction of the organic layers is also frequent and is caused by syn-/post depositional trampling (Figure 7.6.h, Figure 7.10.n).

7.3.1. Trampling and poaching

One of the first signs of anthropic impact on sedimentation is evidenced at the installation horizon of the settlement where the constant trampling due to anthropic and/or animal traffic leads to the compaction of the lake marl surface. Trampling signs are the main component of the occupational layers identified in *MFT-C*.

Some of the characteristic effects and modifications of trampling present in the settlement of La Draga include the compacted nature of the microstructure and the fragmentation of the organic and non-organic materials (bones, charcoal fragments, molluscs) due to pressure and weight loading (Figure 7.4.c, Figure 7.5.j). This pressure due to trampling may sometime be responsible either for pushing downwards material that intrudes the underlying layer (Figure 7.3.i, j, Figure 7.6.c), or for transporting aggregates or nodules of sediment from one place to another (Figure 7.10.c, d). A horizontal arrangement of organic and inorganic material such as leaves, roots, plant fibers, and ash is also characteristic of trampling, as well as the development of laminations with horizontal orientation. In general, in the case of La Draga, MFT-*C* is representative of trampled minerogenic deposits, which constitute a type of non-constructed floor (Rentzel *et al.* 2017). They usually include embedded anthropogenic material such as charcoal fragments, bone, roots, etc. In the case of the layer associated to the first anthropogenic event in sector C, trampled minerogenic deposits appear in the form of a thin laminated and horizontal carbonate layer. Its fabric is crystallitic, while roots and organic material are also included.

Trampling on wet or water -saturated sediments is often described as poaching (Courty *et al.* 1989; Gebhardt and Langorh 1999; Rentzel *et al.* 2017; Macphail and Goldberg 2018). Some microscopic deformation structures are usually associated to poaching, as the result of compression on mostly water-saturated sediments (Karkanas 2018). The features most often observed at La Draga and linked to deformation under ductile conditions are rotation and squeezed features, involutions and convolutions (Figure 7.4.e, f, Figure 7.6.b), as well as wavy layers with distinct sorting (Figure 7.4.i, j) (Karkanas 2018; Rentzel *et al.* 2017).

7.3.2. Accumulation

The accumulation associated with the installation horizon usually consists of wood remains from wood working for construction, other materials used during the process of dwelling construction, as well as food preparation remains (Ismail-Meyer *et al.* 2013). Further accumulation of mixed anthropogenic material is mainly produced after the construction of the pile dwellings and is associated to everyday use of space and a variety of anthropic activities, such as keeping animals in pens, food preparation, local waste disposal, etc (Figure 7.2.d, e, Figure 7.6.e, f) Sometimes accumulations of charred material and ash remains could be evidence of midden deposits (Wiemann *et al.* 2012) related to discard activities, as in the case of sector A.

7.3.3. Fire events

Fire events under relatively dry conditions are common in sector D. They are described by MFT-*F* and are defined as accumulations of burned charcoal fragments, wooden remains and seeds with little or no sediment included. This suggests probably burning on a relatively dry environment. These might be remnants of burnt down dwellings or of burning in an enclosed structure (Figure 7.7.a-f, MP125, MP126-2/3, Appendix II).

7.3.4. Flooding processes & lake level fluctuations

Flooding processes are frequent in lakeside settlements, and they can be of lower or higher magnitude. In the case of La Draga, rainfall may have been responsible for water level fluctuations, as it is often the case for lakes with large catchment areas (Keddy 2010; Ismail-Meyer *et al.* 2013). Some of the most common effects of flooding processes at La Draga include inwash of material brought either from the lake or from the hinterland as well as erosion and redeposition of material. In sector A, terrigenous input has been the result of rain wash/sheetwash episodes over the travertine structures (MP318-5, Appendix I), whereas in sector D, erosion of previous sediments and redistribution of material has occurred before the travertine paved surface was formed (MP2-3, MP126-2/3, Appendix II). In the former case, these effects are visible in the form of grain size separation creating some graded bedding.

In the case of sector C, the deposition of lake marl due to lake level increase and probably lake transgression may have been happened after the anthropogenic accumulations at this part of the settlement.

While most of the studied lacustrine sites in Switzerland seem to have had a last flooding episode resulting in lake marl coverage before the abandonment, this is not exactly the case for La Draga. In the case in sector C, which is closer to the lake, the area has been affected by lake transgression and largescale flooding leading to abandonment. In the case of sector A, a final flooding episode and a lake marl deposit has not been observed microscopically, since this area is at the landward part of the settlement, at greater distance from the lake. The case is probably different for sector D, where although a lake marl flooding episode hasn't been detected, some lake marl layers have been observed macroscopically at the lakeward part of the sector before the travertine pavement.

Based on well distinguished flooding episodes in the sedimentary record through micromorphological observation, seasonal processes can be deduced as well.

7.3.5. Peat formation

Organic matter in lacustrine settlements is usually transported from the close surroundings to the settlement and is later anthropically treated, used, transformed, and eventually integrated into the archaeological record. The accumulation of organic material and the formation of peaty layers are present throughout all excavated sectors at La Draga. Nevertheless, its composition is different depending on the depositional environment under which it was formed.

In sector A, organic matter alongside mixed anthropogenic material was accumulated after the abandonment of travertine structures (MP318-6, Appendix I, Figure 7.2.g, Figure 7.5.i), whereas in sector C, peat was accumulated gradually on the lakeshore through low grade wave action (Figure 7.9.c, Figure 7.10.m, n). For peat to accumulate the water level needs to be stable, otherwise peats would be consumed by fires and decomposition. That's why the rate of accumulation of organic matter must be higher that the decay rate (Keddy 2010). Peats remain wet most of the time due to their capacity to retain water. The most covered they are by water the better they are preserved and less prone to post-depositional deformations.

Post-depositional alterations of peaty sediments include oxidation (sector D), animal and/or human trampling (sector A), humic content (sector D) (Figure 7.2.i, Figure 7.6.h). These signs are visible in sectors A and D as there wasn't enough water coverage over the peaty layers to maintain the organic matter.

7.3.6. Decaying processes

These are closely related to water influence in lakeside settlements and constitute a destruction process of plant material. The decay of plant matter after the deposition under burial conditions is lower than before and during the deposition. Organic material preservation depends on the water fluctuation. During deposition, the decay is faster when the water table drops. On the other hand, diagenesis after burial under permanently anaerobic conditions is minimal. The preservation condition of the organic material has been different between sector A and sector D. On one hand, sector A is situated at greater distance from the lake shoreline on a higher elevation (Figure 4.11) and as a result the organic material associated to the construction of wooden platforms is lost due to drier conditions. On the other hand, the archaeological layers have been preserved anaerobically in sector D, as it is located under the water table.

7.3.7. Processes related to abandonment

The abandonment of a lacustrine settlement is usually difficult to discern due to post-depositional erosion processes. Nevertheless, what is discernible under the microscope, are processes that can be associated with the abandonment of a lacustrine settlement. These are fire events and evidence of lake level increase after the abandonment of the settlement. Normally abandonment is followed by peat formation or lake marl covering. In the case of La Draga, possible abandonment related processes are identified fire events in sector D. These are encountered over the travertine paved surface and before the peat formation, but also after the first occupation phase where mixed discarded/dumped material is observed before an erosion episode and the overlying pavement of travertines (MP125, MP126 2/3, MP2-2, Appendix II, Figure 7.7.a-f). In the last case, a chronological hiatus is suggested, although we cannot determine its duration (*Chapter 8*). In sector A, a similar peat formation is observed (MFT-*E*) after a sheetwash event, associated with flooding processes and transport of material from the hinterland that covered the travertine structures. Finally, in sector C the processes related to abandonment are associated with a lake level increase after the second occupation (C3, Appendix III) and to subsequent peat formations in most recent years (C9, Appendix III).

8. TOWARDS A CHRONOLOGICAL FRAMEWORK OF THE DEPOSITIONAL EVENTS AT LA DRAGA

So far, stratigraphic analysis (*Chapter 6*) and micromorphological observations (*Chapter 7*) suggest the existence of a minimum of two different site occupations characterized by different construction trends of the inhabited space. They are clearly differentiated at the sector B-D, as the travertine pavement overlaps the wooden debris. In sector A, stratigraphical dynamics are totally different, since the levels corresponding to both occupations are coined until they merge into one, making the correlations of layers and phases unclear (Palomo *et al.* 2014). The goal of this analysis is to place both Neolithic occupations in the calendrical scale by integrating radiometric and dendrochronological dates, as well as sedimentary and micro-stratigraphic information and archaeological materials. The resulting chronological model is discussed in the midst of current debates on the origins of the Early Neolithic in the western Mediterranean region.

8.1. The data (^{14}C dates, wiggle-matching)

8.1.1. Radiocarbon dates

62 ^{14}C dated samples from La Dragas' old and new excavations have been used in the present analysis out of approximately 80 radiocarbon dated samples. Nonetheless, many of the dates coming from older excavations (1990s) were mostly charcoals and seeds dated by the conventional method giving more than 50 years of standard deviation. Therefore, they were left out of the analysis. Some of these dates have been published through the years (Bosch *et al.* 2000; 2006; Tarrús 2008; Terradas *et al.* 2013a; Palomo *et al.* 2014; Bogdanovic *et al.* 2015; Andreaki *et al.* 2020; Piqué *et al.* 2021b), while as the research went on, more were included in the present analysis (Andreaki *et al.*, *in press*). The samples come from short and medium-large lived archaeological material from all the sectors of the site (Table 8.1). The total amount of dated samples corresponds to fauna remains, charcoal, cereal grains, bones and wooden material retrieved during excavation. Sectors A and B-D are the best dated, with 29 dates samples coming from sector A, 15 from sector B and 12 from sector D. Only 6 radiocarbon dated samples are available from the underwater sector C, where the variety of sediments affecting the archaeological layers includes carbonated lake marl and sands, as well as peaty sediments full of decayed organic matter.

Most samples have been retained for analysis, even with relatively large lab errors. Only when statistical analysis proved that there is an error in the estimate, the date has been processed as an outlier. AMS and conventional methods have been both considered, and only when discrepancies are very clear, a separate analysis has been carried out.

Table 8.1. Radiocarbon (^{14}C) dates from archaeological samples in La Draga and their respective ChronoModel events.

Lab ID	Sample	Context	Sector	Method	CRA ^{14}C years BP[21]	SD	δ13C (o/oo)	δ15N (o/oo)	Depositional Event
Ua-62940	*Quercus sp. deciduous*	Wooden post PV089	A	AMS	6401	38	-26.8		Event 1. Construction
Beta-453513	*Laurus nobilis*	Wooden post PV1300, Structure 261	A	AMS	6280	30	-28.5		Event 1. Construction
Beta-481571	*Quercus sp. deciduous*	Wooden post PV1311, Structure 260	A	AMS	6270	30	-25.08		Event 1. Construction
UBAR-314	*Quercus sp. deciduous*	Wooden post PV106	A	CON	6410	70			Event 1. Construction
Beta-425194	*Quercus sp. deciduous*	Wooden post PV1399, Structure E258	A	AMS	6170	30	-26.8		Event 1. Construction
Ua-62941	*Quercus sp. deciduous*	Wooden post PV738	B	AMS	6308	39	-27.8		Event 2. Construction
UBAR-1308	*Quercus sp. deciduous*	Wooden post PV605	B	CON	6270	45	-26.77		Event 2. Construction
Ua-62942	*Quercus sp. deciduous*	Wooden post PV986	D	AMS	6285	39	-27.1		Event 3. Construction
Beta-425196	*Quercus sp. deciduous*	Wooden post PV153, Structure E73	A	AMS	6310	30	-25.7		Event 4. Repair
Beta-481572	*Quercus sp. deciduous*	Wooden post PV1441, Structure E263	A	AMS	6320	30	-25.93		Event 4. Repair

[21] Years BP refer to conventional radiocarbon ages (present is AD1950) (Stuiver and Polach, 1977).

Beta-425195	*Quercus sp. deciduous*	Wooden post PV191, Structure E6	A	AMS	6260	30	-26.5		Event 4. Repair
Beta-505910	*Quercus sp. deciduous*	Wooden post PV1450	A	AMS	6210	30	-27.2		Event 4. Repair
Beta-453512	*Charcoal, Quercus sp. deciduous*	Structure E263	A	AMS	6280	30	-25.4		Event 4. Use
UBAR-1247	*Quercus sp. deciduous*	Wooden post PV582	B	CON	6295	45	-27.19		Event 5. Repair
UBAR-1248	*Quercus sp. deciduous*	Wooden post PV584	B	CON	6240	35	-25.08		Event 5. Repair
UBAR-1293	*Wood*	Wooden post PV600	B	CON	6220	45	-28.19		Event 5. Repair
UBAR-1309	*Wood*	Wooden post PV607	B	CON	6205	45	-27.46		Event 5. Repair
Beta-315052	Cereal	Layer NAVII	D	AMS	6310	30	-22.7		Event 6a. Use
ETH-8887**4**	*Hordeum vulgare*	Layer NAVII	D	AMS	6152	26	-23.4		Event 6b. Use
ETH-88873	*Triticum aestivum/durum/turgidum*	Layer NAVII	D	AMS	6131	26	-24.5		Event 6b. Use
Beta-315049	Cereal	Layer NAVII	D	AMS	6140	40	-24.5		Event 6b. Use
ETH-88872	*Triticum aestivum/durum/turgidum*	Layer NAVII	D	AMS	6116	26	-25.0		Event 6b. Use
ETH-88875	*Triticum aestivum/durum/turgidum*	Layer 7001	D	AMS	6110	26	-25.0		Event 28. Use
Echo-2453.1.1	*Papaver somniferum*	Layer 7001	D	AMS	6060	110			Event 28. Use

Beta-278255	Fauna	Underwater layer II	C	CON	6270	40	-21.4		Event 7a. Use
Beta-278256	Fauna	Underwater layer II	C	CON	6170	40	-21.1		Event 7a. Use
ETH-88870	Cereal	Underwater layer II	C	AMS	6098	26	-24.7		Event 7b. Use
ETH-88871	Cereal	Underwater layer II	C	AMS	6123	26	-24.8		Event 7b. Use
Beta-137197	*Quercus sp. deciduous*	Wooden tool, Layer II	B	AMS	6290	70	-25.0		Event 8a. Use
Beta-137198	*Buxus sempervirens*	Wooden tool, Layer II	B	AMS	6270	70	-25.0		Event 8a. Use
Beta-588213	Fauna	Layer II	B	AMS	6260	30	-21.0	+3.9	Event 8a. Use
Beta-0000[22]	Fauna	Layer II	B	CON	6184	27			Event 8b. Use
OxA-20231	Cereal	Layer II	B	AMS	6163	31	-23.4		Event 8b. Use
OxA-20232	Cereal	Layer II	B	AMS	6121	33	-23.4		Event 8b. Use
Echo-2448.1.1	*Papaver somniferum*	Layer II	B	AMS	6090	90			Event 8b. Use
ETH-88869	Cereal	Layer II	B	AMS	6142	26	-25.6		Event 8b. Use
Beta-588214	Fauna	Layer II	B	AMS	6100	30	-21.2	+6.5	Event 8b. Use
OxA-20233	Cereal	Layer IIIb	A	AMS	6179	33	-22.3		Event 9. Second Occupation
OxA-20235	Cereal	Structure E21	A	AMS	6143	33	-22.7		Event 10. Second Occupation
Beta-438952	*Triticum durum*	Structure E6	A	AMS	6150	30	-24.3		Event 11. Second Occupation

[22] Beta-0000 is a date of which we dispose no lab number at the moment. However, the ^{14}C date has been already used in previous publication (Bogdanovic et al. 2015).

OxA-20234	Cereal	Structure E5	A	AMS	6127	33	-22.5		Event 12. Second Occupation
HD-15451	Cereal	Structure E3	A	AMS	6060	40			Event 13. Second Occupation
UBAR-313	Cereal	Structure E56	A	CON	6010	70			Event 14. Second Occupation
ETH-88867	Cereal	Structure E14	A	AMS	6108	26	-24.5		Event 15. Second Occupation
ETH-88868	Cereal	Structure E65	A	AMS	6141	26	-23.6		Event 16. Second Occupation
Beta-579521	Cereal	Structure E26	A	AMS	6140	30	-23.3		Event 17. Second Occupation
Beta-580972	Cereal	Structure E52	A	AMS	6130	30	-23.0		Event 18. Second Occupation
UBAR-311	Charcoal	Structure E40	A	CON	5970	110			Event 19. Second Occupation
ETH-88876	Cereal	Structure E254	A	AMS	6142	26	-24.9		Event 20. Second Occupation
Beta-422871	*Bos taurus*	Structure E260	A	AMS	6210	30	-18.4	+4.8	Event 21. Second Occupation
Beta-428247	*Sus domesticus*	Structure E258	A	AMS	6130	30	-20.8	+4.5	Event 22. Spatial Rearrangement
Beta-422872	*Cervus elaphus*	Structure E261	A	AMS	6120	30	-21.0	+7.1	Event 23. Spatial Rearrangement
Beta-481573	*Bos taurus*	Structure E263	A	AMS	5980	30	-19.94		Event 24. Last Neolithic Occupation
Beta-422869	Fauna	Structure E258	A	AMS	6060	30	-20.9	+4.5	Event 25. Last Neolithic Occupation
Beta-425198	*Sus domesticus*	Structure E261	A	AMS	5990	30	-20.5	+4.6	Event 26. Last Neolithic Occupation
Beta-579522	Cereal	Structure E255	A	AMS	5990	30	-24.1		Event 27. Last Neolithic Occupation
Beta-315050	Cereal	Layer NAIV	D	AMS	6210	40	-23.4		Event 29. Second Occupation

Beta-315051	Cereal	Layer NAIIa	D	AMS	6230	40	-23.7		Event 30. Second Occupation
Beta-298438	Fauna	Layer NAIII	D	AMS	6070	40	-21.1		Event 31. Last Neolithic Occupation
Beta-505896	Organic matter	Peaty layer 5b	C	AMS	5360	30	-29.7		Post-Occupation I
Beta-505895	Organic matter	Peaty layer 3b	C	AMS	5060	30	-26.2		Post-Occupation II
Beta-291443	*Triticum*	Structure E240	D	AMS	4860	40	-24.1		Post-Occupation III

8.1.2. Dendrochronological data

The excavations carried out to date at the site, have made it possible to recover 1271 piles and 494 horizontal timbers, counting 1765 structural timber logs that can potentially be dendrochronologically measured. The dendrochronological analysis of the piles carried out by Patrick Gassmann and Oriol López-Bultó, is still in progress (Gassmann 2000; Piqué *et al.* 2021b; López-Bultó *et al.*, *in press*). So far, tree-rings from 136 piles and horizontal timber logs have been described and measured, providing a floating dendrochronological sequence that covers an interval of 265 years. The dendrochronological sequence could not be correlated with any other, due to the absence of an absolute dated dendrochronological sequence covering the Neolithic period up to the present of the North-eastern part of the Iberian Peninsula.

The preservation of the last growth ring (*cambium. cf.* Rathgeber *et al.* 2016) in 66% of the dendrochronologically measured allows establishing a single depositional event of tree felling during the winter of 237/238 year of the local tree ring sequence (Figure 8.1). The dendrochronological dated piles come from all excavated sectors, and it suggests that the wooden platform or platforms on which the dwellings were built were distributed throughout the excavated area and that trees used in their construction were cut at the same moment (Piqué *et al.* 2021b).

The strict contemporaneity of most of the wooden elements used for construction is quite unusual compared with other apparently contemporaneous lakeside settlements. In Switzerland (and throughout the Alpine Arch) in sites dating to the Early Neolithic period, settlements are generally smaller, and it is unlikely the construction of built structures occurred simultaneously, as it happened in Hornstaad-Hörnle IA, built from 3910 BC onwards (Billamboz 2006), and Sutz-Lattrigen/Riedstation, built between 3393 and 3389 BC (Hafner 1994). On the contrary, settlements grew gradually, expanding to neighbouring areas. Similar processes are documented for more recent settlements like Cortaillod-Est, dated in the Final Bronze period (Gassmann 1984; Arnold 1986).

Prehistoric inhabitants built mostly with 'fresh' tree trunks (piles, planks, and boards), not only with what appears to be recycled wood coming from standing dead oaks, but also from wood stored or recovered elsewhere. Eight percent of the measured logs appear to be older, having been cut between the winter of 233/234 and the winter of

236/237. They may come from reuse, stored wood, or dead standing trees. The latter (year 236) may have the same origins as the older ones or, more plausibly, have been part of a preparatory felling for the main site that would begin the following year (López-Bultó *et al., in press*).

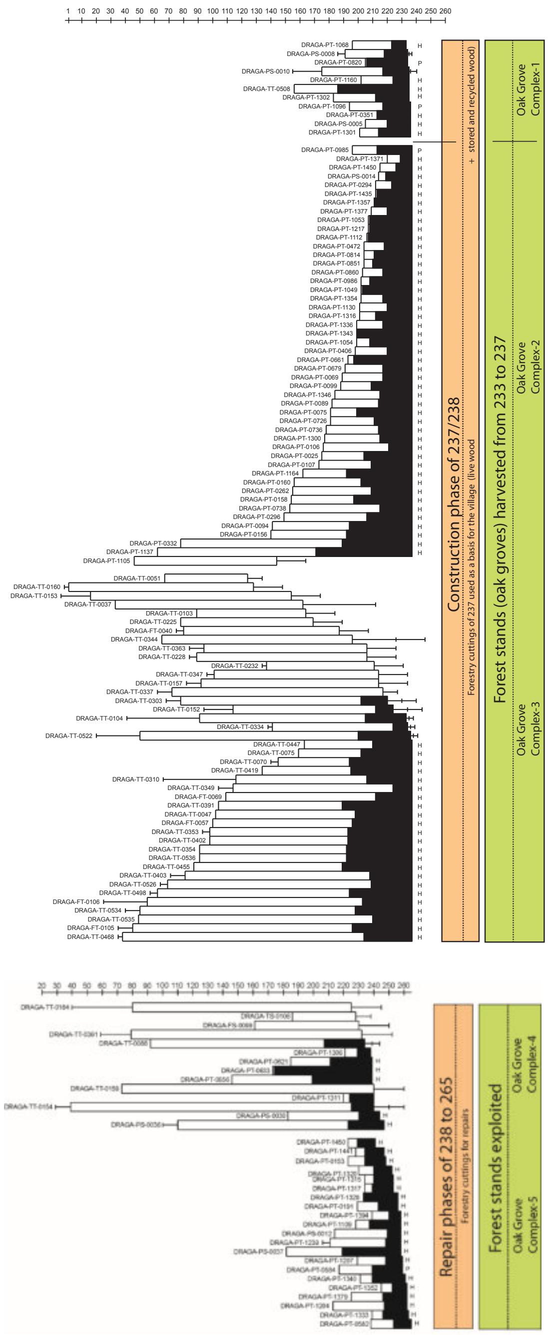


Figure 8.1. The local dendrochronological sequence at La Draga site. The wooden posts corresponding to both construction and repair phases are represented respectively in the diagrams (*Figure after Patrick Gassmann*).

After the year 237/238 new piles were added as reinforcement and repair of the structures (platforms and/or dwellings). These trees were cut between three and 28 years after the first tree-felling. Given that no other pile has a more recent tree-ring, we may assume that maintenance and repair of built structures stopped after 28 years (Figure 8.2). However, it is important to consider that tree trunks used for repair appear to be younger and thinner than those used for initial construction, and they are more difficult to recognize as construction elements (López-Bultó *et al*., *in press*). There are still many thin trunks waiting for tree-ring count, and therefore the available last tree ring (265 in the local sequence) is not necessarily the last one, nor does it represent the final event of the first occupation.

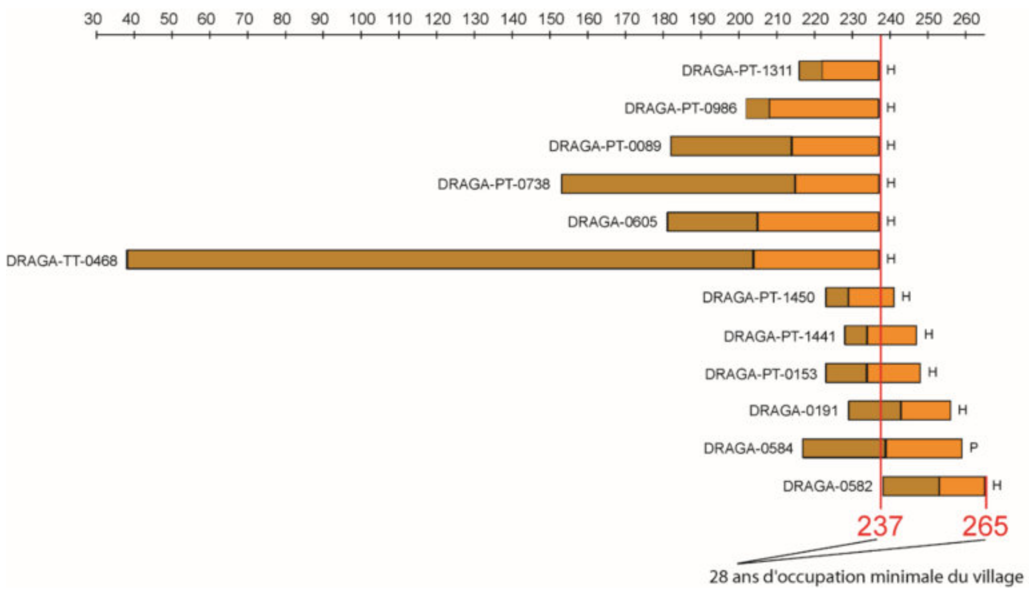


Figure 8.2. An extract of the dendrochronological sequence at La Draga site with the minimal duration of the settlement's occupation based on the twelve radiocarbon dated wooden piles (*Figure after Patrick Gassmann*).

From the concentration of trunks cut at the same year, it appears that most wooden structures in La Draga were built in one year (perhaps two), during the winter of the dendrochronological year 237/238 and during the previous year 236 of the local tree-ring sequence. In all four excavated sectors (*A, B, C, D*), there are logs coming from the same felling in 237/238, suggesting the strict contemporaneity of wooden structures all along the Neolithic settlement (Figure 8.3). This would imply that the first village of la Draga was built in one go, building wooden constructions all around the settlement area (López-Bultó *et al., in press*).

Dendrochronological tree ring estimation and radiocarbon dates for the last growth ring (*cambium*) in twelve samples are available, including seven samples from the installation tree-felling, and other six from timber logs used after that date.

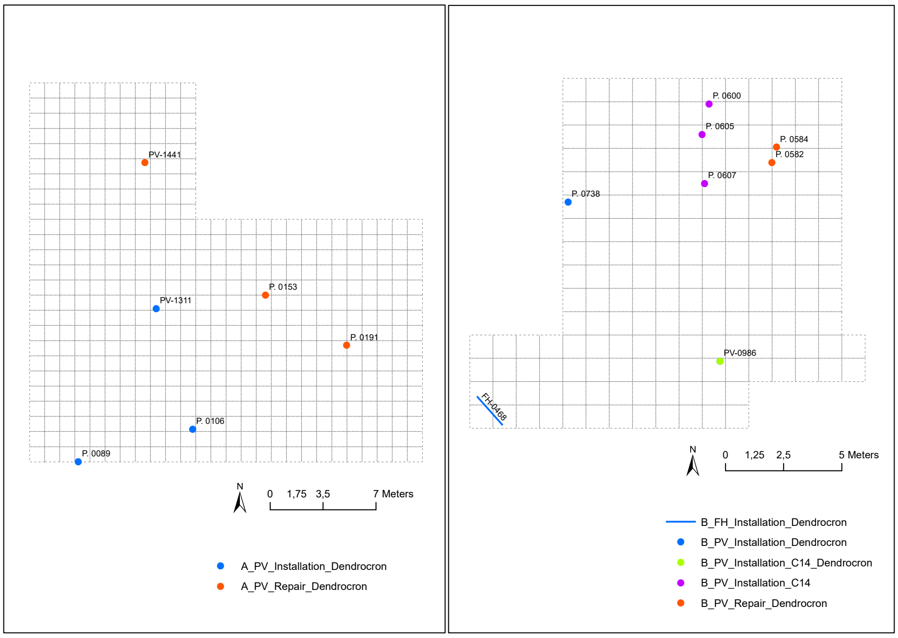


Figure 8.3. Map of spatial distribution of the dated wooden piles at La Draga, including both the installation (year 237/238) and the repair associated piles. Sector A on the left and sector B-D on the right (*Figure after Núria Morera*).

Table 8.2. Results of the dendrochronological analysis of the wooden piles and horizontal elements used either for construction and/or repair purposes at La Draga (Piqué *et al.* 2021b; López-Bultó *et al., in press*).

Number	Sectors	Species	Age	Season of logging	Dendrochronology dating (Internal chronology) First ring date / Date of the last ring	Oak forest stand	Dating ^{14}C							
							Method	Laboratory numbers	BP	sd	1 σ		2 σ	
PT-1311	A	QU	22 y	Winter	216 à 237	II-A	A	Beta481571	6270	30	5299	5225	5316	5211
PT-0986	D	QU	36 y	Winter	202 à 237	II-A	A	UA62942	6285	39	5305	5225	5370	5200
PT-0089	A	QU	56 y	Spring	182 à 237	II-B	A	UA62940	6401	38	5470	5320	5470	5310
PT-0738	B	QU	85 y	Winter	153 à 237	II-C	A	UA62941	6308	39	5320	5225	5370	5210
PT-0605	B	QU	57 y	Winter	181 à 237	II-D	C	UBAR1308	6270	45	5304	5219	5341	5072
TT-0468	D	QU	168y	Winter	38 à 237	II-D	A	UA62943	5971	41	4910	4790	4960	4720
TT-0468	D	QU	168y	Winter	38 à 237	II-D	A	Ua-65467	5979	37	4931	4798	4987	4732
PT-0106	A	QU	59 y	Spring	178 à 237	II-A	C	UBAR314	6410	70	5472	5322	5481	5217
PT-1450	A	QU	19 y	Winter	223 à 241	III-A	A	Beta505910	6210	30	5282	5066	5301	5049
PT-1441	A	QU	20 y	Winter	228 à 247	III-A	A	Beta481572	6320	30	5357	5226	5472	5081
PT-0153	A	QU	26 y	Winter	223 à 248	III-A	A	Beta425196	6310	30	5326	5228	5361	5223
PT-0191	A	QU	28 y	Winter	229 à 256	III-B	A	Beta425195	6260	30	5302	5228	5315	5215
PT-0584	B	QU	43 y	Spring	217 à 259	III-B	C	UBAR1248	6240	35	5303	5085	5308	5071
PT-0582	B	QU	28 y	Winter	238 à 265	III-B	C	UBAR1247	6295	45	5313	5226	5374	5080

8.2. Temporal order of depositional events and the occupational phases at La Draga

The Harris Matrix diagrams (Figures 6.1, 6.5, 6.8) describing stratigraphic relationships between excavated units were translated into a sequence of depositional events, whose temporal range depend on the isotopic events depositionally identified at each minimum spatial unit of reference.

8.2.1. Installation horizon: Construction and repair of pile dwellings. ^{14}C Wiggle-Matching of wooden piles

The oldest depositional events correspond to the construction of wooden platforms, and integrate the isotopic events measured from the installation vertical piles at each sector: Event 1 in sector A, Event 2 in sector B and Event 3 in sector D.

In sector A, deep on the geological lake marl under the archaeological level, only the bottom tips of the vertical piles driven into the original carbonate sands have been preserved (Event 1). At the same time, the occupation layers with organic and anthropogenic remains are affected and compacted by direct or indirect trampling from the travertine slabs above.

Event 4 corresponds to the piles used for the successive repair of the platforms documented at this area, but also archaeological material found in the sedimentary filling of post-holes.

Sectors B and D, where wooden elements and organic material have been very well preserved under the actual phreatic level, have a more complex stratigraphy. High-resolution microstratigraphic analysis (*Chapter 7*) reveals a compact sediment, because of trampling action of the surface, while at the same time the decomposition of organic matter is observed. Sector B is the closest to the old lake shoreline. Radiocarbon dated samples from piles related with platform repair have been integrated into Depositional Event 5.

Most radiocarbon dated wood samples associated to the same dendrochronological year 237/238 (*Beta 481571, UA-62942, UA-62940, UA-62941, UBAR314, UBAR1308*) pass the Ward and Wilson (1978) test. Sample *Beta 505910* appears to be a clear outlier. Using the IntCal20 calibration curve, the statistical combination of the 6 radiocarbon dates that passed the test give an estimate of 6311±17 BP, and a calibrated confidence interval between 5313 cal BC and 5222 cal BC (68.3 % interval). The median is situated at 5254 cal BC.

A wiggle-matching Bayesian model using the radiocarbon dates and the dendrochronological gap between foundational piles and the ones assigned to later reparations has been estimated using OxCal 4.4. (Figure 8.4). The model has very poor agreement (A_{comb}= 28.7) given the presence of three additional outliers (*UA-62940*, *UBAR-314* and *Beta-505910*). After deleting those outliers, general agreement increases significantly (A_{comb}= 136.6) (Figure 8.4).

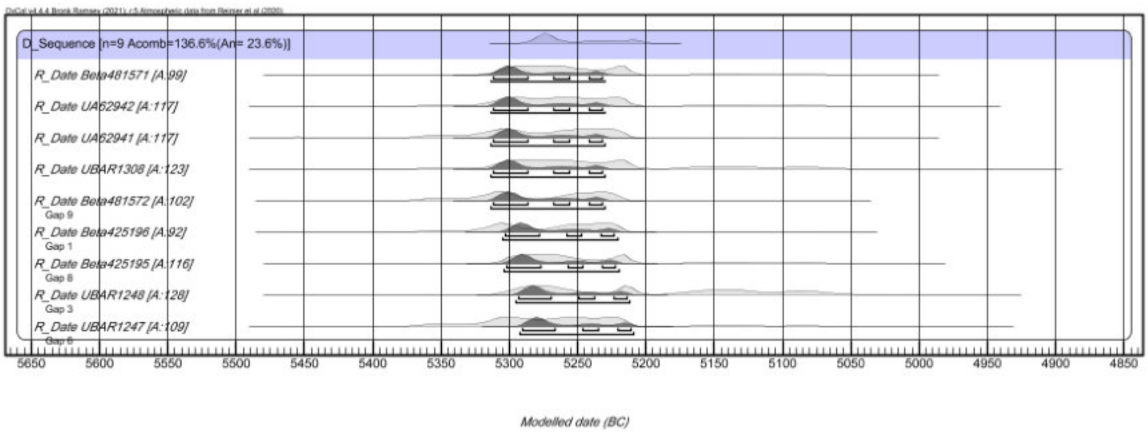


Figure 8.4. Wiggle-matching of dendrochronological ordered piles after deleting outliers. Calculated using OxCal 4.4. and IntCal20 calibration curve.

The model suggests an estimated date around 5293 cal BC (median of the 5312-5233 cal BC at 68.3%) for the tree-felling (year 237/238). Tree-ring 247 cannot be differentiated from tree-ring 237/238. However, the model seems to differentiate successive tree-rings correctly: TR248: 5284 cal BC, TR256: 5283 cal BC, TR259: 5275 cal BC. The last well documented repair (Tree-ring at the year 265) has been documented at an estimated date around -5272 (median of the 5291-5212 cal BC at 68.3% interval).

In practice, the size of the index of agreement in a wiggle-matching model varies depending on the way original dates over-quote or under-quote their respective lab errors, but also on how constrained the wiggle-match sequence is by the shape of the calibration curve (Wacker et al. 2020). At this point, it is important to remark the clear bimodality of IntCal13 and IntCal20 calibration curves after 7100 BP, probably caused by variability of atmospheric ^{14}C content at this time interval or by poor original sampling (Oms *et al.* 2016; Manen *et al.* 2019; Reimer *et al.* 2020; Bayliss *et al.* 2020). This adds uncertainty to the estimation of the calendar age of outer tree-rings. For the time being, only outer tree-rings have been dated using radiocarbon.

We are aware that using inner rings of some of the piles we will have the chance to get a steeper part of the calibration curve into our wiggle-match. Dendrochronological analysis is not yet finished and when more samples get extracted, the more they will "spread out", and the better the resulting precision will be. This can be achieved by minimizing the number of possible positions where the distribution of radiocarbon dates can match the calibration curve. For the moment, existing dates only serve as an initial hypothesis.

Consider radiocarbon date *UBAR1247*, dating tree-ring 265 (Figure 8.5).

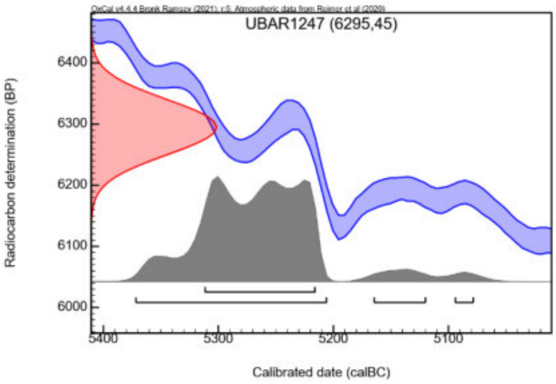


Figure 8.5. Calibration of single date *UBAR1247* (tree-ring 265 of the local dendrochronological sequence). Oxcal 4.4. IntCal20 calibration curve.

Posterior probability is clearly divided into two well-differentiated subintervals, before and after 5200 cal BC, where the calibration curve IntCal20 changes abruptly its direction. The subinterval 5370-5207 cal BC concentrates the maximum confidence (90.2%), and therefore, a much shorter temporal duration is to be expected for the first occupation, between 5310 and 5250 cal BC. Wiggle-Matching allows us to pinpoint the most probable estimate around 5280 cal BC, and this figure has been used as a *Terminus Ante Quem* for dating First Occupation, and for estimating the beginning of the short abandonment of the settlement that followed the First Occupation.

8.2.2. First Occupation: Wooden pile-dwellings

Apart from the depositional events associated to the installation (1, 2, 3, 4 and 5), the first occupation of wooden pile-dwellings at La Draga, also includes depositional events 8 (8a, 8b) in sector B, 6 (6a, 6b) and 28 in sector D and 7 (7a, 7b) in sector C.

Event 8 in sector B consists of nine faunal bones, cereal seeds and wooden tools found in contact with preserved wooden elements. These were recovered from stratigraphic unit *II* in sector B, which corresponds to units *VIII and VII* in sector D.

Depositional Event 6 includes a single associated isotopic event (6a), a cereal seed (Beta 315052), found at the bottom of stratigraphic unit *VII*, as well as four additional cereal seeds (*Hordeum* and *Triticum*), associated with domestic activities that occurred on the wooden platforms (filling of stratigraphic unit *VII*) (6b). Depositional Event 28 is also functionally associated with Event 6, and it corresponds to stratigraphic unit *7001*, in which, two seeds (*Triticum* and *Papaver somniferum*) were dated.

Wiggle-Matching only allowed for an estimate of the temporality of depositional events 1, 2, 3, 4 and 5, based on isotopic events associated with the last growth ring of piles used for construction and posterior repair. There are six additional radiocarbon dated samples that have been stratigraphically associated with this first occupation (Depositional Events 6a, 7a, 8a). They do not pass the Ward and Wilson test and therefore the strict contemporaneity of all archaeological deposited material from this first occupation is not directly suggested, even though its duration was presumably very short given the small number of tree rings between piles used for the installation and the youngest piles used for repair (approximately 30 years).

In Sector A, Depositional Event 4 is statistically coherent around 5266 cal BC (median of the 5303-5217 confidence interval 68.3%), well within the most probable period of use of the wooden platforms estimated by the wiggle-matched model.

In Sector B, all dated samples from Depositional Event 5 pass the Ward and Wilson test and appear to be strictly contemporaneous with sampled dates from Depositional Event 8a. A combined date around 5271 cal BC (5298-5216 cal BC, 68.3% confidence interval) seems to be a good estimate for the moment of platform use and successive repairs. Although sample *Beta-315052* from Depositional Event 6a seems to be older, all dates related with platform use and repairs from sectors B and D pass the Ward and Wilson test. The same can be said about contemporaneous dated samples from sector A.

Two dated samples come from Depositional event 7a from underwater Sector C and pass the Ward and Wilson test. One of these, however, Beta-27856, becomes an outlier when compared with all contemporary sampled dates related with this moment of use and repair of wooden platform. In Sector C, currently covered by lake water, the stratigraphic sequence is affected by subsequent lake marl depositions, preceding and following the archaeological layers. The alteration between depositional processes of peat, carbonate sandy sediments and lake marl silt is usual in wetland sites (Chapter 3, Chapter 7). The first archaeological layer, in close contact with the carbonated sands of the original lake ground, has a mean thickness of 15 cm. It is characterized by the presence of wooden elements, and a big amount of vegetal remains, as well as remains of fauna, pottery, and animal bones.

Radiocarbon dates from underwater Sector C do not change the broader conclusions. Four faunal bones and cereal seeds come from this sector. Statistically, the four radiocarbon dates do not pass the Ward and Wilson (1978) test. The stratigraphically deepest dated sample (Depositional Event 7a) appears to be older (68.3 % confidence interval: 5372-5067 cal BC) than the rest (Depositional Event 7b) (68% confidence interval: 5216-4981 cal BC), showing a relevant degree of chronological overlapping.

8.2.3. Transition

Dated samples from depositional events 6b, 8b from sector B and D, and depositional event 7b from sector C, show recurrent estimates much younger than any sampled date from this first occupation, related with the use and repair of wooden platforms. All of them pass the Ward and Wilson test and give a combined estimate 68.3% confidence interval around 5206-5032 cal BC. They cannot be used to suggest the moment of use or repair of the wooden platform, although stratigraphically they are in close connection with horizontal timber boards._This apparent contradiction could be solved by considering hypothetically two differentiated moments of platform use, one centered around 5270 cal BC and the other around 5097 cal BC (median of the 68.3 % confidence interval 5206-5030 cal BC). However, this hypothesis contradicts with dendrochronological data and the results of high-resolution spatial analysis (N. Morera, personal communication) suggesting a single and relatively short occupation of no more than 30/40 years.

The reasons for this apparent chronological difference within the first occupation lie in post-depositional factors (See *Chapter 7*). A pre- and post-depositional subsidence of the original surface (Iriarte *et al.* 2014) -observed in Sectors D and B but not at Sector A- altered the original deposition at those areas. To test partially this post-depositional alteration hypothesis, we have compared differences in radiocarbon calibrated dates depending on the material of the dated sample. Wooden objects (*Beta-137197* and *Beta-137198*) are clearly older than seeds coming from the same stratigraphic layer *VII* (Figure 8.6). Faunal samples show a clear stratigraphic inversion, where samples found at the top of the archaeological layer *VII* (*Beta-588213*; Depositional Event 8a), appear to be older than samples found at the bottom, in contact with the original lake substrate (*Beta-588214*; Depositional Event 8b).

Social life occurred on platforms, but also on the ground surface, therefore material elements may have been deposited above horizontally disposed boards- and below them. Puddled water below wooden platforms may have caused the slow sinking of material fallen from the platform during use (cereal grains and charcoals) (*Chapter 7*). No chronological difference should exist between samples found in contact with the preserved wooden elements, and those under them, found in contact with the original lake marl surface. The spatial microanalysis of animal bones gives partial support to this hypothesis (Morera *et al.* 2019).

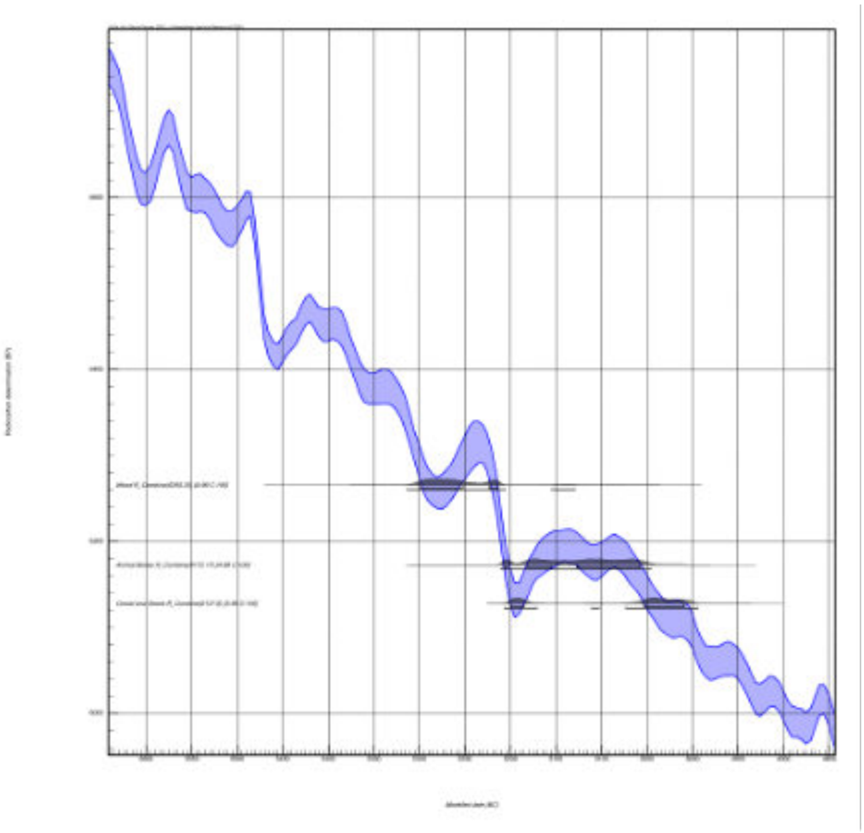


Figure 8.6. Comparison of wood, seeds and faunal samples from Sectors B and D, First Occupation. Using Oxcal 4.4 and IntCal20 calibration curve. In all three cases, R_Combine has been used to create the posterior distribution. In the case of wood and seed samples, this procedure pass Ward and Wilson test. In the case of faunal samples, there is an outlier (*Beta-278255*), 100 radiocarbon years older than the rest. See discussion in text.

It is then very difficult to identify the very last moment of this first occupation associated to the wooden structures. Some elements coming from the second occupation may have been infiltrated into the older occupation debris because of indirect pressure from the accumulation of travertine slabs above. Some light charcoal and seed samples would have floated as they felt in the water table, and as a result would not get sunk immediately, as in the case of heavier wooden artefacts. Furthermore, Depositional Event 28 appears to be a small pit excavated penecontemporaneously or after the start of the second occupation, and stratigraphically affecting the ground below (Figure 6.5).

8.2.4. Second Occupation: The use of travertine slabs

The occupation associated with the use of travertine slabs at La Draga is reflected on depositional events from sector A (9 to 27) and D (29 to 31).

Sector A

In Sector A, most travertine slabs marking the probable presence of features related with the second occupational surface are in contact with the original lake marl surface, probably because of the poor preservation of the wooden platforms at this sector of the site. Nonetheless, the presence of dug pits with basal depression over the marl doesn't rule out the possibility that some of these structures were lying directly over the lake marl surface. Depositional event 9 corresponds to a radiocarbon dated sample from stratigraphic layer *IIIB*, in contact with the travertine slabs. Forty combustion features (hearths) have been identified, arranged with travertine slabs, sandstones or burnt pebbles, and include charcoal, remains of the firewood used and other burnt and unburnt material (Bosch *et al.* 2000b). They are dug pits with basal depression of 80-90 cm in length, and with a sedimentary filling of 10-20 cm of thickness approximately. The stratigraphical sequence of most of those hearths is very characteristic: a first layer containing some charcoals and archaeological material, fragmented travertine slabs and some sandstones and a second layer above, with a bigger number of charcoals. The top of the second layer is covered by a new accumulation of travertine slabs. Depositional Events 10 to 19 correspond to the deposition of cereal seeds and charcoal in ten out of the forty differentiated hearths.

Apart from the identified hearths, there are other differentiated spatial units in Sector *A*, also formed by arranged travertine slabs of various measures, with a certain basal depression approaching 20 cm of thickness. These differentiated structures are filled with large quantities of diverse archaeological material such as charred seeds, animal bones, fragments of pottery, quartz, flint and bone tools, pieces of ornaments and grinding tools. Because of the kind of materials they contain, such structures have been interpreted as landfills for food waste and remains of discarded objects (rubbish) (Morera and Terradas 2017; Terradas *et al.* 2020) (Figure 8.8).

Depositional Event 20 corresponds to *E254* and a single isotopic event is associated to it. Event 21 defines the temporal position of *E260*, where an isotopic event associated to this deposition has been measured from a bone.

Depositional Event 24 corresponds to the formation of *E263*. A single isotopic event from this deposition comes from an animal bone fragment.

An isolated seed coming from a concentration of pottery sherds located in an extreme corner of the excavated area contributes to defining Event 27.

E258, has been divided into two differentiated depositional events (Events 22 and 25). Although the structure is filled with a homogenous dark clayey sediment containing a big number of charcoals, sedimentary differentiation between the bottom and the top allows distinguishing two different moments in its construction and filling. A single isotopic event for each of these depositional events comes from animal bones identified at a precise location.

This is also the case of *E261*. The differentiated sedimentary sublayers have been distinguished depositionally (Events 23 and 26).

Stratigraphic and depositional units defined in Sector A can be explained as syn- and /or post-depositional of the travertine arranged features.

Sector D

In Sector D, this occupation seems to be slightly different. It contains stratigraphic units characterized as pre-depositional and/or syn-depositional with the paved surface made of travertine slabs of various sizes.

The fact that the plant remains from this occupation have only been preserved by carbonization, suggest that these more recent layers remained above the water table for most of their post-depositional history (*Chapter 7*). Event 29 contains a cereal grain coming from a stratigraphic unit *IV*. Stratigraphically above it, depositional event 30 is defined by another cereal grain coming from stratigraphic unit *IIa*.

Apart from these depositional events, additional excavated units have been interpreted as occupation syn-depositional and /or post-depositional events. These are stratigraphic units *III, II* and *I*. Event 31 contains a sample of fauna from a sandy greyish sediment containing travertine sand and fragmented slabs and is stratigraphically correlated with *NAIII.*

To sum up, the oldest remains come from Depositional Events 20 and 21, from Sector A, identified as possible combustion features (Stratigraphic units *E254* and *E260*), and Depositional Event 29, defined from a cereal seed coming *IV* in sector D. This layer extends over all the excavated surface of this sector. Above it, an apparently contemporaneous sample, Depositional Event 30, comes from *Iia* (*Chapter 7*).

Despite their stratigraphic juxtaposition isector A, the first and second occupations are clearly differentiated. A two sequential phases OxCal model gives a $A_{overall}$=134.9 after deleting three outliers. The end of the first occupation can be estimated around 5252 cal BC (median of the 68.3% confidence interval), a transition between both phases around 5211-5199 cal BC, and the beginning of the new occupation after a probable hiatus of more than 50 years, well attested in the settlement areas less affected by the changing levels of the lake's water table.

Material from hearths in sector A (Depositional Events 9-19), made of travertine slabs located in close stratigraphic contact with the original lake marl surface, is the oldest from this occupation. All available dated samples (bones and seeds) have been combined after passing successfully Ward and Wilson test, suggesting a date around 5066 cal BC (median of the 5205-5013 cal BC, 68.3% confidence interval). Only the oldest structures *E254* and *E260* (Depositional Events 20 and 21) would have been contemporaneous with identified hearths in the same sector, with an estimated confidence interval around 5129-5083 cal BC (68.3 % confidence interval).

Two cereal samples from Sector D (*Beta-315050, Beta-315051*) are statistically contemporaneous. They come from two different Depositional Events: 29 and 30. If we consider only the oldest dates from those depositional events (*Beta-422871*, *Beta-315050* and *Beta-315051*), a date around 5140 cal BC would be a good preliminary estimate for the beginning of the new occupation. The reoccupation of Sectors D (near the lake shoreline) and Sector A (700 m away) would have been contemporaneous.

In sector A, a new and later rearrangement of settlement areas can be suggested given the statistical difference between dates from the bottom of structures *E258* and *E261* (*Beta-428247*, *Beta-422872*) (Depositional Events 22, 23) and dates sampled at the top of the sediment filling those structures (*Beta-422869, Beta-425198*) (Depositional Events 25, 26). The oldest dates pass the Ward and Wilson test and can be considered strictly contemporaneous within the interval 5043-5007 cal BC.

Younger dates from the same structures (Depositional Events 25, 26), together with other dates from samples found at *E263*, and the top part of structures *E258* and *E261* are clearly later (Depositional Events 24, 27), and they would be dated around 4930-4882 cal BC (68.3% confidence interval), suggesting a possible modification of previous structures. Event 31, from Sector D, a sample of fauna from *III* would also belong to this very last occupation.

8.3. Synthesis: The sequence of depositional events in time and space

8.3.1. OxCal Global Chronological Model

A detailed chronological model has been calculated based on the assumption of 9 differentiated 'phases' (Figure 8.7, Table 8.3). The first one integrates the original tree-felling and the pile-dwellings construction (Phase 'Construction'; Depositional Events 1, 2 and 3), whereas the Phase 'Use and Repair' brings together all the samples associated to wooden structures use and repair (Depositional Events 4, 5, 6a, 7a and 8a). A single outlier (*Beta-425194*) has been deleted. These first two phases have *TPQ* and *TAQ* constraints based on the results of the previous Wiggle-Matched model based on the difference in the number of tree-rings between logs used for construction and logs used in later repairs from 5290 cal BC until 5250 cal BC. Both estimates have 10 years of standard error given the floating nature of the dendrochronological local sequence.

After a gap of 50 years representing a moment of abandonment of the local area, a 'Transitional Phase' collects samples mostly from first occupation that experimented some form of stratigraphic inversion because of karstic subsidence and changing levels in phreatic level

(Depositional Events 6b, 7b, 8b and 28). During this chronologically separated transition phase, reuse of space is not excluded.

The Second Occupation is analyzed as configured by three different moments: ‘Second Occupation’ (Depositional Events 9-21 from sector A, Depositional Events 29 and 30 from sector D), ‘Spatial Rearrangement’ (Depositional Events 22 and 23 from sector A) and ‘Last Neolithic Occupation” (Depositional Events 24-27 from sector A, and Depositional Event 31 from sector D). Three posterior phases distinguish the dated samples found in more recent layers, affected by ancient and modern erosion.

A preliminary OxCal implementation of this model distinguish four outliers: *HD-15451*, *UBAR-313*, *UBAR-311*, too modern, although global model agreement is very high (A_{model}=108, $A_{overall}$=101). *UBAR-311* is a problematic non-AMS sample, with an excessively long standard lab error. *UBAR-313* is another non-AMS dated sample, and *HD-15451* is an isolated finding. *Beta-315051* is another problematic date. Initially considered characteristic of the second occupation, it was found very deep in the stratigraphic sequence (*NAIV*), but in close contact with travertine samples above. It seems much more related with use and repair of wooden structures than with later phases. We have deleted those dates and executed the model again, with a huge gain in agreement (A_{model} =167.8, $A_{overall}$= 167.8).

Table 8.3. Results of La Draga’s Chronological 9 Phases Model (OxCal 4.4.) (68.3% confidence interval). After outlier elimination.

PHASE	FROM	TO	Median
FIRST OCCUPATION			
Tree Ring 237/238 C_Date(-5290,10)	-5309	-5290	-5299
PLATFORM CONSTRUCTION STARTS	-5302	-5277	-5289
PLATFORM USE AND REPAIR ENDS	-5272	-5247	-5260
Tree Ring 265 C_Date(-5250,10)	-5258	-5239	-5248
TRANSITIONAL PHASE			

TRANSITION STARTS	-5095	-5051	-5076
TRANSITION ENDS	-5031	-4975	-4997
SECOND OCCUPATION			
SECOND OCCUPATION STARTS	-5207	-5048	-5075
SETTLEMENT REARRANGEMENT STARTS	-5061	-5025	-5045
LAST NEOLITHIC OCCUPATION ENDS	-4917	-4821	-4862
POST-OCCUPATION I STARTS	-4779	-4176	
POST OCCUPATION II STARTS	-4479	-3824	
POST OCCUPATION III STARTS	-4564	-3553	
POST-OCCUPATION III ENDS	-3684	-2759	

According to this model, a first occupation on the shores of lake Banyoles can be placed along the temporal interval of 5302-5247cal BC. The hiatus in which areas of the settlement were probably abandoned, although temporal and short reoccupations cannot be excluded would have arrived until ca. 5100 cal BC. The depositional events integrated into the so-called Transitional Phase appear to be later that the most probable start of the Second Occupation. On the one hand, the oldest dates for second occupation (*Beta-422871* and *Beta-315050*), around 5200 cal BC, are a priori too old for dating properly the moment the original ground was insulated with travertine slabs. The remaining dates are grouped around a median of 5075 cal BC. The best hypothesis would be to make emphasis on a relatively long period of abandonment (100 years) and a relatively later reoccupation with restructuring of the ground surface. On the other hand, most dated samples from the Transitional Phase are small seeds between the remains of the wooden debris and the travertine slabs, that may have been affected from the second occupation and the influence of groundwater.

The second occupation would be longer than the first one, from 5075 cal BC until 4860 cal BC. Two successive settlement rearrangements may be suggested, the first around 5061-5025 cal

BC and the second and last one around 4917-4821 cal BC. Very few remains of occupation exist for the period after 4800 cal BC.

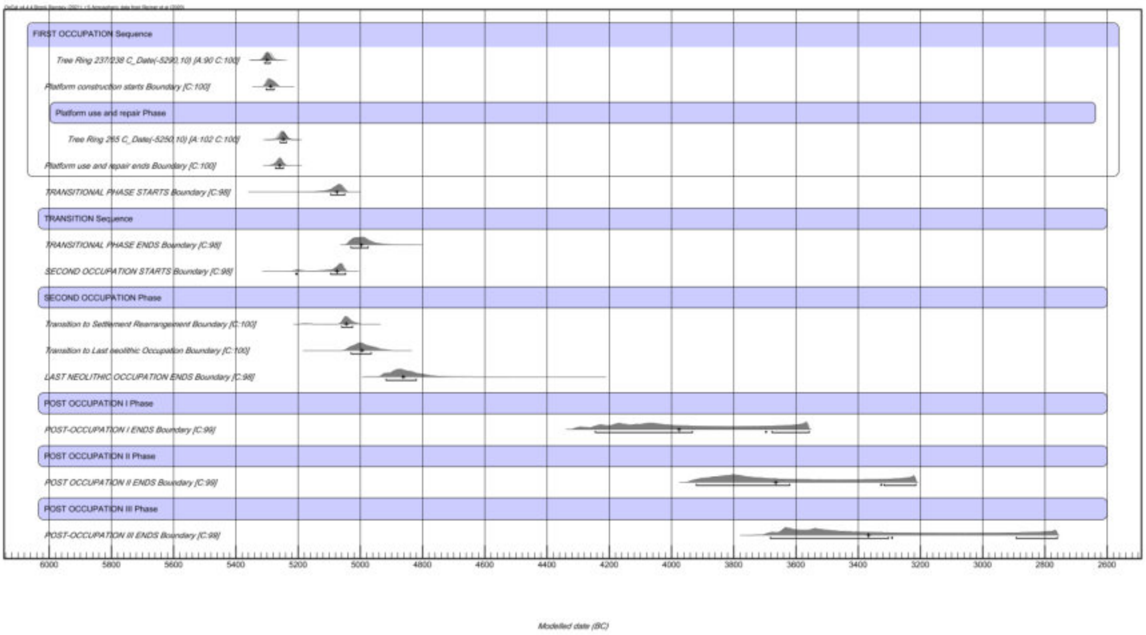


Figure 8.7. Results of a model of 9 partially contiguous, partially sequential and partially overlapping phases and sequences. Oxcal 4.4. IntCal 20 calibration curve.

8.3.2. ChronoModel Global Chronological Model

A more detailed chronological model has been calculated in ChronoModel 2.0 using the stratigraphical constraints and the functional, spatial, and chronological ordering among 33 depositional events (Figure 8.8), and the conclusions from the Wiggle-Matching model (Figure 8.4).

To reproduce exactly the model previously estimated using OxCal, two temporal bounds were included in our ChronoModel estimation, representing the dendrochronologically deduced temporal limits: 5293 cal BC for the beginning of the process (tree felling), and 5272 cal BC for the last documented repair (Figure 8.8). We have added 10 years in this last case concerning the uncertainty of the last moments of wooden platforms occupation. After that bound we have defined a "Transition Phase", with an additional uncertainty of 100 years, and a gap of 50 years before the beginning of the second occupation. This is exactly the same model we defined using OxCal 4.4. The second occupation is differentiated from the later spatial arrangement and the last evidence of a Neolithic Occupation. Post-Occupation evidence has been integrated into three different phases.

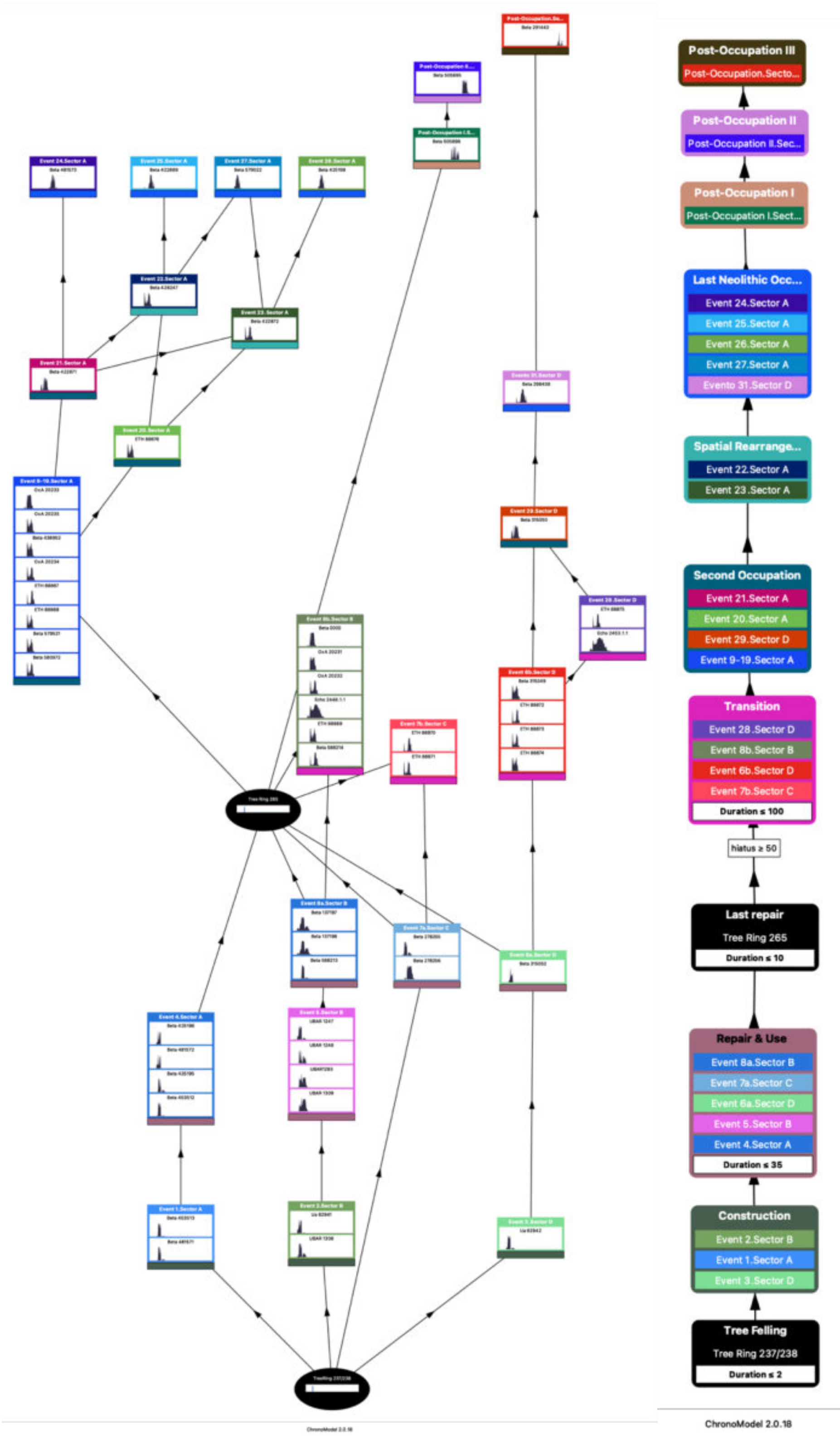


Figure 8.8. An Event and Phase Model with stratigraphic constraints and temporal boundaries based on dendrochonological and Wiggle-Matching estimates. ChronoModel 2.0. IntCal20 calibration curve.

MCMC has been configured with 1000 burn-in iterations, 500 further iterations for the adapting cycle, and finally 100000 iterations for the final acquisition of posterior distributions (thinning

= 10). Gelman-Rubin test is not yet implemented in the current version of ChronoModel 2.0. Consequently, we have checked the MCMC convergence visually by locking at the stability of autocorrelation plots. We have also checked the acceptance rate at 44% in the case of a Metropolis-Hastings with a Gaussian random walk (Roberts and Rosenthal 2001), and the decorrelation of the variables (Lanos, personal communication).

The same outliers that were deleted in the OxCal model were eliminated, once we have checked that acceptance rate in ChronoModel for those dates was also around the 44% threshold.

Results obtained by ChronoModel are in good consonance with those obtained with OxCal (Figure 8.9, Table 8.4). Both models give support to the hypothesis of a hiatus of nearly 100 years between the end of the first occupation and the beginning of the second, but precise estimates for their start and end slightly differ. It is important to consider, however, that this is not an occupation phase, with clear-cut start and end, but a region of temporal uncertainty where post-depositional processes affected previous and posterior stratigraphic layers.

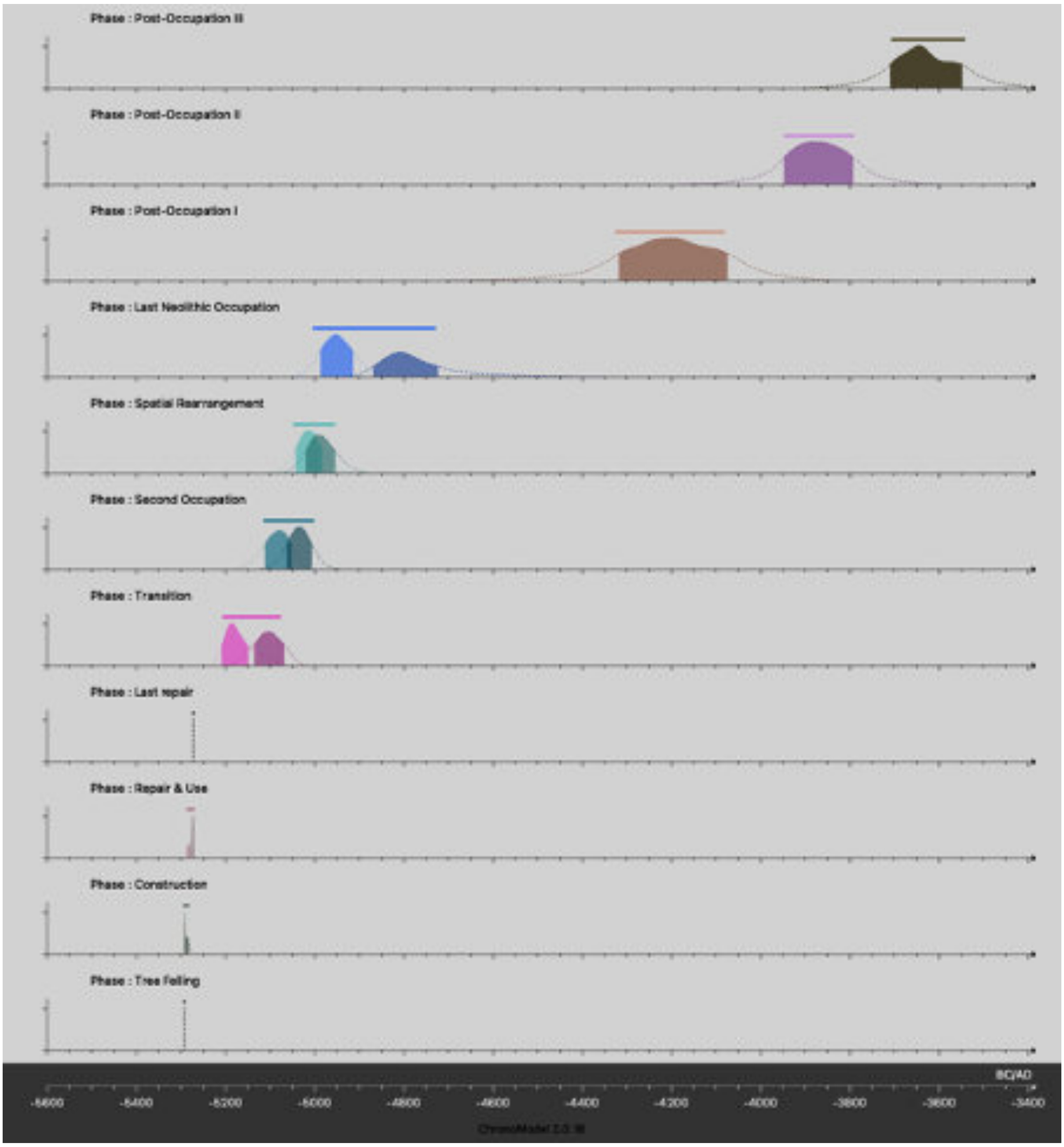


Figure 8.10. Results of a 9 Phases Chronological model. ChronoModel 2.0. IntCal 20. Each Phase is depicted with a different color. The lightest color corresponds to the *a priori* confidence interval, whereas the dark color depicts the *a posteriori* Bayesian estimation. Unlike the previous OxCal model, Post-Occupation layers have been integrated into a single one. This simplification does not affect the results.

A revised Harris Matrix Diagram was created based on the temporal relationships resulting by the ChronoModel results. The original stratigraphic constraints are maintained between the depositional events (Figure 8.10).

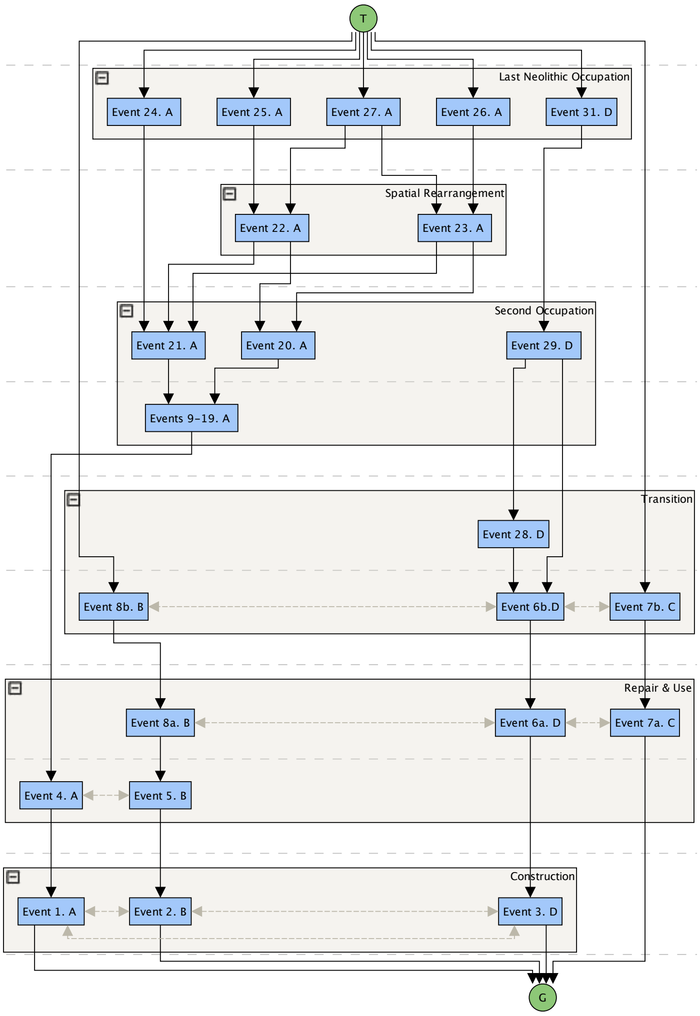


Figure 8.10. Harris Matrix diagram representing the depositional events associated to both structural occupations at La Draga. The events are separated into six temporal groups based on the results from ChronoModel and OxCal. The stratigraphic constraints between the depositional events have been maintained.

Both models agree with an estimate for the beginning of the second occupation around 5090 cal BC (Tables 8.3, 8.4). Nearly 70 years after, there is evidence of a spatial arrangement of built spaces. According to both models, the last evidence of Neolithic occupation was not later than 4780 cal BC.

Table 8.4. Results of La Draga's Chronological 9 Phases Model (Chronomodel) after the elimination of outliers (HPD and Phase Time Range 68.3%).

PHASE	FROM	TO	Median
FIRST OCCUPATION			
Tree Ring 237/238 C_Date (-5290,10)			-5293
EVENTS 1, 2 and 3 START	-5293	-5290	-5291

EVENTS 4, 5, 6a, 7a, 8a END	-5275	-5272	-5274
Tree Ring 265 C_Date (-5250,10)			-5272
TRANSITIONAL PHASE			
EVENTS 6b, 7b, 8b, 28 START	-5209	-5149	-5174
EVENTS 6b, 7b, 8b, 28 END	-5135	-5069	-5104
SECOND OCCUPATION			
EVENTS 9-21, EVENTS 29 START	-5111	-5052	-5084
EVENTS 22, 23 START	-5042	-4984	-5012
EVENTS 24, 25, 26, 27, 31 END	-4868	-4729	-4786
POST-OCCUPATION I	-4324	-4084	
POST-OCCUPATION II	-3945	-3794	
POST-OCCUPATION III	-3705	-3545	

8.3.3. Allen Algebra-based diagram of temporal relationships

Using the above stratigraphical ordering and radiocarbon estimates for the duration of depositional events, a general temporal sequence was defined based on Allen algebra estimated temporal relationships (Allen 1983; Zoghlami *et al.* 2012; Dye and Buck 2015; Belussi and Migliorini 2017; Drap *et al.* 2017; Barceló and Andreaki 2020) (Figure 8.11). The period of transition between the first and second occupation remains in the temporal interval from 5200 to 5100 cal BC, although there is a clear overlapping with depositional events from the second occupation (Depositional Events 29 and 21).

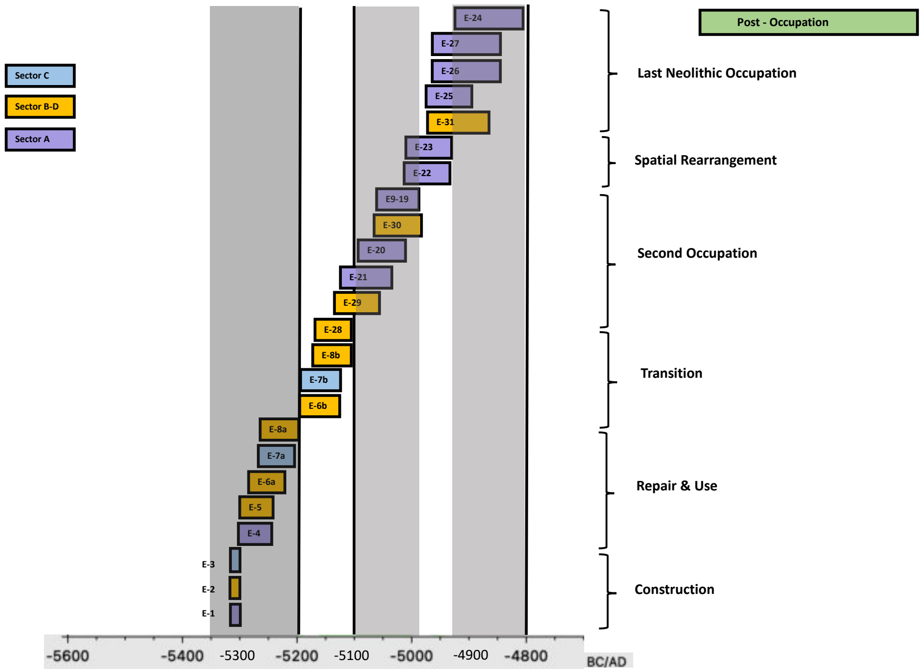


Figure 8.11. Allen Algebra adapted diagram for site occupational temporal sequence representing depositional events E-1 to E-31 and their respective phases. Black vertical lines mark the end of clear evidence from first occupation (5200 cal BC), as well as the beginning (5100 cal BC) and end of second occupation (4800 cal BC)

9. DISCUSSION: RECONSTRUCTING THE SITE BIOGRAPHY

9.1. The sequence of depositional events and La Draga in the chronological context of the Early Neolithic in the Western Mediterranean region

In an attempt to decipher the dynamics of the processes forming and deforming the archaeological record at the lakeside settlement of La Draga, micromorphological observations came along with radiocarbon dates and stratigraphic correlations. The perception of space as a palimpsest is essential in this case of complex depositional processes in order to understand the variety of human and natural factors acting on the same time at different places of the same settlement (Smith *et al.* 2015). The depositional processes can shed light on the formation of the archaeological record both synchronically and diachronically. As absolute dating is available in the case of La Draga (Andreaki *et al.* 2020; *Chapter 8*), it is easier to understand the formation processes in time and integrate them at the overall environmental setting of the lake and its dynamics. The main formation processes affecting the occupation at La Draga are discussed in the chronological context of the Early Neolithic in the Western Mediterranean region.

9.1.1. Pre-occupation

The arrival of new populations with a new economy and a new material culture to the Northeastern region of the Iberian Peninsula around the Banyoles lake coincides with a humid period with very dense vegetation cover. Those conditions would have been detrimental to the easy expansion of agricultural practices (Pérez-Obiol et *al.* 2011; Moreno et *al.* 2013; Berger et *al*. 2016; Peñuelas et *al*. 2017; Bergadà et *al.* 2018; Brisset et *al.* 2018; Revelles et *al.* 2018; Mercuri et *al.* 2019; Revelles 2021). This fact could offer an explanation to the scarcity and dispersion of early Neolithic sites. At a very local level, a climatic anomaly around 5500-5000 cal BC suggests some abrupt cooling associated to temporally reduced precipitation (Jalut et *al.* 2000; Frigola et *al.* 2007; Vegas et *al.* 2010; Pérez-Sanz et *al*. 2013). For that period, immediately before the foundation of La Draga settlement, there is some indirect evidence of human occupation on the shores of Lake Banyoles, although it has not produced any archaeological record up to now. Based on the thickness variability of oak trunks used as vertical piles in the construction of the wooden platforms at La Draga, the number of tree-rings and their estimated age spread, dendrochronologists suggest that timber came from already cleared different forest stands. According to the known growth rate of Mediterranean oaks, this period of area exploration before full sedentary settlement can be estimated in ca. 150 years (López-Bultó et *al. in press*).

It has been suggested that the intensive and continued exploitation of forests for various activities, such as obtaining raw material for tools, platforms, and dwellings, or as fuel in several domestic and communal productions became the main cause for the anthropic transformations documented at the end of the *First Occupation* (Revelles 2017; Mercuri *et al.* 2019). Human impact on the forests around Lake Banyoles is not associated with increasing levels of *Cerealia-t* pollen nor spores of coprophilous fungi. It suggests the limited impact of agriculture and herding on the landscape but the relevance of timber procurement for building issues as a probable cause for small-scale forest modifications (Caruso-Fermé and Piqué 2014; Revelles *et al.* 2014; Revelles 2021). According to excavation results, the density of oak trunks used for building wooden platforms and other structures clearly exceeds 1 trunk per square meter, which amounts to the felling of 1000 trees, only for the excavated area of 800 m^2 (Revelles *et al.* 2018), and the felling of 18,750 trees for the estimated 15,000 m^2 of the settlement's total extension. Using modern figures for oak density in Pyrenean forests (927 trees per hectare. Cf. Banquét *et al.* 2013), this would have involved the logging of twenty hectares of forest in a very short period.

The lake marl constituting a major part of limnic sedimentation at La Draga and the natural substrate for later anthropogenic activities was formed under high water table during the pre-occupational phase. Before the human installation at the shores of Lake Banyoles, marl was deposited under a high-water table, below the influence of wave activity (*Chapter 7.2*). At the same time, arboreal pollen was consistent with deciduous oak *Quercus* type, *Corylus cf. avellana* and *Pinus spp.* before the Neolithic occupation (Revelles *et al.* 2014). However, the presence of soil erosion indicators such as algae and fungi before the installation at La Draga, probably meant a shift in the lake level.

9.1.2. Occupation - Installation Horizon

The hypothesis of colder environmental conditions at the time of settlement foundation is reinforced by $\delta^{18}O$ values obtained from archaeological wooden remains of Phase I of La Draga (Aguilera *et al.* 2011). Differences between sub-fossil and extant samples in $\delta^{13}C$ and $\delta^{18}O$ records suggest slightly lower temperatures and higher plant water availability than at present during the establishment of farming communities at the site (Philippsen *et al.* 2019). These environmental conditions at the time of the first settlement building could possibly explain the exposure of the shoreline of Banyoles Lake allowing its human occupation. A regression of the lake level, exposing carbonate sandy beaches at some points along the lake margin, would make it attractive for Neolithic communities to settle in a place devoid of vegetation. This would be a highly valued space in the context of a densely forested landscape.

Micromorphological data from sectors A and D at La Draga provide information about the oldest occupation, which took place on an exposed lake marl surface with groundwater emanation in both sectors and was based on the construction of wooden dwellings and /or platforms. During the use of wooden platforms shallow water movement and a fluctuation zone is evidenced in sector D.

The upper surface of the lake marl substrate characterizing the ground for installation at La Draga, was found in contact with the first evidence of human activity. The sharp upper boundary of their contact reveals deposition over a surface with constant water emanation. That means the installation at the shores of La Draga took place under relatively drier conditions. The processes that would have led to this depositional environment are probably natural relating to climatic factors and possible lake regression. However, that does not mean no water presence at all. An evidenced ground subsidence (Iriarte *et al.* 2014) in the place where sectors B and D are found would explain the fact that occupation took place under a water saturated environment with occasional fluctuating water zone at this place of the settlement. The choice of settling on sector D even though the water table was higher means cultural choice to adapt in the surrounding environment. Risen pile-dwellings would have been constructed to avoid occasional inundations by water. The cultural deposits found over the lake marl surface at La Draga consisted mostly of organic remnants of anthropogenic activities, such as roots and leaves, charcoal, charred seeds and plant remains, as well as fragmented bones and wooden remains.

Nonetheless, evidence of occupation in sector A is found over an almost water saturated surface, affected by swamping. Subsequent trampling and poaching signs suggest human and /or animal traffic over anthropogenic remains.

According to pollen data, the first installation and construction of pile-dwellings during the Neolithic period is associated to deforestation and environmental changes on one side, and increased Cerealia pollen associated to crop cultivation on the other side (Revelles *et al.* 2018).

The construction of the pile-dwellings seems to have happened at once over all excavated sectors of the settlement. Tree-ring data suggest that all trunks used for construction at La Draga were felt at the same year (the winter of year 237/238 of the local sequence, 5310 cal BC). The cultural remains found over the lake marl surface are dated in the same chronological period as the construction of the pile-dwellings (5292 cal BC), suggesting immediate installation of the first dwellers on the lake shore. Built structures would have involved either risen pile-dwellings on wooden platforms or ground structures directly lied on the lake marl surface. The latter would have required a foundation to avoid water inundation. During occupation, discard remains from everyday use and consumption would have been deposited either *on* the wooden platforms or have fallen *below* them, in the case of pile -dwellings. Evidence of slowly sinking charcoal fragments in sector D, show deposition of anthropogenic material into the water. Water transportation of this material could have led to redeposition of the anthropogenic material elsewhere, depending on the water-table.

Cardial Pottery characterizes the occupation that started in La Draga around 5310 cal BC. Those remains are not the earliest evidence of this kind of pottery in the region, as Bauma del Serrat del Pont and Cova del Toll, distant less than 80 km, are 150 years older and stylistically less evolved that pottery decorations from la Draga (Alcalde *et al.* 2001; Oms *et al.* 2014; 2018; Palomo *et al.* 2021a). Shell impressions predominate, together with dragged shell impressed motives, organized in one or two bands parallel to the vessel rim, that were absent in older settlements (Bosch and Tarrús 2015; Bosch

2012). The relative frequency of shell and comb impressions, and the presence of smooth non digitized cords seems analogous to elements from the French region of Languedoc (Manen and Guilaine 2007; Binder *et al.* 2010; Bosch 2012; Bosch and Tarrús 2015; Oms 2014; Oms *et al.* 2018; Breu and García 2017; Palomo *et al.* 2021a). Radiocarbon dates from Leucate-Corrège are within the limits of La Draga's first occupation (Manen *et al.* 2019). The use of flint raw material from the Narbone-Sigean area at La Draga at this time is another evidence of the particular relationship with South France (Terradas *et al*. 2021).

The end of La Draga´s First Occupation and the suggested abandonment of the site for some years have been explained by a combination of environmental changes that occurred on the shores of Lake Banyoles. Gradual degradation of the surrounding conditions in parallel with the geomorphological evolution of the shoreline and the problems derived from karstic subsidence of the ground near the lake could have provoked a disruption to the farming activities of the settlers. Degradation of the wooden pillars should not be disregarded either given the fact that their endurance would have been challenged. Geomorphological and sedimentary history of Lake Banyoles has always been really very active and complex (Valero-Garcés *et al*. 1998; Höbig *et al.* 2012; Lacey *et al.* 2016) and it would have affected human activites at their changing shores.

9.1.3. Mind the gap: Transition

There is a possible gap of approximately 100 years (or a bit more) between the collapse of the wooden structures and evidence of the beginning of a new occupation, a time interval in which the site may have been abandoned. Signs of exposure have been detected microscopically in the sediment of sector D just above the preserved timber planks, highlighting a period of exposure before the arrangements for the new occupation (*Chapter 7*). Although some short and temporal reoccupations cannot be excluded given the number of piles that have not yet been dendrochronologically dated, a subsidence of the ground surface of those parts of the settlement nearer to the shoreline marks a probable interruption of social life at the site, as the micromophological data suggest. Those analysis suggest that the ground subsidence was already present before the first occupation, to a lower degree, although it would probably not have been perceptible to the inhabitants of La Draga. In fact, the earlier beginning of this subsidence at a smaller degree is what made possible the accumulation of organic materials in sectors B-D and the formation-preservation of peaty strata (Iriarte *et al.* 2014). Further subsidence during the following years and the parallel increase of the water table in this sector of the site may have been the reason of its abandonment. The constant water presence in this area would have also delayed the site's re-occupation for some time.

Pollen data retrieved from the beginning of the new occupation suggest that the forests around the new settlement would have experimented a clear recovery after a period of local deforestation during the first occupation (Revelles *et al.* 2017; Revelles 2017; Revelles 2021). 100 years seem a likely estimate for the time interval during which forest recovered.

Further lowering of the subsidence of the ground surface of the parts of the settlement closer to the shoreline would have interrupted life at the site, by provoking an inundation episode probably followed by the collapse of the pile-dwellings at this part of the settlement. The interplay of water input and sediment accumulation rate constrained the continuity of human activity. Current phreatic level can be related to the lake water level fluctuations. The Wiggle-matched dates from La Draga suggest an estimated date for tree-ring 265 around 5284 cal BC (mean of the 90.2% confidence sub-interval 5370-5207 cal BC) and the hypothetical end of the settlement some years later, but not after 5200 cal BC.

It is important to remark that what seems to have happened at la Draga just after 5200 cal BC is also present in the entire Iberian Peninsula. Studies based on the sum of probability intervals of radiocarbon dates have suggested a decay in the number of known sites after that date, between 7.1 and 7.0 kyr BP (Balsera *et al.* 2015; Bernabeu *et al.* 2016; 2017; Fyfe *et al.* 2019; Pardo-Gordó and Barceló 2020; Martínez-Grau *et al*. 2021). Bernabeu *et al.* (2017) have linked this occupational interruption with dry and cold intervals having occurred regularly on the area. One of them would have happened around 5200-5100 cal BC, possibly related with the North Atlantic ice rafting debris 5b IRD event, dated around 7100 cal BP (Frigola *et al*. 2007; Wanner *et al.* 2011; Finné *et al.* 2019). We must be careful about using these climatic anomalies to explain changes in the archaeological record. La Draga is in a humid region and such an event would not have implied dramatic changes in the landscape and associated resources, as might have happened in more arid regions such as the southeast of the Iberian Peninsula. We must bear in mind that in the case of the Draga, a phase of higher humidity or an increase in rainfall (lake flooding and inundation) would probably have more effect than aridity. With available data, we cannot be certain whether a temporal increment in aridity caused variations on the lake shoreline and the phreatic water level to explain the probable abandonment of the settlement for this time interval.

9.1.4. Re-occupation and use of space

The site was reoccupied less than 100 years after the abandonment of the first occupation, and important work was made for conditioning the ground surface. The practical response to ground sinking and flooding was probably to insulate the swamped and partially sunk surface with locally available travertine slabs in sector B-D, as the ground subsidence continued to grow with the passage of time. The new occupation would have been longer than the first, and some different moments can be distinguished (*Chapter 7*).

The intentional use of travertine slabs and their position over previous wooden postholes in sector A and the construction of a travertine pavement in sector D, attest to the use of this local material as a way of insulating the rise of water. This has happened after the abandonment of the oldest phase of wooden structures which are observed in certain areas of the settlement.

Later on, the transportation of mixed material (such as roots and wood) and their *in situ* burning alongside with anthropogenic material (bones, seeds) into or over these structures attest for their use as occasional hearths, a practice also evidenced in sector D with the construction of similar structures and their use as hearths over the travertine pavement. This practice seems to be repetitive in the studied structures in sector A, whereas occupation was taking place at other parts of the settlement.

Immediately below this accumulation of travertine slabs, the sediment appears in this sector to be ashy and oxidated towards the top making more probable the hypothesis of an insulation layer before the deposition of travertine as the influence of dry conditions is greater. On a microscopic level, charred organic material in the form of seeds and charcoals as a result of fire episodes in a local level is devoid of sediment, indicating burning on a dry environment. In the case of MP2 a burning episode (MFT-*F*) has been observed over the travertine layer (MFT-*D*). Over the travertine slabs layer, a peaty layer was gradually formed with charred plant material, faunal remains and malacofauna.

This new occupation, 5100-4900 cal BC, coincided with the full spread of farming economies in the whole Northeastern Iberian Peninsula. This scenario of human expansion in the area explains the increase in the number of contemporary archaeological sites around the Banyoles Lake. Nearby la Draga, we must consider the case of the open-air settlement of Plansallosa, whose first occupation presents some materials that can be related to La Draga's second occupation, but with imprecise dates around 5250-4940 cal BC and 5230-4910 cal BC. La Dou is a sparsely distribution of hardly contemporaneous huts over an area of 800 m^2, clearly later than archaeological evidence from La Draga and Balma del Serrat del Pont (Alcalde and Saña 2017). In the lowlands around the Mediterranean coast, at 50 km from Banyoles Lake, two new settlements have been identified at a swamped landscape near the shoreline (Ca n' Isach, Puig Mascaró). At Serra del Mas Bonet (Vilafant) (Rosillo *et al.* 2012), an open-air settlement has been excavated (4909-4862 cal BC). The expansion of farming settlement around the Banyoles lake area was also contemporaneous with Full Neolithic population expansion in the Northeastern Iberian Peninsula (Barceló 2009b; Martín *et al.* 2010; Oms *et al.* 2016; Bernabeu *et al.* 2017; Oms 2017; García-Puchol *et al.* 2018; Manen *et al.* 2019; Martínez-Grau *et al.* 2020).

9.1.5. Post-occupation: Abandonment

Erosion has heavily affected the upper layers of La Draga and archaeological remains were not as abundant or well preserved as those from the first occupation. In any case, very few remains can be dated after 4700 cal BC. Balsera *et al.* (2015), Bernabeu *et al*. (2017*)*, García-Puchol et *al*. (2017; 2018*)*, Drake *et al.* (2017), Fyfe *et al.* (2019), Pardo-Gordó and Barceló (2020) have argued about a probable decline in accumulated probability of dating archaeological sites after 4700 cal BC, and hence a relevant change in settlement patterns and population estimates from this date on. Nevertheless, post-depositional activity and erosion of the upper layers at the site cannot allow explaining the possible abandonment of the site nor its connection with higher scale depopulation trends in temperate Europe, like those analyzed by Shennan *et al.* (2013) among many others.

The causes of this sudden 'bust' following the demographic boom of the 5100-4900 cal BC remain unclear, but it should be related with the rapid fission within early farming communities, fission in turn caused by competing centrifugal and centripetal economic forces within small-scale egalitarian groups (Leppard 2021). Internal (Shennan et *al.* 2013; Bernabeu et *al.* 2015; 2017) and externals drivers (Gronenborn 2009; Walsh *et al.* 2019) have been proposed to explain this phenomenon. At La Draga, no big depositional episode seems to be related with the abandonment, nor we have any evidence regarding a change in local environmental circumstances after the 4900 BC. In sector A, the dark brown sediment covering all combustion features includes mixed material and organic matter. It seems to be of natural origin and its compaction is probably due to posterior human and or animal trampling. Water must have been occasionally present. On the other hand, a darkish sediment with decayed organic matter and mixed anthropogenic material was formed under wet conditions in sector D. Finally, in sector C, lake marl sedimentation took place after the last occupation signs on the lake shore. Occasional shallowing reveals lake level fluctuations. Peat formation at the lakeside part of the settlement has been dated first around 4120/3869 cal BC and after a short episode of lake marl deposition, around 3826/3647 cal BC.

During the Middle Neolithic period, the Lake Banyoles area would have been less frequented than in the previous period, although not depopulated. Short time occupations are known, around Serinyà, during the so-called Post Cardial Neolithic period (4500-3900 cal BC) (Tarrús 2000; Revelles *et al.* 2014; 2018). A relevant impact of agricultural practices is not well confirmed until Late Neolithic-Chalcolithic (after 3500 cal BC), when short deforestation processes occur, producing a combination of evidence of crops (*Cerealia t-type*) and weeds (*Plantago major-media*, Chenopodiaceae) and local fire episodes affecting riparian forests, probably associated with slash-and-burn agriculture (Revelles *et al.* 2014).

10. CONCLUSIONS

10.1. Research accomplishments

This research had as a principal objective the reconstruction of La Draga site's biography. The methods applied included the integration of absolute chronology, stratigraphic analysis and high-resolution micromorphological analysis of the sediments at La Draga. Rearrangement of the macroscopic units observed during excavation according to the definition of depositional events (*Chapters 2*), helped ordering the sequence of stratigraphic units in Harris matrix diagrams (*Chapter 6*). Further microscopical observation and micromorphological analysis of the sediments helped define better the limits of the depositional events. That was achieved by deciphering the source of sediments, as either anthropic or natural, as well as highlighting the taphonomic processes that affected them. The interplay between anthropogenic and natural formation processes has formed the archaeological record of La Draga.

The privileges of life in the wetlands have been discussed and have provided an essential background for assessing occupation on the lake shore during the Neolithic period. Although, life nearby a water source, would have been favorable in many aspects already discussed (*Chapter 3*), there were also drawbacks. The selection strategies of the Neolithic dwellers are reflected by choosing lakeside settings for occupation.

Anthropogenic activities in a lacustrine settlement that is dynamic in terms of depositional processes, come affected by natural processes and an alternating water regime. On one hand, the water has been favorable in terms of preservation of the archaeological record, but on the other hand, syn and post/depositional alterations due to water activity have been the most common ones, observed in La Draga. Occupation both on ground surfaces and especially on pile-dwellings has posed an additional problem at the time of identifying the anthropogenic activities lying below the occupation surfaces. A lot of the remains of anthropogenic activities have been removed intentionally or naturally from their context and redeposited elsewhere.

Theoretically, this project has raised the question of depositional events, their definition, ordering and application on a lakeside settlement. The choice of a lakeside settlement shows the complexity and dynamics of a setting that can affect the depositional processes. The interplay of geogenic and anthropogenic processes has also raised the question of decision making during the Neolithic period. As the research has shown, although environment and climatic factors have certainly favored human occupation on the lake shore of Banyoles during the Neolithic, this wouldn't have determined exclusively the making of decisions, but they would have been also affected by cultural factors.

Furthermore, after the chronological hiatus of non-occupation signs between the called *first* and *second* occupation, instead of abandonment, reuse of other spaces of the settlement was preferred. Or for example, adaptation was preferred, through the construction of a travertine pavement in sectors B-D.

10.2. The biography of the site of La Draga

The site of La Draga is a lakeside archaeological settlement in the Northeastern Iberian Peninsula, with extraordinary preservation of wooden elements and other organic materials.As it is evidenced from the Harris Matrix diagrams gathered from all excavated sectors, at least two phases of occupation during the Neolithic period are evidenced. These have been further identified through micromorphological analysis of the sediments and radiocarbon dating of the depositional events. XRF analysis of the sediments in sector C in combination with chronological information of the core in the underwater sector (Figure 6.9) informs us not only about the lake water effects on the stratigraphic sequence, but also about the occupation and abandonment periods in the lakeside settlement. A local tree-ring sequence of 265 years has been obtained from the piles used for the construction during the settlement´s First Occupation. The research carried out so far, concludes that most trees for construction were cut at the same year (the winter of the 237/238 year in the local sequence), suggesting a single prominent construction event at the beginning of the occupation. Using radiocarbon dates from the last ring in 7 of these logs, we have estimated the installation year around 5310 cal BC. This first occupation ended in a rather sudden way 30/40 years after the first construction. Two different wiggle-matching models estimate the possible abandonment of the site around 5280-5200 cal BC. The first occupation of the shores of the Banyoles Lake correspond to a classical Cardial Pottery Early Neolithic, and relationships with contemporaneous settlements in Southern France have been argued.

La Draga's first occupation constitutes the largest known settlement in the extreme Northeast of the Iberian Peninsula, and it appears to be more carefully planned in its construction and organization than others in the region. This gives an image of very dispersed small groups during Early Cardial Neolithic, occupying a mostly depopulated area, and concentrating the settlements in rationally selected points that had the best conditions for their initial and still partial farming economy.

The abandonment of the site after the first occupation would coincide with a decay in the population signal in the Northeastern Iberian Peninsula and elsewhere, related with changing local environmental conditions and a transformation in the way of occupying the territory.

100 years after the abandonment of the first settlement, around 5100 cal BC the settlement is reoccupied. Important preparatory work of the ground surface probably to prevent swamping is attested since the earliest moments of this new occupation. Its architecture, however, has not been recovered, but the archaeological materials show cultural relations with most sites in the surroundings, within the global trend of Full Neolithic population expansion in the Northeastern Iberian Peninsula. Most recent layers are modified and post-depositionally altered, and therefore not many details are available about possible post-Neolithic occupations. There are very few remains of human population dated after 4700 cal BC at the site, but dispersed archaeological evidence is present around Banyoles lake. Although the period after 4800 cal BC has been explained in terms of depopulation, also related with climatic oscillations, nothing in the archaeological record of La Draga can be used to test such hypothesis.

The combination of radiocarbon dating and dendrochronological analysis with the depositional sequence of the different sectors at La Draga, permitted in high grade to evaluate the chronological framework of the settlement. Additional ordering of the depositional events in a relative temporal scale throughout all the excavated sectors allowed to understand even in a schematic way their time-space correlations. As every site is a living organism changing through time, in order to decipher its biography, it is necessary to consider not only the depositional processes that have formed it but also the post- depositional effects that have altered its course.

10.3. Limitations and future research perspectives

Apart from the accomplishments of this research on both theoretical and methodological levels, there were also limitations. These were partly related to the availability of data. Since the discovery of La Draga, there have been archaeological interventions under different scientific direction. At the same time, excavation, recording and sampling equipment and techniques have undergone notable changes over thirty years of archaeological interventions. As a result, the data have been registered in different ways and the archaeological record lacked homogeneity. This was especially a problem at the time of describing the sedimentary attributes of stratigraphical units in each sector. In addition to that, samples for micromorphological analysis were not a priority during first seasons of excavation. For the purposes of micromorphological analysis, sampling of sediments begun in 2010. Although focused on a sector of the site, this work provided a first approach to the micorostratigraphy of the site and very valuable data for the present research. Since 2017, sampling of sediments for micromorphological analysis became part of a systematic sampling during the excavation project, when more samples were available, especially during ongoing excavations of sectors A and C.

In the meantime, radiocarbon dates were available during later years for most of the recovered artifacts, but still the record had to get cleared and systemized to be used in the present research. Finally, even if it was possible to reconstruct the chronostratigraphical framework based on available data, more radiocarbon dates on a lateral distribution of the sequence would be necessary for deciphering activity areas. This could be further complemented by targeted sampling for micromorphological analysis in order to better identify more specific activity areas (stabling, craftwork, food preparation, etc.) inside the settlement.

Another future perspective, already partially introduced in the theoretical framework and methodologically applied on a preliminary basis previously (Andreaki 2016) is the visual reconstruction of the occupational surfaces. This would be possible thorugh multidimensional modelling of the depositional events already defined in the present research.

On the other hand, although innovative on a theoretical and methodological level the objective proposed in this research including the reconstruction of depositional events will remain a challenge for archaeological practice. Even if the maximum detail is achieved during the excavation process, it may never be enough to unravel every event of a past society's biography.

These limitations and practical problems encountered in every real-time excavation have especially raised the question about the geoarchaeological aspect of every excavation. Site formation processes are a valuable ally at the time of evaluating the biography of a site and therefore, should not be dismissed as a discipline from any archaeological scientific project in the future.

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Figure 4.10. Map of the distribution of twelve cores realized during the 2013 excavation campaign at La Draga site. The cores are marked as green dots (Iriarte *et al.* 2014).

Figure 4.11. Geographical position of La Draga site in the map on the left and general view of the excavated sectors in the lakeshore of Lake Banyoles on the right (Plan modified after Núria Morera). Dark grey color represents the square meters excavated under old direction in sector A (1991-1995), sector B (1997-2005) and sector C (1995-2005). Instead, in light grey, the square meters excavated since 2010 until 2021 are represented. The black line represents the lake shoreline.

Figure 4.12. Plan of two different uses of materials in sector B-D. On the left side, view of the oldest occupation with the presence of wooden material for the construction of the platforms over the exposed white lake marl surface. On the right, view of the same space with travertine slabs covering the previous occupation in the form of paved surface. Two separate structures corresponding to fireplaces were marked with red squares **(***Modified after Piqué et al. 2021a*).

Chapter 5

Figure 5.1. Statistical test to assess the consistency of ^{14}C determinations (Ward and Wilson 1978).

Chapter 6

Figure 6.1. Harris Matrix diagram of sector A of the settlement of La Draga (edited with Harris Matrix Composer). The stratigraphic units are separated by grouped in four phases (HM diagram by *V. Andreaki*).

Figure 6.2. Vertical and horizontal view of the same plan of the combustion features *E254*, *E256*, *E257*, *E258*, *E259* and *E260*. *E261* and *E263* are only shown in the left plan (*Modified after Morera and Terradas 2017*). The alphabetical letters a-a′, b-b′, c-

Chapter 7

Figure 7.2. Microfacies types in thin sections from sectors A (Appendix I) and D (Appendix II). a) MFT-*A*, silty carbonate muds (lake marl) above the structures. MP307-1, sector A. b) Transition from lake marl (MFT-*A*) to lake marl with terrigenous sediment embedded (MFT-*B*). Note the laminations at the upper right part of the thin section. MP318-3, sector A. c) Transition from MFT-*B* to the heterogeneous sediment associated to occupation (MFT-*C*) at the upper part of the TS. MP318-2, sector A. d) MFT-*C* .MP318-4, sector A. e) Transition from MFT-*A* to the first archaeological layer associated to wooden platforms (MFT-*C2*), MP2-4, sector D. f) Carbonate groundmass of a travertine paved surface (MFT-*D*), MP2-3, sector D. g) Heterogeneous peaty sediment including clasts and organic material (MFT-*E*), MP318-6, sector A. h) Heterogeneous humus-rich sediment (MFT-*H*), MP2-2, sector D. i) Peaty sediment with decayed organic matter (MFT-*G*), MP2-1, sector D. j) Heterogeneous grey yellow sediment with angular blocky microstructure (MFT- *E1*) at the middle upper part of the thin section, MP125, sector D. k) MFT-*F* including charred material (*Quercus sp. deciduous*) at the middle bottom part of the thin section, MP126-2, sector D.

Figure 7.3. Microphotographs of Microfacies *A, A1* and *B,* sector A. **a)** Massive, carbonate rich lake marl with *in situ* mollusk shell. MP318, PPL**. b)** Example of framboidal pyrite. MP65, PPL**. c)** Cross sections of charophyte algae, MP318, PPL, **d)** and oogonia *Trichoderma*. MP307, PPL. **e)** Lake marl with terrigenous yellow brown sediment in the form of sand silt grains and subrounded quartz, including mollusk shells and **f)** root remnant evidencing gradual exposure of lake marl. MP65, PPL. **g)** Characteristic laminations of lake marl and terrigenous sediment, suggesting a water fluctuation zone. MP318, PPL. **h)** Same as g, XPL. **i)** Lake marl surface with some charcoal pieces. Note the sharp transition to the overlying occupational level with abundant anthropogenic material. MP307, PPL**. j)** Same as i, XPL. Note the transition from a crystallitic to an undifferentiated b-fabric and the random gypsum crystal intergrowths (arrow).

Figure 7.4. Microphotographs of Microfacies *C,* sector A. **a)** Transversal section of a wooden fragment (coniferous species). MP307, PPL**. b)** gypsum crystals surrounding a root in transversal section. MP307, XPL**. c)** Charcoal and bones in a heterogenous groundmass consisted by travertine sand and terrigenous sediment. Note the cracking effect of trampling on the shell (arrow). MP318, PPL. **d)** *Nummulite foraminifer*, part

of the larger group of benthic foraminifera, incorporated in the occupational debris. Its size attests for low hydrodynamic regime. Probably transported by water into the settlement. MP318, XPL. **e)** Squeezing/poaching of the groundmass. MP318, PPL. **f)** Deformations around mollusk shell, MP318, PPL. **g)** Ash presence MP291-D, PPL. **h)** Same as g, XPL. **i)** MFT-*C1*, inclined laminations probably due to trampling MP65-2, PPL. **j)** Same as i in XPL. Note the carbonate thin laminations alternating with more heterogeneous sediment.

Figure 7.5. Microphotographs of microfacies and associated features in sector A (Appendix I). **a)** Gradual change from microfacies *C* to *D*. MP65, Sector A, XPL. **b)** Microfacies *D*. Brownish oxidation feature (arrow) due to exposure and weathering, MP318, PPL. **c)** Microfacies *E.* Clay coatings and iron staining of a heterogeneous groundmass in MP291-M, PPL. **d)** Microfacies *D*. Iron staining on anthropogenic sediment associated to travertine slabs in MP291-D, XPL. It could be associated with occasional water saturation. **e)** Microfacies *E.* Massive microstructure of mixed terrigenous sediment with a lot of minerogenic clasts and amorphous organic matter, MP318-6, PPL. **f)** Fragmented bone embedded in terrigenous sediment. Probably trampled by the indirect pressure of the surrounding travertine fragments (MFT-*D*). MP291-D, PPL.

Figure 7.6. Microphotographs of microfacies types in sector D**. a)** Lake marl with massive to almost spongy microstructure due to bioturbation. Snail in living, primary position. Microfacies *A*, MP2-4, PPL. **b)** Trampled lentoid forms of brownish terrigenous sediment pushed downwards into the lake marl (*MFT-A* in contact with *MFT-C2*), MP3-6, Sector D, XPL. Note the convolutions attesting for poaching conditions (arrow). **c)** Microfacies *A* in contact with Microfacies *C2*, MP2-4, PPL. **d)** The tip of a wooden log in contact with sediment associated to microfacies *C2* in MP2-4, PPL. **e)** Heterogeneous groundmass consisted of a mixture of carbonate and terrigenous sediment comprising MFT-*C2* in MP2-4, PPL**. f)** same as e, in XPL. Note the compacted microstructure. **g)** Aggregate of sediment with embedded charcoals, shells and some travertine fragments, probably coming from the travertine pavement. Part of Microfacies *F*, MP2-2, PPL. **h)** Peaty sediment with decayed organic matter and other mixed material formed under seasonally waterlogged conditions. Microfacies *G*,

MP2-1, PPL**. i)** Charcoal fragment embedded in microfacies *C2* associated to wooden remains (*Quercus sp. deciduous*). Note the growth rings. MP3-7, PPL.

Figure 7.7. Microphotographs of Microfacies *F* in Sector D (Appendix II). **a)** Charred seeds associated to some roots and other organic material in MP125, PPL. **b)** Charred charcoal fragments (*Quercus sp. deciduous*) devoid of sediment, probably burnt on a dry environment in MP126-3, PPL. Note the growth rings. **c)** Charred charcoal fragment with embedded seed conserving the cellular structure in the middle. MP126-3, PPL. **d)** Horizontally laminated roots overlain by travertine fragments in MP125, PPL. **e)** Leaf and wooden remains in a not entirely burnt state, MP125, PPL. **f)** Same as e, in XPL.

Figure 7.8. Structures E260 on the left and E258 on the right from sector A at La Draga. Examples of the stratigraphic sequence of structures from recent phase overlapping postholes and wooden vertical piles from the oldest phase of occupation at the site of La Draga (*Modified after Rafa Rosillo;* Palomo *et al.* 2018).

Figure 7.9. Microfacies *C, D* and *P* and variations of MFT-*A* at sector C (Appendix III). a) Lake marl with terrigenous sediment and semiplastic forms of the carbonate silts (C1). These are overlain by a thin carbonate layer MFT-*C3* and a travertine slab MFT-*D*. Wet conditions. b) Heterogeneous sediment associated to the occupation remains, mostly charred material (*Quercus sp. deciduous*) and travertine fragments MFT-*C* (C2). c) Natural peat formation MFT-*P*, with compacted decayed organic matter (C9). d) MFT-*A* lake marl variation with presence of roots and bioturbation. Shallow waters (C5). e) MFT-*A* variation with calcite encrustations around former algae and precipitation of micrite mostly from the bottom until the middle of the thin section. Lake level increase (C11). f) MFT-*A* variation with inclined parallel laminations, probably affected by wave activity (C7).

Figure 7.10. Microphotographs of Microfacies types in sector C (Appendix III). **a)** Thin carbonate layer with horizontally aligned root remnants (MFT-*C3*), C1, PPL**. b)** same as a) in XPL. **c)** Large aggregate (MFT-*C3*) between the thin layer (MFT-*C3*) below and sharp contact with the travertine (MFT-*D*) above, C1, PPL. **d)** Same as c, in XPL. **e)** Upper part of carbonate aggregate (MFT- *C3*) with charcoal fragments and ash

remains under the overlying travertine slab, PPL and **f)** same as e, in XPL, C1. **g)** MFT-*C*. Leaf preserving its cellular structure due to wet conditions, surrounded by carbonate groundmass, C2, PPL. **h)** MFT-*C*. Roots and plant material in a carbonate groundmass; some appear charred and are probably associated with occupational remains, C2, PPL. **i)** Same as h. Note the presence of ash under XPL. **j)** *In situ charophyta* and a caracean gyrogonite in the center indicating natural deepening of the lake, C3, XPL. **k)** Highly bioturbated groundmass with pelletal microstructure including a vertical root and mollusk shells (MFT-*A*), C5, PPL. **i)** Horizontal roots associated with bioturbation, embedded in a pelletal microstructure of lake marl (MFT-*A*), C5, XPL. **m)** MFT-*P*. Peaty sediment and horizontal laminations; contact between lake marl and overlying peat, C9, PPL. **n)** Peaty sediment with embedded decayed organic material and massive microstructure, C9, XPL.

Figure 7.11. XRF scanning of the *Core Draga 2017_ Sector C.* View of the core with **(a)** distribution of Ca-Ka (calcium) in comparison with **(b)** Fe-Ka (iron) and Pb-La (lead) areas. **(c)** Distribution of the dates over the *Core Draga 2017_ Sector C* obtained through radiocarbon dating (yellow color) and Uranium/Thorium (red color). From the bottom up, the 1st occupation at La Draga is found between the first two estimated dates, while signs of the 2nd occupation should be found between the second and the third date.

Chapter 8

Figure 8.1. The local dendrochronological sequence at La Draga site. The wooden posts corresponding to both construction and repair phases are represented respectively in the diagrams (*Figure after Patrick Gassmann*).

Figure 8.2. An extract of the dendrochronological sequence at La Draga site with the minimal duration of the settlement's occupation based on the twelve radiocarbon dated wooden piles (*Figure after Patrick Gassmann*).

Figure 8.3. Map of spatial distribution of the dated wooden piles at La Draga, including both the installation (year 237/238) and the repair associated piles. Sector A on the left and sector B-D on the right (*Figure after Núria Morera*).

Figure 8.4. Wiggle-matching of dendrochronological ordered piles after deleting outliers. Calculated using OxCal 4.4. and IntCal20 calibration curve.

Figure 8.5. Calibration of single date *UBAR1247* (tree-ring 265 of the local dendrochronological sequence). Oxcal 4.4. IntCal20 calibration curve.

Figure 8.6. Comparison of wood, seeds and faunal samples from Sectors B and D, First Occupation. Using Oxcal 4.4 and IntCal20 calibration curve. In all three cases, R_Combine has been used to create the posterior distribution. In the case of wood and seed samples, this procedure pass Ward and Wilson test. In the case of faunal samples, there is an outlier (*Beta-278255*), 100 radiocarbon years older than the rest. See discussion in text.

Figure 8.7. Results of a model of 9 partially contiguous, partially sequential and partially overlapping phases and sequences. Oxcal 4.4. IntCal 20 calibration curve.

Figure 8.8. An Event and Phase Model with stratigraphic constraints and temporal boundaries based on dendrochonological and Wiggle-Matching estimates. ChronoModel 2.0. IntCal20 calibration curve.

Figure 8.9. Results of a 9 Phases Chronological model. ChronoModel 2.0. IntCal 20. Each Phase is depicted with a different color. The lightest color corresponds to the *a priori* confidence interval, whereas the dark color depicts the *a posteriori* Bayesian estimation. Unlike the previous OxCal model, Post-Occupation layers have been integrated into a single one. This simplification does not affect the results.

Figure 8.10. Harris Matrix diagram representing the depositional events associated to both structural occupations at La Draga. The events are separated into six temporal groups based on the results from ChronoModel and OxCal. The stratigraphic constraints between the depositional events have been maintained.

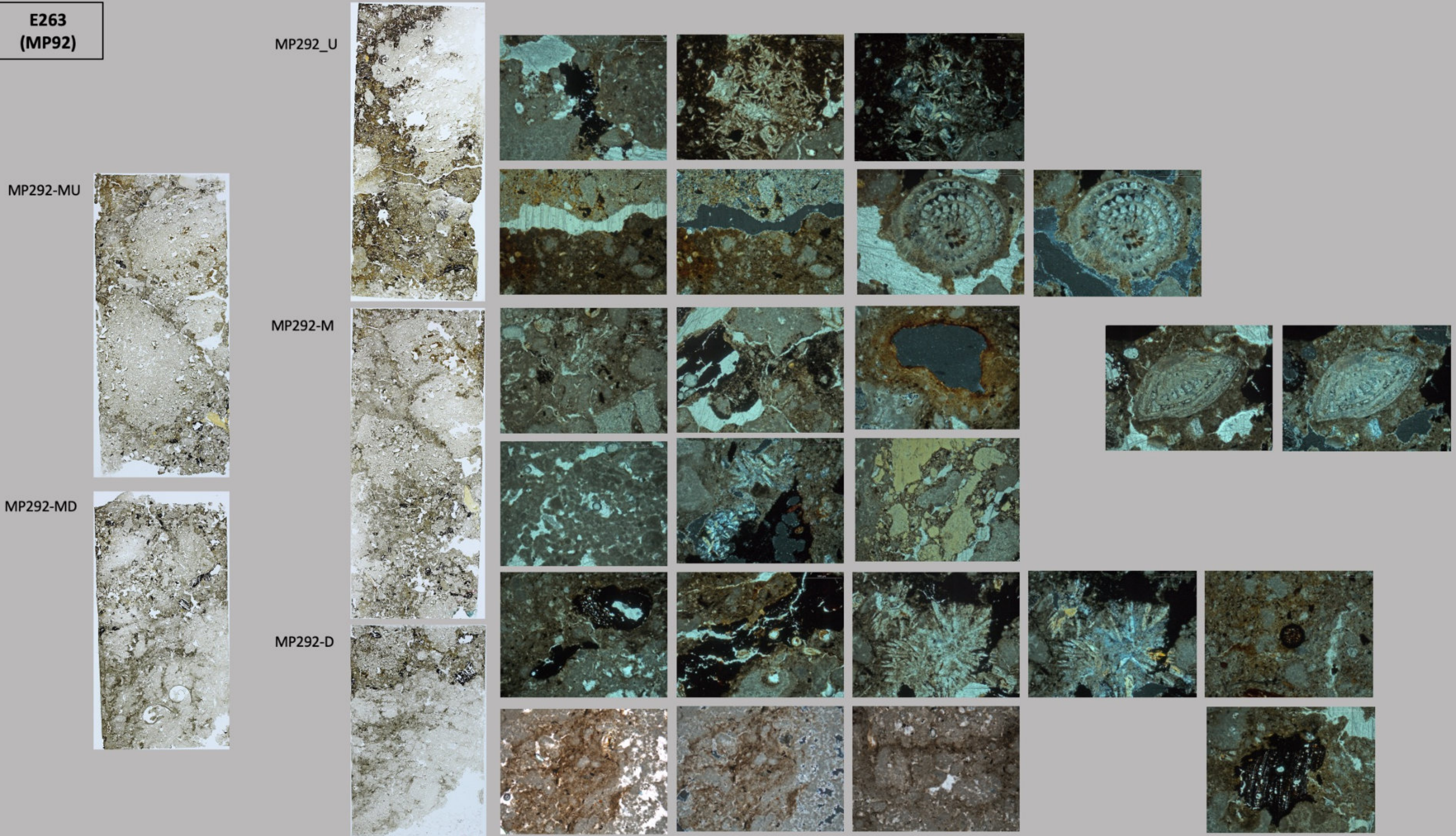
Figure 8.11. Allen Algebra adapted diagram for site occupational temporal sequence representing depositional events E-1 to E-31 and their respective phases. Black vertical lines mark the end of clear evidence from first occupation (5200 cal BC), as well as the beginning (5100 cal BC) and end of second occupation (4800 cal BC).

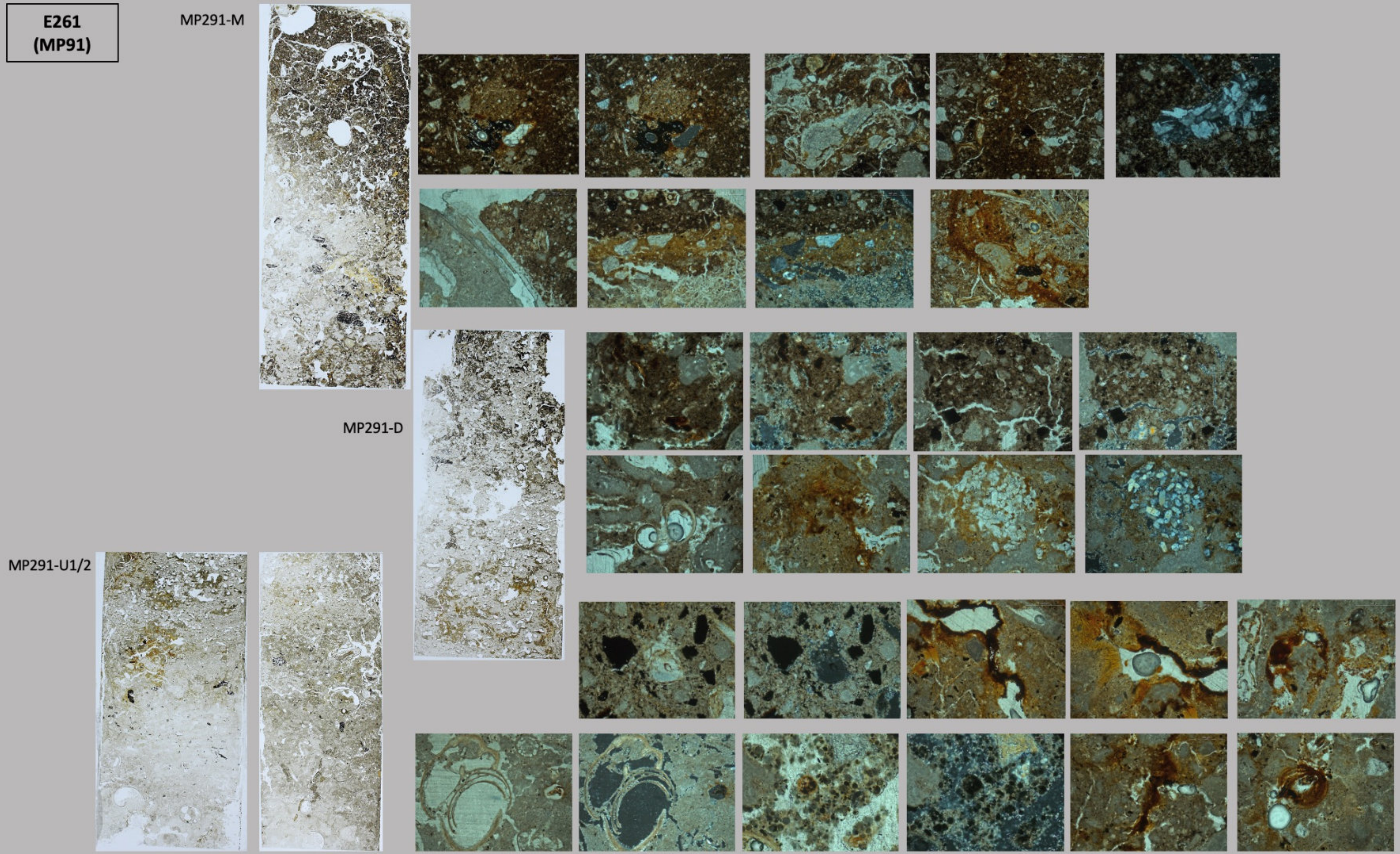
LIST OF TABLES

Chapter 8

Appendix I

E263 (MP92)

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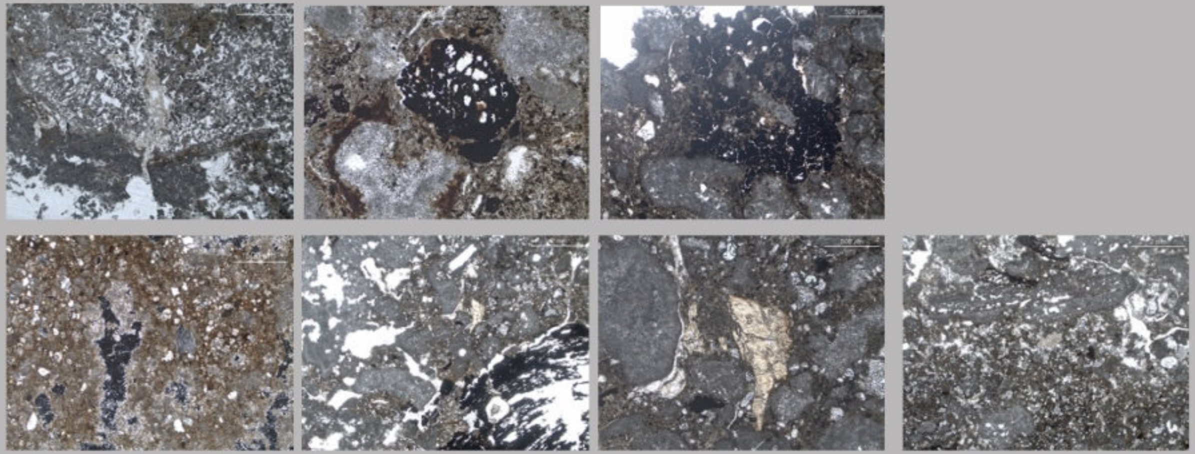
MP291-D
MP291-U1/2

E258 (MP65, MP66)

MP65-1

MP65-2



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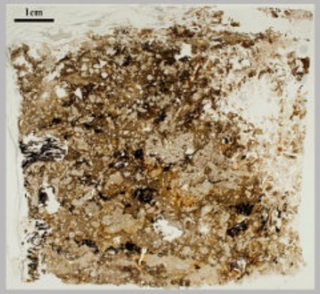

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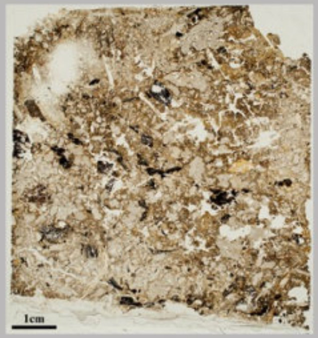

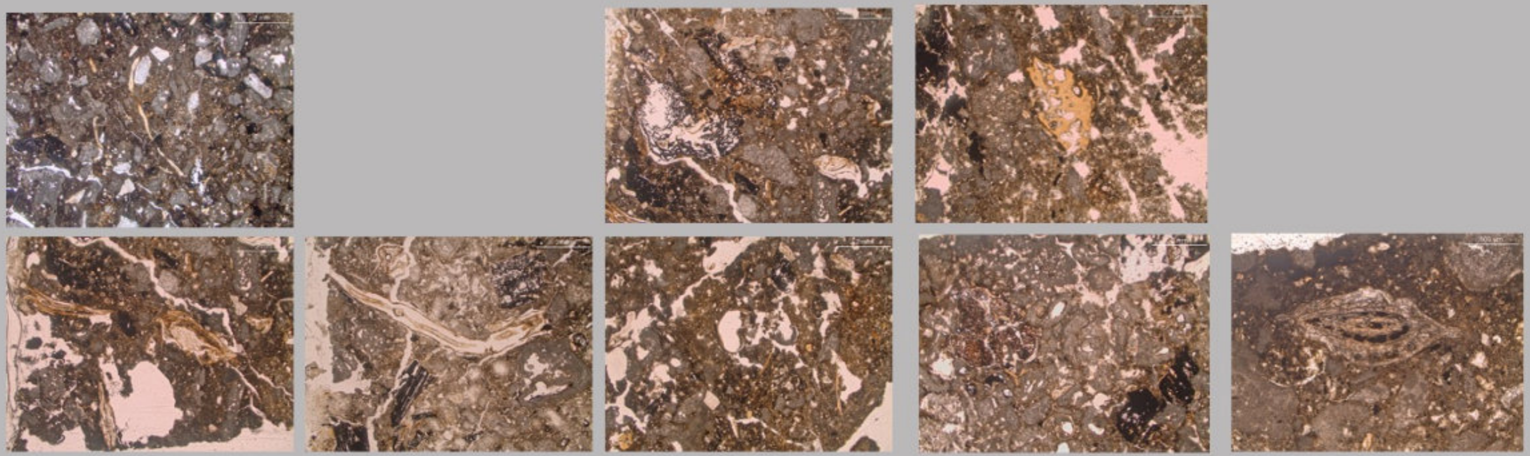

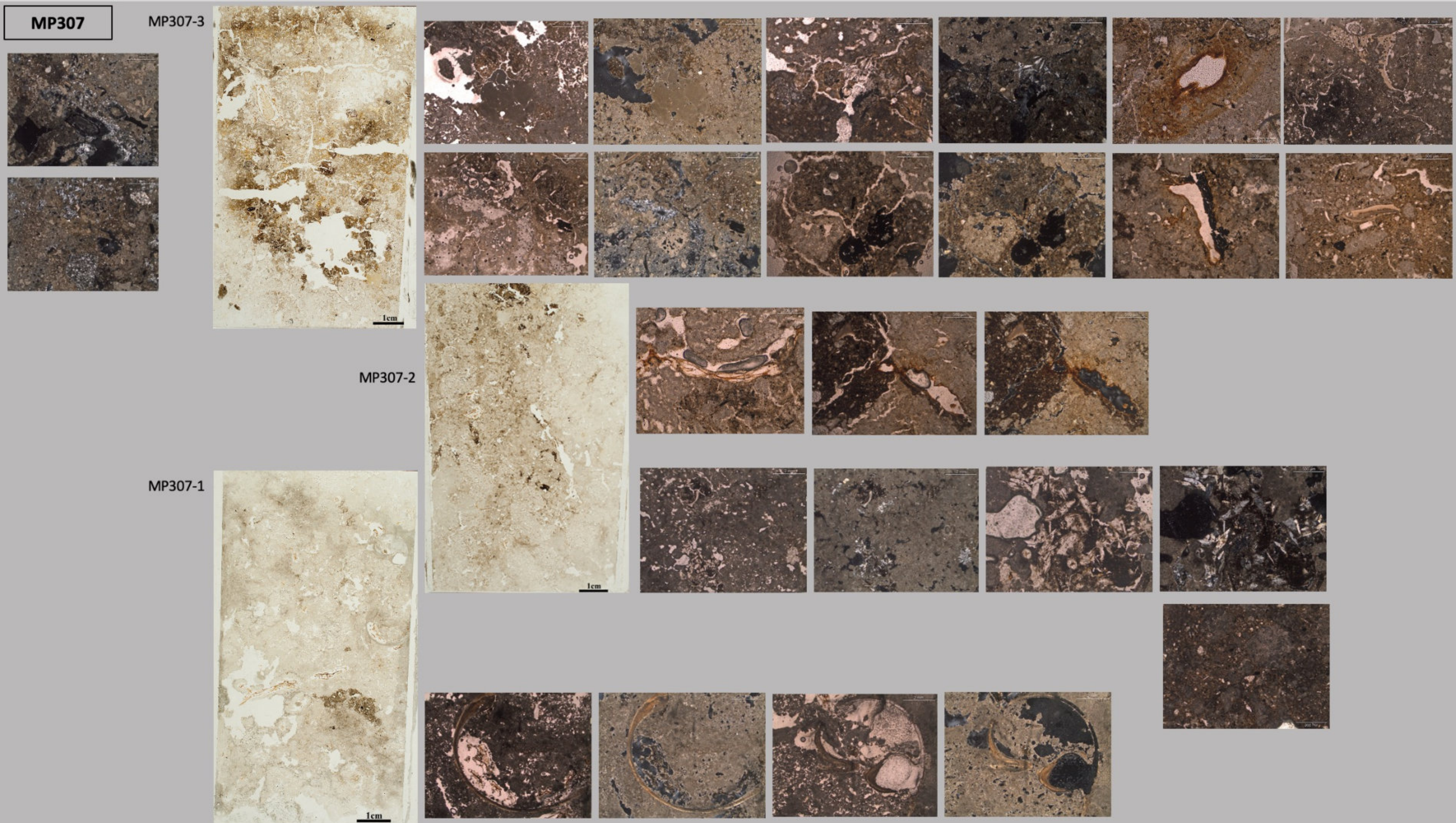
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MP307-2
MP307-1
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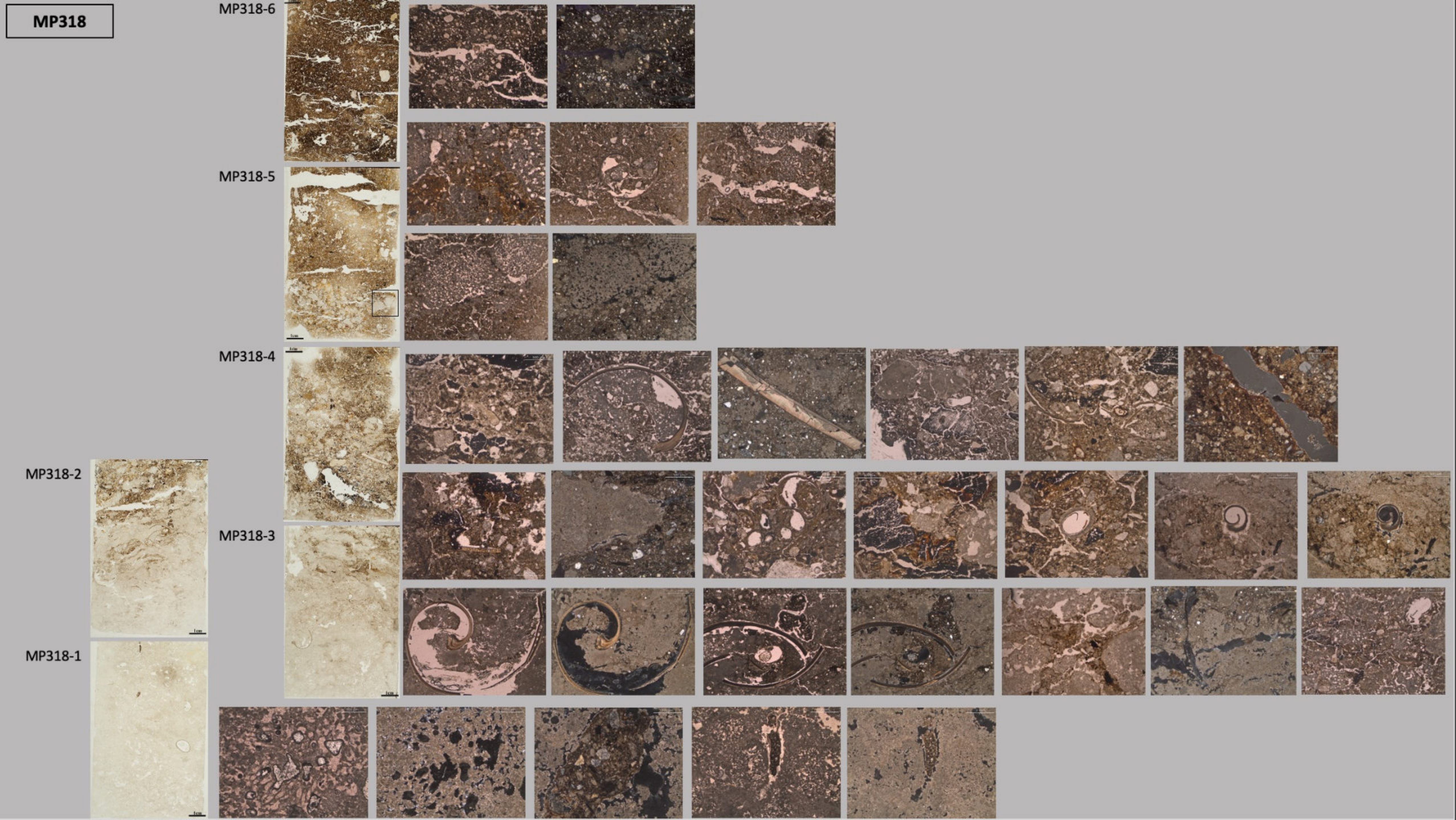
1cm
1cm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MP318-1

Appendix II

MP2

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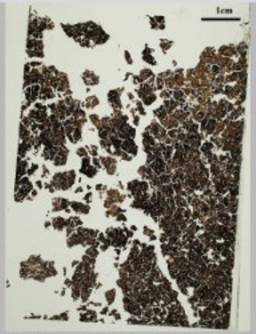

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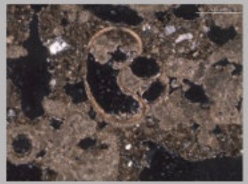

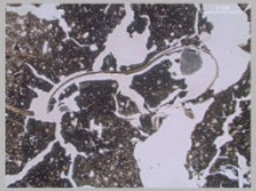

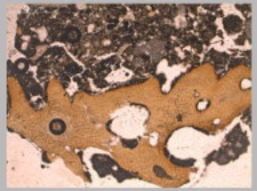

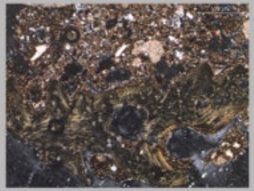

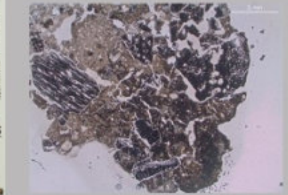

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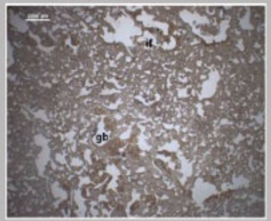

gb: gas bubble
if: infilling

Photo by Andrea Balbo

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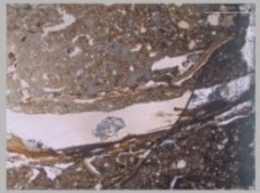
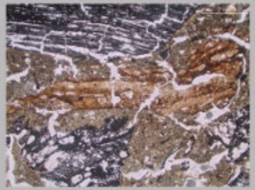
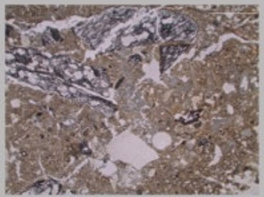
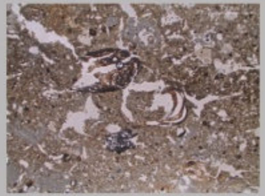
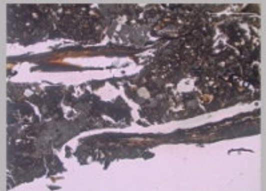










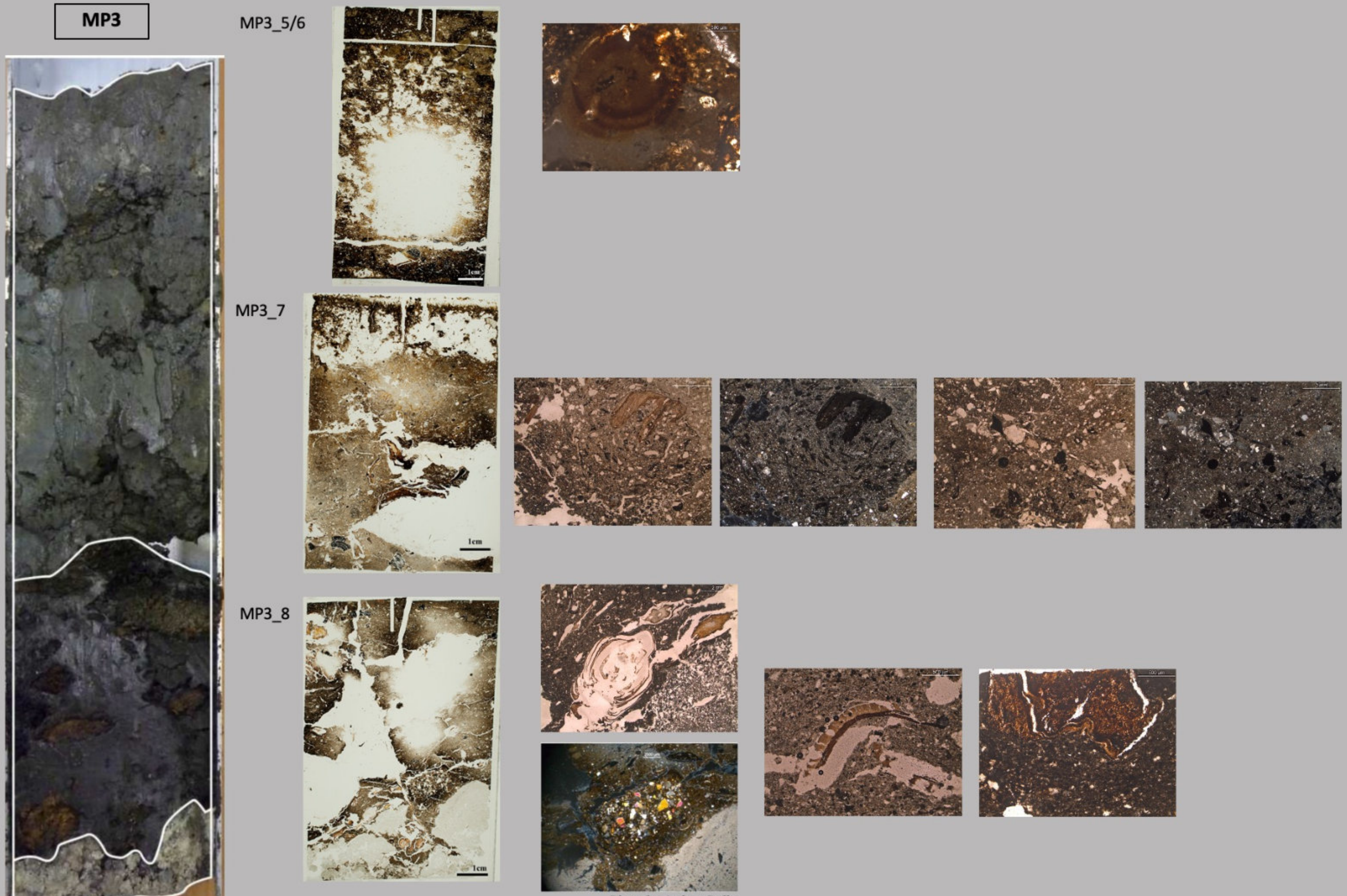
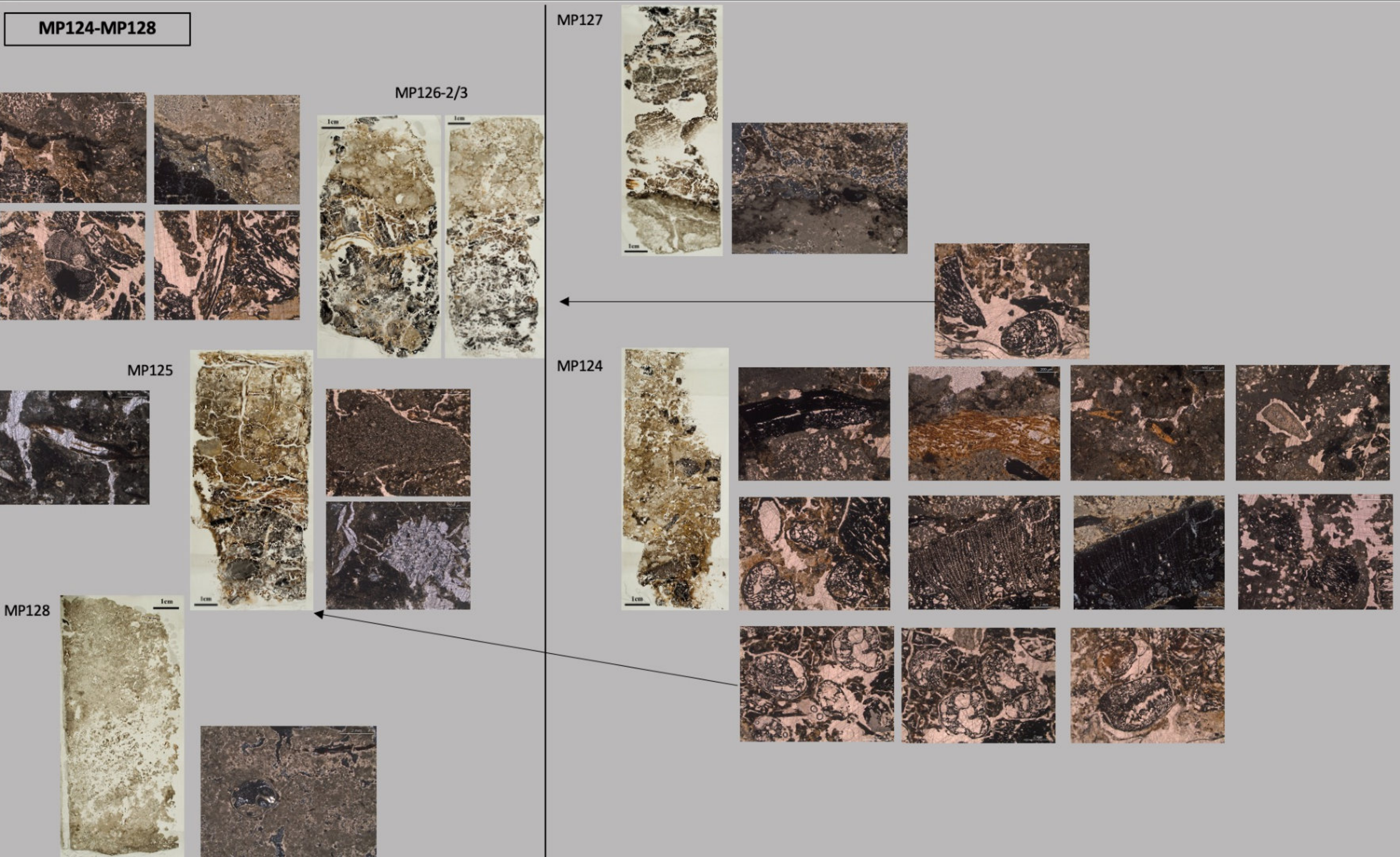


Photo by Andrea Balbo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MP125
MP124
MP128
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Appendix III

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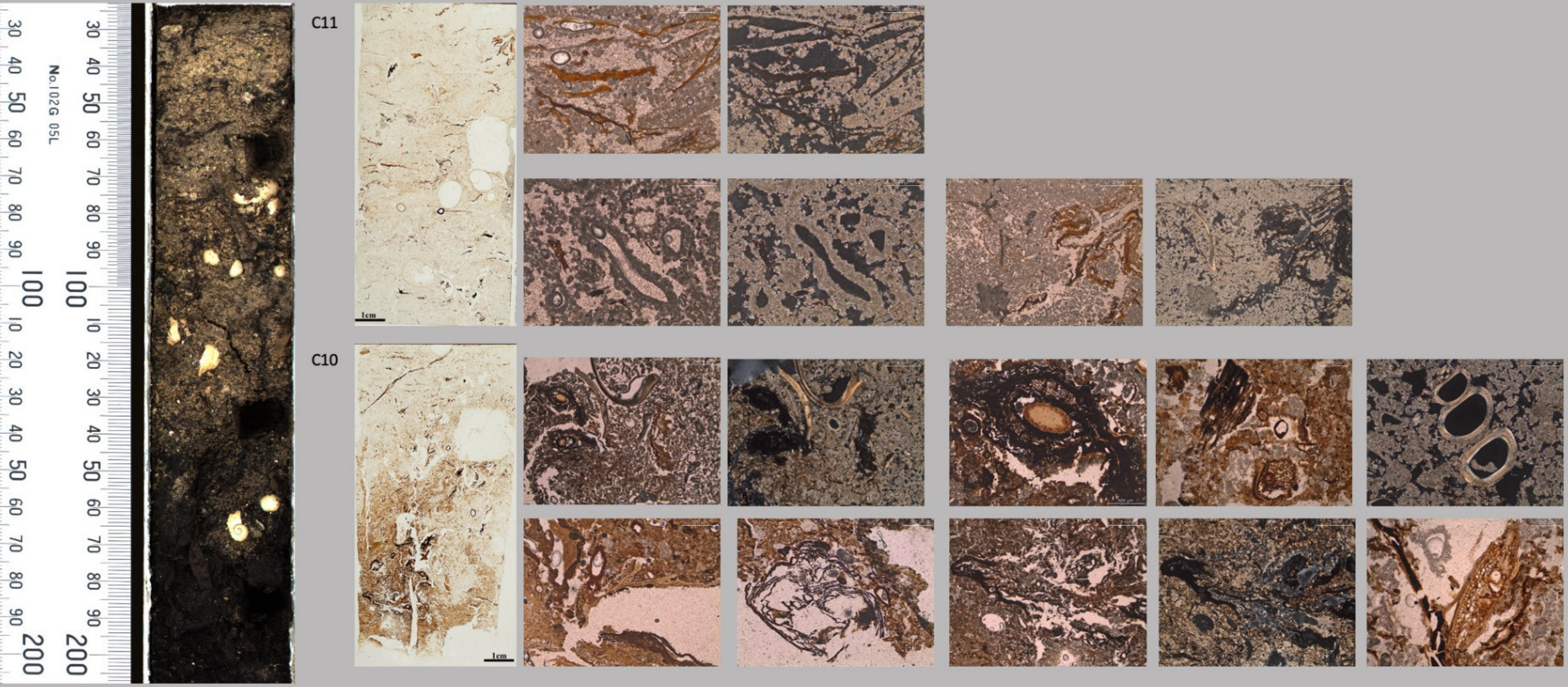

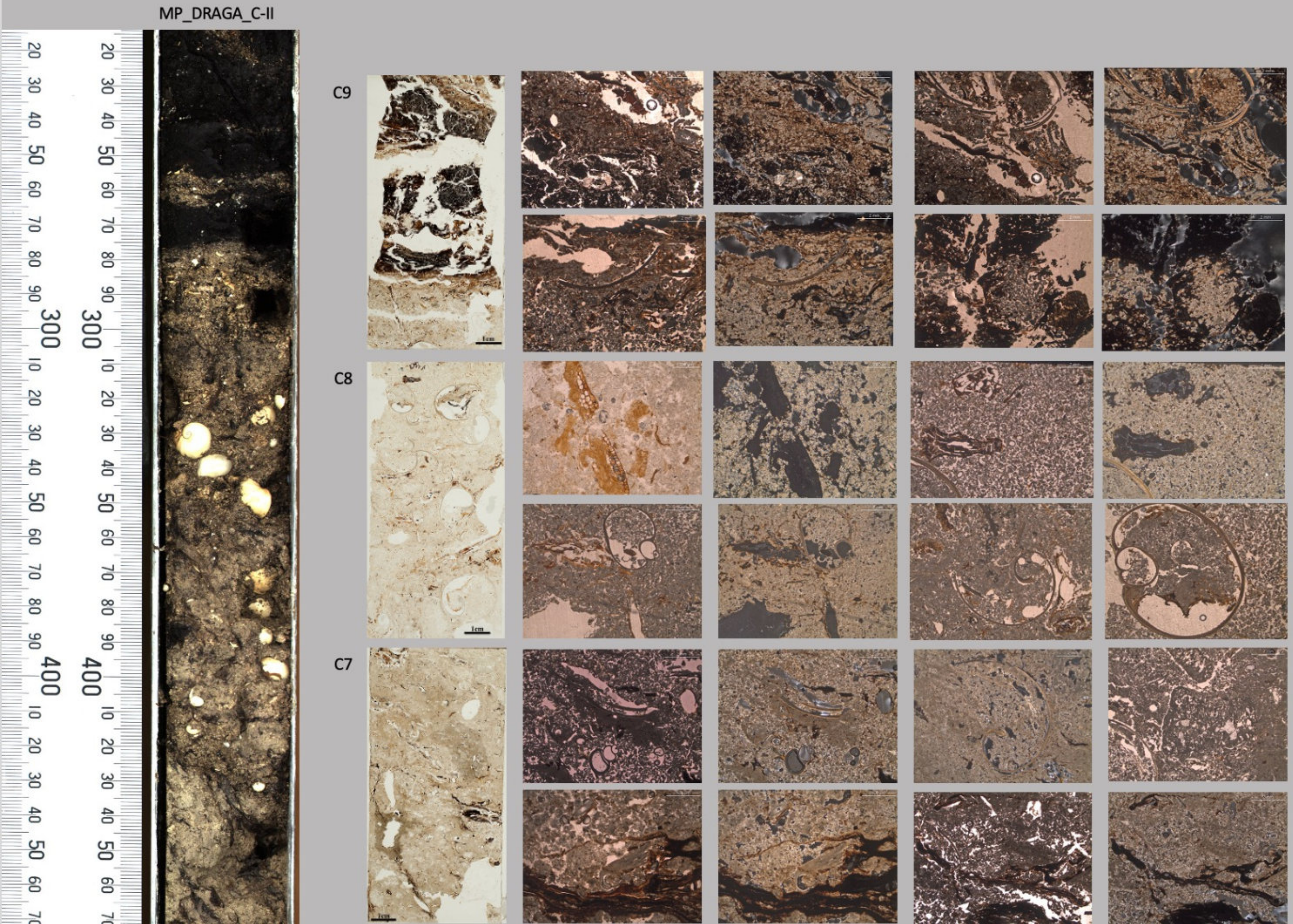
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C8
C7
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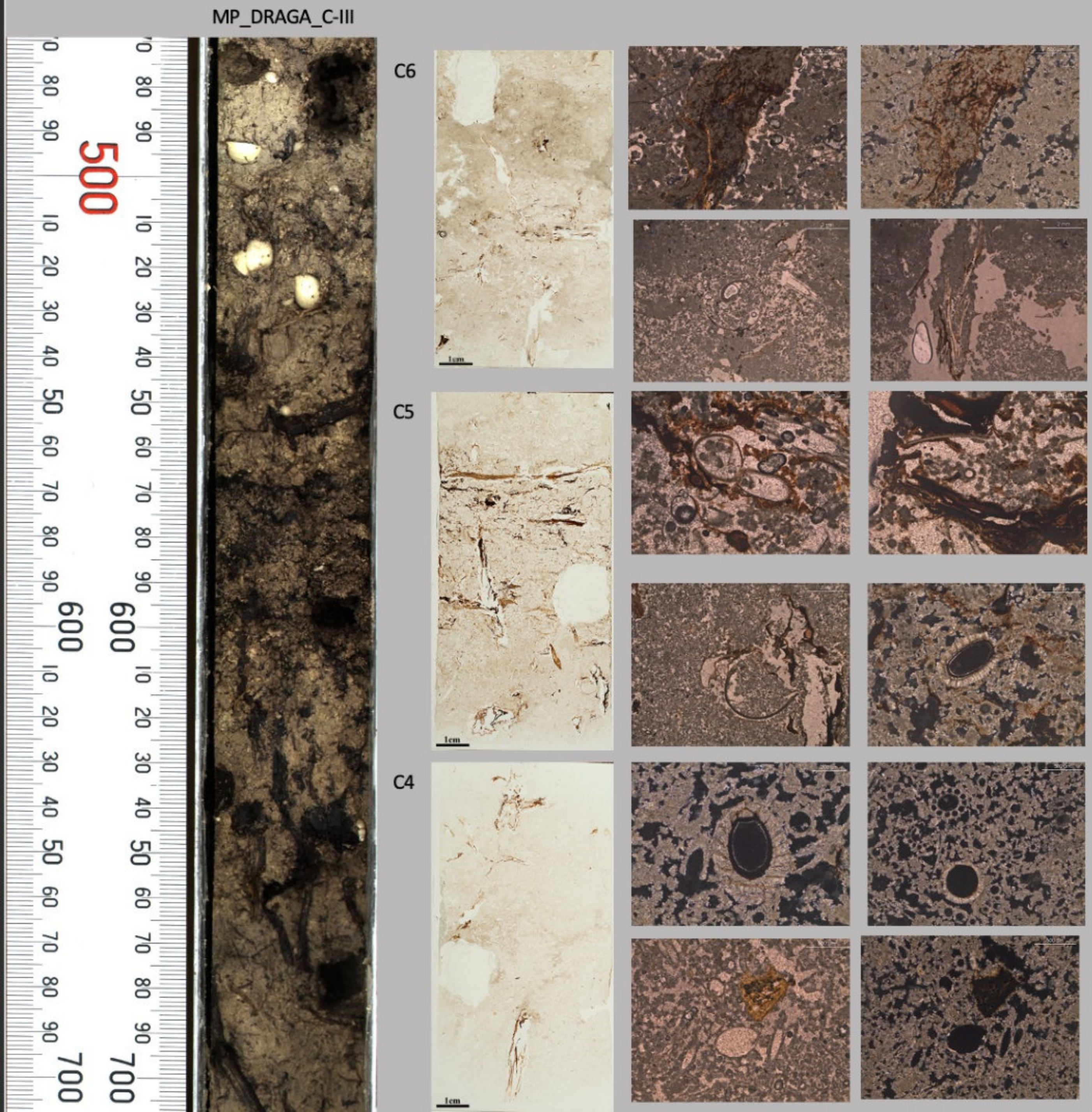
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1cm
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