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**La formación de concheros en el litoral atlántico ibérico en el Mesolítico.**

Perspectivas geoarqueológicas y micromorfológicas sobre las adaptaciones costeras de los cazadores-recolectores del Holoceno

PHD THESIS

**The formation of shell middens in Atlantic Iberia during the Mesolithic.**

A geoarchaeological and micromorphological approach to the coastal adaptations of the Holocene hunter-gatherers


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# The formation of shell middens in Atlantic Iberia during the Mesolithic

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Doctoral Thesis
in
Prehistoric Archaeology


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*To my family*

*“Ninguém sabe quem sou... e mais, parece*
*Que há dez mil anos já, neste degredo,*
*Me vê passar o mar, vê-me o rochedo*
*E me contempla a aurora que alvorece...”*

Antero de Quental, *Homo* (1886)

*“Era como uma árvore da terra nascida*
*Confundido com o ardor da terra a sua vida*
*E no vasto cantar das marés cheias*
*Continuava o bater das suas veias”*

Sophia de Mello Breyner Andresen, *O primeiro homem* (1947)

*“Não quero entrar em vãs filosofias, mas responda-me se vê alguma ligação entre o facto de um macaco ter descido duma árvore há vinte milhões de anos e a fabricação duma bomba nuclear, A ligação é, precisamente, esses vinte milhões de anos [...]”*

José Saramago, *A Jangada de pedra* (1986)

“*Roque Lozano juzga por las apariencias, con ellas forma una razón que es suya y buena de entender, contémplese la serenidad bucólica de estos campos, la paz del cielo, el equilibrio de las piedras, las sierras Morena y Aracena igualitas desde que nacieron, o, si no tanto, desde que nacimos nosotros [...]”*

José Saramago, *La balsa de piedra*, (1986)

*“And at once I knew I was not magnificent*
*Strayed above the highway aisle*
*(Jagged vacance, thick with ice)*
*And I could see for miles, miles, miles”*

Bon Iver, *Holocene* (2011)

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# INTRODUCTION AND OBJECTIVES

Shell middens are one of the strongest indicators, in the archaeological record, of systematic reliance on marine resources by hunter-gatherer societies (Aldeias and Bicho, 2016, Marean, 2014). The evolution of human coastal adaptations, including human dispersal and adaptative behaviours in intertidal environments, has been constructed based on the global distribution of this type of archaeological deposits (Balbo et al., 2011, Briz Godino et al., 2011, Marean, 2014, Erlandson, 2013, Erlandson, 2001, Álvarez et al., 2011). As these shell deposits are strongly associated with systematic exploitation of coastal resources, when absent in the archaeological record lead some authors to hesitate on inferring the reliance of human populations on these resources, as it happened with some cases in Iberian Peninsula (Marean, 2014, Straus, 2008, Bicho et al., 2011b). Therefore, very few sites in Iberia dating from the Middle Palaeolithic have been reported as representing systematic shellfish collection, being only with the Anatomical Modern Humans appearance that aquatic resources start to be more intensely exploited (Bicho and Haws, 2008, Haws et al., 2010). In fact, it is in the end of Pleistocene that an increase in shell middens around the world is verified (Bailey and Milner, 2002, Erlandson, 2013).

Although there were shell-rich deposits since the Paleolithic, confirming the importance of marine resources since then, it is during the Early Holocene that larger shell middens appear, associated with Mesolithic populations. Mesolithic hunter-gatherers' subsistence, growing social complexity and sedentism are reflected in the shell midden sites, that represent their broad-spectrum exploitation of resources, integrate their funerary rituals and reflect other economic activities and settlement organization. For that, shell middens enclose crucial issues of human history.

Shell midden archaeology is a global issue which research has following a same trajectory in different regions of the world through the last decades of the 20$^{th}$ century until nowadays. Substantial advances have been achieved in what concerns the study of lithic technology and faunal remains associated to these sites, allowing the increment of disciplines like archaeomalacology and sclerochronology (Andrus, 2011, Gutiérrez-Zugasti et al., 2017, Prendergast, 2017). The widespread association of human burials to shell middens, also allowed detailed studies on those palaeoanthropogy, namely palaeodiets and palaeopathology (Peyroteo Stjerna, 2016, Umbelino et al., 2015, Figueiredo, 2012, Lubell et al., 1994, Fontanals-Coll et al., 2014, Arias Cabal, 2005, Schulting and Richards, 2001, Fischer et al., 2007). One of the aspects of human behaviour that recently has been more exploited specifically from shell midden deposits is seasonality patterns (see, e.g., Surge et al., 2013, Colonese et al., 2009, Colonese et al., 2012) which allowed to reconstruct seasons of shellfish gathering based on the Oxygen isotopic analysis of the shell's growth lines. At regional scale, shell middens have also been explored as palaeovironmental proxy. Their location has been used for mapping changes in Holocene costal environments (Villagran and Giannini, 2014) and isotope and elemental analysis of shells' growth lines have also been used for palaeoclimatic reconstructions, namely sea surface temperature variations (Gutiérrez-Zugasti et al., 2015).

Such studies demonstrate that shell middens are excellent sources of knowledge, given the density of archaeological materials that characterises them, most of it resulting directly from exploitation of aquatic resources (among others), for what they are also optimal archives of palaeoenvironmental information. Both aspects of shell middens potential for archaeological interpretations (human behaviour and palaeoenvironment) are increased by the fact that this type of deposit is known in coastal areas worldwide and from different, chronologies.

However, it remains largely unknown how shell middens were produced, maintained and used. In this thesis, I depart from the hypothesis that the answer to these questions is mostly preserved in the sediments. As referred above, considerable amount of information has been produced from artefacts and bioarchaeological remains recovered from shell middens, but what about the sedimentary matrix that contains all those items?

In the case of shell middens, a detailed study of the sedimentary matrix is crucial because it is also largely anthropogenic. The formation of shell middens generates components of sedimentary nature that preserve behaviourally relevant data, a reason for what shell midden might be considered artefacts themselves. The potential of studying shell midden as artefact can be maximised by the study of its microscopic sedimentary record, where most of the human signatures in the formation process are preserved and are susceptible to be interpreted in terms of behaviour. This converts shell middens in a type of site particularly interesting from a geoarchaeological point of view. The hypothesis considered is that the study of these signatures allows to enlarge the knowledge about how humans adapted to coastal areas of Iberia during the early Holocene, when substantial geographic changes occurred due to sea-level rise.

Therefore, the main objective of this dissertation is the reconstruction of the formation processes of Mesolithic shell middens, looking for sedimentary signatures of specific actions behind the accretion of shell-rich deposits. To accomplish this objective, it is proposed that the application of micromorphology is the best way to achieve high resolution reconstruction and individualisation of the various accumulation events, incorporating the microscopic sedimentary record in the interpretation of these sites, which enhances the identification of specific micro-contexts.

To carry out this general objective, selected sites will be studies systematically with micromorphology, with the purpose of gathering information of the following specific topics:

1) Microstratigraphy: individualise different moments of shell-rich deposits accretion is one of the main challenges faced by archaeologists when investigating shell middens (Bailey, 1983, Gutiérrez-Zugasti et al., 2011). Here micromorphological analysis is intended to overcome this essential obstacle in the reconstruction of shell midden stratigraphic record, using utterly different types of deposits and sedimentological environments for the purpose.
2) Context: the former will allow the definition of particularities at sedimentological level, the macro- and microscopic components of each context, the artefact they contain and their relationship with the surrounding matrix and to determine its nature. This will allow to discern individually the influence of anthropic, geogenic and biogenic agents responsible for the formation and post-depositional alterations of each context, which is essential for their interpretation, as well as the material recovered from them.
3) Palaeoecology: since shell middens are composed essentially of molluscs and other components of high palaeoenvironmental informative potential. Sediments are also propitious to preserve palaeoenvironmetal signatures. Being anthropogenic accumulations, shell middens constitute then excellent archives to investigate human coastal adaptations in the Mesolithic.

Data collected within these three topics to achieve the general objective aims to contribute to the reconstruction of the historical and evolutive processes of the coastal adaptations of the Mesolithic hunter-gatherers, a fundamental moment in Prehistory, representing the way towards social complexity and sedentism of human societies.

## Thesis structure

The body of this thesis is divided in three parts: Background, Data and Results, and Discussion. Each part is in turn divided in different chapters. The figures and tables refferred to throughout the text are embodied in the text.

The first five chapters comprise Part I of this thesis, stating the theoretical and methodological background. Chapter 1 is thus focused on the conceptual frames of this thesis. The reconstruction of formation processes using geoarchaeological approaches is the first subject being addressed, explaining the concepts of geoarchaeology and the evolution of the formation processes theory in Archaeology. Next, a brief section on shell midden research is entailed, focusing on current challenges and the research question that occupy archaeologists when facing shell middens, to demonstrate that they are largely related with the difficulties of formation processes reconstruction, and how geoarchaeological techniques are particularly suitable to answer it.

Chapter 2 presents the geological and paleoenvironmental setting of the geographical scope of the thesis. Chapter 3 is dedicated to a chrono-cultural synthesis of the Mesolithic archaeology and the role of shell midden for its understanding, centred on an attempting systematization of the shell midden record in Iberia. Chapter 4 provides a critical literature review concerning specifically geoarchaeological studies previously undertake on relevant contexts for my research questions. Each one of the three section has two separate sub-sections, each one dedicated to each Iberian region under study: the Cantabrian Region and the Sado valley.

In Chapter 5, the methodological approach implied, and a description of the field and laboratory works is provided. The technique of micromorphology, central in this thesis as proposed technique to decipher the formation processes of the studied sites, is explained in this chapter, as well as the specific concepts, like that of microfacies, nomenclatures and references used for the analyses.

Chapter 6, 7, 8 and 9 together form Part II, dedicated to the exposition of data and results of the analysis of each context studied for this dissertation. The contexts are the sites of La

Fragua, El Mazo and El Alloru, in the Cantabrian region, and Poças de São Bento, in the Sado valley. Each chapter consists in monographic approaches presenting similar organisation separarted by sites' presentation and specific research questions, sampling strategy, presentation of results, discussion and specific conclusions. The plates referred to in these chapters are displayed in individual Appendixes corresponding to specific chapters, included in the annexed CD.

Finally, in Part III is composed of two chapters. Chapter 10 consist in a broad discussion of the results obtained in the monographic cases presented in Part II, placing them on a global perspective regarding shell midden formation processes and how geoarchaeological, particularly micromorphological observation help in reconstruct the formation processes and subsequently making inferences on human actions and intentions behind the accumulation of shells, focusing on the particular traces of this phenomenon during the Mesolithic in Iberia. The last chapter, 11, synthetises the aspects on carbonate materials generated with this research and its implications in contexts such as shell middens, where calcium carbonates have a critical role due to its origins and diagenetic diversity.

A Conclusion section, at the end, summarises the applications of micromorphology to shell midden contexts, and future challenges regarding the series of issues that remain unanswered, and to which the results of this dissertation helps in providing new venues of research.

# PART I

# BACKGROUND

Chapter 1

# Geoarchaeology and Shell Middens

The methodological approach of this thesis is inserted in the field of geoarchaeology, and the main way to achieve the objectives is through the reconstruction of site formation processes of shell midden sites. These concepts constitute the theoretical background of this dissertation and are introduced in the first section of this chapter. The second section is dedicated to a brief synthesis of the mains questions involved in shell midden research and the specific challenges that these sites present, that are intimately related with difficulties regarding formation processes reconstruction.

## 1.1 Geoarchaeological approaches

Geoarchaeology is a methodological field that comprehends those approaches to archaeological questions using tools and concepts from geosciences (Butzer, 1982; Rapp and Hill, 1998; Goldberg and Macphail, 2006). The consolidation of the term “geoarchaeology” in the 1970’s (Butzer, 1973; Butzer, 1975; Rapp, 1975; Renfrew, 1976) was the formalisation of a long-term practice in the search for past human behaviour, combing geological and archaeological perspectives.

Since its beginning, prehistoric archaeological investigations in the 18$^{th}$ and 19$^{th}$ centuries, counted with geoscientific insights, and one of the most remarkable aspects of this by that time is the concern in the stratigraphic integrations of archaeological artefacts. The regions focused in this thesis are good examples of this (see sections below). Curiously, one of the earliest multidisciplinary approach to archaeological deposit concerned shell middens (Hill, 2017). It was in Denmark, when collaborative work between the geologist Johan Forchammer, the archaeologist Jens Worsaae and the paleontologist Japetus Steenstrup demonstrated that the shell mounds were human habitation sites (Hill, 2017) .

These early investigations were already concerned with the importance of understanding the sedimentary context from which the artefacts are recovered. The sedimentary context in archaeological sites is essentially geologic in nature, and many of the archaeological material removed from it are themselves composed of sediments and rocks. For these reasons, Renfrew (1976:2) advocated that "every archaeological problem starts as a problem in geoarchaeology".

The geoarchaeological focus is thus primarily on the context in which archaeological artefacts or sites are inserted, be it a sedimentary deposit, a soil, or a landform, to investigate, still in the words of Renfrew (1976), the "circumstances which governed its location, its formation as a deposit and its subsequent preservation and life history". To achieve such purpose, geoarchaeologists use whichever technique more effectively answers the specific archaeological questions, from a range as wide as that of the geoscience's disciplines, including geophysical, geochemical and microscopic techniques.

In the contextual approach to archaeological record defined by Butzer (1982), and in concert with the variety of geoscientific disciplines that can help investigating human past, geoarchaeological research deals with several spatial scales of analysis. According to French (2003) there are four scales of resolution in the geoarchaeological analysis of a given context. The first is the regional context, defined, for instance, by a watershed, which has its own hydrological, climatic, geological and topographic dynamics and influence the human settlement through time. A first intermediate scale would be the immediate region where a site is located, where specific natural dynamics directly affecting the site formation are addressed, such as land-use, position, as well as the transformation and burying of archaeological sites. The third scale of resolution if the site itself and immediate environment, i.e., the area around the site, which natural characteristics, such as water availability, determine its location and organisation, as well as its preservation. The finer scale of analysis is the archaeological contexts, that French called "within-soil micro-environment", ironically, the one that is the most overlooked by archaeologists.

The larger scales of analysis in geoarchaeological research are mainly concerned with environment, placing geoarchaeology along with other environmental archaeological and ecological disciplines, namely all bioarchaeological subfields, in the aim of reconstruct ancient environments and the influence of it in human societies, as well as human influence of it at local and regional levels over time. Thus, traditionally geoarchaeology is concerned with the study of the evolution of the reciprocal relationships between humans and environments, and how and when one had major impacts on the other (Hill 2017).

This broader perspective is closely linked to geomorphology and aims to reconstruct the evolution of the landforms in a given environmental system. For that it counts with specific knowledge of environmental sedimentology (Perry and Taylor, 2009) in the application of general laws of sedimentology of environments such as hydrological (fluvial, lacustrine, etc), aeolian, coastal, glacial or karstic systems, to give a few examples (French, 2003, Goldberg and Macphail, 2006). Associated to the effort of decipher landscape transformation or reconstruct paleolandscapes is the search for human impacts on those (Stein and Farrand, 1985, Waters, 1992, Rapp and Hill, 1998) over past times and differentiate the influence of climate and human inputs. One of the main sources for this endeavour is the record of soils and paleosoils, making soil science an important discipline in geoarchaeology (French, 2003, Benedetti et al., 2011).

Butzer (1982) introduced an important aspect in the role of geoarchaeology in the human/environment relations analysis: the notion that environment is what provides context, which can range from food residues to sediment, to landscape matrix. He states (Butzer, 1982) that in the framework of human/environment relations, geoarchaeology should be concerned with the multidimensional expression of human decision making within the environment, more than explain ecological phenomena such as energy flows and food chains, in order to stimulate holistic research into the complex interactions among cultural, biological, and physical factors and processes.

These statements from Butzer called attention for the role of geoarchaeology at the finer scales of analysis, at site and artefacts' context level, and for the importance of site formation processes. Among these processes are the anthropogenic ones, because "people are geomorphic agents" (Butzer 1982:39). However, it is only recently that it is becoming widespread the idea that humans are sediment producers in the archaeological record, thus, the sedimentary deposits generated by people are also artefacts themselves (Shahack-Gross, 2017), and must be treated as such, and this is a primal responsibility of geoarchaeology.

However, the persisting of application of traditional sedimentological techniques to archaeological deposits lead to a long-lasting situation of difficult integration of results from the geological and archaeological perspectives. Butzer (1982) realised this problem and identified the reason, stating that most geoarchaeological work on archaeological context then "have failed to focus on cultural factors in site formation, on physical disturbance and modification of cultural residues, and on the unique potential of this research mode in archaeological survey. (…) Sometimes, when the direct or indirect impacts of land use are implicated, authors continue to insist on the primacy of climatic impulses."

In this context, the microscopic and micro-contextual geochemical techniques gained relevance over traditional sedimentological ones (e.g., grain-size analysis, pH, organic/carbonate content, etc.), that are not suitable for the analysis of strongly anthropogenic archaeological contexts since these do not follow the laws of environmental sedimentology (Shahack-Gross, 2017, Goldberg and Byrd, 1999, Goldberg and Berna, 2010). With the implementation of microscopic approaches to sediments (e.g., micromorphology, FTIR, phytoliths, organic chemistry, isotopes etc. (see, for instance, Albert and Weiner, 2001; Schiegl et al., 2003; Goldberg et al., 2009; Berna et al., 2012; Shahack-Gross and Ayalon, 2012; Weiner, 2010), it became clear that the sedimentary context could be considered the central object of study of geoarchaeology to approach human past since it "provides critical environmental and stratigraphic information" (Butzer 1982: 77), but also because it is geoarchaeology that offers the tools to study such context as any other artefacts removed from the field to laboratory.

### 1.1.1 Formation processes theory

The main approach adopted in this thesis is the reconstruction of formation processes of shell middens sites. Several authors highlighted that formation processes are the major link between archaeology and geosciences, thus the prime task of geoarchaeology (Butzer 1982, Waters 1992, Mandel, 2000, Stein, 2001). Shahack-Gross (2017:37) defines formation processes theory as "one of the most important achievements in modern archaeology, identifying mechanisms that allow archaeologists to better understand and interpret the archaeological record.". Today it is settled that the fundamental unit of analysis to study archaeological formation processes is the sedimentary deposit. The most complete knowledge of how a sedimentary context was created is vital for making interpretations and behavioural conclusions from the artefactual assemblages that it contains (Waters 1992, Stein 2001), since its three-dimensional distribution patterns may have result from both cultural or natural causes, and changed since the primary deposition (Nash and Petraglia, 1987, Goldberg et al., 1993).

This is a particularly critical aspect in those cases when the sediments are the artefact themselves and the object of direct manipulation by humans, as are shell middens.

The systematisation of the concept of formation processes is primarily due to the conceptualisation of Schiffer (Schiffer, 1987). The author defined formation processes as “the factors that create the historic and archaeological records” (1987:7), responsible for post-depositional alterations as well, that can modify and obliterate evidence of past human activities (LaMotta and Schiffer, 2005, Mandel et al., 2017). Since both cultural and natural processes are responsible for the transformation of the archaeological record, Schiffer (1987) divided those factors in two major groups, one regarding the cultural factors, that he called C-transforms and other related to the non-cultural factors, or N-transforms, and both are the concern of geoarchaeological approach to a given site or context.

C-transforms result from anthropogenic activity, including all human-induced elements in the archaeological record, from discarded objects, such as human-altered food remains or construction materials, to rock materials, sediments or sedimentary deposits which deposition, transport and erosion are driven by human activities. More recent approaches also called these context “occupation deposits” (Golberg and Macphail 2006). N-transforms refer to the dynamic environment where those actions take place, that are not static, and undergo physical, chemical and biological processes during and after the C-transforms (Mandel 2017, Shahack-Gross 2017), After burying, diagenesis affect the archaeological record, being pedogenesis (soil formation) particularly relevant in open-air settings (Goldberg and Macphail 2016).

All these transformation processes contribute to the record that is excavated by archaeologists, and their occurrence is promoted by action of different agents, that have anthropic, geologic and biologic origins. These are usually combined in the archaeological record formation, preservation and alteration (Butzer 1982), hence the vital necessity of deciphering each one of them.

Anthropogenic processes include the producing, manipulations and abandonment of objects as well as modifying actions such as trampling, sweeping or dumping. These actions lead to accumulation of manufactured objects or exogenous materials in determinate patterns, and sedimentary deposits such as midden dumps, several types of combustion-related layers (ash- or charcoal-rich deposits, rubified subsurface) or incorporation of exogenous fine-grained sediments and sedimentary components. Most of these actions correspond to quick processes that generate discrete features that demand high-resolution techniques to be identified and well-studied. Major intentional sediment removal from one locality to another are reported in prehistoric sites, either for spatial rearrangements, infilling of abandoned negative structures, or mound construction, all features that preserve potential sedimentary signatures of their anthropogenic origin that can help in interpreting the behaviours and actions behind it, if correctly understood.

Geogenic processes correspond to naturally-induced erosion, transport and deposition of sedimentary material at every scale, from those responsible for the burying of the sites to micro-depositional environments (Butzer 1982). Some examples affecting prehistoric archaeological sites are aeolian dust, water-laid silt and sand, slope and cryogenic movements, roofspall and speleothem formation in the case of caves, among others. The geologic setting dynamics can determine if a site is rapidly covered or exposed to erosion for a long time, which has great influence in the preservation conditions of the archaeological remains. Geochemical processes such as carbonate dissolution/reprecipitation or phosphatisation also affect archaeological deposits and impact the integrity of the organic materials, which is critical factor in the case of anthropogenic ones, such as ashes or bone (Karkanas et al., 2000; Weiner et al., 2002; Karkanas, 2010).

The biogenic processes refer to the action of the flora and fauna present at a site that can subject the archaeological remains to both vertical and horizontal displacements. Such agents are extremely varied, from roots to burrowing mammals, and it is crucial to understand their influence at a site to assess the integrity of the record. This mechanical reworking can lead to the homogenisation of sedimentary structures or mixing of several layers. Biogenic processes can also be responsible for addition of sediments such as organic or phosphatic accumulations like bird guano or coprolites (Goldberg, 2000; Shahack-Gross et al., 2004; Bergadà et al., 2013). The visiting of carnivores to caves usually also produces accumulations of bones. At open-air locations, the colonisation of an abandoned surface by flora and fauna leads to soil formation and alteration of the stratigraphic record.

All anthropogenic, geogenic and biogenic processes may act syn- and post-depositionally, i.e., during or after the formation of the archaeological record, respectively, and can be, and usually are, combined. The "non-traditional" geoarchaeological techniques, the microscopic ones preserving micro-contextual integrity (Goldberg and Macphail 2006) are the most suitable to decipher what processes are behind the sedimentary features and components in the archaeological record.

## 1.2 Research questions and current challenges in shell midden archaeology

Shell middens constitute one of the most distinctive type of prehistoric archaeological site at both regions studied in this dissertation; the Cantabrian region and the Sado valley, respectively in the northern and southwestern coasts of Iberia. As stated by Price (1987), and therefore concerning these two regions, shell middens “represent the basic contextual unit for information on the Mesolithic”. The author recommended that “further insight into their organization and structure is essential”, which is as valid nowadays as it was then. This dissertation aims to approach this objective, still not fully exploited in archaeological research, using geoarchaeological techniques to accomplish it.

As mentioned before, shell middens are extremely interesting deposits from a geoarchaeological point of view, since they constitute an exception in the record of hunter-gatherer behaviours in the archaeological context of Iberia. Most contexts are heavily modified by post-depositional processes of natural sedimentation of various origins (fluvial, colluvial, aeolian, etc.) that not only change the configuration of the anthropogenic remains, but also provides a sedimentary matrix that does not have to do with human activity. All these processes need a thorough geoarchaeological approach as seen previously regarding the importance of formation processes reconstruction in archaeological interpretations. In the particular case of shell middens, despite subjected to erosive action by the same natural agents, their sedimentary matrix is essentially anthropogenically induced, being one of the very few deposits which accumulation might be directly linked to hunter-gatherers’ specific actions. Another type of sediments that have the same characteristics are combustion features, a type of deposit which sedimentary material was created by humans.

Giving their importance, several attempts of definition of shell midden, as well as a few designations, have been proposed. In general, such efforts reflect the specificities of the regional issues regarding the shape and volume of the deposits, and more or less subjective criteria concerning the abundance of shells, or the shell/matrix ratio. Definitions based on shape and size, one of the most common are “shell mounds”, “shell rings” or “shell middens”, and are used when a site is predominantly formed by of several overlapping deposits containing shells (Álvarez et al., 2011, Andersen, 2000, Balbo et al., 2011, Claassen, 1991, Erlandson, 2013, Luby, 2004, Marquardt, 2010, Milner et al., 2007, Stein, 1992, Thompson et al., 2016, Valente et al., 2014, Villagran, 2014b, Villagran et al., 2011b, Villagran and Giannini, 2014, Waselkov, 1987). Concerning individual deposits rich in shells, some definitions found are "shell-rich", "shell-bearing" or "shell-matrix" sediments or deposits. Despite some of these terms have a connotation regarding their functionality, which has generated some debate (e.g., Claassen, 1996) and references therein), e.g., midden is associated to waste refusal, or "mound" sometimes associated to intentional monumentality, in the majority of works the designation is not necessarily dictated by the function attributed to the site, and when it does, usually clear arguments are presented.

One of the most common designation for the type of deposits that are focused on this dissertation is "shell mound". Marquadt (2010:551) relies on sedimentology to sustain that a "shell mound is a sediment that is attributable at least in part to the action of humans and that contains at least some mollusk shells". The amount of shells required is arguable, however, he author highlithed the use of the term sediment to enphasise the need for the study of it as such, i.e., geoarchaeologically, in order to know the origin and its contents the agent of transport, the environment of its deposition, and its postdepositional alteration, as previously recommended by Claasen (1996) and Stein (2001:10).

According to Marquadt (2010:554), "shell mounds are middens, if by midden we mean an accumulation of debris". In this dissertation, we adopt "shell midden" to refer to the sites studied, based on the Marquadt's insight, and because the shell middens both at the Sado valley and Cantabrian region do not constitute actual mounds in the current topography. Occasionally, the term "shell-rich" will be implied when referring to a specific, individual deposit within a stratigraphic framework of a shell midden.

The previous aspects are also revealing of the fact that shell middens are among the most challenging types of deposits that archaeologists face, especially in what concerns to the reconstruction of such human-driven formation processes. Shell-rich deposits might present macroscopically an apparent sedimentary homogeneity that hampers the isolation, in the field, of the individual events involved in the accretion of these types of deposits (Stein, 1992, Gutiérrez-Zugasti et al., 2011). It was early noticed by J. Roche (1966), regarding the Muge shell middens, in Portugal, that individualised occupations relatively independent from each other, might generate continuous stratigraphic sequences, and the artefacts embedded in those sediments, which has serious implications in archaeological interpretation due to unaware mixing of materials from different events. Such intricate stratigraphic record also makes shell midden deposits archives of detailed information for both human behaviour and the palaeo-ecological conditions they exploited.

One of the questions more intensely debated regarding shell middens is their functionality. Habitation, waste refusal, intentional monumentality and feasting behaviour are the most cited (Claassen, 1996; Marquardt, 2010; Thompson and Andrus, 2011; Gonçalves et al., 2014; Thompson et al., 2016; Gamble, 2017), using criteria of diverse orders to support one or another. In terms of formation processes reconstructions, and as amply demonstrated by works like that of Stein (Stein, 1992, Stein, 2008), Marquadt (2010) or Koppel (Koppel et al., 2015, Koppel, 2017), the main challenge of shell middens is that they constitute intricate palimpsests. In particular, Claasen (1996) noted that "shell orientation, fragmentation, and articulation tell us much about disturbance in middens and mounds, and constitute microstratification", and re4marked the urge in the appliucation of new approaches regarding the formation processes of shell middens. Stein (1992, 2008) and Marquadt (2010) argue that sedimentological studies are essential to the understanding of this challenging exercise. Since Goldberg and Byrd (1999) demonstrated the potentials of micromorphology to interpret shell midden sites on Camp Pendleton, systematic studies of South American sites by X. Villagrán (Villagran et al., 2011b; Villagran, 2014b) proved that the microscopic observation of sediments in their contextual integrity plays a major role in the reconstruction of the formation processes of these complex sites.

Apart from the work of Aldeias and Bicho (2016) in Cabeço da Amoreira, micromorphology is still not implemented in the context of the European Mesolithic, in which shell middens are relevant protagonists. In this dissertation, micromorphological analysis of different shell midden sites is carried out in order to address the question related to formation and post-depositional processes and their potential do infer the behaviours of its Mesolithic constructors.

Chapter 2

# Geological and palaeoenvironmental setting

The archaeological case studies used in this thesis to address the formation of Mesolithic shell middens in Iberia are located in two distinct, geographically well-defined areas of Atlantic coast of the Peninsula: the Sado valley, in southwestern Portugal, and the Cantabrian region, in northern Spain (fig. 2.1). Each one of these areas have distinct archaeological issues related to the Mesolithic (see sections 3.2 and 3.3). Likewise, at a geologic and climatic level, these two regions present quite different characteristics. Therefore, an overview of the main geological and paleoclimatic features of each one is needed for a better contextualization of the

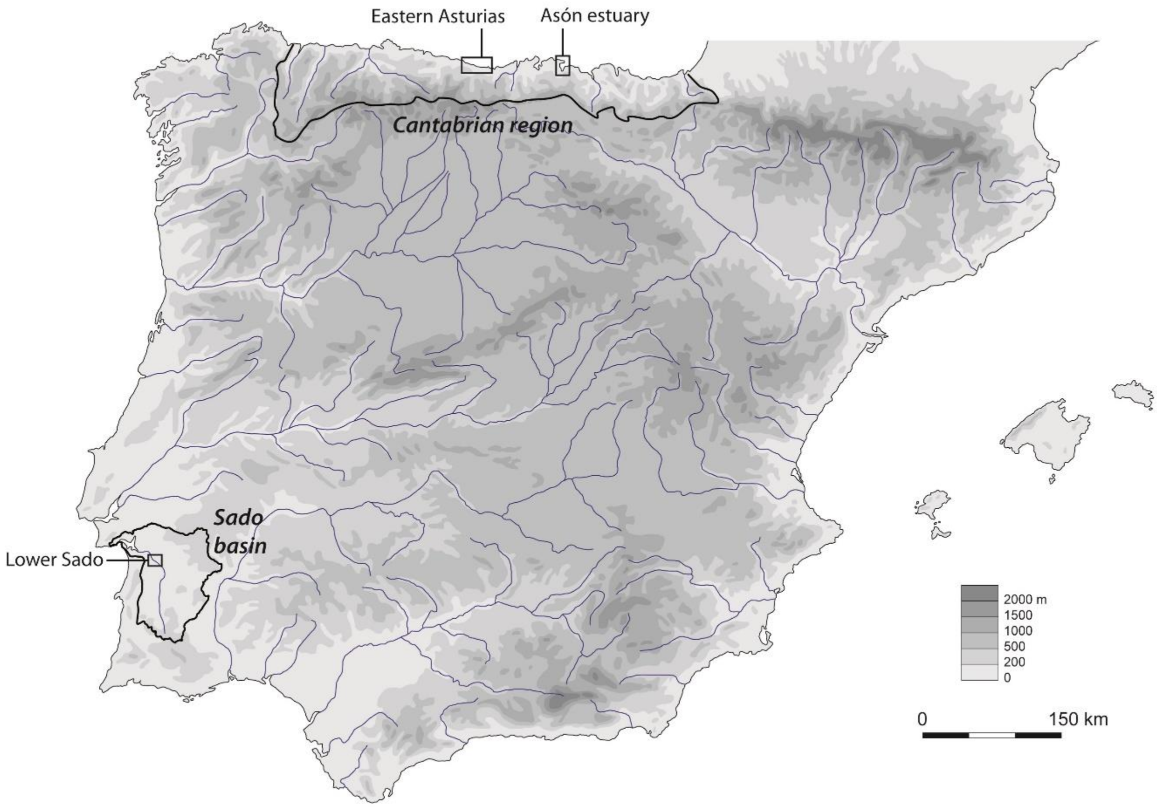


**Figure 2. 1** Map of relief and hydrography of the Iberian Peninsula with the Cantabrian region and the Sado basin delimited (black lines); with indication of the specific areas in focus in this work

human occupations at the studied sites and the natural sedimentary dynamic to better understand the anthropogenically-driven ones.

The aspects considered the most relevant for the present study are the lithological environment and geomorphological dynamics, especially the active processes in the Quaternary related to the studied archaeological sites. Since shell middens result from the exploitation of coastal resources, and considering the important Holocene sea level variations, the evolution of the respective coastlines is an essential issue, traditionally associated to shell midden archaeology (e.g. Villagran e Giannini, 2014), therefore the available data regarding the aspect will be analysed.

The geographic areas focused on this dissertation are naturally part of wider geological units that structurally conform the Iberian Peninsula (Vera, 2004), which are the following (fig. 2.2):

i) Iberian Massif, the Hercynian basement characterised by igneous, plutonic and metamorphic rocks and an important system of faults; some uplifted areas such as the western sector of the Cantabrian Mountains, the Toledo Hills and Sierra Morena resulted of the Alpine orogeny, in the Cenozoic.

ii) Meso-Cenozoic sedimentary rocks that uplifted during the Alpine orogeny, such as the Lusitanian and the Algarve basins, the eastern sector of the Cantabrian Mountains correspondent to the Basque-Cantabrian Basin, the Pyrenees, the Baetic System, the Iberian System and Catalanids. The sites of this dissertation in the Cantabrian region are all located in the domain of rocks deformed during the Alpine orogeny.

iii) Cenozoic Basins, subsiding areas of the Iberian Massif or depressions in the Alpine chains, that were filled with clastic sediments through the Cenozoic, namely the Douro, Ebro, Tagus, Lower Tagus, Guadalquivir, and several other smaller basins, such as the Alvalade Basin, that is incised by the River Sado and provides the geological environment to the Mesolithic shell middens.

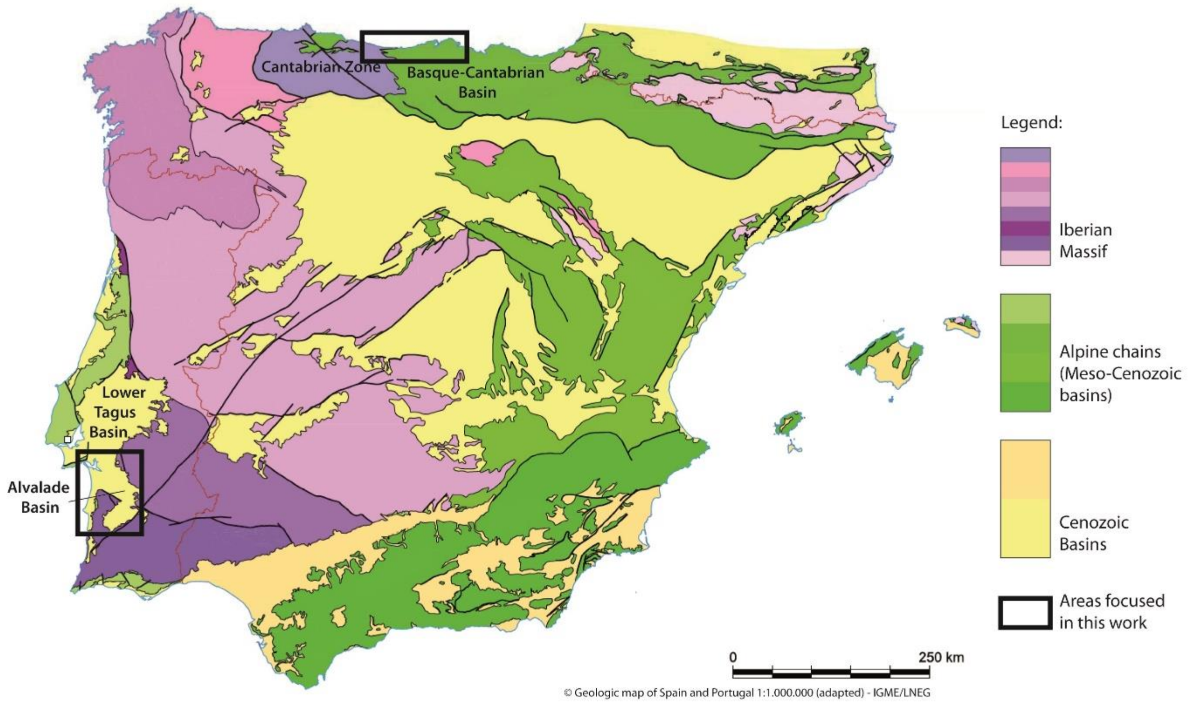


**Figure 2. 2** Geologic map of main geomorphic units of Iberia and location of the areas which geology is described in more detail in this work

## 2.1 The Cantabrian region

The Cantabrian region corresponds to the littoral landmass stripe incised by the hydrographic systems that spring in the Cantabrian Mountains and drain to the Bay of Biscay, in the North of the Iberian Peninsula (fig. 2.1). Its eastern and western limits are the Bidasoa and Eo rivers basins respectively, thus comprising a small portion of Navarre, major parts of the Basque Country and Cantabria, the whole Principality of Asturias and reduced areas of Galicia; in the southern border, also small areas of Castile and León, which equals a total of 20.801 km$^2$ (CHC 2018). The maximum width (north-south) of the Cantabria region is of approximately 100 km, in the western extremity, but in Eastern Asturias and Cantabria, where this dissertation is centred, is around 35 km.

The Cantabrian Mountains is an over 400 km long chain parallel and very close to the coast, as a western continuum of the Pyrenees, with over 1000 m. of altitude in most of its longitude and 2650 m. maximum in the Picos de Europa. Due to this configuration, oceanic air masses are retained and determines the climate of the region, humid and temperate, as well as intense development of well vegetated soils and extensive deciduous woodland, thus utterly different from the predominantly Mediterranean conditions of the rest of the Iberian Peninsula (CHC 2018). The generally abrupt topography is reinforced by torrential rivers deeply incised running mainly with a South-North orientation (García Codron, 2004).

The Cantabrian coastline has over 450 km and major headlands are Cape Peñas in Asturias, Cape Ajo in Cantabria and Cape Matxitxaco in the Basque Country. The largest sea inlets in the Cantabrian region, both in Cantabria, are the estuarine systems of the River Miera, in Santander and the River Asón, in Santoña, both augmented by several smaller rivers draining to the same estuaries.

The area concerning this dissertation, where most of the Mesolithic shell middens are located, comprises both paleogeographic units mentioned before, the Cantabrian Zone, in eastern Asturias, and the Basque-Cantabrian Basin, mainly in Cantabria. Specifically, in Asturias, the area of the council of Llanes, in the Eastern coastal area of the region will be focused. In Cantabria the estuary of the Asón, in Santoña is the most significant coastal area for this dissertation (fig. 2.1).

### 2.1.1 Geological setting of the littoral of eastern Asturias and Cantabria

The littoral platform of eastern Asturias is a 5-7 km wide stripe between the Cantabrian Sea and the Sierras Pre-litorales, a ca. 1300 m. high mountain range in the northern foothills of the Cantabrian Mountains (fig. 2.3 and 2.4). Geologically corresponds to the westernmost border of the Asturian Massif, the most external emerged zone of the Hercynian Massif in the Cantabrian Zone, before being covered by the Mesozoic sedimentary rocks of the Basque-Cantabrian Basin further west (fig. 2.3). The geologic substrate in the North-east limit is constituted by Paleozoic rocks organised in several larger thrusting units, forming a large sheet strongly folded and influenced by Alpine tectonic (Bastida, 2004).

The substrate of the littoral platform of the region of Llanes is a series of two main limestones intercalated (fig. 2.3). One is the so-called Caliza de Montaña, characterised by two formations: Valdeteja formation, with a characteristic fine lamination (1-5 mm) caused by intercalation of light microspar layers and darker micritic layers, and several fossils; and Barcaliente formation, a pale biosparitic limestone with abundant organic remains and massive aspect. Both Asturian sites studied in this dissertation, El Alloru and El Mazo, are inserted in this limestone. The other limestone type intercalated with the Caliza de Montaña formations

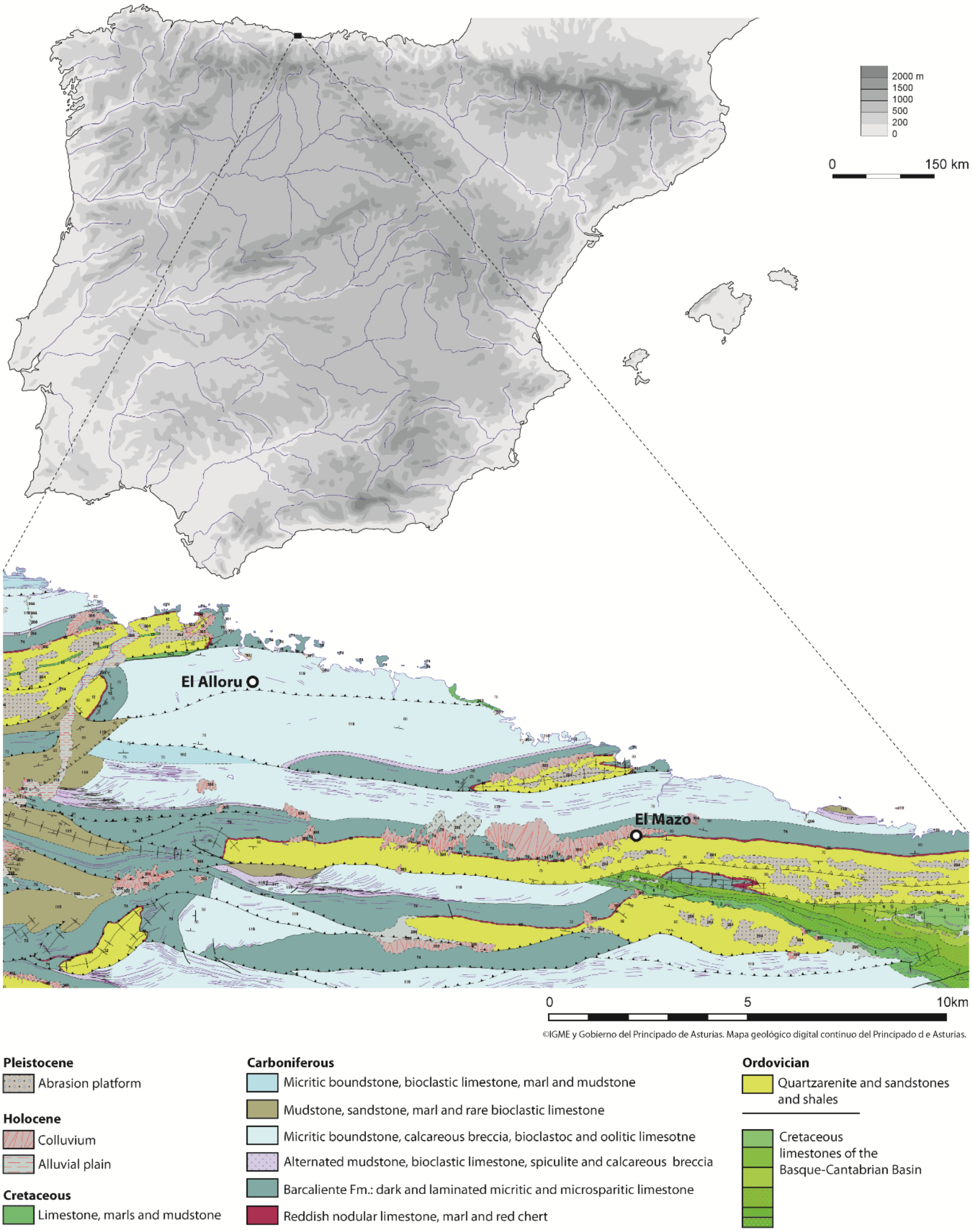


**Figure 2. 3** Geologic map of Eastern Asturias, with location of the two Asturian sites studied

corresponds to Picos de Europa formation, characterised by a lighter colour compared with former and a banded fabric at larger scale and abundant foraminifera (Martínez García, 1981).

This substrate is intensely affected by karstic processes, that constitutes an intricate subterranean system, partially inundated by the sea (Hoyos and Herrero, 1989). The origin of karstic genesis in the area of Llanes goes back to the Neogene, acting on the carboniferous limestones. The main geomorphological feature of this early period karstic activity are smoothly irregular heaps in the landscape which original morphology has been changed by later karstic phenomena and by the development of higher marine abrasion platforms prior to the Pliocene (Jordá Pardo et al., 2014). The most evident geomorphological feature nowadays in the region of Llanes correspond to the Quaternary karstic modelling (fig. 2.4). It acted over Palaeozoic and Mesozoic rocks in conjunction with sea level oscillations throughout the Pleistocene (Jordá Pardo et al., 2014), forming numerous sinkholes, uvalas, blind valleys, subterranean marine galleries and canyons. Naturally, numerous caves and rockshelters were formed and many were occupied since the Upper Palaeolithic (Vega del Sella, 1930; Clark and Clark, 1975; Straus et al., 1986). Holocene karstic activity is also evident in today's landscape by active phenomena such as speleothem formation, interior beaches inside sinkholes, and the characteristic *bufones* (Jordá Pardo et al., 2014), natural wells that communicate with subterranean sea caves invaded by tides and waves that make the sea water to be ejected in a geyser-like effect.

The coastline itself is marked by abrasion platforms at the base of cliffs, dissected by rivers incision, in which mouths some beaches and small estuarine systems form. The soils of the littoral platform are generally thick, as they correspond to decalcification areas where insoluble sandy reddish clays accumulate, associated to sinkholes and uvalas (Martínez García, 1981) (fig. 2.4).

In Cantabria, the basin of the Asón is inserted in the Mesozoic sedimentary rocks of the Basque-Cantabrian Basin (fig. 2.2). This is a sedimentary basin formed firstly in consequence of the opening of the Bay of Biscay during the Cretaceous, when a shallow sea separated the Iberian plaque from the European plaque. Afterwards, the Alpine orogeny, ended in the Miocene, made both plaques converge and causing the uplift of the sedimentary rocks previously deposited, originating the Pyrenees and the eastern hills of the Cantabrian Mountains, in today's Cantabria and Basque Country (García Mondejar et al., 1985).

In the Basque-Cantabrian basin, the main geological formations are massive reef deposits and terrigenous facies of Albian and Aptian ages, being in the latter the bedrock where the case study in Cantabria of this dissertation, La Fragua, is inserted. The Aptian limestones,

**Figure 2. 4** Landscape and geological environment of Eastern Asturias; above) view of the coastal platform between the Sierras Pre-litorales, the mountain chain in the left background, and the abrupt and irregular coastline dominated by cliffs and small coves; note the intense karstic modelling; most of the shell middens are located in this platform; below) Example of a doline filled with decalcification sediments in the coastal platform; at the left at the distance, an older elevated abrasion platform (Sierra Plana) can be observed

with rudists and corals, correspond to shallow marine carbonated platforms formed under warm temperatures, and its emersion is attributed to an early rift episode created by the opening of the Bay of Biscay (García-Mondéjar et al., 2004). This substrate in Cantabria is also heavily karstified (Hoyos and Herrero, 1989), being abundant caves and rockshelters with long Paleolithic sequences (e.g., Gonzalez Echegaray and Freeman, 1971; González Echegaray, 1980; Butzer, 1981; Hoyos Gómez, 1995; Straus et al., 2001, among many others).

### 2.1.2 Evolution of the Cantabrian coastline and environment in the Holocene

A major coastal geomorphological feature of the Cantabrian coast are marine terraces. In Eastern Asturias, several levelled marine abrasion platforms are preserved, resulting from variations in sea level. The Sierras Planas are isolated ridges running parallel to the coast in the littoral platform, with flat platforms at the top slightly inclined toward the sea (Flor and Flor-Blanco, 2014, Mary, 1983, Jiménez-Sánchez et al., 2006) (fig. 2.4). In Cantabria and the Basque Country, the marine terraces have been mostly dismantled by fluvial erosion (Aranburu et al., 2015). These terraces are reminiscences of sea-level oscillations occurred prior to the late Pleistocene, that reach the lowest stand at 100 to 120 m. below the mean sea-level, during the Last Glacial Maximum (LGM), at 15.000 years ago (Leorri et al., 2012). The deglaciation marked a period of consecutive sea level rise that continues through the Holocene up to the present sea-level.

A recent sea-level curve for the Cantabrian coast since the LGM has been provided by Leorri and colleagues using inferred relationship of foraminiferal assemblages with elevation derived from different estuarine areas (Leorri et al., 2012). According to the data they obtained from those sea-level index points, the post-LGM sea level rise occurred with changes in rate. At 10.000 years ago, the sea level started rising relatively fast from -27 m. to up to -5 m. at ca 7000 years ago, when it slowed down until it reached its current position. This means that during the period of the Mesolithic occupation of the Cantabria coast, broadly between 10.000 and 7.000 years ago, the sea-level was rising at a rate of 9-12 mm $yr^{-1}$. This sea-level evolution is broadly fits previous attempts of sea-level rise reconstruction for the Cantabria region based on available multidisciplinary data (Gutiérrez-Zugasti, 2009).

It was halfway in this period between 8.000 and 5.000 cal BC that the Cantabrian estuaries start to develop, around 6.500 cal BC (Cearreta and García Fernández, 2015, Cearreta and Monge-Ganuzas, 2013, Leorri and Cearreta, 2004). The Mesolithic occupation of La Fragua cave, a case-study of this dissertation, is intimately linked with the development of the Asón estuary (see section 2.1). Cearreta and Murray (1996) found evidence of marine transgressions in the Holocene infill of the Asón estuary by the presence of exogenous marine foraminifera together with endogenous estuarine ones. However, Cearreta and Murray (2000) noticed that those samples yielded stratigraphically inverted C14 AMS results, questioning the suitability of those samples to reconstruct such transgressions, that finally they associate to the particularly high-energy character of the Asón estuary that promotes reworking of sediments and foraminiferal tests.

Currently, the inlet through which the Asón estuary meets the ocean is located at south of Mount Buciero, but in the early Holocene it was located at west (where now is Berria beach), in a more incised valley that was progressively submerged (García Codron, 2004, Marín Arroyo, 2005) (fig. 2.5). The eastern side of Mount Buciero was exposed to sea-level advance, which contributed to the important erosive processes that constantly caused cliffs destruction in the Cantabrian coast (Leorri et al., 2012). Fano (2004, 2018) noted, concerning Mount Buciero in the Asón mouth, the evidence of sites nowadays "hanging" in the cliffs faces (e.g., La Fragua, La Peña del Perro) because this marine erosion destructed the slopes that had connected the sites with the valleys.

**Figure 2. 5** View of the Asón estuary from the top of Mount Buciero, towards south and west; the current mouth in Laredo spit is visible on the left; the early Holocene mouth was located where nowadays are marshes and Berria beach, at the right

Concerning the evolution of climate in the Cantabrian region, since the cold phase at 9.000 cal BC, known as Younger Dryas, the gradual warming noted since the end of the Last Glacial Maximum was accelerated until nowadays' conditions, as Morellón et al. (2018) recently conclude from synthesis of lake, speleothem and pollen records. Speleothem studies in El Pindal Cave (Asturias), also attested the rapid climatic amelioration since the LGM (Moreno et al., 2010). Fano (2004) noticed that environmental indicators from archaeological deposits, including shell middens, such as polen (Leroi-Gourhan, 1986), macrobotanical remains (Uzquiano, 1992, Uzquiano, 1995, Zapata, 2000, López-Dóriga, 2016) and microvertebrates (Murelaga et al., 2007, Altuna et al., 2004) are coherent with a temperate, oceanic climate and presence of pine and birch forests in higher altitudes, while deciduous woodland occupied the valleys, also attested in polen analysis from Asturian bogs (e.g., López Merino et al., 2010).

The evolution of the coastline in the Cantabrian region implies that Holocene sites, including most certainly shell middens, have been progressively submerged by the sea level-rise (Fano, 2004). This is notorious in cases of cemented shell middens in eastern Asturias nowadays exposed to wave action during the high tides (Fano, 2004, González Morales, 1982).

## 2.2 The Sado valley

The River Sado springs in the northern slopes of the hills of Serra da Vigia (municipality of Ourique, region of Alentejo), at 230 m of altitude and drains the largest entirely Portuguese hidrographic basin, with 8341 $km^2$ (PGRH, 2012) (fig. 2.1). The Sado has the particularity of being the only major Portuguese river flowing northerly and, with 180 km of extension (PGRH, 2012), is the longest river in Iberia doing so. In its initial course, the Sado flows mainly straight through wavy plains of wheat, cork oaks and olive trees, basically at the surface level of the Devonian/Carboniferous metamorphic rocks of the Iberian Massif. Entering in the Alvalade Cenozoic Basin, the river starts to incise its sedimentary infill forming a meandering valley with a wider alluvial plain at the bottom. In the northern sector of the Alvalade basin, the flowing course turns northwest after the confluence with the Xarrama river from East, its main tributary, and the alluvial terraces are replaced by rice fields. Hereafter in this work, the phrase “lower Sado” will refer to this sector of the river as a synonym of the area of concentration of the Mesolithic shell middens, in both margins of this incised (40-60 m), wide (average lenght of ~500 m of alluvial plain), and meandering valley. Finally, saltworks and marshes form one the largest wetland areas of the Portuguese coast (~160 $km^2$). The sand spit of Tróia separates the estuary form the Atlantic Ocean and forms the mouth of the Sado by south, across of which are the city of Setúbal and the Serra da Arrábida mountain.

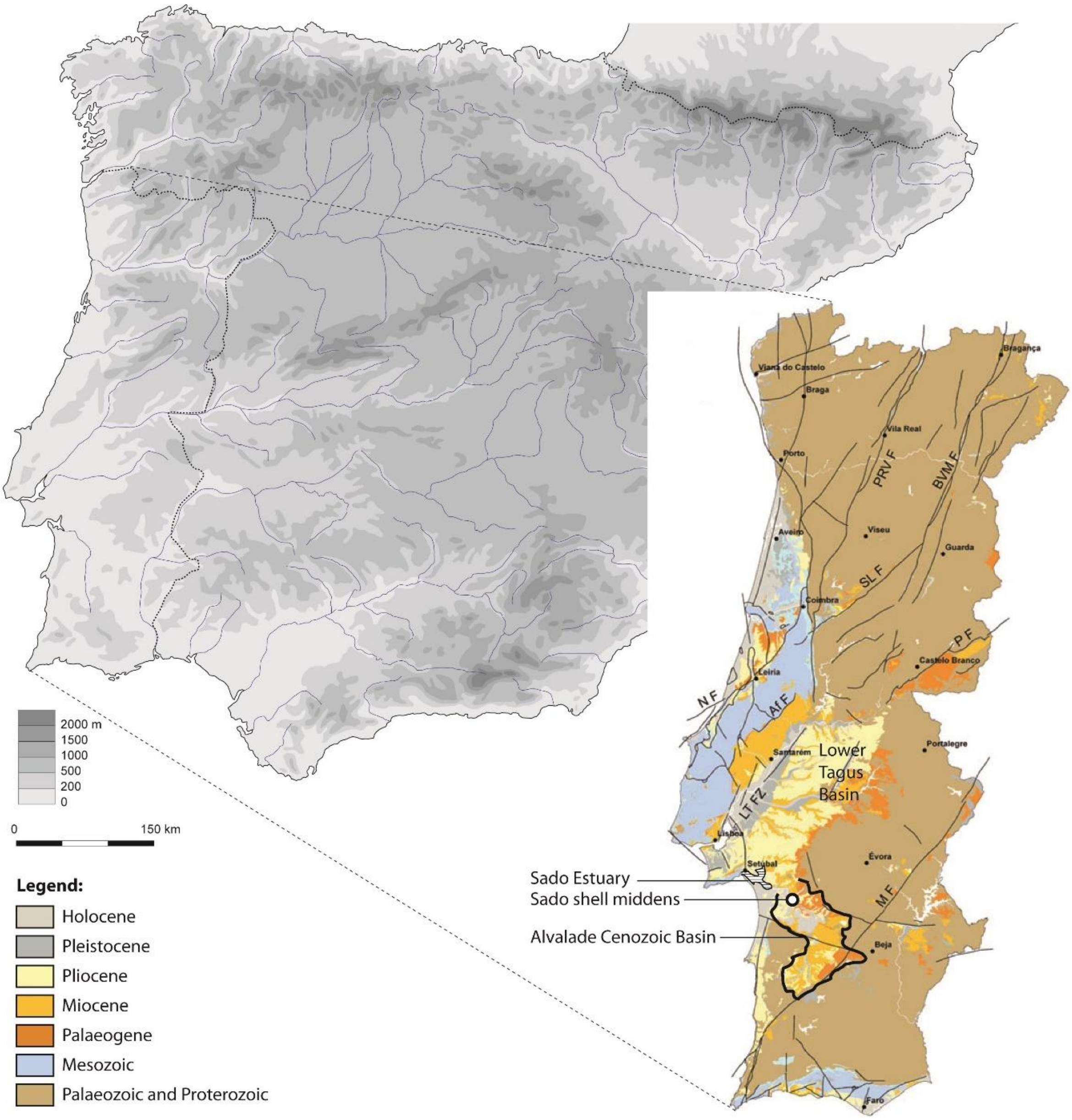


**Figure 2. 6** Location of the Alvalade Cenozoic Basin in the general geologic context of Portugal, after Pais et al. (2012)

### 2.2.1 The lower Sado in the geological context of the Alvalade Cenozoic Basin.

In the lower Sado sector, the fluvial system incises the Cenozoic sedimentary infill of the Alvalade basin (Antunes et al., 1986) (fig. 2.6). The Alvalade Cenozoic Basin is contiguous to the much larger Lower Tagus Cenozoic Basin, that extends to the interior of Iberia, with reminiscent isolated areas in the region of Plasencia, in Spain. For many years both were considered the same unit (Galopim de Carvalho et al., 1983-85, Pimentel and Azevêdo, 1994). This wider unit, then designated Tagus-Sado Cenozoic Basin, was formed by tectonic subsidence during the Upper Cretaceous-Paleogene alpine compression (De Vicente et al., 2011, Pais et al., 2012). In the southernmost sector of this basin a depression developed and originated the Alvalade basin, structured by the reactivation of late Hercynian faults, forming horsts and grabens in the interior of the depression (Pimentel, 1997), then filled by several deposits during the Cenozoic.

The lower Sado, where the shell middens are located, corresponds to the northern sector of the Alvalade basin, close to the limit with the Lower Tagus basin. The Cenozoic lithostratigraphic sequence is presently exposed in the slopes formed by the Quaternary incision of the Sado hydrographic system and was object of detailed study by N. Pimentel (1997). The older of these fillings in the Alvalade basin, also present in the Lower Tagus Basin, corresponds to the Vale do Guizo Formation, mainly coarse detrital deposits, exhibiting important diagenetic features such as phreatic carbonates. These deposits present massive to graded sedimentary structures indicating predominance of debris-flows and mud-flow processes directly overlying the Hercynian surface of the Iberian Massif, as alluvial-fan materials (Pimentel, 1997) and biostratigraphically correlates with formations dated to the Eocene in the Lower Tagus basin (Antunes et al., 1986).

It seems likely that a marine transgression invaded the northern sector of the Alvalade depression in the middle Miocene, as suggested by presence of marine deposits of the Alcácer do Sal Formation, with biocalcarenites (Antunes et al., 1986), with an extended outcrop at the base of the slope of Arapouco, upon which the furthest downstream shell midden is located.

The reactivation of regional Hercynian tectonic accidents during the Baetic Phase, in the end of the Miocene, lead to the uplift of Paleozoic rocks of the Valverde-Senhor das Chagas horst, creating a paleogeographic barrier between the Lower Tagus and the Alvalade basins, that since then underwent independent fillings as two autonomous units with different geometries (Pais et al., 2012).

The first of this fillings results from a marine incursion well dated to the Messinean (Upper Miocene), recorded in the Esbarrondadoiro Formantion (Antunes et al., 1986), with marine fossiliferous deposits in the central zone of the basin and more continental facies in the borders of the basin, allowing a palaeogeographical reconstruction of a narrow and shallow marine gulf with terrigenous contributions from the emerged areas to the East (Pimentel 1997).

The region eventually emerged and in the Pliocene the arkosic sandy and sandstone deposits of the Ulme Formation (CGP 42-B), also called Alvalade Formation by Pimentel

(1997), highly ferruginous, were deposited. The presence of gravelly layers intercalated with sands indicate braided flow facies of an important "pre-Sado" fluvial system (Oliveira et al., 2013). The resulting deposits covered most of the Paleozoic rocks of Valverde-Senhor das Chagas horst, making the Alvalade basin and the Lower Tagus basin coalesce (Oliveira et al., 2013). Regional tectonic uplifting seems to have caused the surface to reach the present-day altitudes close to the hundred metres, during the upper Pliocene-Pleistocene transition (Cabral, 1995, Pimentel, 1997).

In the Quaternary, the Sado river hydrographic system incises the sedimentary fill, connecting again the Alavalde basin with the Lower Tagus basin (Pais et al., 2012). The incision of the Sado fluvial system in the Alvalade basin originated terraces and alluvial deposits. In the lower Sado the Pleistocene terraces are relatively small and, as pointed out by Burke et al. (2011), somehow difficult to identify due to the abundance of sandy colluvial deposits. These terraces are characterised by sandy, fine gravel, hardly suitable as raw material for lithic industry, as noted by Pimentel et al. (2015). At the bottom of the valley, alluvial deposits are highly affected by recent agriculture practices that converted them in rice fields crossed by several artificial irrigation canals, especially in the lower Sado, thus its natural configuration is completely obliterated (fig. 2.7).

Other important Quaternary deposits are extensive continental dunes resulting from aeolian reworking of Pliocene sands during phases of rhexistasy (Oliveira et al., 2013). The dunes widely cover the high interfluvial platforms (fig. 2.7) which substrate are clayey, impermeable Miocene deposits, that promote the formation of some permanent and temporary small lakes in areas of more intense aeolian depletion (such as Lagoa Salgada, in the proximity of the shell midden of Poças de São Bento) as well as the development of podzols (CGP – 42B). These dunes are characterised by poorly sorted, white/yellowish and incoherent sand deposits (Pimentel., 1997) over which some of the shell middens were accumulated, like that of Poças de São Bento (chapter), the case study of this dissertation in the Sado valley.

### 2.2.2 The Sado Estuary during the early/middle Holocene

The Holocene sea level variation curve proposed for the Portuguese coast mark a period of rapid sea level rise, about 40 m, between 10 000 and 7000 / 8000 years ago, according to Dias (2000). The transgression continues more slowly and approaches values close to the

**Figure 2. 7** Aspects of the Sado valley. Above: view of the alluvial plain in the area of the Mesolithic shell middens, which typical location is near the edge on the top of the slopes bordering the alluvial plain. Below: view towards the River Sado from an intermediate point between the margin and the site of Poças de Sao Bento, located further inland

present-day level sometime between 5000 and 3000 years ago. During this time, the former late glacial valleys, now submerged, developed fringing estuarine environments as consequence of constant fluvial sediment input (Dias, 2004).

The Mesolithic phenomenon of large shell middens with necropolis in Portugal is closely associated to the formation of these extended inland estuaries (Bicho, 1994, Carvalho, 2009, Araújo, 2016b). In this frame, the Sado and Muge shell middens are considered prime examples of human adaptation to these changing littoral landscapes. Despite this model is accepted in its general implications – and clearly perceptible in the case of Muge –, recently this frame has been questioned for the case of the Sado in its particularities, because we still know very few about the influence of estuarine environment in the shell middens area (Diniz and Arias, 2012, Arias et al., 2015b).

Find an answer for the question – how the environment in the lower Sado during the formation of the shell middens was? – is extremely important because we do not know how close to aquatic resources these populations were. On the other hand, several studies in the lower Tagus and Muge valleys indicate that the aquatic resources exploited by the Muge populations were available right next to the shell midden sites (van der Schriek et al., 2008). Such uncertainty might be biasing our interpretations concerning general Mesolithic adaptations, behaviour, settlement and economic patterns at regional scales of analysis.

The lower Sado valley infilling is presently object of sedimentological investigations regarding the reconstruction of the environmental conditions and landscape evolution during the Mesolithic occupation (Costa, 2015, Costa, 2017). So far, it is possible to infer from preliminary results of sediment cores collected in the alluvial plain since 2013, that there was a marine influence in Arapouco (the furthest downstream shell midden), between c. 1650 and 1400 cal BC (Bronze Age), when sea level was similar to the present. However, there is not yet sufficient data to characterise the environment in the lower Sado 8000 years ago (Costa, 2017) when the mean sea level was 8-10 m below the present level (Dias 2004, Leorri et al. 2012).

In turn, the Sado Estuary itself and adjacent coast – a coastal arc of Holocene sand beaches creating abundant coastal and back-barrier lagoons that offer good Holocene sedimentological records – have known several paleogeographic and paleoenvironmental studies over the last decades that provide a good frame of the regional Holocene coastal evolution (Cearreta et al., 2003, Alday et al., 2006, Cearreta et al., 2002, Cearreta et al., 2007, Freitas et al., 2002).

The study of Psuty and Moreira (2000) of sediment cores in the Sado Estuary suggested that the Holocene accretion of sediments over the Pleistocene sandstones during the marine transgression was continuous from about 6300 to 2600 years ago, rising from 7 m to 1 m below the present high marsh surface (in turn, 2 m above the mean sea level), forming a narrow zone of marine incursion. According to the same data, the horizontal expansion of high marshes would have begun in 2600 years ago, and "the innermost encroachment of the estuarine system occurred about 2000 year ago" (Psuty and Moreira 2000: 136). Psuty and Moreira (2000) support their data with pollen evidence from Mateus and Queiróz (1991), that show increasing wetland pollen during this more recent period. The remaining question is thus where can we trace the geographical limit of this “innermost encroachment” since this study concurs that the sea level was about 8 m below in the Mesolithic.

However, Costas et al. (Costas et al., 2016, Costas et al., 2015) pointed out that the data from Psuty and Moreira (2000) contradict several other curves from other coastal areas of southwestern Iberia that locate the attenuation point of the rapid sea level rise about 7000 years ago (Leorri et al., 2012, Vis et al., 2008, Teixeira et al., 2005), just like Dias (2004) had pointed out previously. The analysis of Costas et al. (2015, 2016) consisted in integrate GPR (ground penetrating radar) geophysical prospection, high-resolution terrain models and OSL (optically stimulated luminescence) dating and radiocarbon dating applied to costal barrier stratigraphy in the Tróia sand spit. Costas et al. (2015) suggest that the evidence of fringing marshes in 2 600 years ago that Psuty and Moreira (2000) related with the beginning of the slowing down of sea level rise, are instead related to the specific responses to local hydrodynamics that do not reflect general trends, aggravated by the northward progradation of the Tróia sand spit earlier than previously thought. They provide evidence for their interpretation of Psuty and Moreira (2000) data by reporting dates of 6 500 to 4000 years ago for the initial elongation phase of the Tróia spit, the onset of beach deposits in the central zone of the spit at 3 500 years ago and the development of marshes after 3 300 years ago (Costas et al., 2015). Ultimately, Costas et al. (2016) defend a slow rate of sea level rise of 2 m over the last 6 500 years. Despite contributing greatly to the reconstruction of coastal environment evolution in the River Sado mouth, it is still difficult to extrapolate this data regarding the appearance of estuarine margins in the lower Sado during the Mesolithic occupation, for what the research currently carried out by A. Costa (2015, 2017) will be crucial.

Focusing on palynological (pollen, *algi*, *fungi*, microinvertebrates) and macrobotanical (plant macroremains and *cladocera*) evidence from cores collected in perimarine mires and interfluvial laketelets in the littoral region of the Sado Estuary, E. Mateus and P. Queiróz (Mateus and Queiróz, 1991, Mateus and Queiróz, 2000, Mateus, 2001, Queiróz and Mateus, 2004) elaborated a comprehensive reconstruction the Holocene paleoecological evolution of the littoral ecosystems of the region. They recognised a phase of marine transgression associated to a coastline retreat from 7500 to 5500 years ago. This phase roughly corresponds to the whole life-time of the Sado shell middens; in fact, as pointed out by Diniz and Arias (2012) radiocarbon dating seems to indicate that the sites were virtually abandoned by the

Mesolithic hunter-gatherers slightly before 5500 years ago, when, according to the authors, the marine incursion reached its maximum extension. Mateus and Queirós (2004) recognised a phase of slowing down of the sea level rise, with development of extended estuarine environments further inland such as in Carvalhal (just south of the present Sado Estuary) between 5500 and 4150 years ago, but still, we don't have sufficient data to pinpoint geographically the innermost development of the early phases of the Sado Estuary.

In terms of vegetation, the palynological analysis of Mateus (2001) and Mateua and Queiróz (2000) in coastal mires and interfluvial lakelets, show that with the beginning of the Holocene, *Quercus faginea* forest grew on the higher littoral plains, replacing the previous deciduous forest, as well as *Pinus pinaster* forest progressively replaced the previous late glacial sylvester pinewoods at the slopes, while alder carrs developed at the valleys bottoms. The permanent shrubs in the region during this phase are essentially *Erica scoparia* and *Quercus coccifera* "maquis". This picture means that the climate was getting progressively drier during this time span, approaching the Mediterranean climate that dominates in the region today (Mateus, 2001).

To sum up, the available data from different proxies in the Sado estuary and other coastal contexts in Portugal agree that the rising sea level was about 8 to 10 m below the present level in the 6$^{th}$ millennium BC. The available data also seem to concur that the Sado mouth was a marine inlet, without sand bar formation at the Mesolithic (Freitas et al., 2013, Psuty et al., 2000, Costas et al., 2015), but we don't know the innermost point in the valley where there was marine influence. The development of estuarine marshes close to the coast in Sado Estuary is dated to between 5500 (Mateus and Queiróz, 2004) to 3 300 (Costas et al., 2015) or even 2 600 years ago (Psuty and Moreira, 2000), all of these dates post-dating the abandonment on the shell middens, so it seems likely that there were estuarine marshes exploited by the Mesolithic occupants of the lower Sado further upstream, but we have not spotted precisely its geographical position, which is somehow trickier in such an incised valley (Freitas et al., 2013). Preliminary data seem suggest that there was estuarine influence in the lower Sado in the second millennium BC, but it remains unknown when did the slower sea level rise rate combined with sediment input created such conditions in the lower Sado.

Chapter 3

# Shell middens and the Mesolithic societies in Iberia

## 3.1 Introduction

The period of human history that concerns this dissertation is the Mesolithic. The Mesolithic is understood here as the period in which lie those archaeological contexts between the establishment of Postglacial conditions at the end of the Pleistocene, in the eighth millennium BC, and the adoption of farming (Crombé and Robinson, 2014, Jochim, 2011, Bailey and Spikins, 2008). Thus, the end of the Mesolithic is variable along western Europe but can be broadly fixed in the sixth millennia BC in Iberia (Arias, 1999, Carvalho, 2008). These contexts were therefore formed by Holocene hunter-gatherers who during this period experimented a process of adaptation to environmental changes, namely concerning growing sedentism, eventually leading to greater complexity (Price, 1987). In the view of Zvelebil (1986:112), "the complex foraging adaptation ought to serve as the defining characteristic of the Mesolithic period", considering that rather than only chronological or economic definitions, it is the successful adaptations that constitute the most important achievement of these hunter-gatherers. The availability of previously glaciated inland territories, that allowed exploitation of mountain resources, and intensification of marine resources exploitation as the sea-level was rising are also general trends common to the Mesolithic of Atlantic Europe (Bailey, 2008).

Innovations in technology are also noted in this period, in western Europe in general, namely the appearance of small, highly specialized flint implements, microlithic tools made from bladelet segments through microburin or truncation (Bailey 2008). These microlithic armatures constitute the main source for the study of Mesolithic societies and their chronological and geographic variability (Price, 1987, Crombé and Robinson, 2014), in systematic association with contexts where exploitation of aquatic resources are many times the most visible base of subsistence (Binford, 1968; Price, 1987; Milner et al., 2007; Gutiérrez Zugasti et al., 2011).

Coastal and fluvial areas are those in Iberia where most of the Mesolithic settlement are concentrated, with special incidence in central and southwestern coast of Portugal and the Cantabrian coast (Arias, 1999). The human settlement in these areas in the late Mesolithic shows evidence of year-round frequentation and was progressively relocated within these areas through the early Holocene due to postglacial flooding (Binford 1968, González Morales 1982). Meanwhile, aquatic resources assumed a permanently significant role, most probably underestimated due to the submerging of most of the coastal areas that must have been more intensely occupied (Price, 1987, Bailey, 2008).

In Iberia, a reference site for observation of the evolution of the Mesolithic microlithic industries is Cocina Cave (Valencia, Spain) (García-Puchol et al., 2017), with its characteristic triangles, similar to those of Muge shell middens (Portugal) (Bicho et al., 2011a), in the opposite extreme of Iberia. According to Carvalho (2008) this occurrence if only explained by long-distance contacts through inland areas, where the Mesolithic settlements are scarce, and might have been only marginally or occasionally exploited, and its archaeological record is rather difficult to track.

The Iberian Mesolithic is also characterised by some technological diversity, that many times lead to specific regional designations (Bailey, 2008, Straus, 2008). In the case of the Cantabrian region, the first postglacial archaeological contexts are Azilian, which is a late Upper Palaeolithic technocomplex that extends into the Holocene and overlaps partially, in terms of chronology, the regional Mesolithic. Today both archaeological realities are well differentiated, and most Azilian sites are located in the mountainous inland, contrarily to the Mesolithic ones, that are concentrated in the coast (Straus et al., 2002). Yet in the Cantabrian region, the Asturian culture is distinguished in the west of the region, mainly due to the presence of crudely knapped macrolithic pebbles in the shell middens (Clark, 1975, Fano, 2018, González Morales, 1982), a theme developed in further on, in section 3.2.1. The presence of macrolithic industries in early Postglacial contexts seem to be generalised in Iberia. In Portugal researchers defined local technocomplexes, such as the Ancorian, in reference to macrolithic objects found in the basin of the river Âncora (Rodrigues and Ribeiro, 1991, Serpa Pinto, 2018) or the Mirian, in the river Mira (Carvalho, 2007, Raposo, 1994), although in these cases the association to shell middens is rare.

Shell middens are the most visible archaeological remain of this groups (Gutiérrez Zugasti et al, 2011), result of a successful diversified exploitation of aquatic and terrestrial resources existent in these areas, to the point that this type of site persisted along with the adoption of pottery until de definite establishment of the Neolithic productive economy (Arias, 2007, Arias, 1999, Zilhão and Carvalho, 1996, Zilhão, 2001, Stiner et al., 2003, Carvalho 2008). Examples are major shell middens of Comporta, in the Sado estuary (not in the further upstream lower Sado valey like the Mesolithic shell middens), and other smaller sites from the sixth millennium BC that start to appear in similar mid-Holocene coastal lagoons in the Portuguese coast (Valera and Santos, 2010). The same seems to occur in late shell middens containing ceramic in the Cantabrian region (González Morales, 1982, Arias, 2007, Fano et al., 2015, Cubas et al., 2016).

The research on Mesolithic shell middens has a long tradition in the Iberian Peninsula (Gutiérrez Zugasti et al., 2011, Straus, 2008), being intimately related with the origins of scientific Archaeology itself both in Portugal and northern Spain. The Sado valley and the Cantabria region Mesolithic archaeology share general problematiques (palaeoecological, social, economic, etc.) however they also have important taphonomic, material and chronological particularities.

## 3.2 Mesolithic shell middens in the Cantabrian region

As mentioned before concerning the geological setting of the Cantabrian region, the intense karstification of the littoral platform of eastern Asturias and Cantabria led to the formation of abundant caves and rockshelters and the consecutive occupation of those by prehistoric human groups. Mesolithic shell midden contexts in the Cantabrian region are spread along the littoral platform, most of them located within the first two kilometres away from the coastline, invariably in caves and rockshelters, between the basin of river Sella in eastern Asturias and along the Cantabrian and Basque coasts (Fano, 2004, 2018).

Aquatic resources started to be exploited in the Cantabria region with the consumption of estuarine species during the Solutrean and open coast species during the Magdalenian, specially its final periods (Gutiérrez Zugasti, 2009), both together a diversification of the

**Figure 3. 1** Two examples of cemented remains adhered to walls and ceiling of rock-shelters in Eastern Asturias; Above: Puerta de Vidiago rockshelter; below: la Huerta del Monge rockshelter.

terrestrial fauna exploited, which is associated with demographic growth (Straus, 2015, Straus, 1979). It is in the transition to the Holocene, that a diversification and intensification of aquatic resources clearly assume an important role in human subsistence. This is evident during the Azilian period, from when the first shell midden deposits were dated (Casado and Morales, 2000, Gutiérrez Zugasti, 2009). However, most Azilian contexts evidence still a high reliance on terrestrial resources and are mainly located in the inland areas (Gonzales Morales, 1982, González Sainz and González Urquijo, 2004). It is in the Mesolithic that shell-middens are the most visible archaeological deposit and the coastal platform is heavily occupied.

The Mesolithic shell midden in the Cantabrian region reflect the exploitation of the nearby rocky coastal environments. In the coast of eastern Asturias and Cantabria, characterised by rocky coves, the most represented species are limpets (*Patella*, especially *Patella depressa*), top shells (*Phorcus lineatus*) mussels (*Mytilus galloprovincialis*), echinoderms and crustaceans, but also species from sandy substrates are present to a lesser extent, e.g., *Tapes decussatus*, *Ostrea edulis* (Bailey and Craighead, 2003, Arias et al., 2016, García-Escárzaga et al., 2015, Gutiérrez-Zugasti et al., 2016, Bello-Alonso et al., 2015, Alvarez-Fernández and Altuna, 2013, Álvarez-Fernández et al., 2013, Álvarez-Fernández, 2015). The opposite is rare, but cases such as Santimamiñe (Basque Country) and La Chora (Cantabria) have higher number of species from muddy environments, evidencing the gathering of shellfish in the nearby extensive estuaries of Urdaibai and Asón, respectively (Quintana and Lizasu, 2006) (Gutiérrez Zugasti, 2009). Accumulation of terrestrial molluscs are also reported (Cobo and Smith, 2001, González Morales, 2000).

Increasing research on the Cantabrian shell middens also yielded evidence of other sources of subsistence besides shellfish exploitation. Further marine resources such as fish (Roselló Izquierdo and González Morales, 2014, Roselló-Izquierdo et al., 2016) and vertebrates like seals (Marin Arroyo, 2004, Marín Arroyo and González Morales, 2007) have been documented. The topographic and climatic characteristic of the lower-altitude littoral rocky hills, where mixed deciduous woodland was expanding since the LGM, allowed the Mesolithic groups to practice an economy also based on the exploitation of fruits (Zapata, 2000), birds (Elorza, 2012, Sanchez Marco, 2001) and game, being deer and wild boar the most represented (Marín-Arroyo, 2013, Altuna et al., 2004). These characteristics make the Cantabrian littoral platform rich and easily accessible, a crucial factor for the dense settlement networks established in the coast in the Mesolithic (Gonzales Morales, 1992, Arias 1999, 2007, Bailey and Craighead, 2003).

From information available in publications, Mesolithic layers in general in the Cantabrian contain large numbers of shellfish remains and present quite diverse characteristics, that can be tentatively grouped in four types: 1) cemented remains adhered to walls and ceiling of rock-shelters and cave's entrances (fig. 3.1), 2) single homogenous layers (fig. 3.2), 3) several superimposed intra-homogenous shell-rich layers (fig. 3.2); and 4) Layers with internal fine stratifications in form of lenses (fig. 3.3). The cases mentioned below do not aim to be exhaustive lists, they are cited with base on published information, which have different degrees of descriptive detail.

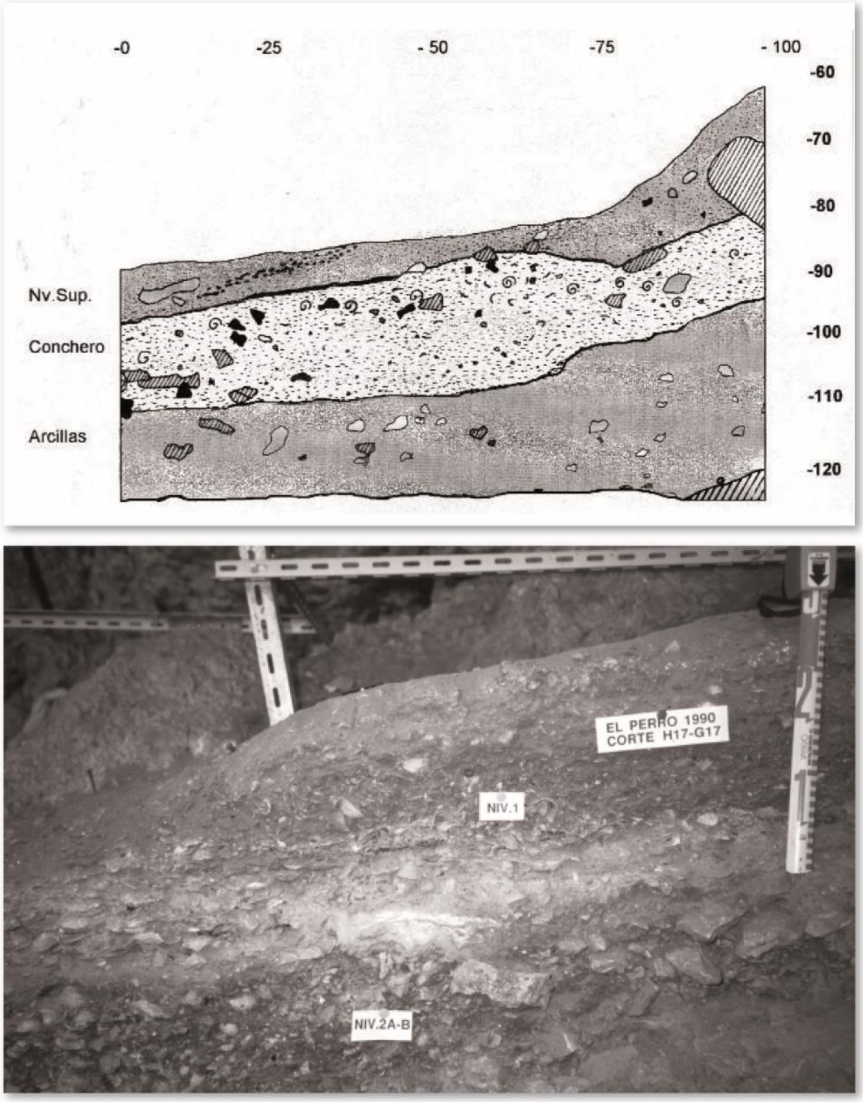


**Figure 3. 2** Single homogenous shell midden layer (above) and stratified shell midden layers (below); Examples from Cubio Redondo, after Ruiz Cobo and Smith (2001) and Peña del Perro, after Fano (2004), from M. Gonzalez Morales works, respectively.

Cemented remnants of shell middens hanging from cave’s walls and ceilings constitute most shell middens, over a hundred sites only in eastern Asturias, where other types are extremely scarce (Clark, 1976, González Morales, 1982, Fano, 1998). These are the classic Asturian shell middens that will be focused later. An important sedimentological aspect is that these the cemented shell midden usually lack interstitial terrigenous sedimentary matrix besides the carbonate cement.

Single homogenous layers are normally Mesolithic layers rich in shells, usually 10 to 30 cm thick, where no structures were identified. In this category could be included the site of Tarrerón (Apellániz, 1971), Carabión (Bartolomé et al., 2016) or Cubío Redondo (Cobo and Smith, 2001) (fig. 3.2), all in eastern Cantabria, among others.

Major shell middens are those where several shell-rich layers are identified, but no structures are recognised. The different layers are homogenous and distinguished from each

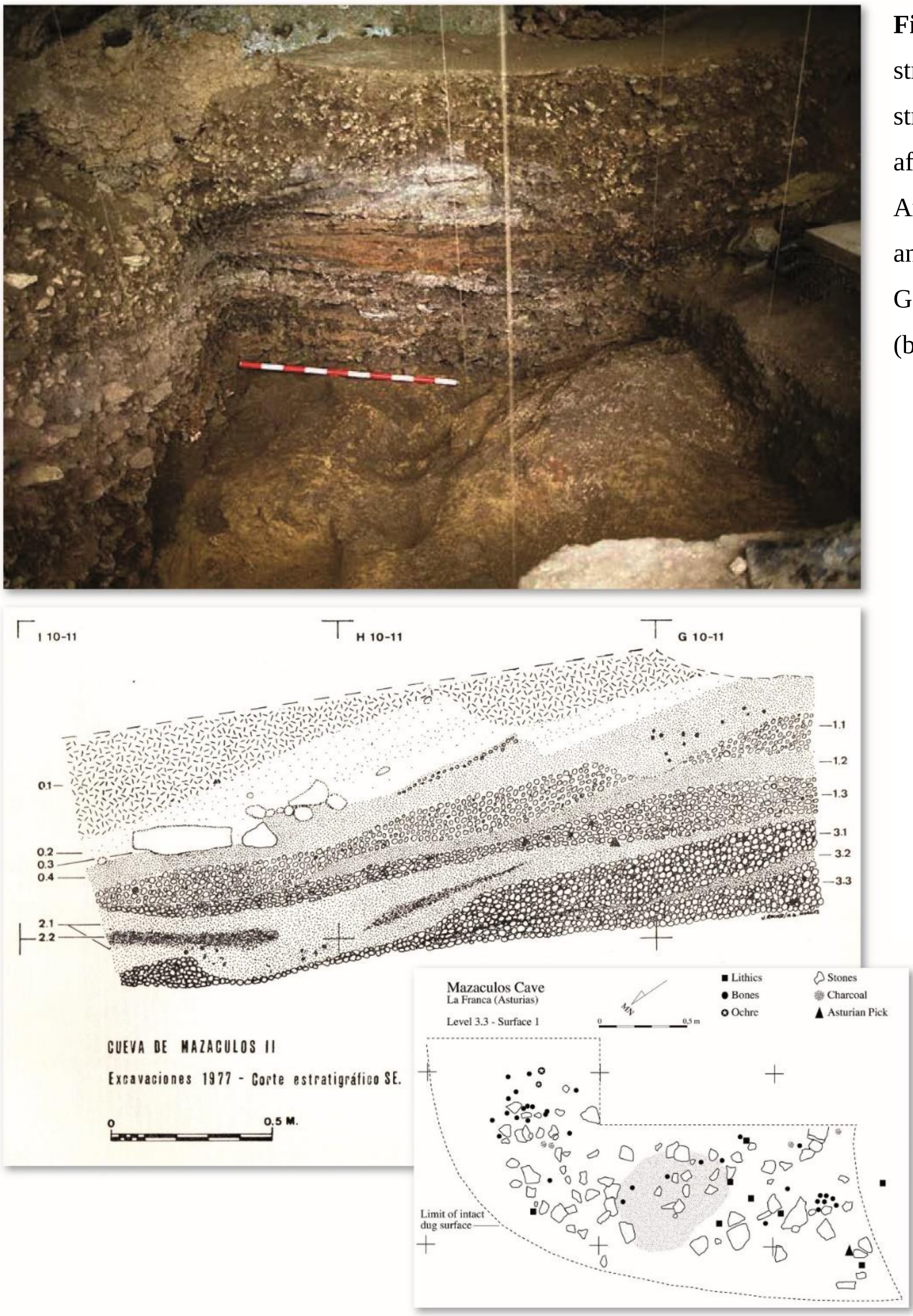


**Figure 3. 3** Examples of finely stratified shell midden with structures from Santa Catalina, after Berganza Gochi and Arribas Pastor (2014) (above) and Mazaculos II, after González Morales (1982) (below)

other by differences in the sedimentary matrix or archaeological content (shells taxonomy, lithic technology, pottery…). In these cases, normally the layers are 20-30 cm thick and correspond to different chronologies (Magdalenian, Azilian, Mesolithic or Neolithic), but not always. Examples of this type are Barcenilla (Munoz fernández et al., 2013) La Chora (González-Echegaray et al., 1963), Peña del Perro (Casado and Morales, 2000) (fig. 3.2), Pico Ramos (Zapata, 1995, Zapata et al., 2007), Kobaederra (Zapata Peña et al., 1997), most of J3 sequence (Iriarte-Chiapusso et al., 2010) or Poza l'Égua (Arias et al., 2007). The two latter cases bear human remains. The site of El Cierro also preserves three shell-rich layers at the top of a long Paleolithic sequence, the upper one Mesolithic and the two underlying ones

Magdalenian. The Mesolithic shell midden of El Cierro is in contact with the cave ceiling and strongly cemented, whereas the Magdalenian layers are only slightly affected by cementation, with terrigenous sediment preserved in significant amounts (Álvarez-Fernández et al., 2016).

The last group is composed by shell midden layers with internal fine stratifications in form of lenses, that makes the layer intra-heterogenous, where sometimes, combustion and other habitat structures are reported. Examples are Santimamiñe (Quintana and Lizasu, 2006), Marizulo (Cava, 1978), Arenaza (Apellániz and Altuna, 1975, Arias and Altuna, 1999), Kobeaga II (Apellániz, 1975, Quintana, 1998/2000), Santa Catalina (Gochi and Pastor, 2014) (fig. 3.3) or La Fragua (Marín Arroyo and González Morales, 2007, González Morales, 2000), the latter a case-study of this thesis (chapter). Another well-documented example of this case is the shell midden of Mazaculos II, that yielded a sequence of 0.5 m. of shell midden layers alternating with sandy lenses (fig. 3.3), overlying a clayey geologic substrate, in an area of 3 $m^2$ (Gonzalez Morales and Marquez Uria, 1978). In this substrate and in the shell lenses immediately over it, habitat structures were found (fig. 3.3), including small limestone blocks (virtually absent in the overlying shell midden layers), remains of a hearth with greasy charcoal, numerous mammal bones (deer and horse), and lithic artefacts, including a macrolithic object, so-called Asturian pick (see section 3.2.1). González Morales (1982) also refers charcoal lenses within one of the intermediate sandy layers but prevents its interpretation as hearths. The features at the base of the shell midden allowed the author to consider that context as an *in-situ* occupational floor, introducing the in the discussion of the shell middens functionality as habitat spaces instead of waste disposal middens exclusively (González Morales, 1982). He reconstructed the formation process of the shell midden as a shift in activities carried out. First, the area was occupied for domestic activities involving abundant shellfish processing and consumption among other mammal fauna, with three superimposed occupation surfaces marked by the presence of abundant charcoal and ash. Then, a moment when the at the same area were accumulated waste from another posterior occupations situated nearby within the rockshelter. The author does no refer a specific formation process for the intercalated sandy layers. A post-depositional process of cementation of the basal shell midden layers is noted, in the contact with the clayey substrate, by action of dripping water from a stalactite in the shelter ceiling, after the accumulation of the upper layers of the shell midden, through which the water had percolated (González Morales 1982:104). Is the case of El Toral III, a densely stratified shell midden and what was interpreted as post-holes opened in the surface of one of the shell-rich layers. The shell midden had clayey lenses intercalated, some of them containing shells that were interpreted as secondarily deposited by action of running waters (Noval, 2007). Currently, El Mazo rockshelter has the most complex shell midden stratigraphic deposit under investigation in Asturias (Gutiérrez Zugasti et al., 2013, Gutiérrez Zugasti et al., 2014), exhibiting thin interfingering lenses and unconformities, and constitutes one of the case-studies of this dissertation (section).

Other sites that must be considered are open-air Mesolithic sites, although these are rare in the Cantabria region, most probably due to strong fluvial erosion characteristic of the region and submersion of substantial coastal areas (Fano 1998, Gutiérrez Zugasti, 2009). The site of Pareko Landa (Quintana, 1996) (Biscay, Basque Country) and Sierra Plana de la Borbolla (Asturias) did not bear shell-rich contexts but contain Mesolithic industry, including macrolithic cobbles in the case of the latter (Arias and Suarez, 1990), and constitute evidence that Mesolithic groups also established camps at open-air locations. Open-air shell middens are also virtually absent from the record, but there are few exceptions in Asturias. One is the cemented shell midden of Tina 6 (Fano, 1998), and other recently discovered Mesolithic occupational layer with significant amount of shells is a locality in front of El Alloru rockshelter (Arias et al., 2016, Arias et al., 2015a), one of the case-studies in this dissertation (chapter).

The record of human burials in the Cantabria region is fragmentary. One Azilian grave was found at Los Azules (Tresguerres, 1976), a cave located in the mountainous interior. Mesolithic inhumations are scarce. The first mention of a human complete skeleton is from the coastal site of site of Molino de Gasparín, a grave excavated in an occupation surface, surrounded by limestone blocks and covered with an earthen mound (Carballo, 1926, as quoted by Arias, 2007). Other complete Mesolithic skeleton was found at El Truchiro rockshelter, in Cantabria (Arias and Alvarez-Fernandez, 2004). The only context that provided a collective burial ground is Los Canes, an inland cave where five inhumations, three of them complete and two of which superimposed, were identified (Arias and Garralda, 1996). Apart from J3 (Iriarte-Chiapusso et al., 2010), only isolated human bones have been found in shell middens, namely Cuartamentero (Garralda, 1982), Mazaculos II (González Morales and Márquez Uria, 1978), Balmori (Clark and Clark, 1975), anatomically associated bones of a left leg in Colomba, and Poza l'Égua, all in Asturias (Arias et al., 2007). In the latter, the finding of a human mandible lead to the interpretation of the context as secondarily deposited, which could explain the finding of isolated human bones in shell middens (Arias et al., 2007). This record does represent an increment in the number of human elements in relation to the Paleolithic, which has been interpreted as evidence that funerary practices were common among the Mesolithic groups in the Cantabrian region, though its structures have been mostly dismantled due to the nature of the deposits, most of them severely eroded (Arias and Alvarez-Fernandez, 2004).

Stable isotope analysis carried out on some of the human remains mentioned above revealed that the individuals from two coastal shell middens in Asturias and J3 consumed similar proportions of terrestrial and marine proteins, being the latter probably from fish rather than invertebrates. However, stable isotope of the individuals from Los Canes are fully derived from terrestrial proteins, among which meat should have been important. These results strongly suggest that the interior was not completely abandoned neither only sporadically visited for hunting, as demonstrated by the analysis from Los Canes (Arias, 2007). Furthermore, according to the author these results suggest a territorial behaviour of the last hunter-gatherers in the region, established by the co-existence of groups situated in interior mountainous lands which subsistence depended on terrestrial resources, and groups established on the dense shell midden network in the littoral, exploiting marine resources. But what else can we say about these coastal hunter-gatherers from their most abundant and obvious legacy, the shell middens? One way of taking most of the informative potential of shell middens, is by addressing these anthropogenic sedimentary contexts as artefacts. Micromorphological studies applied to some of the sites mentioned would help to answer this question.

### 3.2.1 The Asturian record

Within the geographical scope of the Cantabrian Mesolithic, the littoral platform between Cape Peñas and the surroundings of Santander Bay is where the Asturian culture developed (fig. 3.4). Hugo Obermaier (1916) used the term to refer the Holocene shell middens in eastern Asturias, the first in being identified. Since some years before Ricardo Duque de Estrada, Count of the Vega del Sella, had been working on the stratigraphic position and chronology of the shell middens (Vega del Sella, 1914). He carried out excavations in some sites, that finally allowed him to correctly classify the shell middens as “pre-Neolithic” (Vega del Sella, 1923, Vega del Sella, 1914). This chronology was contested at some point, using

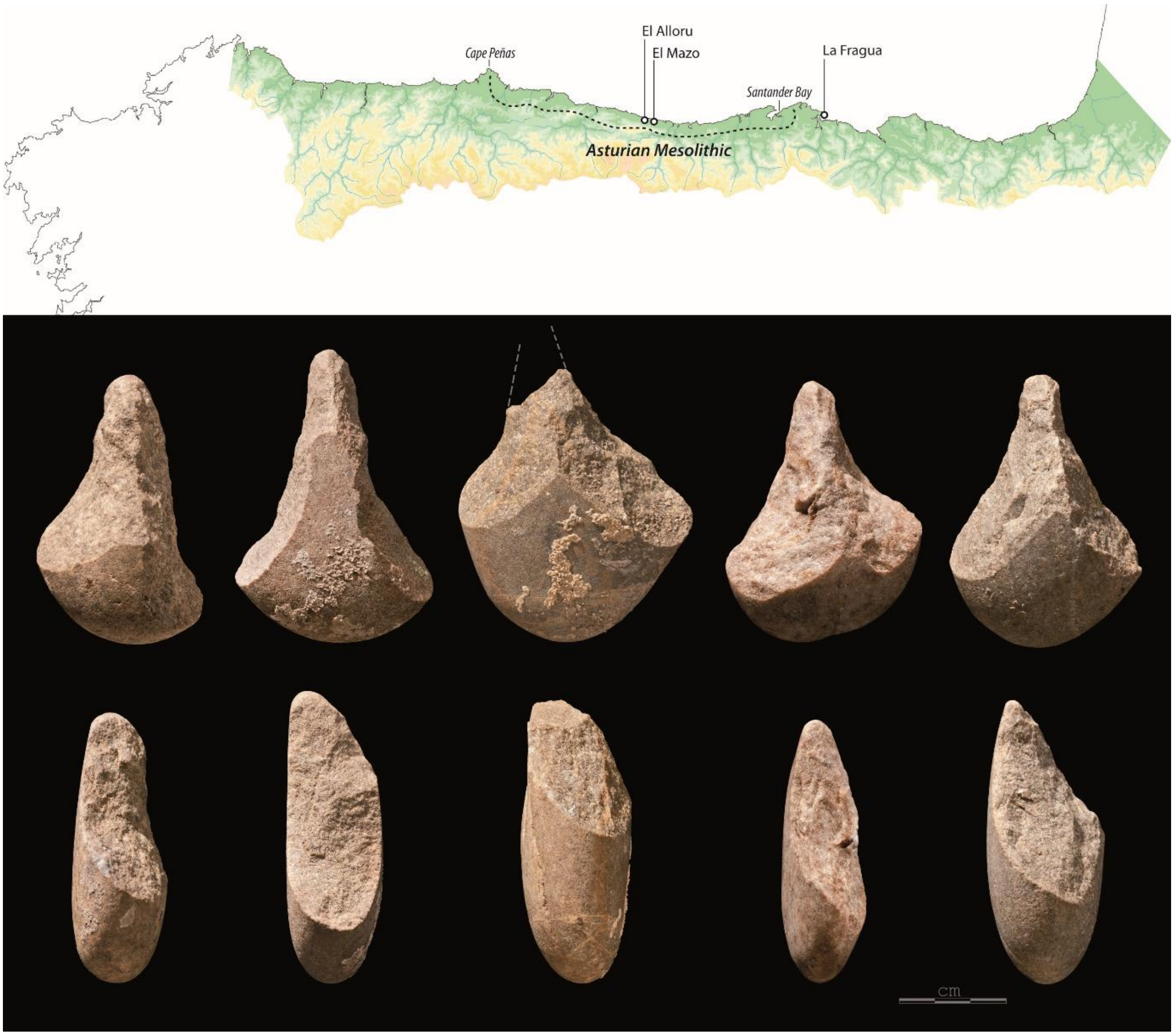


**Figure 3. 4** Map of the Cantabrian region and the Asturian area, with location of the sites studied in this work, and examples of Asturian picks from El Alloru, after Arias et al. (2016) (photo by J. P. Ruas)

puzzling geologic explanations arguing for a pre-Upper Paleolithic age of the deposits (Jordá, 1959), and finally established with the first radiocarbon dates of these contexts (Clark, 1976).

In some extent, perhaps what was misleading the researchers in the first half of the 20$^{th}$ century regarding the chronology of the Asturian was the macrolithic industry systematically associated to the cemented shell middens, that looked like several steps back after the microlithic trend of the Upper Paleolithic technology. The scarce lithics found in these contexts are heavy-duty tools made on quartzite pebbles (fig. 3.4), being the most typical one the so-called Asturian pick, an extremely standardised tool, shaped by direct percussion to create a triangular point, while in the other side the cortex was left intact (González Morales, 1982, Arias et al., 2016, Fano, 2018). Recent excavation projects applying sediments flotation and fine-mesh screening have revealed that microlithic industries like geometrics are also present (Gutiérrez Zugasti et al., 2014; Arias et al., 2015).

The designation "Asturian" is used in recent research mainly because of the coincidence between two factors that give an unitarian consistency to the archaeological record of the Mesolithic contexts in that geographical area. One is this type of macrolithic industry just mentioned. The other is the preservation condition: except for the few cases mentioned above, most deposits are cemented and hanging from walls and ceilings of karstic cavities, and not integrated in a stratigraphic framework (Clark, 1976, González Morales, 1982, Fano, 1998). These two factors are not present in the shell middens further west (eastern Cantabria and Basque Country), where furthermore the microlithic industry is more abundant, which has contributed to a separation between both "Mesolithics" (Arias, 1999, Fano, 2004, 2018).

The Count Vega del Sella was also concerned in explain the formation process of the Asturian shell middens. After a few attempts, Vega del Sella managed to find a shell midden in stratigraphic superposition on an Azilian layer, overlying an Upper Paleolithic sequence, at La Riera Cave. At this site, a stalactite speleothem developed until touch the shell midden surface and cement it (Straus et al., 1986). Vega del Sella then argued that the Asturian shell middens should have filled completely the caves, sealing the access to its interior. Later, the massive deposits become cemented by carbonate precipitation as result of phreatic water circulation in the cave walls, to be finally eroded, remaining uniquely the strongly cemented parts adhered to walls and ceilings (Vega del Sella, 1923). The general lines of this process are still accepted today and used to reconstruct and estimate the original volume of the shell middens occupied in the cavities (Gutiérrez Zugasti et al., 2014, González-Morales et al., 2004, Fano and González Morales, 2004)). However, the origin and formation processes of the calcium carbonate cement and its implications in the alteration of the archaeological deposits remains unknown. Regarding the lack of sedimentological studies in these contexts, González Morales questioned it by stating that the "stalagmitic crusts" are the only element unequivocally descript (without mentioning any description exactly), but the "conditions for their formations are also discussible and with it their exact significance" (González Morales, 1982:64, free translation from Spanish original). The author furthermore assumed that the question of the "stalagmitic layers" that are contained in the shell middens and covering it, are crucial for the discussion about the chronology of the Asturian (González Morales, 1982:64). However he uses it to explain, at regional scale, that at least one period of intense rainfall was responsible for the destruction of the deposits, and that period has to be posterior to the end of the Atlantic chronozone, which is when the humidity and temperature conditions are established (González Morales, 1982). Overall, the way that the calcium carbonate cement has been addressed reveals mainly an aiming for general interpretations regarding regional-scale climate and the reinforcing of the pre-Atlantic chronology of the shell middens.

The functionality of the shell middens has been object of more intense debate and research. The hypothesis of Vega del Sella led him to consider the shell midden as waste dumps and the corresponding occupation areas were located outside, near the caves (Vega del Sella, 1923, Clark, 1976). Recent excavations in the outside area next to El Alloru rockshelter, object of analysis in this thesis (chapter 6), found Mesolithic occupation layers and structures (Arias et al., 2015, 2016). However, the already mentioned sites of not cemented and stratified shell middens of Mazaculos II, El Mazo and El Toral also yielded habitat structures in the shell midden layers.

Another unresolved question is the temporality of the occupations, an issue that is also been investigated more deeply in recent years by applying schlerochronological analysis to the shells (Gutiérrez-Zugasti et al., 2017)) and is critical to understand the settlement pattern behind the dense network of shell middens in the coast of Asturias. Fano (2004) suggests that most of the cavity with cemented shell middens were relatively stable or repeated habitation spaces, analysing specific sites conditions in terms of insolation, available space and topography. The researcher also takes into consideration that some shell middens might have been used for specific activities, suggesting a hierarchised model where base-camps in the platform were more permanently occupied while other sites, closer to the coastline, were seasonally occupied for exploitation of marine resources. Above all, Fano (2018:10) summarises all these remaining questions in one: what dynamics generated these archaeological deposits? Geoarchaeological and particularly micromorphological analysis, applied to three shell middens in the Cantabrian region, two of them Asturian, is particularly suited to identify naturally-driven processes and human actions behind the accumulations of anthropogenic deposits and therefore infer dynamins of human behaviour in the archaeological formation processes of this type of sites.

## 3.3 Mesolithic shell middens in central and southwestern Portugal

The Mesolithic in Portugal is broadly known for the shell middens of Muge and Sado valleys (e.g., Price, 1987, Arias, 1999, Straus, 2008) (fig. 3.5). These contexts constitute prime examples of the human adaptation to the coastal environmental changes that characterise the early Holocene. The impact of these environmental processes in the landscape and resources is evident in archaeological record by shifts in human behaviour, concerning funerary practices and growing sedentism. These adaptative, socio-economic and symbolic new factors, materialized in these shell middens, are what most defines Mesolithic as a period (Zvelebil, 1986, Bailey, 2008), and makes these contexts essential archives of information from a geoarchaeological point of view.

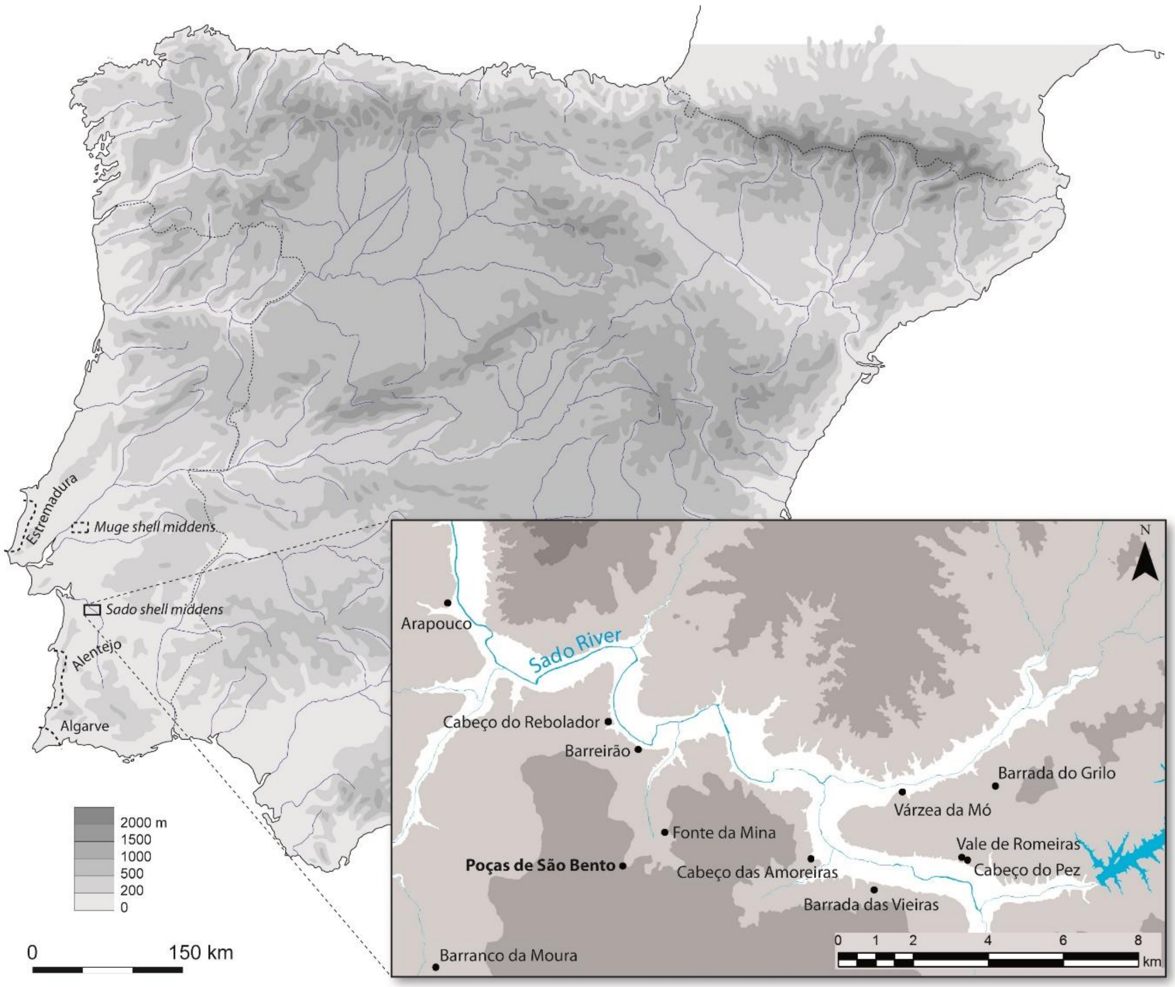


**Figure 3. 5** Map of Iberia with the Portuguese areas of higher concentration of shell middens (dashed lines) discussed in the text and close-up on the Sado shell middens

The human settlement of this inner estuarine margins started around 6.500 cal BC (Peyroteo Stjerna, 2016) in the Sado and 6.100 cal BC at Muge (Bicho et al., 2013), while both estuaries were developing into the hinterland as effect of the gradual sea level rise since the Last Glacial Maximum (Dias, 2000; Leorri et al., 2012). These two clusters of shell middens are the best representatives of a reorganisation of the settlement in the territory, that contrasts with the scenario of preceding period of the early Holocene, i.e., before ~6.300 cal BC, the accepted time for the shifts that characterise the change from Early to Late Mesolithic (Bicho, 1994; Carvalho, 2009; Araújo, 2016a; Araújo, 2016b). The shell middens of the Early Mesolithic show an overall disperse distribution along the present-day coast of Estremadura (central Portuguese coast), Alentejo and western Algarve (southwest coast) (fig. 3.5). As stated by Araújo (2009:541), “the molluscs constitute the more visible and dense vestige of this reality”, but what constitutes the context of the shell middens themselves?

Estremadura is the westernmost coastal stripe of Iberia and corresponds to a hilly mass of land between lower Tagus the Atlantic Ocean, formed by sandstones, marls and limestone from the Cretaceous and Jurassic, emerged during the opening of the Atlantic Ocean (Kullberg et al., 2013). The compression of these rocks with the Iberian Massif originated the biggest heights of the region, bordering it by west, that are the calcareous massifs, highly karstified, and rich in chert, intensely exploited since the Paleolithic (Zilhão, 1993, Bicho, 1994). These interior mountainous areas show evidence of marine and estuarine resources exploitation dating also from the Early Mesolithic, or Epipaleolithic, in cave and rockshelter sites (Zilhão, 1992b; Bicho, 1994; Bicho, 1999; Araújo, 2009). Araújo (2003) suggests that the dense hydrographic system network characterised by small rivers incising the sedimentary rocks, that spring in these massifs and from several geographic accidents throughout the region, were major crossroads for these groups to reach the littoral to obtain such aquatic resources.

The coastline is characterised by cliffs consecutively broke by those many small rivers' mouths. Plio/Pleistocene aeolian reworking of these rocks promoted the formation of extensive and thick dunes that became lithified and contribute for an accidented topography of a quite linear coastline. These aeolian sands or estuarine beds constitute the geological substrate of the Early Holocene shell middens (Araújo, 2009; Araújo, 2016; Sousa and Soares, 2016), open-air sites located over the mouth of these rivers and its estuaries. As noted by Araújo (2003), these rivers were more incised by that time and its estuarine systems presented different configurations, that became gradually submerged with the sea-level rise. The composition of the Estremadura shell middens reflects this inference: estuarine species like peppery furrow and common cockle constitute the majority of the archaemalacological assemblages, although marine species from rocky habitats are also present to a lesser degree (Dupont, 2011, Araújo et al., 2014, Soares, 2003, Sousa et al., 2016),

Most of these sites are characterised by one or more shell-rich accumulations, that are circumscribed and homogenous in its matrix, dispersed through small areas. The two sites that give a more moderately well-preserved record are São Julião and Magoito (fig. 3.6: a, b). The Early Mesolithic occupations at São Julião are located in the present encroachment of the small estuarine system and correspond to two spatially separate shell middens, 1m and 30 cm thick compact accumulations, the second with several fireplaces (Sousa and Soares, 2017). Magoito shell midden, currently covered by a Holocene aeolianite, is was originally extended from the top to the base of the slope today bordering the Magoito beach, and consisted of an organic, homogenous shell-rich layer, with evidence of fireplaces, namely one identified as a depression excavated into the basal reddish sands (Soares, 2003). These accumulations are interpreted as result of single occupations. The site of Toledo is the regional exception for presenting several shell-bearing occupations superimposed and reworked by the consecutive occupations, resulting in a single homogenised thick layer (Araújo, 2011). Combustion features are another type of archaeological context systematically found in Early Mesolithic sites, most of it structured with stones. Ponta da Vigia is a site located in a Pleistocene coastal dune where hearths were unearthed, without any shellfish remains (Zambujo and Lourenço, 2002, Zilhão et al., 1987a), but Araújo (2003) points to taphonomic reasons as possible explanation for the absence of shells, namely wind deflation. Except from one shell-rich context of São Julião (Sousa and Soares, 2016), separated from the Early Mesolithic ones, no Late Mesolithic shell middens are known in Estremadura. Meanwhile in Muge, as the estuarine ecosystems of the coast were being submerged (Araújo, 2003), the Tagus estuary was advancing inland, and the shell middens emerge on its margins.

In Southern Portugal, Early Mesolithic sites, with and without shell middens, are disperse along the coast of Alentejo (Soares and Silva, 2003, Soares and Silva, 2004) and Algarve’s most southwestern promontories (Carvalho and Valente, 2005, Valente et al., 2014) (fig. 3.5). Overall, the coast of Alentejo south of Sines shares similar geographic features with Estremadura, and only three shell midden contexts are known (Soares and Silva, 2003). Their locations mirror those of Estremadura, located atop sea cliffs or small coastal streams, in sandy or sandy-clayish substrates. The oldest site, Pedra do Patacho, in Alentejo coast, reveals a higher diversification with both marine and estuarine species, namely common periwinkle,


**Figure 3. 6** Examples of the types of Mesolithic shell midden in Portugal; a) shell midden associated to hearths at São Julião (after Sousa and Soares, 2016) b) Magoito; the shell midden is layer III (after Sousa and Soares, 2016); c) and d) stratified shell midden and combustion feature at Castelejo, respectively (photographs from the DGPC archaeological sites online database “Endovelico”); e) shell midden with stone-structured combustion features at Armação Nova (photographs from the DGPC archaeological sites online database “Endovelico”); f) shell mound of Cabeço da Arruda, Muge (photographs from the DGPC archaeological sites online database “Endovelico”)

limpets, mussels, and peppery furrow shells (Soares and Silva, 1993). This site is composed by a single shell-rich layer 25 cm thick extended for about 2000 $m^2$, with a matrix of slightly cemented sands and reddish-brown clay; no structures are reported (Silva and Soares, 1997).

In Western Algarve, an uplifted Mesozoic basin like Estremadura, some areas of limestone are rich in flint sources, incised by small ravines, and lithified dunes on cliff tops (Valente et al., 2014). This southern shell middens' malacological content reflects the exploitation of the rocky cliffs that characterise the coastline, with marine species such as mussels, limpets, and common topshells prevailing over estuarine species (Dean et al., 2012; Valente et al., 2014). Some sites in western Algarve yielded a more complex stratigraphy. Is the case of Castelejo (fig. 3.6: c, d), throughout an estimated area of 3000 $m^2$, a 1m thick sequence of shell-rich deposits intercalated by sandy layers interpreted as abandonment periods, resulting from short, logistical occupations from the Early and Late Mesolithic and the Early Neolithic (Silva and Soares, 1997). At Castelejo, stone-structured combustion features are known in all periods, but its relationship with the shell-rich layers is not clarified in the available documentation. Barranco das Quebradas is a ravine where several shell middens were identified, two of them on limestone rockshelters with 1/1.5 m thick accumulations, one of which with two occupation phases of the Early Mesolithic. Other sites in region are open-air shell middens up to 50 cm thick accumulations, with either a single layer or exhibiting multiple thin layers of overlapping shell deposits (Dean et al., 2012).

In terms of lithic technology, at both Estremadura and southwestern Early Mesolithic sites it is overall simple and expedient, as suggested by is based on local raw materials and represented by poor assemblages in number and quality. Early Mesolithic sites have thus been interpreted as result of distinct and successive occupational episodes of short duration and logistical character by highly mobile groups. These camps would be centred on the exploitation of specific faunal aquatic and terrestrial resources, as well as chert as raw material in the case of western Algarve (Araújo, 2016b, Valente et al., 2014).

Differently from Estremadura, the shell middens of the southwest coast were not abandoned during Late Mesolithic, as already advanced with the mention of Castelejo above. On the contrary, more shell middens are added to the archaeological record (Valente el al., 2014, Silva and Soares, 1997). These sites revealed more complex combustion features associated to shell middens, using stones to structure the features "in cuvette" or placing flat stones at the base (Valente et al., 2014, Dean et al., 2012). Fireplace cleaning deposits, or "ash deposits" have been reported at Vale Marim I and Armação Nova (fig. 3.6: e) (Soares and Silva 2003, 2004 (Soares and da Silva, 2018, Soares, 2017). In the Late Mesolithic in the southern coast of Alentejo, along with the formation of the Sado shell middens, similarly extensive sites appear around Mira valley and adjacent coast, such as Samouqueira I, Vidigal and Fiais. All three are composed of a single shell-rich layer extended through large areas. About the shell midden of Vidigal, it is said that it was “generally 10-20 cm thick, probably accreted laterally during many human visits” (Straus, 1991:899). Moreover, artificial pavements of local sandstones and schists slabs are reported, “roughly two layers of stones thick; many of the stones are heavily burned”. The author describes that after abandonment, the pavement is covered by shell “dumps” (Strauss, 1991). The site of Fiais is 13 km away from the present coastline and several functional areas were distinguished in the shell midden, c. 40 cm thick (Soares, 1996): hearths, post-holes, stone pavements, as well as post-depositional cementation of different accumulations of shells and ashes are reported (Arnaud, 1993). Large mammal pieces, some still anatomically connected, and human bones were found at the site, suggesting the presence of human burials (Arnaud, 1993). Overall, in these southwestern Late Mesolithic sites the diversification of both faunal and lithic assemblages points to a rather residential type of site (Valente et al., 2014, Soares and Silva, 2004), instead of logistical like the Early Mesolithic sites. Many of these characteristics of Late Mesolithic sites of the southwest coast are comparable to some aspects of the contemporary shell middens of the Sado.

Climatic constrains such as the cold event Bond 5, at 6200 cal BC, (so-called 8.2k cal BP event) and its implications on the upwelling of nutrient-rich cold waters to the sea surface, has been pointed out as a trigger for this change in settlement pattern (Bicho et al., 2010, Bicho, 2009). But the appearance of abundant aquatic and wetland resources such as molluscs, crustaceans, fish, birds in these inland regions where game like red deer, wild boar, auroch (Dias et al., 2016, Dupont and Bicho, 2015, Dias et al., 2015, Lentacker, 1994, Lentacker, 1986, Rowley-Conwy, 2015, Detry, 2007) and plant resources (Monteiro et al., 2017, Monteiro et al., 2015, López-Dóriga et al., 2016) were also available seem to have been a crucial factor (Araújo, 2009, Carvalho, 2009). Lithic assemblages analysis revealed that raw-materials are overall available locally at both Muge and Sado surroundings (Pereira et al., 2015, Pimentel et al., 2015).

Such conditions make these areas attractive ecotones and created conditions for the beginning of more permanent settlements, which evidence is strengthened by the emergence of collective necropolis in Muge and Sado, a phenomenon that again evidences a change in human behaviour. These human burials allowed several analyses of paleoanthropology and paleopathology, funerary practices and diet reconstruction (Cunha and Umbelino, 1995, Cunha et al., 2003, Umbelino et al., 2015, Cunha and Umbelino, 2001, Umbelino et al., 2007, Peyroteo Stjerna, 2016). Stable isotopes analysis from Muge individuals systematically reveal evenly balanced between animal and vegetal resources of terrestrial and aquatic origin with values of marine diet from 40% to above 60% (Lubell et al., 1994, Umbelino et al., 2015, Umbelino et al., 2007, Peyroteo Stjerna, 2016). The more permanent character of these shell middens is also attested by several habitat structures reported in Muge and Sado sites, such as post holes and pits (Roche, 1966, Roche, 1989, Arnaud and Larsson, 1994, Arnaud, 1989, Arnaud, 2000, Diniz and Arias, 2012). The Muge shell middens display a similar stratigraphic record of up to 5 metres thick mounds (fig. 3.6: f) of superimposed shell-rich lenses cross-cutted by major rearrangement episodes of the mounds, which details will be discussed later (section).

At the present moment of investigations, the general idea of inexistence of coastal sites in Estremadura dating from Ealy Mesolithic is challenged. Recently the littoral site of Cova da Baleia, in the proximity of coastal shell middens of Estremadura, provided the highest record of clay combustion structures of western Europe (Sousa et al., 2018), that came to contribute to diversify the archaeological record of the Early Mesolithic in Estremadura. The stratigraphic layer at Cova da Baleia that covers the so- called "paleosoil" where the clay features were built, and of one shell midden context at São Julião (Sousa et al., 2016), yielded dates contemporary to the Late Mesolithic of Muge and Sado (Sousa et al., 2018). These recent data force a rethinking of the apparent abandonment of the coast, although with the current archaeological record, as pointed out by Araújo et al. (2014), it seems that there was a confluence of the groups towards the large inland estuaries. Meanwhile, Late Mesolithic sites in the southwest offers evidence for high mobility indexes in a logistical system that might have been done in consonance with residential camps in the interior not yet identified (Carvalho, 2008, Zilhão, 1992a, Zilhão, 1993, Valente et al., 2014), although clay combustion structures from this period are known in interior regions of southern Portugal (Gonçalves et al., 2008, Gonçalves et al., 2013). The present record offers new research venues on the relation of these groups with the coast that future multidisciplinary data should contribute to incorporate in the historical process and allow comparisons with the inland shell middens, and geoarchaeological investigations are fundamental for the complete understanding of these sites' formation.

### 3.3.1 The Sado shell middens

The earliest human occupations in the Sado basin goes back to the Acheulian, documented by the recovery of lithic artefacts from surface surveying, mainly from the southern area of the Sado basin (Burke et al., 2011). The authors were able to hypothesize the exploitation of the seasonal lakes that have formed in the Cenozoic plain and jasper outcrops by Neanderthals, followed by generalised populational decrease during the Upper Paleolithic, probably in favour of the most productive coastal areas (Burke et al., 2011). It will be the emergence of the Mesolithic shell middens in the lower Sado that mark the establishment of human groups year-round in the region (Arnaud, 2000).

A single published note mentioning shells at such distance from the coast (Barradas, 1936) compelled Manuel Heleno to conduct excavations in several of the Sado shell middens during the 1950s and 1960s (Arnaud, 2000). The fieldwork was supervised by Jaime Roldão, that made trenches, enlarging the areas where skeletons appeared. Roldão was receiving directions from Heleno, then director of the National Museum of Archaeology at Lisbon, and periodically sending to him the materials, reports and plans of the excavations (Arnaud, 2000). This dynamic caused the progressive accumulation of material, including lithic artefacts and blocks of human burials consolidated with paraffin (Peyroteo Stjerna, 2016). In the meanwhile, new sites were being discovered by M. Farinha dos Santos that studied some artefactual collections (Santos, 1968, Santos, 1967, Santos et al., 1974).

However, most of the truly reliable data to trace interpretations about the Sado shell middens, presented further below, comes from the efforts of later multidisciplinary projects that entailed systematic study of artefactual collections stored at the Museum and returned to the Sado for sampling and excavation with scientific recording techniques (Arnaud, 1989, Araújo, 1995-1997). The first of these projects was directed by J. Arnaud in the 1980s (Arnaud, 1989, 2000). The second and more recent project, established since 2010, is a collaborative project co-directed by Pablo Arias (University of Cantabria, Santander, Spain) and Mariana Diniz (University of Lisbon, Portugal) (Arias et al., 2015b, Arias et al., 2017, Diniz and Arias, 2012).

The shell middens are spread in both margins of the Sado along 40 to 50 km upstream from the current estuary. The sites topographic and geographical positioning was analysed by Gonçalves (2014) that recognize two patterns: one concerning the sites located at the banks of the Sado, and another comprising the sites located in tributary systems of the Sado (fig. 3.5). The group of shell midden at the banks of the Sado includes, downstream to upstream, Arapouco, Cabeço do Rebolador, Barreirão (recently discovered by Arias et al., 2015) Cabeço das Amoreiras and Barradas das Vieiras in the south bank, and Cabeço do Pez and Vale de Romeiras in the North bank. This group of shell middens are located on the border of the

Miocene platform at altitudes between 40 and 60 metres (Gonçalves, 2014, Diniz and Arias, 2012, Arnaud, 2000), overlooking the meandering and incised river valley. An exception is the site of Barrada das Vieiras, as noted by Araújo (1995/1997), at 20 m of altitude.

In the group of sites located in the tributary systems are included the following: at North of the Sado (right bank), Várzea da Mó and Barrada do Grilo, located at the left margin of the Algalé river; at South of the Sado (left bank), Poças de S. Bento and Fonte da Mina, close to the springs of a small stream tributary of the Vale dos Açudes river, and the site of Barranco da Moura is the furthest from the Sado, but close to its tributary Arcão. Araújo (1995/1997) notes that the last three sites, south of the Sado, are less exposed to the ecological conditions proportioned by the paleo-estuary, for being located inland on the platform. Arnaud and Larsson emphasize that freshwater springs must have been determinant in the location of these sites, in particular Poças de São Bento, where they've conducted collaborative excavations (Larsson, 1996, Arnaud, 1989, Arnaud, 2000, Arnaud, 1987, Larsson, 2010). Regardless, all shell middens are mostly composed by variable related amounts of the estuarine peppery furrow (*Scrobicularia plana*) and common cockle (*Cerastoderma edule*).

Human burials are known from Arapouco (n=32), Cabeço das Amoreiras (n=6), Vale de Romeiras (n=26), Cabeço do Pez (n=32-36), at the banks of the Sado, and from Poças de Sao Bento (n=16) and Várzea da Mó (n=1), at the tributaries (Stjerna, 2016). Isotopic analysis at the skeletons showed that Arapouco and Poças de São Bento revealed a mixture of terrestrial foods complemented by over 40% of protein from marine-estuarine sources (Stjerna, 2016, Umbelino, 2006). This data is coherent faunal record of the site, presenting a significant number of marine species of fish, molluscs and crustaceans along with estuarine ones (Arnaud, 2000, Marques Gabriel, 2015). In the rest of sites, all located further west, the skeletons isotopes indicate a full terrestrial diet (Stjerna, 2016, Umbelino, 2007), which is also inferred from the faunal record of these sites that present a higher number of mammal fauna, mostly red deer and wild boar, compared to the eastern sites (Arnaud, 1989, Rowley-Conwy, 2015). Overall, the presence of such high number of burials in the Sado shell middens reinforces the interpretation of this groups as more sedentary at the scale of the territory (Arnaud, 2000).

The successive excavations at Sado shell middens revealed a constant pattern: one single shell-rich layer, horizontally sparse and not always continuous, lying on Pleistocene aeolian sands and covered by recent agricultural soils. Based on observations at Cabeço das Amoreiras, Arnaud (1986) states that this is the result of shell-rich deposits accretion by horizontal juxtaposition rather than vertically accumulated, by the successive occupations of the site (Arnaud, 1986), of short, seasonal character. Overall, the shell midden layers at the Sado sites are not more than 80 cm thick (Diniz and Arias, 2012), and individual structures are scarce. In 2010, a complete dog skeleton was found within the shell-midden layer of Poças de São Bento, stressing out the symbolic behaviour of these groups (Arias et al., 2015). In the same site, the several projects recorded habitat structures like putative post-holes and negative structures, like pits, seem to indicate a more permanent settlement (Arnaud 1989, 2000, Larsson, 1996, Diniz e Arias, 2012, Arias et al., 2015), whereas Cabeço do Pez is the only shell midden with intercalated sterile sandy layers reported in the Sado by Arnaud (2000) (see section 4.2.2).

Chapter 4

# Georchaeological research on Mesolithic and shell midden contexts

When one proposes a methodology to approach a specific issue in a certain region, the first thing to do is reunite the available information regarding that issue, especially those data collected within the same methodological field, in this case, geoarchaeological approaches to shell-rich anthropogenic deposits or other related Mesolithic contexts.

In the next sections, specific data from Earth sciences' techniques applied to shell middens and micromorphological approaches to coeval contexts to the case-studies of the dissertation will be analysed, entailing a critic analysis of the evolution of the applied techniques, to identify the aspects or questions that remain open. In this section the purpose is bifold: firstly, to review what do we know about geoarchaeology of shell middens and Mesolithic contexts and, secondly, how can those previous works help us in the interpretation of our own data?

For this purpose, two situations will be addressed, that are: 1) general geoarchaeological approaches specifically to prehistoric shell middens, to evaluate, at sedimentological level, independently of the analytical technique applied, the documented responses of shell-rich matrix deposits to different formation processes, and 2) specifically micromorphological analysis of Mesolithic contexts, because being micromorphology the basal methodology that I propose in this thesis to address Mesolithic behaviour, it is extremely important to know the several microscopic signatures of anthropogenic formation processes in coeval contexts. First, the two geographic areas of this thesis will be revised, for a matter of acknowledging the work of those who previously contributed to the same issues we aim to contribute too and whose data we are gathering to support our arguments.

## 4.1 The Cantabrian case

Since M. Sanz de Sautuola (Sanz de Sautuola, 1880) first spreading evidences of prehistoric artefacts and cave art in Altamira, prehistoric research in the Cantabrian region has been one of the most dynamic in Iberia. In the first decades of the 20$^{th}$ century, the increasing finding of caves with long Pleistocene sequences in eastern Asturias was due to the intense survey activity of R. Duque de Estrada, the Count of the Vega del Sella, that applied stratigraphic-based field methods in the excavations he carried out (Vega del Sella, 1923, Vega del Sella, 1914, Vega del Sella, 1930, Vega del Sella, 1916). In the study of El Morín Cave (Cantabria), Vega del Sella not only studies each layer, but also makes climatic and geologic interpretations of the formation processes of each one (Vega del Sella, 1921). As already said, Vega del Sella (1923) also worked on the formation processes of the Asturian shell middens, what was quite challenging giving their preservation conditions, most of them disconnected from stratigraphic deposits. H. Obermaier was also an important figure in the early stages of the research in the Cantabrian region, undertaking excavations at El Castillo Cave, among other sites (Obermaier, 1916). The geologist Henri Brueil was one of the first and most active geologists in undertake intensive field-work in caves of Cantabria, attracted mainly by the paleolithic artistic heritage, side by side with prehistorians like H. Alcalde del Río (del Rio et al., 1911).

In the Basque Country, it is thanks to the intensive prospecting activity of J. M. de Barandiarán, an ethnographer, that several sites were discovered, including Santimamiñe, where he proceeded to excavations in close collaboration with the anthropologist T. de Aranzadi and the geologist E. Eguren (Aranzadi et al., 1935, Aranzadi et al., 1931). At this site they found the first Mesolithic shell midden outside of the Asturian geographic area, by the same time Vega del Sella was studying it. Most of the fieldwork of the Comision for Palaeontological and Prehistoric Investigations, seated in Madrid, were carried out in Asturias, espetially by the action of the geologist Hernández Pacheco (Ayarzagüena-Sanz, 2018).

These early works were mainly focused on establishing the stratigraphic sequence of the evolution of mankind, therefore the interest mainly on the Pleistocene deposits of these caves. In this context, F. Jordá Cerdá was a geologist that actively worked in several sites in Asturias (Jordá, 1954, Jordá, 1958). The Asturian shell middens were target of attention of the geologists Jordá Cerdá and the also geologist N. Llopis Lladó, who intended to demonstrate that they pre-date the Paleolithic deposits of the caves where they were found (Jordá, 1958, Jordá, 1959, Llopis Lladó, 1953a, Llopis Lladó, 1953b). They argued that the shell middens were accumulated in the Lower Paleolithic, filling the caves completely. A reactivation of karstic activity would have washed out the shells, remaining only the cemented parts in the contact with the cave walls. Afterwards, the Upper Paleolithic occupations took place, explaining why there was no record of Mesolithic layers in stratigraphy. For them, this explanation was also supported by the macrolithic industry characteristic of the Asturian shell middens.

After a short period of stagnation, it can be said that geoarchaeological studies in the Cantabrian region were officially launched only in the 1970's, because the father of the term "geo-archaeology", K. W. Butzer, started working in the region. It was by the will of J. G. Echegaray that international teams come to Cantabria to conduct interdisciplinary projects, initiating a collaboration with L. Freeman. Butzer was then dedicated to the study of several cave deposits investigated by Freeman and Echegaray (Gonzalez Echegaray and Freeman, 1971). American researchers kept working in Asturias in the following years and revisited one of the key-sites for Vega del Sella's work: La Riera Cave (Straus et al., 1986, Straus et al., 1981). At this site, they counted with the collaboration of the sedimentologist H. Laville, that studied integrally the sequence of the site, and later revised the stratigraphy of El Pendo Cave with M. Hoyos, rebating many of Butzer's insights (Hoyos Gómez and Laville, 1982). From this history of intense debate between researchers it becomes clear that since very early the Cantabrian region has been a stage of remarkable geologic interest of archaeological deposits. However, this interest was mainly addressed to questions related to the Pleistocene sequences. The systematic palaeoecological studies in the 1970's carried out in the framework of Clark's thesis about the Asturian Mesolithic and La Riera project were the first in applying clearly geoarchaeologically-oriented studies on Mesolithic shell midden contexts (see sections below).

In the 1970's and 1980', M. Hoyos Gómez conducted sedimentological and geomorphological study of the Quaternary cave deposits in Asturias and Cantabria, building a climatic evolution of the Quaternary in the region (Hoyos Gómez, 1995). Hoyos continues the tonic on Pleistocene deposits, but the synthesis of his observation concerning the sedimentation during the Holocene are described as floodings and irregular stream action and flowstone formation under temperate and humid conditions, and drier conditions at the end of the sequence, marked by alteration processes such as pedogenesis and calcareous crusts. Although exhaustive in terms of number of cave sites and sedimentological information managed, Hoyos does not consider aspects related to anthopogenic activity inputs as an active factor regarding the formation processes the cave archaeological deposits. But overall it is in this aspect that the generality of traditional sedimentological studies fails, because they lack the ways to identify those aspects, that are intimately related with context.

Only in the 21st century this gap would be bridged with the incorporation of micromorphological studies in the Cantabrian region. It is still only a handful of sites that count with micromorphological analysis, namely El Mirón (see section 4.1.7), Sopeña (Pinto-Llona et al., 2012) and Esquilleu (Mallol et al., 2010) caves. The miroarchaeological multidisciplinary work at the latter allowed the identification of diagenetic processes affecting the archaeological record and Paleolithic grass beds at the site, that were missed in the previous traditional sedimentological analysis of loose samples. Very recently, micromorphology has been applied at Pleistocene deposits of La Güelga and Lezetxiki II caves (Menéndez et al., 2017, Kehl et al., 2018, Arriolabengoa et al., 2015).

Concerning Holocene layers, particularly shell middens, apart from three samples in Clark's (1976) work, geoarchaeological analysis of Asturian shell middens were avoided by sedimentologists that worked in the Pleistocene sequences of the same caves, because of the cemented character that hampered the application of most traditional techniques. It was only in the last decade of the 20th century, with the discovery of stratified shell middens in the Basque Country, that the first sedimentological analysis in these anthropogenic deposits were attempted in loose samples from shell middens of Pico Ramos, Kobeaga II and Santa Catalina caves.

### 4.1.1 Cemented Asturian shell midden samples

The first geoarchaeological study of samples from cemented shell midden were carried out in the framework of G. Clark's thesis (Butzer and Bowman, 1976). Clark selected three samples from different sites using their radiocarbon chronology as main criterium: a Magdalenian sample from El Cierro (10.712 ± 515 BP), a Mesolithic sample from La Riera (8909 ± 309 BP) and a "post-Asturian" sample from Les Pedroses (5932 ± 185 BP) (Clark, 1976). The first two were found in contact with Paleolithic deposits underlying them. The sample from La Riera is said to correspond to layer B (Level 29 in the latest re-definition by Straus, 1986), a cemented shell midden with occasional thin layers of organic dark, greasy sediment. Les Pedroses was a semi-horizontal cornice cemented along the cave wall, at 3 m. from the cave floor. Macroscopic examination of structure, colour, grain-size analysis, pH and carbonate content. A microscopic examination of the sand fraction included a semi-quantitative estimation of roundness and wear of the grains. The samples are described as “semi-cemented” and, after carbonates removal, and the remaining sediment was a clayey loam, that the authors interpreted as colloidal precipitates, just as the carbonates. They furthermore note the absence of aeolian inputs, being the angular quartz grains from bedrock alteration.

### 4.1.2 Balmori

Clark’s (1976) work at Balmori Cave consisted in several tests, having collected samples for se3dimentological analysis from tests E and D. Test E revealed a shell midden with six layers, distinguishd by discrete sedimentological differences, and only level 1 was classified as Asturian, being the lower ones Upper Magdalenian, like the entire shell midden from Test D.

The samples reveal a vertical variation in relative amounts of humus and shells, and a non-carbonate silty-loam sediment. The samples from Balmori, apart from traditional grain-size, morphology and pH analysis, because they were not cemented, could be submitted also do potassium and phosphorus analysis. The results of those revealed a much higher values of all these analysis in test E than in test D, whichi was interpreted as result of more intense human occupation on the former (Butzer and Bowman, 1976).

That fact that the sedimentological analysis did not recognise any evidence of colder climate in the Magdalenian deposits is attributed to three possible effects, namely the relative stability provided by the marine climate, stable conditions inside the cave or the elevated cultural components of the sediments that might be masking the physical processes (Clark, 1976). Once again, if the formation process was anthropogenic, there were no “natural” process there to identify, and those sediments should be valued as important archives for archaeological interpretations.

### 4.1.3 La Riera

At La Riera, a cave on the karstic massif of La Llera (Llanes, Asturias), sediment from several sectors of the excavation was systematically sampled for global granulometry, morphology of coarse constituents, texture, colour, structure and consistency analysis (Laville, 1986). Nature of concretions affecting the deposit was taken in consideration from a macroscopic perspective, as well as the nature of boundaries and transitions between levels in order to isolate possible episodes or erosion. This protocol demanded the previous removing of all objects of anthropogenic origin (lithics, bones, etc) and a separation of the illuvial calcareous concretions as well as non-calcareous elements were separated (Laville, 1986). One of the aspects that by the same time was started to be criticized in this analysis were that this procedure causes the loss of potentially valuable contextual information that could be recovered through micromorphology (Goldberg, 1980, Courty et al., 1989). Furthermore, with traditional sedimentological techniques it was impossible to analyse the upper layers (levels 30-25) mainly because they were heavily cemented, and their geometry made appropriate representativeness of the samples impossible, although some observations of geological character were made (Straus et al., 1986, Laville, 1986).

The upper sequence consisted, from top to bottom, of level 30: a stalagmitic crust, or tufa, in the outer cave, incohesive and weathered in the centre of the cave. Its base was less crystallised and continuous with the concretion which affected underlying deposits. It was interpreted as having formed during an episode of great humidity, also responsible for the concretion of most of levels 29, 28 and 27 in most of the cave. The first archaeological deposit was thus level 29, an Asturian shell midden, composed by molluscs and sea urchin spines and carapace fragments, along with slightly rounded limestone rock fragments and a dark greyish brown (10YR 3/2) colour (of the carbonate cement?). Levels 28 and 27 are Azilian layers, also with cemented patches from percolation of carbonates, are attributed to a same climatic event of greater humidity, based on the presence of rolled limestone pebbles and gravels. The presence of frost-weathering products associated with the smaller blunted debris along with coarse sands, as products of mixture of older deposits from the cave exterior makes the authors suggest colder, but still humid conditions.

Layer 26 consisted of localised lenses of black, sticky sandy-silty clay, with small mollusc shell fragments and concretions, interpreted as a habitation surface of Magdalenian or Azilian age. No definitive interpretation is proposed, but it is advanced that the fine material could indicate alluvial transportations of at least part of the material. This association of natural processes with the interpretation of being a habitation surfaces is not explained. Finally, level 25 is a thin stalagmitic layer profoundly weathered, apparently broken after its formation, that testifies very humid climatic conditions (Laville, 1986).

The interpretations advanced for the formation processes of the shell midden as garbage dumped in areas adjacent to the occupation ones (Straus et al., 1986), did not arise from geological observations, but it is advanced, with reservations, that levels 28 (Azilian) and 29 (Asturian) present signs of water flowing, perhaps from the outside of the cave, under temperate and possibly humid conditions, judging for of the presence of rounded pebbles (Laville, 1986). In Straus et al. (1981) it is remarked, concerning the upper layers, that the high density of cultural debris disturbed sediment conditions and original texture of the sediments, namely by organic matter impregnation and artificial enrichment of carbonates by shells. But isn't the original texture of the sediment culturally induced after all? This problem should be addressed in archaeological deposits and shell middens are excellent examples of anthropogenic deposits that integrative contextual techniques in examples like La Riera can produce knowledge about human behaviour and its interaction of the surroundings.

### 4.1.4 Pico Ramos

In the small cave of Pico Ramos (Bizkaia, Basque Country), a shell-midden layer ca. 30 cm thick (level 4) was excavated. The shell midden was interpreted as a low-resolution palimpsest of several short occupations, giving the long time span revealed by radiocarbon dates, from Late Mesolithic to Neolithic, despite no stratigraphic differences were identified (Zapata, 1995, Zapata et al., 2007). The whole sequence of the site, that includes a Chalcolithic burial ground (Level 3), was sampled for sedimentological analysis by (Areso and Uriz, 1995). This study consisted in grain-size analysis, macroscopic study of morphological characteristics of the coarse components, pH, organic matter and carbonate content.

The four samples collected in different areas of level 4 revealed two distinct sedimentological environments. One is present at the top of the layer only in one area of the site and is characterised by predominance of coarse components, that are heterometric pebbles. In the samples underlying the former, the coarse fraction is less abundant and composed by small pebbles. It is noted that the presence of comminute shell fragments alters the grain-size values of the fine fraction. This difference of the upper sample was interpreted as a higher-energy and colder first sedimentation moment, and then a second moment more humid in which the voids were filled with fines. Zapata (1995) stresses out that this distinction was only detected by sedimentological analysis, since the archaeological material was overall very scarce, and might correspond to the period between the abandonment of the shell midden and the use of the cave for the Chalcolithic burials.

The lower samples, corresponding to the shell midden occupational material deposit, revealed no indicators of cold climate and the appearance of further lithologies beside limestone (quartzite, sandstone) suggest some activity of the karstic conducts. We wonder, in the context of a shell midden, if this are anthropogenic inputs rather than natural.

### 4.1.5 Kobeaga II

The small cave of Kobeaga II (Bizkaia, Basque Country) had a shell-rich deposit that, similarly to Pico Ramos, corresponds to short occupations since the Mesolithic until the Neolithic (Quintana, 1998/2000). The sedimentological study of the shell-rich layers of Kobeaga II was undertaken by collection of 7 samples of loose sediment in column. The study consisted in grain-size analysis, macroscopic study of morphological characteristics of the coarse components, pH, organic matter and carbonate content (Areso and Uriz, 2000).

The deposit of Kobeaga II is marked by the presence of combustion features. One was identified in early excavations in 1976 (Apellániz, 1975) at the base of the archaeological deposit, dug into the clayey substrate and filled with pebbles, with abundant charcoals and marine molluscs. Later re-excavations in an area contiguous to the former also revealed combustion features structured with stones at the base, but occupying natural hollows resulting from erosional processes (Quintana, 1998/2000). This layer is ca. 15 cm. thick. and defined by abundant charcoal concentrations, small lenses of rubified clay, some mammal calcined bones and molluscs. This layer was superimposed by another that was considered a 10 cm thick concentration of mammal bones together with marine shells, mainly limpets.

More combustion facies were identified upper in the deposit, in the form of lenses of rubified clay with inclusions of charcoal and shells, forming a discontinuous layer between the Mesolithic lower sediments and the Neolithic upper ones (Quintana, 1998/2000). This rubified lenses were sometimes combined with another greyish lenses that the authors interpret as carbonates precipitation, but we wonder if those could be ashes, like Apellániz (1975) had also suggested in his earlier excavation. In any case, these contexts seem to constitute very interesting microstratigraphic associations related to the transition from the use of the cave by the last hunter-gatherers and the first Neolithic groups, which microscopic study could provide valuable information about different ways of "making fire", like Apellániz (1975) had suggested, and infer different adaptations of these both shell-gathering groups.

From the study it is inferred that the samples avoided the lenses associated to combustion, probably selecting areas of more homogenous composition. This is a good example of a significant advantage of micromorphology in relation to traditional techniques, that is that these contacts are targets in the sampling, allowing the study of this transitions chronologically significant. The sedimentological study revealed quite homogenous results in all samples, although a post-depositional episode of colloids and carbonates leaching evidenced by the higher values of fines and carbonates in the lower samples, as well as of iron nodules. No formation processes are suggested from a geoarchaeological point of view, only general temperate and humid climatic conditions are inferred. Regarding the most superficial sample, colluvial and pedogenic processes are identified by the depletion of clays and abundant organic matter, which is simultaneously attributed to human inputs (Areso and Uriz, 2000).

### 4.1.6 Santa Catalina

At Santa Catalina Cave (Bizkaia, Basque Country), a shell midden divided in three major layers was excavated, with a large number of finely stratified combustion features in all three layers, which detailed macroscopic analysis revealed different activities related to combustion at the site (Roselló-Izquierdo et al., 2016). In parallel, sedimentological samples were collected for grain-size analysis, macroscopic study of morphological characteristics of the coarse components, pH, organic matter and carbonate content (Areso Barquín and Uriz Galarraga, 2014). The discriminated layers are level I, Azilian, level II, Late Magdalenian, and layer III, Upper Magdalenian.

The author used several factors, namely the presence and abundance of burnt components (bones, shells, fire-cracked pebbles…), to interpret macroscopically the combustion activity dynamics. At level I, the shell midden has maximum thick of 21 cm and is composed of a succession of combustion-related darkish sediment with lenses of ash and charcoal. Sometimes, clean yellowish clay that the excavators attribute to natural decantation of pure clay during abandonment periods between occupations represented by the hearths. These alternation and spatial variability between the ashy lenses and rubified clay lenses served to infer successive combustion activities and moments in which some material would have been displaced, trampled or cleaned. At the base of the layer, an accumulation of particularly abundant shells and carbonaceous sediment, without signs of rubefaction in the adjacent clays, was interpreted as a deposit of fireplace cleaning or a combustion features altered by natural reworking, possibly by dripping water that is observed in that zone of the cave.

Level II, with 55 cm of maximum thickness, stands out by the occurrence of two sub-units: an upper one, constituted by successions of interspersed ashy lenses with abundant charcoal, sometimes hardened by post-depositional cementation; that stood out for the presence of a thick layer of indurated and rubified clay, forming a clay slab. Different combustion moments could be individualised here. In the upper unit, one feature 8 cm thick composed by a succession of ashy lenses overlying rubified sediment. Below it, the surface was occupied by carbonaceous isolated spots associated to accumulations of burnt shells and bones, interpreted as the remains of a combustion feature strongly eroded. In the lower unit, a 50 cm. thick accumulation of finely stratified combustion products, with some cemented, rubified and carbonaceous lenses, overlies a 15 cm thick slab of strongly red clay with abundant charcoals. This feature was not homogenous, but intercalated with lenses of dark sediment, which was surrounding the feature in plan, and over which the ashy sediment was deposited. Shells were rather rare in this feature. Unlike the features in level I, that were not spatially coincident, these features seem to result from a consistent use of the combustion events of high intensity at the same place.

Level III, 66 cm thick at most, had large boulders (over 50 cm of diameter), and remains of combustion activity given several ashy crusts, charcoal concentrations and rubified clays. In this level, the shells were not as abundant as in the upper ones. At the base of the layer, an accumulation of carbonaceous greasy sediment was concentrated inside a hollow in the cave substrate, by its turn rubified, pointing to a combustion features in cuvette.

Overall, the combustion features were not structured, although fire-cracked pebbles were abundant ubiquitous. Nonetheless, the analysis of the combustion features revealed combustion structures in flat surface and in cuvette, and not structured combustion remains. The sedimentological analysis recognised an increment in colder condition between the natural clay sediments of the substrate and level III, judging by the accumulation of coarse gravels, interpreted as roofspall. The granulometry of the fine fraction did not offer any conclusive trends. In level II, the bigger presence of sandy material and rounded clasts led to infer inputs from the outside of the cave under more humid conditions, that were overall maintained in level I.

The chronology of Santa Catalina shell midden is out of this thesis framework, but being a shell midden with combustion features where a sedimentological study was carried out, it is worthwhile to note. Furthermore, the detailed analysis of the combustion features, although macroscopic, allowed interesting insights on the dynamics of combustions and occupations of the cave. The work at Santa Catalina was done by considering the lenses in sets, but with micromorphology would allow the individual study of each combustion event with greater degree of resolution.

### 4.1.7 El Mirón

El Mirón cave does not have a shell midden, but the Mesolithic layer identified is the only that has micromorphological analysis (Courty and Vallverdu, 2001) in the Cantabrian region, and given its location in the river Asón basin, it provides good correlation with the Mesolithic shell midden of La Fragua, a case-study of this dissertation. Furthermore, the site was object of a comprehensive sampling for sedimentological analysis in all excavation areas (Straus et al., 2001).

The micromorphological thin section of the Mesolithic layer, level 10.1, revealed a fine channel to spongy microstructure, densely packing yellowish grey, weakly decalcified, micritic, biogenic aggregates and rare, highly altered to phosphatised, sand-sized, limestone fragments, in a total excremental fabric. These microscopic observations allowed the authors to infer intense dripping and slow water percolation under high humidity conditions. Low evapotranspiration and sedimentation rate, associated to dense plant colonization of the cave floor and walls, corresponding to climatic warming and rainfall increase and soil stabilisation on the slopes

This Mesolithic layer shows a sharp contact with the underlying unit (level 11), and closer observation revealed that the fine mass was weakly dissolved, which was interpreted as result of a formation process divided in two stages. During stage 1, major carbonate productivity occurred, associated to a regeneration of thick soils on the slopes under a warm and wet climate. In stage 2, a slight acidification took place, implying a substantial cooling and percolation, that the authors associate with snow melt and a change of ecosystem towards more acidifying plant associations.

According to the authors and excavators, these observations contributed to explain apparent contradiction in the radiocarbon dating of the Mesolithic contexts at the site (Straus et al., 2001), in the sense that dissolution processes of stage 2 implied significant loss of material accumulated during stage 1, that caused a chemically-induced compaction superimposed to the entire layer. Overall, it is concluded that level 10.1 formed during an episode of warming with high rainfall during the warm season at the beginning of the Holocene, followed by a significant cooling with abundant rainfall and possibly snow fall during the cold season. The latter effects (stage 2) is related by the authors with the of 8.2k cal BP cold event. This allowed to contextualise the radiocarbon dates obtained for the Meoslithic occupations. The earliest one, of the ninth millennium cal BC, would correspond to the Mesolithic occupation during stage 1, whereas the more recent dates would relate to the later Mesolithic occupation and provided explanation for the lack of stratigraphic distinction between both (Straus et al., 2001).

Concerning the sedimentological analysis, the samples collected at the site were submitted to grain-size analysis, lithology, morphology of coarse fraction, carbonate and organic matter content and clay mineralogy. Overall, the comprehensive sedimentological study provided evidence for generic geogenic processes at site scale rather than specific layers. Important contributions are clear evidence for continuous lateral facies variation in the geological manifestations from the front to the rear of the 30-m-deep vestibule, and the inputs from internal sources (mainly colluvial and roofspall, not associated to each other) and external sources (windblown silt) and carbonate variation in relation to minerogenic clays, all throughout the entire late Quaternary sequence. Lastly, the author state that geogenic features are complicated by anthropogenic inputs that migh be masking regional climate signals, recognising that more subtle fluctuations were tracked by micromorphological analysis.

## 4.2 The Portuguese case

Scientific pre-historic archaeology in Portugal started in the 1850's when the geologists Carlos Ribeiro, Francisco Pereira da Costa and Joaquim F. Nery Delgado directed the successive national commissions responsible of the geological survey in the country. These geologists eventually dedicated much of their work to Quaternary deposits and to the lithics and fauna they found within it. Aldeias (2003) already remarked how these early works were oriented by the prime objective of searching for proof of the antiquity of humankind, in the context of the same trend in the European scientific community. To accomplish that objective, they undertook pioneer scientific excavations in order to find reliable stratigraphic records, in sites such as Cabeço da Arruda, a major Mesolithic shell midden in Muge discovered by Ribeiro in 1863, among other sites (Cardoso, 2002). As Cardoso (2002) noted, the influence of Charles Lyell's *Geological evidences of the antiquity of Men* (1863) is clear in Nery Delgado's *Of the existence of Men in our ground in very remote times proved by the study of caverns* (free translation of the Portuguese original: "*Da existencia do Homem no nosso solo em tempos muy remotos provada pelo estudo das cavernas*"), of 1867, as his further published works reveal a clear stratigraphic-based methods for the spatial record of all artefacts recovered in Casa da Moura (1865) and Furninha caves (1879).

Later, the organic law of 1918 of the Geological Services of Portugal assigned to that institution studies in the specific field of Pre-Historic Archaeology among its competences (Cardoso, 2002). It was in this context that Henri Brueil stayed in Portugal, closely collaborating with the geologist Georges Zbyszewski and together they entail intense field work and recover lithic artefacts from Pleistocene terraces of the Lower Tagus and coastal outcrops. Those findings were widely published integrated with sedimentary chronostratigraphic analysis of the corresponding deposits (Breuil and Zbyszewski, 1942, Zbyszewski, 1943, Zbyszewski, 1977, Zbyszewski et al., 1982). Already in the mid-20th century, Octávio da Veiga Ferreira might be considered the last representative of this generation that accumulate both geologist and prehistorian functions.

After this early period, the application of Earth science to archaeology in Portugal is rather heterogeneous, characterised by a wide diversity of situations, most of them focusing on territory-scale geomorphological analysis (for a synthesis, see Aldeias, 2003). In fact, the only work that stood a precedent of our methodological approach to a shell midden context is the recent micromorphological analysis of Cabeço da Amoreira, in Muge (Aldeias and Bicho, 2016).

Further geoarchaeologically-oriented works that specifically addressed shell midden contexts were the sedimentological analysis of Cabeço do Pez (Arnaud, 2000) and Toledo (Trindade, 2011b) (see below). As for micromorphology, it is in an early phase of consolidation in Portuguese archaeology but appearing already as a systematic presence in more recent projects' conceptions. There were two contributions for the introduction of micromorphological studies in Portugal: the collaborative work of José Meireles with Jean-

Pierre Texier, that studied Quaternary slope deposits of Northern Portugal (Texier and Meireles, 2003), an analysis centred in the environmental genetics of such natural deposits, with no archaeological implications. The establishment of micromorphology in archaeological contexts was largely driven by Diego Angelucci who, among several projects in Portugal (see Angelucci, 2003 for a list), sampled and studied the open-air Mesolithic site of Barca do Xerez de Baixo, in the Guadiana valley.

Numerous Mesolithic shell middens are known along the central and southwestern Portuguese coast (see Carvalho, 2009, Valente et al., 2014, Araújo, 2009 and references therein) of which the previous section 3.3 gives a general view but going through all of them specifying stratigraphic details is beyond the scope of this methodological research background. In the following sections we will focus on the cases mentioned above because these provide specific geoarchaeological data relevant for the knowledge construction about the sedimentary record of shell middens, their formation processes and Mesolithic behaviour.

### 4.2.1 Early observations on shell midden formation processes at Muge

Significant contributions regarding the Mesolithic and shell midden formation processes were made in the 1950 and 1960's investigations at the Muge shell middens. In the sites of Moita do Sebastião, Cabeço da Arruda and Cabeço da Amoreira, all part of the Muge group, Jean Roche, later with Veiga Ferreira, addressed specifically the complexities of shell midden stratigraphy. Such concerns are particularly evident in Roche (1981) paper "*Some observations about stratigraphy of shell midden-like sites and the problems they raise to excavators"* (free translation of the original in Portuguese), but throughout his work, Roche (particularly (Roche, 1966, Roche, 1964/1965) is constantly pointing out some of the problems that remain largely unresolved and serve as basis of this thesis objectives (see also current challenges section).

One of the most outstanding aspects of Roche's effort to deal with the complex stratigraphies of Muge shell middens is how he recognise general groups of deposits and classified them in several types, based on the sedimentological character. Although not systematically, Roche tried to associate some of the types to specific processes (Roche, 1966, Roche, 1964/1965, Roche, 1967, Roche, 1972). In the 1972 paper (p. 83), Roche clearly enumerate the following types of deposits:

- dark earths, rich in charcoal and organic matter (mainly at the most recent levels);

- hearths;
- grey earths, often hardened, packed, bedded and mixed with fine debris of shells and charcoals;
- beds of shells usually crushed by trampling;
- pockets of intact shells (silos?);
- Lenses of yellow sands;
- Remains of ancient soils as form of carbonaceous trails.

Roche mentions that these types of deposits result from an array of actions and operations carried out by the occupants of the sites, namely, tossing, trails, trampling, excavation of pits and inhumations (1965, 1966, 1967). More complex, in the sense that demand site-scale planning, are arrangements to allow new occupations and periodic levelling of the shell midden, comprehending mass removing of detritus from former occupations and throwing the material out in the slopes of the shell midden (at least three times at Cabeço da Arruda, according to Roche, 1966). These reconstruction of formation processes are based on observation of the profiles and the stratigraphic contacts between the general phases, that exhibit several unconformities and intercrossings (Roche, 1981). Roche and Ferreira (1957) hypothesize that thin dark beds at Cabeço da Amoreira possibly correspond to destroyed hut floors; micromorphology would have been a useful tool to test this hypothesis, especially if combined with techniques of spatial analysis, which is demonstrative of the much work that still can be done in such contexts.

A review of further works from Roche allows us to find some extra types of deposits, such as "charcoal layers" and "ash layers", associated to the internal stratigraphy of combustion features, that assume a few different morphologies described by Roche as always having imprecise borders (Roche, 1966, Roche, 1952, Roche, 1954). Thus, surficial hearths were identified by a single ashy layer or a layer of fire-cracked pebbles. Recent experiments tell us now that ashy accumulations might also be in secondary position as result of sweeping or rake-out of a hearth, and these deposits are quite straightforwardly identified through micromorphological analysis (e.g. (Mentzer, 2014, Miller et al., 2010), enlarging de degree of detail of our understanding of the dynamics of formation processes. In Moita do Sebastião Roche identified a hearth with two successive utilizations separated by an abandonment period, and some pits were interpreted as fire pits, which infilling is an intercalation between ashy "breccia" and with dark earths lenses (Roche, 1966).

Roche interpreted what he called cooking pits as preserving several periods of use and abandonment, by the succession of layers of charcoal-rich sands, which he considers indication of occupation, intercalated with beds of crushed shells, these indicating abandonment periods (Roche, 1966). Here the concept of "abandonment" must be taken carefully, as Roche possibly means abandonment of the activity of cooking and not an occupational abandonment of the area, because in other instances, the author considers the lenses of crushed shells as results of trampling by the occupants (Roche, 1965), which reminds us of the importance of the context.

A recurrent reference in Roche's work in Muge is the cementation by secondary calcium carbonate of the basal layers, in the contact with the basal sands of Moita do Sebastião and some areas of Cabeço da Arruda, what he called "breccia" and assumed being a result of dissolution of shells from upper layers (Roche, 1965, 1966) and remarks that this allowed for the preservation of the older human skeletons buried in the basal sands (Roche and Ferreira, 1957). In their excavations in Cabeço da Amoreira, contrarily to what they had observed in Cabeço da Arruda and Moita do Sebastião, Roche and Ferreira (1957) did not found a cemented "breccia" at the base. This led them to wonder why it did not happen there and most importantly, giving the similarity of composition of the substrates at both sites, what does it implies and the problems of not having an explanation for the phenomenon? Roche (1966) furthermore refers to the possible destruction of earlier occupation remains at Cabeço da Amoreira due to the absence of cementation. Nonetheless, in the recent investigations in a different area of the site, a cemented layer was found at the base (Aldeias and Bicho, 2016). The issue of cementation of basal layers of shell middens and its implications will be addressed in the discussion under the light of the micromorphological results from Poças de São Bento (see chapters). Aside from percolation of carbonates, Roche (1966) also remarked the importance of recognise post-depositional downward displacement of organic material into the basal sands, including charcoals eventually used for radiocarbon dating.

Natural factors of sedimentation were equally always considered in interpretations of Muge shell middens. Roche (1966) considered hard to accept the hypothesis proposed by Carlos Ribeiro of archaeologically sterile thin layers of sand within the shell midden of Moita do Sebastião being caused by occasional flooding of the Muge river. However, Roche and Ferreira (1957) admit flooding as possible reason in the origin of sandy lenses at Cabeço da Arruda, giving the low altitude of the site in comparison to the others.

An important inference of Roche (1966) is that the Mesolithic occupants of the sites at Muge were living on the shell midden and not around it, hence the periodic levelling and mass rearrangements of detritus. To corroborate this inference, Roche carried out several soundings and geomagnetic survey around the shell middens and did not found any occupational layers or magnetic anomalies (Roche, 1966). Recently, however, Bicho and colleagues excavated several Neolithic and Mesolithic layers in a lower area outside of the mound at Cabeço da Amoreira (Bicho et al., 2011a, Bicho et al., 2013). Later in his literary production, Roche (1990) elaborates the issue of the seasonal *versus* permanent character of these occupations, leaving the question open to future debate. This and the former issue of shell middens as habitat places itself and not only wasting mounds, are both topics still in debate today for most of European Mesolithic shell midden contexts (Gutiérrez-Zugasti et al., 2011, Arias et al., 2016).

The work of Roche at Muge is certainly innovative and accurate (the author even mentions specifically a total of 27 occupations, between two major levelling events at Cabeço da Arruda) in grouping the types of deposits and their associations to refer to different occupations, paying attention to subtle details, such as millimetric lenses of crushed shells, to reconstruct the site formation. This might be considered one of the earliest facies-based approach to the archaeological record, even though based on macroscopic observations of the resulting profiles, and not so much in the individualization of the deposits. Recently, Aldeias and Bicho (2016) provided evidence that this work of reconstruct the activities involved in the formation of the shell midden can be substantially better understood with micromorphology (see section 4.2.6).

### 4.2.2 Cabeço do Pez

In the 1980's there was a growing interest in paleoecological issues in Portuguese archaeological research (Aldeias, 2003), which led to the formation of multidisciplinary projects, among them the aforementioned project of José Morais Arnaud for the Sado shell middens. Within Arnaud's project appeared the first clearly geoarchaeological strategy concerning a Mesolithic shell midden in Portugal, materialized by the sedimentological characterisation of the stratigraphic units of Cabeço do Pez, the largest of the Sado shell middens, by Fernando Real. Apart from extensive work with a formative character related to the discipline of geoarchaeology (Real, 1984, Real, 1988, Real, 1986), Real collaborated with several projects, systematically performing grain-size analysis, total carbonate content and quartz morphoscopy to infer sedimentary environments and paleoclimatic reconstructions, such as the cases of Pleistocene sequences of Caldeirão Cave and Vale Almoinha open-air site, or the Neolithic sequence of Feteira Cave (Zilhão et al., 1987b, Real, 1985a, Real, 1985b).

However, the analysis of the Mesolithic shell midden of Cabeço do Pez is only briefly exposed in Arnaud (2000), where it is explained that an area of 2x1m was excavated to obtain a complete stratigraphic section and collect bulk samples for sedimentological characterisation, with the purpose of trying to understand the formation processes (Arnaud, 2000: 27).

Relevant interpretations about the formation processes of Cabeço do Pez and its anthropogenic implications were made, although without specifying which techniques were applied apart from the inferred textural classification. It is noted, like it was in Muge by Roche, that the clayey-silty basal layer was cemented by calcium carbonate resulting from dissolution of shells from the upper layers. Overlying this substrate, discontinuous sandy deposits, alternated with silt and clayey-silt layers, are interpreted as an indication of different periods of human occupation and abandonment, reflecting the semi-permanent character of the site's occupations (Arnaud, 2000:27), however, it is not specified how do these occupations and abandonments relate with one or another layer.

The shell midden layers are qualified as compact, and overall presenting a sandy matrix with many charcoal remains and heated pebbles, suggesting, according to the author, that the molluscs were opened by fire and consumed in the place or immediate proximity (Arnaud, 2000). In the drawing of the North profile provided, it is represented a lens of charcoal within a shell-rich deposit, but it is not analysed nor interpreted in the text as an individualised layer, although its presence, together with the mentioned intercalations, evidences the great microstratigraphic potential of Cabeço do Pez shell midden as one of the few sites in the Sado that presents a clearly stratified anthropogenic Mesolithic sequence. From these data it seems like Cabeço do Pez is an ideal context to address open questions concerning the seasonality in the Mesolithic settlement of lower Sado.

### 4.2.3 Montes de Baixo

In the context of the coastal shell middens research carried out by C. Tavares da Silva and J. Soares, they identified and sounded the stratified shell midden of Montes de Baixo, 2 km away from the coast, in the north flank of Seixe river, in the border between Alentejo and

Algarve. They collected samples for sedimentological study from each layer, though they don't provide any details of the sampling process and specific analysis (Silva and Soares, 1997). The stratigraphic sequence is composed of alternated of dark brownish-grey clayey-sands layers with abundant shells (layers 1A, 2, 4A, 4B and 6), and yellowish sandy layers rich in sandstone blocks and scarce shells (layers 1B, 3, and 5) that are interpreted as having formed during possible abandonment periods. Layer 4B is the thickest (c.70 cm thick) and is said to be consolidated by calcium carbonate from shells dissolution. No further interpretations regarding formation processes are made.

### 4.2.4 Toledo

The shell midden of Toledo, in central coast of Estremadura, was object of comprehensive investigations led by A. C. Araújo (Araújo, 2011), that incorporated a sedimentological approach. This study included a comprehensive geomorphological analysis of the site surroundings for contextualization of the terrace on which the shell midden rests, complemented by grain-size and total carbonate content analysis of the stratigraphic layers, all carried out by J. Trindade (Trindade, 2011).

In Toledo, the geological substrate, layer D, is a Jurassic whitish-yellow sandstone with carbonate concretions and its surface is disaggregated, having suffered leaching of ferruginous silty-clayey particles downwards prior to burial. The author argues that layer D was truncated by an "erosional level", hypothesising its nature as result of concentrated draining phenomena. Layer D is overlaid by layer C, a laterally discontinuous deposit with complete valves of *Scrobicularia plana*, fewer clay and poor sorting of sand grains, interpreted as a fluvial deposit preceding the Mesolithic occupation. Once buried, Layer C was affected by carbonate illuviation from the upper layer indicated by a sharp increase in carbonates content. Layers C and D are thought to have suffered the same erosional process, which led to the lateral discontinuity of C.

The overlying layer B, which lower limit contacts with both C and D, is interpreted as a colluvial deposit embedding the archaeological materials (numerous mollusc bivalve species, lithics, vertebrate fauna and concentrations of large pebbles, interpreted as combustion structures) and presents a grey clayey sand with increasing abundance of pebbles towards the top. The increase in fines is attributed to the genetic difference in relation do C, a fluvial deposit, while B is considered colluvial, as an effect of runoff processes along the slope and deposition in areas with smaller slope, like the terrace where the site rests on. Layer B also correspond to the shell midden itself. The Mesolithic occupation of Toledo is referred to a context of diffuse runoff processes, less efficient and more selective in reworking of coarse elements but effective in the transport of fines, which is noted in the sharp increase of clay and particle sorting in the transition from C to B. According to the author, this dynamic was promoted by different biotic factors (e.g. vegetation) at the surface during the time of occupation. Referring palynological data from Mateus and Queirós (1993), the author argues that the increasing abundance and size and angular clasts towards the top of layer B might be originated in local landslides caused by environmental conditions of growing aridity, that promoted concentrated erosional events of short transport.

Above all, the sedimentological study of Toledo made a crucial contribution: distinguish the two different origins between layers C (fluvial) and B (colluvial), that had been previously considered as different horizons of the same archaeological horizon with different degrees of anthropization (D. Lubell as cited by Araujo, 2011). The sedimentological study raised the hypothesis that post-depositional vertical migrations are responsible for the few archaeological materials in layer C had and thus is a layer which deposition is natural and predates the Mesolithic occupation.

Araújo (2011) interprets the overall record of Mesolithic occupation at Toledo as combined effect of superposition and juxtaposed anthropogenic deposits resulting from several occupations of the site, impossible to discriminate at the scale of radiocarbon dating neither easily individualised spatial and stratigraphically. These occupations produced pits for combustion activities and shell and other debris accumulations, that were heavily affected by post-depositional alterations due to erosional processes, both between the several occupations during the Mesolithic and after the burial of layer B.

Depicting this general apparent homogeneity of shell midden deposits is one of the objectives of this dissertation and Toledo, giving its archaeological significance is a good example that bulk analysis of sediment contribute for broad aspects of geomorphological order, but fail in accurately characterising the anthropogenic processes, and this, in our opinion, is because these analysis do not provide the microcontext of what it is measuring, as pointed out by other authors in other contexts (Goldberg, 1980, Shahack-Gross, 2017, Karkanas, 2010). Apart from offering a good departing point for the accurate characterization of the microscopic components to distinguish between different occupations, both spatially and vertically, a micromorphological analysis could help in clarify, the relation of the combustion features with the colluvial dynamics *versus* occupation surfaces, by distinguishing, for instance, possible ash remains from secondary carbonates. Later in the discussion chapter we will address this issue on the light of the results of Poças de São Bento shell midden concerning this aspect.

### 4.2.5 Barca do Xerez de Baixo

Barca do Xerez de Baixo is an Mesolithic site, dated to the 8th millennium cal BC, located in the right bank of the River Guadiana, at 112 m a.s.l. in the interior of Alentejo, southern Portugal (Araújo and Almeida, 2003, Araújo and Almeida, 2013). The archaeological occupational layers and several combustion stone structures, some of which in *cuvettes* and pits, are embedded in a homogenous alluvial sequence, where intact block samples were collected for micromorphological analysis (Angelucci, 2006). The micromorphological analysis of this alluvial sequence revealed that the two sampled layers associated to human occupations took place over sandy deposits driven by low-energy alluvial processes, during short-term interruptions in the cyclical flooding events of the river while forming the lateral bar. The geogenic fraction generally corresponds to the regional lithology. In the layers associated to human occupations, an increase in fine amorphous organic matter is noted and interpreted as a human input. Further anthropogenic inputs in thin section consist in bones with some evidence of bacterial activity along their edges and weak birefringence (features interpreted as possible result of moderate thermal alteration), a quartzite lithic artefact and exogenous rock fragments. It is interesting that "surprisingly, the sample does not contain charcoal or coarse fragments of amorphous organic matter, as it would be expected" (Angelucci, 2006:15), even if the sample was collected by a small stone-structured hearth.

The areas in thin section corresponding to archaeological layers show interesting human-induced sedimentary features besides fine organic matter, such as weak lamination, slaking and higher compaction, besides to fine organic matter, that Angelucci (2006) considers a possible effect of trampling over temporary stable surfaces in active fluvial environments.

The micromorphological study of Barca do Xerez de Baixo by Angelucci was essential to characterise some key-aspects of site formation: i) the short-term character of the Mesolithic occupations at the site for they do not correspond to any significant interruption of sedimentary accumulation or soil formation; ii) thus, the incorporation of organic matter most likely did not derive of processes related to pedogenesis but is essentially human-derived; and iii) the human inputs also acted over the sedimentary record by causing weathering of some mineral grains possibly related to thermal impact, although it is not possible to determine for sure whether these features derive from natural or anthropically influenced dynamics.

### 4.2.6 Cabeço da Amoreira

Cabeço da Amoreira has been mentioned throughout this work mainly because of two factors: for being one of the sites among the Muge shell middens and because a micromorphological study was carried out there (Aldeias and Bicho, 2016). Comparing to geoarchaeological analysis from other sites, micromorphology has proven to be the best technique to clearly identify shell midden deposits in primary and secondary positions, very much thanks to the micro-contextual recognition of the shells' matrix and internal geometry. The authors were able to reconstruct specific actions like single tossing events, several degrees of anthropogenically reworked shell-rich sediments and occupational surfaces affected by trampling. The systematic association of occupational surfaces over reworked deposits, only observed through the contextual preservation offered by a micromorphological sample, allow to infer that a possible purpose for intentional displacement of sediments was surface regularisation for renewed occupations. Furthermore, the thin section allowed the recognition of discrete lenses of aeolian silt attributed to periodic abandonment periods between shell rich layers of certain areas, which has a great potential for the understanding of mound formation dynamics. Finally, the samples from a negative structure interpreted as a pit revealed that natural process dominated the infill, rather than anthropogenic ones. The micromorphological analysis of Cabeço da Amoreira has overall demonstrated that the understanding of shell middens formation must take into account aspect of the geologic matrix and fabric of the shells to correctly interpret the successive events of shell-rich deposits accretions.

## 4.3 Balance: contribution of the thesis

From the review undertook in previous lines it becomes obvious that micromorphology will cover important gaps in the understanding of formation processes of shell middens and post-deposition alterations. Both aspects had been only superficially referred to in both in Sado and Cantabrian region contexts, but the interpretations regarding specific anthropogenic formation processes are scarce. Most of the geoarchaeological information regards regional climatic reconstruction and in shell midden contexts the sedimentological analysis were complicated because of the predominantly anthropogenic-derived sedimentary components. This is mainly because traditional sedimentological techniques are not the most indicate to identify anthropogenic processes (Goldberg, 1980), and at the same time, the cultural inputs on the sediments formation can mask the natural signals that those techniques seek, as frequently noted by the works mentioned above. It is also important to stress that in the cemented character of the Asturian shell middens prevented the application of sedimentological techniques.

In this work we propose micromorphology to face those problems by integrating contextual geologic approaches to these archaeological sediments and infer the anthropogenic actions, that potentially provides a more profitable dialogue between archaeology and Geosciences. Moreover, micromorphology can be also applied to the cemented shell middens, allowing a comparison with not-cemented deposits and observe the internal organisation of the components and its relationship with the cement, a critical aspect concerning the post-depositional alterations of these deposits.

As mentioned throughout the lines above, the cases studies are quite representative of the different realities and allow to encompass major archaeological questions that remain unresolved. The studying of a finely a stratified Asturian shell midden (El Mazo) and cemented shell middens (El Mazo and El Alloru), an open-air Asturian occupation deposit (El Alloru) and the not Asturian shell midden of La Fragua, with stacked combustion features associated, covers much of the different archaeological realities of the Cantabrian region. In the Sado valley, different contexts of one of the several extensive open-air shell middens (Poças de São Bento) are analysed.

Chapter 5

# Methods

This chapter is concerned with the geoarchaeological methodology followed, based mainly in micromorphology, that will be addressed in the first section, where the theoretical concept of microfacies, recurrently used in our approach, will be introduced. The last sections are dedicated to the practical aspects of application, from field sampling to laboratory analysis.

## 5.1 Archaeological micromorphology

Micromorphology is the microscopic study of undisturbed and oriented block samples of artificially consolidated "soils, sediments, and archaeological features and materials in thin section" (Goldberg and Aldeias, 2016:269). This technique allows the preservation of the contextual arrangement of the deposits and identification of the spatial and chronological relationships between the components and the matrix, in order to infer its genesis (Stoops et al., 2010, Stoops, 2003, Nicosia and Stoops, 2017). Therefore, in archaeology, it allows for the observation of the cultural remains and their geometric relations with the surrounding sedimentary matrix. As a technique based on petrographic technical principles, the main tool for micromorphological analysis is the petrographic polarising microscope, where descriptive aspect registered are mineralogical composition, size and shape of the particles, and the finer matrix (Courty et al., 1989, Macphail and Goldberg, 2017, Goldberg and Berna, 2010, Karkanas and Goldberg, 2017). Stereoscopic microscope for meso-scale analysis and ultra-microspcopic techniques are also applied (Goldberg and Aldeias, 2016, Mentzer and Quade, 2013, Nicosia and Stoops, 2017).

"Soil micromorphology" is the generalised term to refer to the methodology idealised by Walter Kubiena, that he initially called "micro-pedology" (Kubiena, 1938). Both terms reflect the origin of the method in the field of Soil Science. Kubiena demonstrated that in thin section of undisturbed block samples from a soil profile, the transformations that a soil undergoes during the complex dynamics of pedogenesis are observed unaltered. This was a crucial turning point in the study of soils, allowing to understand how all parts of the soil function together, instead of the fragmented vision provided by traditional analysis of elements separately undertake on bulk samples. For example, in a B-horizon of a soil is composed by clay-rich groundmass and coatings of illuvial clay covering the voids, these are two different types of clay representing different phenomena in time, occurred under different environmental conditions. However, such differences are undetectable in bulk analysis such as mineralogy and grain size, that mix both types of clay and give potentially equivocal interpretations (Karkanas and Goldberg, 2017). In thin section, the two processes are clearly distinguished by the arrangement of clay features pertaining to each process.

In geoarchaeology, micromorphology becomes a vital technique for reconstruction of formation processes, giving its potential to identify the depositional and post-depositional agents. For this reason, micromorphology has proven to be the most suitable technique for the study of archaeological deposits (Courty et al., 1989, Goldberg et al., 2009, Mallol et al., 2013b, Mallol and Mentzer, 2017, Aldeias et al., 2014, Polo-Díaz et al., 2016b, Angelucci et al., 2013, Goldberg et al., 1993, Karkanas et al., 2015, Goldberg, 2000, Goldberg et al., 2003, Angelucci et al., 2007, Kehl et al., Karkanas and Goldberg, 2010b, Goldberg et al., 2001, Goldberg and Bar-Yosef, 2002, Karkanas, 2001), since it tracks significant aspects of human-derived signatures that other traditional analytical techniques fail in identify. Karkanas and Goldberg (2017) put as illustrative example of the former the case of calcium carbonate: in prehistoric archaeological contexts, ashes are one of the most abundant components of sediments, that are composed of calcium carbonate, as well as are geogenic cementing concretions, that are also common in cave and calcareous soils settings. Carbonate content analysis would not be able to recognise between these features, since they are all composed of calcium. These two different processes can be superimposed on the same sedimentary material, thus the unviability of treat archaeological sediments only as bulk samples (Courty et al., 1989, Karkanas and Goldberg, 2017).

Micromorphology becomes essential in archaeology sedimentary deposits of anthropogenic origin. By removing the geological material where artefacts are embedded, archaeologists are destroying critical information since, as seen in previous sections, that material can be anthropogenic and preserve relevant specific signatures of the activities behind its formation (Butzer, 1982). Such signatures are usually expressed at microscopic scale, and often generate microstratigraphic deposits impossible to sample individually (Goldberg and

Macphail, 2017). Micromorphology provides a way to overcome this obstacle and observe the individual characteristics of each laminae, that allows to take part of those contexts to the laboratory and study them in detail as it occurs with other artefacts.

The strengths of micromorphology for archaeological interpretations were first tested already in the 1950's by Ian Cornwall, who applied micromorphology to paleosoils in a Mesolithic archaeological context in Scotland (Cornwall, 1958). Since then, micromorphology has proven to be a powerful technique for several relevant aspects of the prehistoric archaeological record interpretation, such as the distinction between anthropogenic and natural processes (e.g., Karkanas, 2002; Goldberg et al., 2003; Mallol et al., 2010; Aldeias et al., 2014), including the nature and significance of stratigraphic contacts and discontinuities (Mallol and Mentzer, 2015). Particularly, it has been very successful in the identification and assessment of the degree of preservation of anthropogenic features such as combustion features, having contributed to the understanding of both positive and negative evidences of the origins of control of fire (Aldeias et al., 2012, Shahack-Gross et al., 2014, Schiegl et al., 1996, Berna et al., 2012, Goldberg et al., 2001) and occupational surfaces – including Mesolithic ones (Zerboni, 2011) – and the recognition of human activities such as bedding, trampling (Goldberg et al., 2009; Miller et al., 2013), intentional reworking of debris (Shillito et al., 2011, Sherwood and Kidder, 2011), or the origins and development of domestic animals management (Polo-Díaz and Eraso, 2010; Égüez et al., 2014; Polo-Díaz et al., 2016a,).

### 5.1.1 Microfacies analysis

The application of micromorphology in archaeology allowed the introduction of the concept of microfacies in the field, in its most original sense as it is used in sedimentary geology (Courty, 2001, Karkanas and Goldberg, 2017). Flügel (2004:1), defined microfacies applicated to the petrographic study of carbonate rocks as "the total of all sedimentological and paleontological data which can be described and classified from thin sections, peels, polished slabs or rock samples." The application of the concept in geoarchaeology reflects much of Flugel's definition adapted to the characteristics of archaeological samples, aiming to synthesise deposits that share a set of specific microscopic attributes in thin section (Karkanas


**Figure 5. 1** Micromorphological sampling; a) samples with plastered bandages applied before extraction from El Mazo shell midden profile; b) and c) samples from El Mazo and Poças de São Bento, respectively, right after successful extraction; note the different layers included in the block; d) and e) sampling at the cemented shell midden of El Alloru with hammer and chisel and electric saw; f) and g) process of sample extraction, wrapping and identification and orientation marking

and Goldberg, 2017, Goldberg et al., 2009, Miller et al., 2013, Karkanas, 2015). The subsequent interpretation of those attributes, a combination of sedimentary components, their spatial organization and geometry, or other parameters, when consistently isolated from adjacent deposits, are interpreted as result of a certain process.

In archaeological sediments, different microfacies types might be recurrently in close association (e.g., Goldberg et al., 2009). This approach helps to describe anthropogenic-derived millimetre-thick strata, which can be difficult to isolate in the field, and scale up their relationship with the broader archaeological context. The microfacies approach can, therefore, significantly contribute to the reconstruction of formation process and human activities at a given site.

A microfacies approach has been successfully applied in shell mounds of the southern coast of Brazil (Villagran et al., 2009, Villagran, 2014b) and in the ethnoarchaeological work at historical shell middens of Tierra del Fuego (Balbo et al., 2010, Villagran et al., 2011b). Recently, this approach allowed for the recognition of different types of deposits in primary and secondary positions, due to both natural and anthropogenic processes, as well as occupational surfaces, within the Cabeço da Amoreira shell mound (Aldeias and Bicho, 2016), a site which is in the regional vicinity and roughly contemporaneous to the deposits of Poças de São Bento studied in this thesis.

## 5.2 Sampling and Samples Processing

### 5.2.1 Collecting samples in the field

The first step for micromorphological study of a site is the field sampling. The fact that all sampled contexts are in general rich in coarse components such as shells, pebbles and bones, the technique of collecting sampled that most efficiently ensure a not-disturbed block extraction is the use of gypsum-plastered bandages (Goldberg and Macphail, 2003, Goldberg and Macphail, 2006, Nicosia and Stoops, 2017). For that, the selected area to extract in block is isolated in the profile by carefully removing the sediment around the targeted area, with a knife or trowel. The area to be extracted is then covered with the wetted plastered bandages (fig. 5.1: a, b, c). In the case of the cemented shell midden remnants at El Alloru and El Mazo, a hammer aned chisel and an electrical circular saw, in the former, were implied to extract the blocks (fig. 5.1: d, e). Once dried, the bandages result in a solid container totally adapted to the irregularities of the block caused by the coarse components, ensuring its cohesion. The sediment around the plastered area must be removed further deep into the profile until the block is integrally extracted, totally covered in plaster and finally wrapped in plastic and tape for a safe transport (fig. 5.1: f, g). During the process, the name and vertical orientation of the sample were marked directly in the surface of the packed block. All samples for this thesis were collected by the author in different field seasons in the years 2013, 2014 and 2015.

### 5.2.2 Sample processing

The steps to follow once the sample arrives at the laboratory are drying, until no moisture is present in the sample, and subsequently, impregnation with a solution of polyester resin and styrene in a 7:3 ratio to which a 0.7 fraction of catalyser, in the case methyl ethyl ketone peroxide (MEKP) was added. These steps were carried out by the author, since it was considered an advantage that the he had the chance of controlling the specific section to be represented in thin section. However, most of the thin sections were manufactured at several specialised laboratories (table 5.1), since the instruments available in the University of Cantabria (UC) were not the most appropriated for large-format demanded for micromorphological analysis. Regardless, some probes were made at the UC by the author for practice and preliminary thin sections.

The processes of drying and impregnation were carried out as follows: the first samples collected were unpacked and dried until no humidity was present at ambient temperature in protected environment at the storage/field laboratory facility of the Instituto Internacional de Investigaciones Prehistoricas de Cantabria (IIIPC) in the locality of in Omoño (municipality of Ribamontán al Monte, Cantabria) where they were also impregnated with resin and left at ambient temperature for as much time as needed until fully consolidated. For samples collected later, the drying process was carried out in the Departamento de Ciencia y Ingenieria del Terreno y de los Materiales (DCITYM) and for the impregnation, a fume hood was available at the Departamento de Ingenierias Química y Biomolecular, both departments of the UC. In both cases, apertures were carefully made in the plaster and the block was placed in a container and submerged in resin leaving the surface on air to allow the resin to be absorbed. The containers were refilled each next day until the samples were saturated, i.e., stop absorbing resin.

Once totally consolidated, the blocks were cut into smaller slabs at the DCITYM-UC in order to create a regular surface and trimmed to the size of the future thin sections (fig. 5.2). The resulting slabs were mailed to different laboratories at different times, that produced

**Figure 5. 2** Examples of dried resin-impregnated and cutted slabs from El Mazo, El Alloru and Poças de São Bento (left to right), from where the thin section were obtained

variable thin section sizes, according to the list in table 3.1, all with thickness of around 30 µm, normalised for petrographic analysis. The exceptions were most samples from El Alloru, that were thin-sectioned at the DCITYM-UC using a solution of epoxy resin and hardener under vacuum conditions, since the samples were small enough to fit the equipment existent at this laboratory.

**Table 5. 1** List of all studied for this thesis, dimensions and place of manufacturing*

| Site | Sample | Thin section | | | Laboratory |
|---|---|---|---|---|---|
| | | **Code** | **Size (mm)** | **Cover slip** | |
| La Fragua | FRA1 | FRA1 | 73x48 | | Univ. de Granada (Spain) |
| | | FRA2 | 73x48 | | |
| | | FRA3 | 73x48 | | |
| | | FRA4 | 73x48 | | |
| | | FRA1/3 | 140x67 | | CENIEH (Burgos, Spain) |
| | FRA4 | FRA-LAYER4 | 140x67 | | |
| El Mazo | MAZ1 | MAZ11 | 139x67 | ✔ | Earthslides (Cambridgeshire, UK) |
| | | MAZ12 | 139x67 | ✔ | |
| | MAZ2 | MAZ21 | 139x67 | ✔ | |
| | | MAZ22 | 139x67 | ✔ | |
| | MAZ3 | MAZ31 | 139x67 | ✔ | |
| | | MAZ32 | 139x67 | ✔ | |
| | MAZ4 | MAZ41 | 139x67 | ✔ | |

| | | | | | |
|---|---|---|---|---|---|
| | | MAZ42 | 139x67 | ✔ | |
| | MAZ6 | MAZ61 | 139x67 | ✔ | |
| | | MAZ62 | 139x67 | ✔ | |
| | MAZ7 | MAZ71 | 139x67 | ✔ | |
| | | MAZ72 | 139x67 | ✔ | |
| | MAZ-C | MAZ-C1 | 140x67 | | CENIEH (Burgos, Spain) |
| | | MAZ-C2 | 140x67 | | |
| El Alloru | LV3 | LV3 | 100x45 | | DCITYM-UC (Santander, Spain) |
| | LV4 | LV4 | 100x45 | | |
| | LV5 | LV5 | 100x45 | | |
| | LV6 | LV6 | 100x45 | | |
| | LV7 | LV7.1 | 100x45 | | |
| | | LV7.2 | 100x45 | | |
| | ALL1 | ALL1 | 139x67 | ✔ | Earthslides (Cambridgeshire, UK) |
| | | ALL2 | 139x67 | ✔ | |
| | | ALL3 | 139x67 | ✔ | |
| | | ALL4 | 139x67 | ✔ | |
| | | ALL5 | 139x67 | ✔ | |
| | ALL2 | ALL6 | 100x45 | | DCITYM-UC (Santander, Spain) |
| Poças de São Bento | PSB102 | PSB102 | 110x76 | ✔ | Earthslides (Cambridgeshire, UK) |
| | PSB103 | PSB103.1 | 75x50 | ✔ | |
| | | PSB103.2 | 75x50 | ✔ | |
| | PSB104 | PSB104.1 | 75x50 | ✔ | |
| | | PSB104.2 | 75x50 | ✔ | |
| | PSB105 | PSB105.1 | 75x50 | ✔ | |
| | | PSB105.2 | 75x50 | ✔ | |
| | | PSB105.3 | 75x50 | ✔ | |
| | PSB106 | PSB106.1 | 110x76 | ✔ | |
| | | PSB106.2 | 75x50 | ✔ | |
| | PSB107 | PSB107 | 110x76 | ✔ | |
| | PSB108 | PSB108 | 110x76 | ✔ | |
| | PSB510 | PSB510 | 110x76 | ✔ | |
| | PSB913 | PSB913B1 | 110x76 | ✔ | |
| | | PSB913B2 | 75x50 | ✔ | |
| | | PSB913D1 | 110x76 | ✔ | |
| | | PSB913D2 | 75x50 | ✔ | |

*Further details on the sampling strategy and location of the samples in the archaeological sites are provided in the correspondent monographic chapter of Part II: Results.

## 5.3 Samples analysis

### 5.3.1 Meso-scale analysis

The first approach to the thin section study consisted in observation at natural scale, i.e., 1:1, of the micromorphological slabs and thin sections, and smaller magnifications using digital scans of them (Courty et al., 1989, Arpin et al., 2002, Goldberg and Aldeias, 2016). This approach allows for the clear identification and delimitation of microstratigraphic or bioturbation (e.g. passage features, filled channels) features not easily seen in the field. With this *a priori* identification, in the posterior microscopic examination one is aware of areas well-preserved from those that are disturbed. The largest thin section formats were found to be more advantageous because they provided a wider area of interpretations at meso-scale, especially for layers distinguished mainly by different geometric patterns of the shell fragments, that could pass unnoticed in smaller formats, giving the general coarseness of shell midden sediments.

The digital scan of the thin sections and micromorphological slabs was carried out using a flatbed scanner at 800 and 1200 ppp, at normal light and, in the case of thin section, also in dark field mode, as defined by Goldberg and Aldeias (2016), resulting in two images of each thin section. Dark field mode enhances the highly reflecting materials, such as carbonates, being thus a particularly efficient way to analyse thin section with abundant shells and ashy sediments, among other material of interest. The meso-scale observation of the thin section and slabs is usually when it is decided if a microfacies approach will help in the analysis of the thin section, a decision complemented by later microscopic aspects. A stereoscopic microscope was also used for meso-scale observation of thin section, however, unfortunately, the equipment used did not allowed image capturing, a step that was replaced by flatbed-scanned images.

### 5.3.2 Microscopic analysis

The optical study of thin sections was carried out under polarizing petrographic microscopes in three institutions: the DCITYM-UC where most of the research was carried out, and two institutions abroad where research stays were carried out in the framework of this thesis, the Department of Human Evolution of the Max Planck Institute for Evolutionary Anthropology in Leipzig (Germany) and the Instituto de Geociências e Museu de Arqueologia e Etnologia of the University of São Paulo (Brazil). The equipments used allowed magnifications between 400x and 20x under plane-polarised and crosspolarised light (PPL and XPL, respectively). Observation at oblique incident light (OIL) using a torch were also made, as well as fluorescent blue light (BLF) was used recurring to an epifluorescence microscope at the Institute of Biomedicine & Biotechnology of Cantabria (UC). All these lighting modes are recurrent in micromorphological analysis (Stoops et al., 2010, Stoops and Nicosia, 2017).

### 5.3.3 Micromorphological descriptions

The description of thin sections is based on the guidelines provided by Courty et al (1989) and the organisation follows, in general lines, the tabled structure recommended by Goldberg and Macphail (2003) and Macphail and Goldberg (2017) for archaeological micromorphology. However, the models provided in those publications were not strictly copied but adapted in different ways in order to evidence in the clearest way possible the specificities of each site and context, seeking also to generate the most efficient dataset for posterior interpretation of the data. The samples are very diverse, thus different description layouts were adopted according to the complexity of the samples, e.g., for Poças de São Bento the different microfacies are descript in plain text (chapter 7) whereas for El Alloru cemented shell midden, the microfacies descriptions are organised by a subheading and topics system (chapter 6) (coarse components, micromass, etc). Specific nomenclature for features is based on the terminology proposed by Bullock et al Bullock et al. (1985) and Stoops (2003).

For semi-numeric and indication of relative abundance of component in thin section, the terms and relative values provided in Macphail and Golberg (2017, table 3.5) were used. For visual estimatation of relative amounts, the charts available at the mentioned works, in addition to Baccelle and Bosellini (1965), were used.

For each context, in terms of petrographic observation, the parameters observed included the identification of the coarse materials, mineral and organic, when possible, and the of the micromass (carbonate, clay, organic…) and their relative organisation. The mineral fraction id described its lithology or mineralogy and morphological aspects as perceptible at two dimensions, such as shape, roundness or angularity, following Stoops (2003). Another aspect of interest was the identification of sedimentary structures, based on the criteria of Goldberg and Macphail (2003). These observations complement previous field notes on bulk sediment samples. The relation between coarse and fine fraction is determine by ratios and geometric arrangements according to nomenclature of related-distribution patterns of Stoops (2003), but using as much as possible plain English expressions, as recommended by Macphail and Goldberg (2017). All these microscopic parameters combined with meso-scale observations determine the definition of microfacies if considered helpful in the interpretation of the sample, which is not always the case, for instance as in the homogenous samples from El Alloru Test 1 (Chapter 6), in which case the concept is not operative.

PART II

# DATA AND RESULTS

Chapter 6

# La Fragua

## 6.1 Introduction

The micromorphological study of the archaeological deposit of La Fragua cave aimed to geoarchaeologically characterise a critical moment in the Cantabrian early Mesolithic when it is overlapping the Azilian period. Furthermore, the finely stratified Mesolithic shell midden at the top of the sequence is dominated by stacked combustion features, which constitutes an exceptional opportunity to contrast the value of two of the most outstanding types of anthropogenic deposits in the Iberian prehistory combined: shell midden and combustion features. With the application of a microstratigraphic approach to this shell midden it was also envisioned a high-resolution reconstruction of the human activities behind the formation of the deposit.

### 6.1.1 Geological and Archaeological Context

La Fragua is a small cave located in the southeast cliffs of Mount Buciero (fig. 6.1, 6.2), a hilly headland of Cretaceous fossiliferous limestone culminating at 378 m above the sea level, surrounded by the open sea of the Bay of Biscay by north and east, the mouth of the River Ason by south and the extensive estuarine mudflats and the sandy Berria beach by west. The southeast face of Mount Buciero is characterised by abrupt cliffs, where La Fragua cave is located, with the entrance at 130 m of altitude (fig. 6.1, 6.2).

The rocks in the cave formation belong to Aptian clear-grey limestone with rudist, coral and Orbitolinidae fossils (Olivé Davó et al., 1982), crossed by a system of joints that determined the geometry of La Fragua cave. The main axis of the cave is defined by a NE-SW joint which caused the subsidence of the block at SE. This joint is perpendicular to another one, that defines the plane of the outcrop face where the cave entrance is open (fig 6.2). La Fragua cave has a wedge-shape plan, with approximately 10m by 3m at most (fig 6.3a). The entrance is oriented to south and opens to a natural amphitheatre formed by erosion of the cliffs, as seen by the large collapsed boulders in front of the cave entrance and a steep rockfall cone towards the sea (fig. 6.1b). These rugged geomorphological features would have been significantly different by the time of the prehistoric occupations of La Fragua cave and other sites nearby (such as Peña del Perro rockshelters, also in Mount Buciero). González Morales (1998) pointed out that the present scarp and the rockfall cone would result from the erosion caused by the sea level rise in the beginning of the Holocene, submerging extensive coastal lowlands and forming what is today the bay of Laredo (fig. 6.2). Thus, by the time of the prehistoric occupations, the cave entrance should have had access by a smoother slope providing easy connection between the cave and those coastal lowlands.

The 1990's excavations at La Fragua revealed an important sequence for the Pleistocene/Holocene transition (Gonzalez Morales, 1998, Marin-Arroyo, 2007). Previous studies dedicated to artefactual assemblages such as lithics (González Morales, 2000), malacological fauna (Gutiérrez Zugasti, 2009) and mammal fauna (Marin Arroyo, 2004, Marín Arroyo and González Morales, 2007) allow to infer the short duration character of the successive occupation of La Fragua throughout the late Pleistocene, marked by a seasonality centred in winter and summer, perhaps reflecting logistical visits for hunting (Marin Arroyo, 2007). In these excavations, a Holocene deposit designated Layer 2 yielded abundant microfauna and no anthropogenic material and, which was interpreted as a period of occupation of the cave by birds, therefore human were not present (González Morales 1998). The mammalian archaeozoological assemblage recovered from the Mesolithic shell midden, overlying layer 2, where the wild boar followed by red deer and roe deer, suggest that La Fragua continued to be used as a support base for seasonal incursions to this area of the for exploitation of terrestrial and marine resources from the coastal plains that where being progressively submerged by sea-level rise at that time (Marín Arroyo, 2007, Gutierrez Zugasti, 2009).

In 2015, given the important stratigraphic record of human occupations in the Pleistocene-Holocene transition of La Fragua, the north profile of the 1990's sounding was enlarged in 50 cm northwards during a campaign directed by I. Gutiérrez Zugasti with the purpose of conduct a multidisciplinary sampling of the sequence.

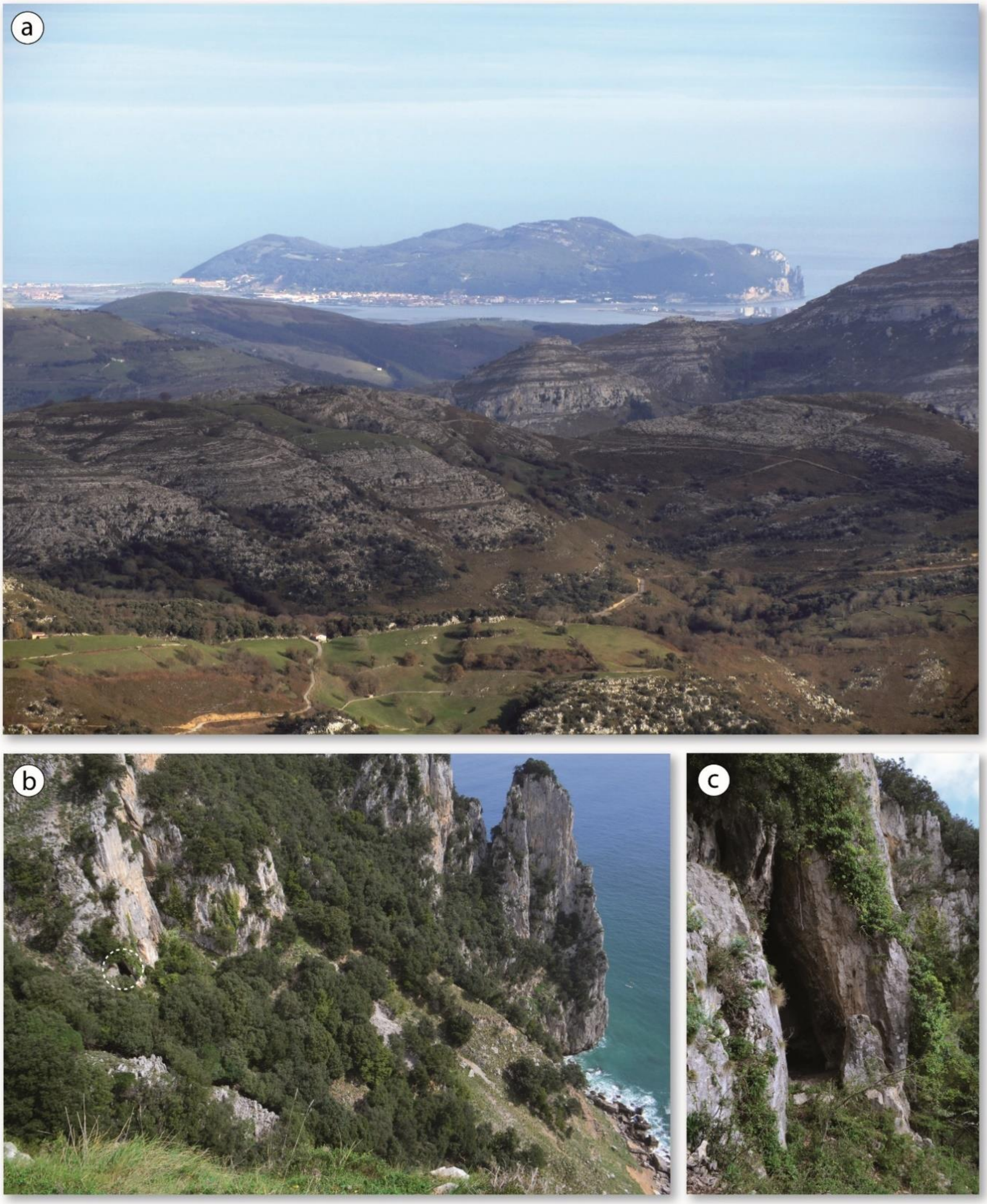

**Figure 6. 1** The surroundings of La Fragua cave: a) perspective of Mount Buciero from Porracolina peak (1740 m), surrounded by salt marshes; the mouth of the Asón, to the right, was in the early Holocene located at the opposite side; the abrupt cliffs where La Fragua is located can be observed at the right. b) Aspect of the steep slope from where is made the access to the cave entrance (dashed circle), result of erosion from sea-level rise since the Glacial Maximum. c) the entrance of La Fragua Cave.

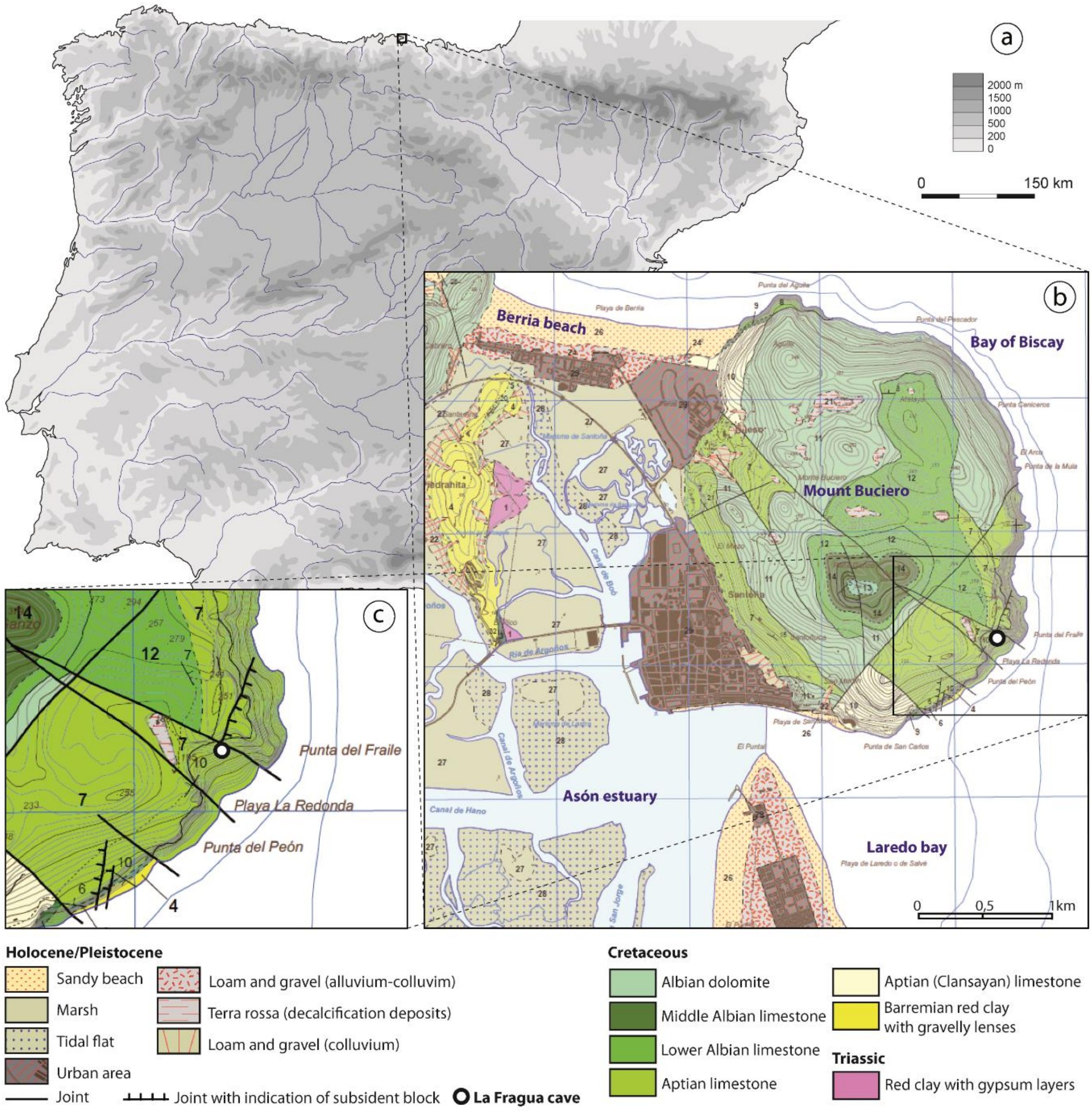


**Figure 6. 2** Geographical and geological setting: a) location of Mount Buciero in the northern coast of Iberia. b) location of La Fragua cave (circle) in Mount Buciero and surrounding environment and topography; Berria beach corresponds to the former mouth of the Asón; the "Barremian red clay" formation, signed in yellow, is the formation where glauconite occurs. c) The geological environment of La Fragua Cave; note the system of joints that determinate the cave formation and morphology

### 6.1.2 Stratigraphy and Chronology

The stratigraphic sequence excavated in La Fragua in 2015 is presented in table 6.1, where the new radiocarbon dates obtained from materials recovered in 2015 are also indicated. The prehistoric deposit is divided in three major lithostratrigraphic units (fig. 6.3). The basal unit is Unit 4, Late Pleistocene, is 1 m thick to the lowermost excavated quote, not reaching the bedrock. It consists in a homogenous accumulation of orange/brownish silty clay and little sand with abundant, unsorted gravelly quartz and carbonate debris, limestone gravel and cobbles and archaeological remains.

Unit 3 overlies Unit 4, but the contact between them is highly disturbed by the action of medium mammals (possibly rabbits) that burrowed in between cobbles and large limestone blocks that were found accumulated in the 30 cm of disturbed sediments. The presence of pockets of land snails in large void chambers and materials that have clearly migrated downwards from the Mesolithic shell midden attests the strong disturbance of the sequence at this level, making impossible to accurately trace the contact between Units 4 and 3. Unit 3 is intact in its upper 15/20 cm and consists in friable yellowish silty clay with little fine quartz and calcite sand and fine gravel size carbonate crust fragments. The radiocarbon dating yielded an early Mesolithic chronology at the lowermost part of the well-preserved deposit (table 6.1). The non-anthropogenic layer 2 was not identified in the 2015 works.

Unit 1 is radically different from the underlying deposits, with a sequence of stacked combustion features formed by sediments dominated by the presence of molluscs in ashy matrix, which internal subdivisions that were possible to excavate individually in the field are discriminated in table 6.1. Two radiocarbon dates reveal a coherent Mesolithic accumulation of these sediments, but with significant gap of 2000 years in relation to the date obtained for Unit 3. The contact between Units 3 and 1 is characterised by the rubefaction of the sediment within the upper centimetre of Unit 3, which suggest the effect of heating from the combustion activities represented by Unit 1 deposits.

**Table 6. 1** Stratigraphy and chronology of La Fragua after the 2015 campaign

| **Stratigraphic units and field description** | | **Radiocarbon dates (2015 sampling)** | | | |
|---|---|---|---|---|---|
| | | **Material** | **Taxa** | **Result** | **Average cal BP** |
| 0 | Light-brown loamy sediment, compacted by recent trampling. Contains mixed archaeological material (shells and few bone). | - | - | - | - |
| 1.1 | Very loose, brown-greyish fine sediment with abundant shells, some bone and charcoals. | Shell | *Mytilus galloprovincialis* | 7320±40 | 7887 |

| | | | | | |
|---|---|---|---|---|---|
| 1.2 | Light grey, ashy unit with shells and some charcoal. | - | - | - | - |
| 1.3 | Charcoal lens well delimited, occurring in quadrant 3. Composed mostly by charcoal. | - | - | - | - |
| 1.4 | Loose sediment with varying colouration (reddish to darkish/greyish brown). Corresponds to different combustion events, however a field individualisation of each one was impossible in the field. Mollusc shells are the predominant archaeological component. | Shell | *M. galloprovincialis* | 7500±40 | 8063 |
| 1.5 | White to ligh grey, very loose, ashy unit with virtually no archaeological material, identified in the East of quadrant 3 | - | - | - | - |
| 1.6 | Loose, reddish sediment with darkish speckles for the presence of charcoals, restricted to quadrant 3. Very few archaeological remains, mostly shells. | - | - | - | - |
| 3 | Orange/yellowish sediment, with small gravel and gravel size crust fragments. It contains charcoals, mammal bones and lithics. It is remarkable the presence of burrows indicating intense animal activity that removed the original sediment and replaced it with materials from the "trench", which embeds also material from the shell midden layers and from the Stratigraphic unit 3 itself. The burrows are more abundant in the lower part of the unit. | Bone | *Cervus elaphus* | 8940±40 | 10.052 |
| 4 | Orange/brown, clayey sediment, slightly compacted, with several clasts and crust fragments of varying sizes. Archaeological material is abundant, namely shells, bone, lithics, charcoals, and bone tools. | Shell | *Patella vulgata* | 16315±70 | 19339 |
| | | Shell | *P. vulgata* | 17620±90 | 21305 |
| | | Shell | *P. vulgata* | 17845±75 | 21218 |
| | | Shell | *P. vulgata* | 17735±75 | 21069 |
| | | Shell | *P. vulgata* | 17550±70 | 20817 |
| | | Shell | *P. vulgata* | 19010±80 | 22586 |
| | | Shell | *P. vulgata* | 18960±75 | 22535 |
| | | Bone | Ungulate | 19560±110 | 23570 |
| | | Bone | *Rupicapra rupicapra* | 19160±100 | 23087 |

## 6.2 Sampling strategy and analysis

During the 2015 intervention at the site, the ashy sediments of Stratigraphic Unit 1 and the underlying deposits of Unit 3, both Mesolithic (see table 6.1), were sampled in a in a single, large block (fig. 6.3c), in a zone of the profile that showed the greater amount of millimetric layers in order to obtain the most of microstratigraphic information. The contact between Units 3 and 4 was severely affected by medium mammals' (possibly rabbits) burrows, admixture of

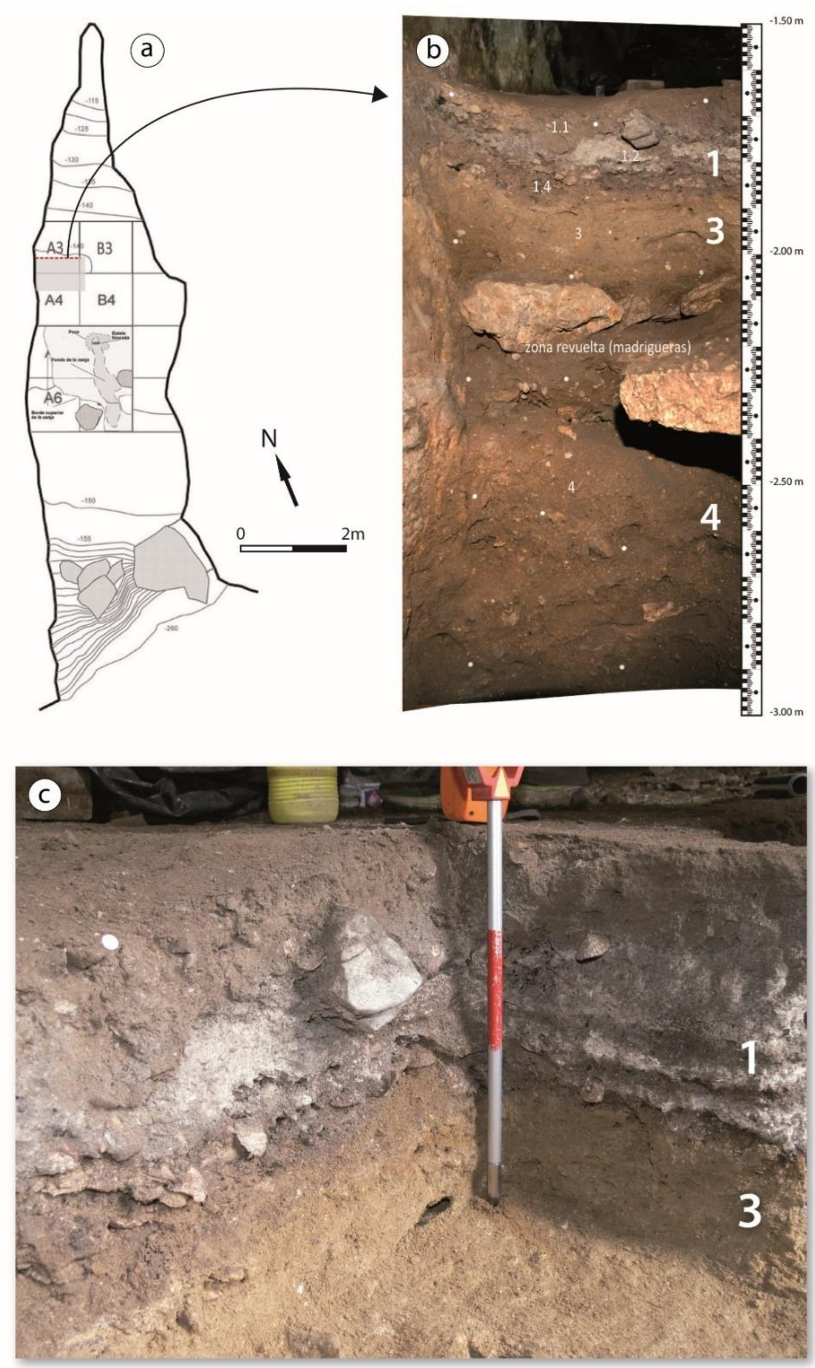


**Figure 6. 3** La Fragua Cave: a) plan with indication of the area excavated in 2015 for multidisciplinary sampling over the 1990's excavations; the resulting profile is marked with red dashed line; b) profile at the end of the 2015 campaign; note the intense burrowing ("madrigueras") in the contact between Units 4 and 3. c) detail of the Mesolithic shell midden and ash lenses (Unit 1) and underlying Unit 3, in process of excavation; note the fine stratification of the former, better observed to the right of the image, where the micromorphological sample was collected.

sediments and materials and were excessively loose, thus a second block sample was collected only further below, where Unit 4 appeared to be intact.

The micromorphological analysis followed the criteria established by Courty et al. (1989) and Macphail & Goldberg (2017) recurring also to Stoops (2003) terminology and Goldberg and Aldeias (2016) recommendations. The microfacies approach was applied as preconised by Goldberg et al (2009) and largely based on Flugel (2004) for carbonate materials, for which terminology of Pentecost (2005) was also followed.

## 6.3 Results

Following there are the sedimentary components discrimination, then a section dedicated to carbonate tufa clasts because these components turned out to be very meaningful in the geoarchaeological interpretation of the site, and finally the microfacies classification followed by specific observations regarding the geoarchaeological sequence.

### 6.3.1 Sedimentary Components

The sedimentary components of La Fragua are extremely heterogenous. Table 6.2 lists all components and provides descriptions and comments on their origin.

**Table 6. 2** List and description of the sedimentary components observed in thin sections from La Fragua cave.

| **Component** | **Description/comments** | **Genetic interpretation** |
|---|---|---|
| Silt and sand | Poorly sorted particles are moderately common and mostly within silt and fine sand classes (plate 6.1a). Mostly quartz and calcite in all Units, but also muscovite and traces of feldspar. Glauconite medium sand grains occur occasionally only in Unit 3 (plate 6.1: c, d). | Erosion of calcite in the cave, shell fragmentation, and terrigenous soils reworked into the cave, except for glauconite, that seems to come as a non-intentional by-product of anthropogenically accumulated sediments from tidal mudflats. |
| Roofspall | Gravel sized to centimetric clasts of fossiliferous limestone and some | Detached from the cave walls by cryoclastic and biological (micro-organisms) action. |

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|---|---|---|
| | calcite, are considered to come from the cave roof and walls (plate 6.3b).<br>Some calcite clasts exhibit diagenetic alterations like "spyky" edges, and intense microboring and micritization, both indicative of microbially induced erosion (plate 6.1b). | |
| Lithic artefacts | Mm-size fragments exhibiting planar shape and faceted edges (plate 6.1a). | Probably correspond to knapping residues, thus an anthropogenic input. |
| Silty-clay aggregates | <u>Type 1</u>: up to a few mm sized, irregular shapes and more or less diffuse limits, with a micromass of dark brown clay, undifferentiated to weakly stipple speckled b-fabric, 01% organic impurities and quartz and muscovite silt, 5% abundant each; coarser inclusions are quartz fine sand; common diatoms. This type of aggregates is abundant in Unit 3; in Unit 1 they appear rubified and exhibiting cracks perhaps caused by heat exposure (plate 6.1: e, f).<br><u>Type 2</u>: up to a few mm sized, irregular shape and sharp limits, with micromass composed of yellowish clay with organic inclusions, presenting crystallitic (not calcitic) and grano- and poro-striated b-fabric, 15% quartz silt and 5% muscovite silt; Quartz fine to medium sand grains occupy 5% of the aggregates; common diatoms and humified organic tissues and some phytoliths. This type of aggregates is common un Units 3 and 1, being the interference colour more vivid in the latter, possibly due to heat exposure (plate 6.1: g, h). | Terrigenous soil aggregates reworked into the cave. |
| Bones | Most of the bones in thin section belong to small vertebrates or correspond to | Brought to the cave mostly by carnivores/birds. |

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| | comminute fragments (maximum 3 mm), overall undergoing intense diagenesis (structural breakdown and loss of birefringence). In Unit 1, some of the coarser fragments seem to be burnt (strong orange-reddish colour and loss of birefringence) (plate 6.2: a-d). | |
| Fibrous charcoal | Stringers of charred fibrous plant material, very similar to those described by Goldberg et al. (2009), namely in its distribution, generally aligned but also disperse, depending on the microfacies (see below), and in the fact that many seem humified or reddened. Fine carbonate sedimentary material (including common tubular microfossils and micritic mud) is finely mixed within the charred fibrous stringers (plate 6.2e). | Charred grassy plant material, anthropogenically accumulated. |
| Wood charcoal | Sand sized to several millimetres, angular pieces, whose general characteristic vary between deposits (plate 6.2f).<br>In Units 4 and 3, charcoals appear reddened (humified?) and with the cellular structure very deteriorated.<br>In Unit 1, the woody cellular structure of charcoals is well preserved. | Anthropogenic combustion activities. |
| Char | Char aggregates are sand sized, black and isotropic, with the characteristic amorphous shape with vesicles resulting from trapped air bubbles and dehydration cracks (plate 6.2g). | Anthropogenic product of combustion of fatty substances. |
| Molluscs – terrestrial | Small (few mm) fragments of aragonitic shells, most probably from terrestrial gastropods (land snail) (plate 6.1a). | Ambiguous origin. Both animal and human consumption might be considered. |
| Molluscs – marine | Marine gastropods, mainly limpets (*Patella*), both complete sections and fragments, are the dominant coarse component of several deposits of Unit 1, but also other indeterminate bivalves | Anthropogenic input resulting from shellfish resources exploitation and consumption. Single clast in Unit 3 is more likely a seidmentary bioclast, i.e., non-intentional by- |

| | | |
|---|---|---|
| | and gastropods are present, with abundance variations depending on the microfacies. Many valves are complete and present varying degrees of burning (plate 6.2f). | product of anthropogenically accumulated sediments from tidal mudflats. |
| Sponge spicules | Siliceous mono- and multi-axon spicules and spherulitic, easily recognizable by their morphologies and central hollow, are common in Unit 3 sediments, mostly dispersed, but some are contained in clayey aggregates. In Unit 1 they are rare, mixed with ash (plate 6.3: a-d). | Marine bioclat, non-intentional by-product of anthropogenically induced sediments from tidal mudflats. |
| Diatoms | Both pennate and centric specimens, with varying distributions, from isolated, interstitial ones, to associated with tubular microfossils, and contained in silty-clay aggregates. A few colonies or some articulated diatoms are preserved (plate6. 6: e-h). | Non-intentional by-product of anthropogenically induced sediments from tidal mudflats. |
| Phytoliths | A few isolated and dispersed phytoliths, sometimes articulated, were observed in both Units 1 and 3 (plate 6.4: a, b). | Human use and processing of plants. |
| Phytolith slag | Coarse sand sized, recognized by presence of vesicles resulting from air bubbles trapped during the phytolith melt cooling down and optical isotropy (Canti, 2003, Mentzer, 2014). Phytolith slags are more or less dirty (darkened by organic impurities as described by Canti, 2003) and affected by secondary microsparitic calcite precipitation over their surfaces and inside vesicles (plate 6.4: c-e). | Meltdown of phytoliths as result of high temperature combustion of plants. |
| Ashes | Ashes in the form of rhombic, micritic pseudomorphs of calcium oxalate crystals (Mentzer, 2014) were identified exclusively in Unit 1 sediments where they are the main component. Depending of the | Anthropogenic combustion activities, locally affected by diagenetic dissolution and reprecipitation of carbonate and phosphates. |

| | | |
|---|---|---|
| | microfacies, their preservation varies from very-well preserved, articulated ash rhombs, to locally decalcified or phosphatised, to cemented (plate 6.5). | |
| Filamentous microfossils | Calcareous structures, with tubular shape of varying lengths, usually no more than 100-150 µm, with an inner hollow of ~10 µm of diameter and 25-30 µm of total diameter counting the calcitic walls (plate 6.6: a, b), some of them curved and often branching (plate 6.6d). Each body seem to correspond to a single carbonate crystal. They are commonly associated to micrite, specially peloids.<br>Remarkably abundant in the Unit 3 sediments, both isolated and in tangled clusters. In Unit 1 they are not as abundant, and sometimes seem burnt and/or phosphatised, judging by dark, cloudy appearance and loss of birefringence (plate 6.6: g, h). | These structures are tentatively interpreted as calcified sheaths of filamentous cyanobacteria or green algae due to their size (Flugel, 2004). Cyanobacteria can be arranged in colonies (coccoid forms – not calcified examples of which are present in Unit 3 sediments) or in filaments that can be branched and enclosed in a protecting mucilaginous sheath (Flugel, 2004). In most cases in carbonate sediments, the preservation of these structures is possible because most cyanobacteria are subjected to nucleation of calcium carbonate within (impregnation) or upon (encrustation) of the protective sheath, which generates a fossil of micritic microfabric (Pentecost, 1991, Merz-Preiß, 2000, Riding, 1991a, Riding, 2000). These tubular microfossils, however, present a distinctive hyaline conservation, i.e., each fossil is formed by a single crystal, which is unusual (Riding, pers. com. 2017). No visible micritic extracellular encrustations probably indicates that the remaining fossil seen in thin section corresponds to the protective sheath that encased the microbe cells (trichomes) that decayed after death. |
| Echinoids | Echinoid (sea urchin) fragments in thin section consist in cross-sections of | Anthropogenic input resulting from shellfish resources exploitation and |

| | | |
|---|---|---|
| | spines and a few shell fragments with typical echinoid calcitic microstructure (Scholle and Ulmer-Scholle, 2003). A different pattern is noted: in Unit 3 the fragments are rare and comminute, whereas in Unit 1 complete sections of spines and coarse shells are very common, some of them burnt (plate 6.2f). | consumption. Comminute fragments in Unit 3 are more likely a sedimentary bioclast, i.e., non-intentional by-product of anthropogenically accumulated sediments from tidal mudflats. |
| Foraminifera | Dispersed between aggregates, calcareous foraminifera, multichambered planspiral, uniserial and biserial morphologies, are common in Unit 3 sediments, and rare in Unit 1, where sometimes they are burnt (plate 6.7). | Marine/brackish environment bioclast; non-intentional by-product of anthropogenically accumulated sediments from tidal mudflats. |
| Seaweed (Rodophyta/calcareous red algae) | Coralline algae are easily identified by their very fine-scale reticulate, cellular internal structure that reflects the filamentous fabric of these organisms (Scholle and Ulmer-Scholle, 2003) (plate 6.8: a-d). The observed grains have morphologies compatible both to detached segments of the branching type and fragments of the encrusting type of calcareous red algae. In unit 1, some fragments are burnt (plate 6.8: e, f). | Marine bioclats, non-intentional by-product of anthropogenically accumulated sediments from tidal mudflats in Unit 3. In Unit 1 their presence might be associated to limpets gathering. |
| Earthworm calcicitc biospheroids | Round or ellipsoidal aggregates of biogenic calcite crystals radially arranged. Their large dimensions, all above 500 µm, seem to be characteristic of surface feeding species (Durand et al., 2010) (plate 6.9). | Colonisation of the subsurface by earthworms. |
| Calcitic spherulites | These spherulites are 50 µm diameter at most, usually embedded in micritic matrix, isolated, in couples or clumps.<br>These spherulites, in appearance, size and shape, do not look nothing like those commonly existent in archaeological contexts related to herbivore dung | Most likely product of bacterial calcification, associated to cyanobacteria (Flugel, 2004). |

| | | | |
|---|---|---|---|
| | | (Courty et al., 1989, Canti, 2003, Durand et al., 2010). | |

### 6.3.1.1 Calcareous tufa

La Fragua sediments present a wide variety and number of biogenic carbonate clasts related microbial and plant activity. Due to the informative potential of these, it is more practical to describe them separately from the general components. The description of the tufa clasts, based on the different microfabrics that potentially indicated their origin, is based on Flugel (2004) and Pentecost (2005) terminologies. The carbonate microfabric terms used throughout the text thus refer to the corresponding description and genetic interpretation in table 6.3.

**Table 6. 3** Mirofabrics present in the relict clasts at Unit 3 of Fragua corresponding to structured carbonates

| **Carbonate Microfabric** | **Unit** | **Description** | **Inferred source** |
|---|---|---|---|
| Stromatolitic | 4 | Laminated micrite and microsparite. The lamination alternates between very dense and massive to lighter and porous, which has been associated to seasonal growth of algae. This microfabric is dominant in the carbonate clasts of Unit 4, that in thin section have 1 cm of maximum thickness and 3 cm of maximum length, angular edges and lie in horizontal position (fig. 6.13: a, b).<br>Alternate bands:<br>- Flat to wrinkle laminae, alternated dark and brownish, dense micritic laminae.<br>- Laminated columns, sometimes branching, with small fenestral pores (~2mm) and somentimes porous microspar between laminated micritic collumns.<br>- Flat to wrinkle laminated, light and porous microspar alternated with µm-thick laminae of dense, dark and brownish micrite with some micro-columns. | Possible tufa deposit at the entrance of the cave. |
| Dendritic calcite | 4 | Dendritic spar crystals with sweeping extinction under XPL, creating a feather-like pattern, | Possible tufa deposit at the entrance of the cave. |

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| | | forming a layer ~5 mm thick, which orientation of the dendrites seem to suggest that they served as substrate for the clotted microfabric concretion (see this table above) (fig. 6.13: a, c). | |
| Clotted | 3 | These microfabrics are composed of rounded, diffusely to well defined, micritic aggregates of bacterial origin (also called clots, peloids and bacterial clumps (Ford and Pedley, 1996, Chafetz and Folk, 1984) of ~100 µm maximum diameter, cemented by microspar and spar and micritic irregular protuberances (dome- and finger-like) interpreted as microbial growths (fig. 6.13: d, e).<br>Occurs as clasts are up to 7 mm in thin section; Varieties include: (1) well defined clots cemented by clear coarse microspar and (2) diffuse clots exhibit filamentous microfossils within diffuse micrite and calcified cyanobacteria and cementation by alveolar septal calcite in the pores. | Algal/moss tufa from fluvial or marsh environments (Flügel, 2004). The microbial variety suggests to having been exposed to fungi colonisation in a pedogenic environment. |
| Concentrically laminated | 3 | These clasts present concentric and irregular laminae of micrite and small peloids (rounded aggregates of carbonate mud). The laminae are separated by voids following the concentric scheme (possibly after decomposed bacterial colonies), being some of them filled by microspar. These clasts have maximum 8 mm in thin section and an oblate shaped and are sub-horizonally oriented (fig. 6.13: d, f). | Possible subaqueous oncoid-like objects from (exogenous) stream or marsh tufas. Alternatively, but less probable, soil glaebule from a pedogenic calcrete horizon. |

There is a clear difference in the tufas between Units 4 and 3. In Unit 4, these carbonate clasts are coarse, crust-like fragments, with angular shapes and horizontally displayed in thin section (as the flat pebbles in general). At meso-scale, they exhibit the main diagnostic characteristics of typical tufa deposits, namely: (1) they are laminated, (2) the laminations have both stromatolitic and thrombolithic meso-fabrics, and (3) they show little, fenestral porosity (Pentecost, 2005, Flügel, 2004). Microfabric observations (see details in table 6.3) also supports this interpretation. The stromatolitic microfabrics in these clasts exhibit the micrite fine laminations grouped in millimetre-thick layers marked by colour and density variations resulting from seasonal growth of algae, which is typical of algal tufas (Pentecost, 2005). Some layers present discontinuous and broken laminae and globular, vertically elongated voids interpreted as gas bubbles (Flügel, 2004). Another diagnostic microfabric diagnostic of tufa present in Unit 4 crusts is a layer consisting of coarse feather-like arrangements of calcite crystals. Dendritic calcite seems to form under increasing precipitation rates (Pentecost, 2005) and driving force – supersaturation and supercooling (James and Jones, 2015) – and are common in cave tufa deposits and under flowing water on sloping surfaces as in cascade tufas (Pentecost, 2005). Crystalline tufas from via rapid precipitation from fast-flowing waters and result in dendrites and feather crystals of calcite and aragonite (James and Jones, 2015). This crust fragment with feather-like calcite has also a stromatolitic layer, indicating that they belong to the same tufa deposit. In fact, the feather-like crystals growth direction indicates they formed over the stromatolitic calcite layer, indicating a change in the water regime under which the tufa formed. In Unit 3, the carbonate clasts are considerably smaller and generally rounded (fig 6.13: a, d) and present different type of microfabrics, not related to typical tufa spring deposits, but to sub-aqueous more or less static environments, which formation is mainly related to microbial activity, which is important regarding the exogenous origin of Unit 3 sediments.

### 6.3.2 Micromorphology and microfacies

The micromorphological analysis of the thin sections yielded a total of seven microfacies types, two of which (mF types 1 and 2) in Unit 3 and the rest in Unit 1. Unit 4 is homogenous both in the field and in the correspondent thin section, so henceforth its own designation will be used to refer also to the microscopic aspects concerning it, since there aren't any actual internal microfacies. The micromorphological descriptions are presented in Table 6.4, as well as brief interpretations concerning the processes involved in the formation of the deposits, which are discussed in detail in a following section.

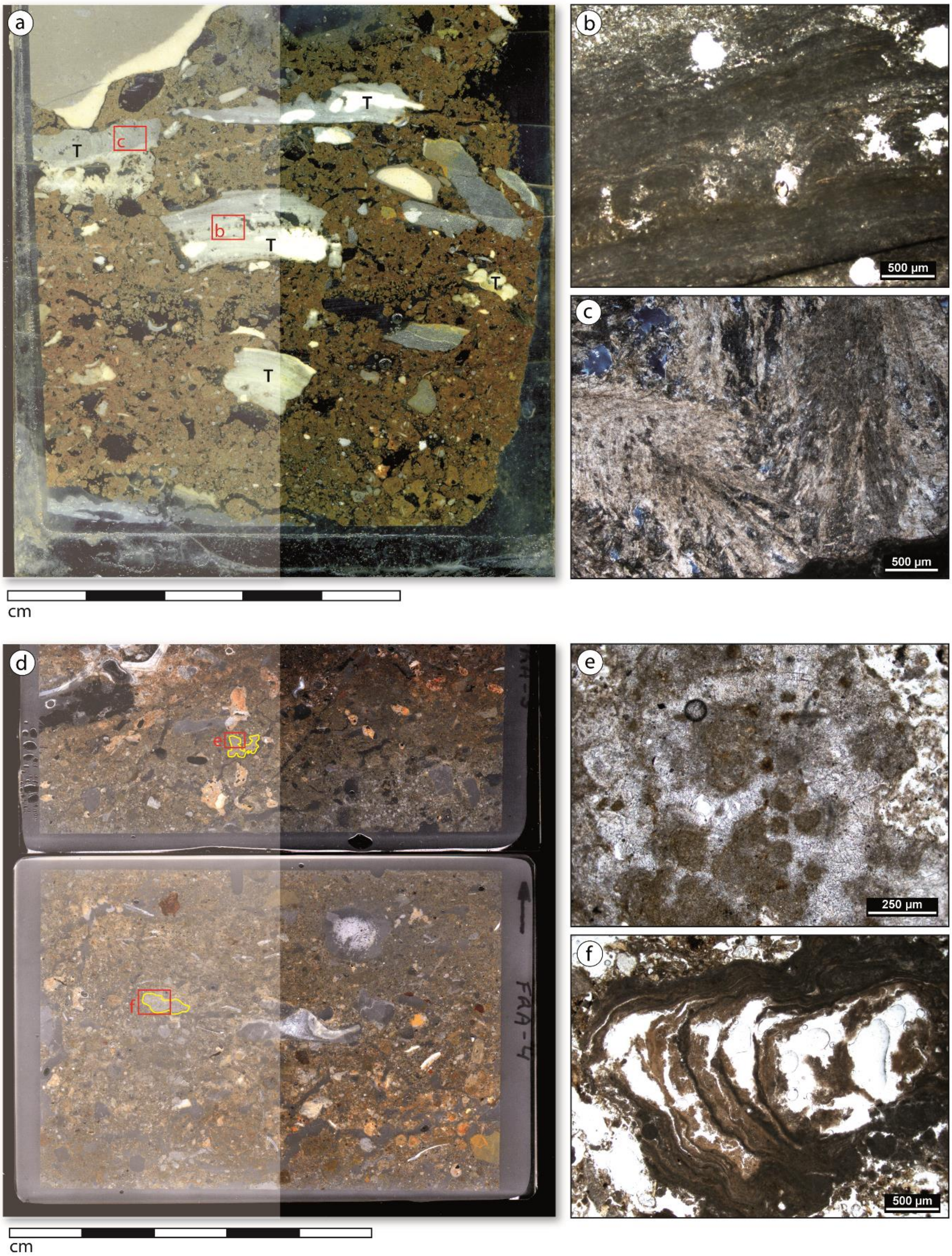


**Figure 6. 4** Carbonate microfabric types and differences between units 4 and 3: a) dark-field scan of the lower half of thin section from Unit 4, where the tufa fragments (T) are concentrated; note that all fragments lay flat. b) microphotograph of the area indicated with red rectangle in a, showing the stromatolitic banded microfabric; note wrinkle lamination, columns and fenestral porosity, typical elements of tufas; PPL. c) feather-like dendritic

calcite from the corresponding red rectangle marked in a; XPL. d) dark-field scan of thin sections from Unit 3, with two of the coarser tufa fragments delimited in yellow; note the much smaller size of the fragments in comparison with those in Unit 4. e) clotted microfabric, in the corresponding rectangle marked in d; PPL. f) concentrically laminated microfabric, in the corresponding rectangle marked in d; PPL.

**Table 6. 4** Synthesis of microfacies types (mF) and Units described in thin section from La Fragua cave

| Unit | mF | Description | Interpretation |
|---|---|---|---|
| 1 | 1 | Ash, few remains of articulated ash pseudomorphs, very coarse reddened silty-clayey aggregates and shells. Gravel size quartz grains and rubified silty-clay aggregates are frequent in this mF, whereas charcoal is rare. The shells, mainly limpets, are more homogeneously burnt, fragmented, interconnected and exhibit a tendentiously horizontal orientation pattern, especially at the bottom of the mF. In the upper part of the mF, most shells are calcined and phytolith slag is more abundant. Burnt echinoid spines are also present, as well as burnt calcareous red algae segments and earthworm calcitic granules (plate 6.10). | In-situ combustion, possibly for roasting shells. The materials in the upper part seem to have been disturbed, possibly by soil fauna colonizing the exposed surface once abandoned. |
| | 2 | Dispersed ashes supporting above all coarse wood charcoals (from sand size to several mm), shells and rubified terrigenous aggregates. The limpet shells are both burnt and unburnt and comprise complete or nearly complete cross sections of the shells as well as comminute fragments. Apart from limpets, echinoid fragments, mostly burnt spines, are also common. The charcoals present variable degrees of preservation, but the woody cellular structure is clearly visible. Silty-clayey aggregates are present, exhibiting a reddish colour and sizes up to 1 cm. Other less common components observed include concentred and isolated filamentous microfossils and calcareous red | Dumping of combustion debris. |

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| | algae, and one gravel sized limestone clast is observed in thin section (plate 6.11). | |
| 3 | Very well-preserved ash with cemented and phosphatised areas, with abundant articulated pseudomorphs in anatomical position after the plants, with substantial parts of it preserved intact. Silty-clayey reddened aggregates (10%), rounded to angular, dispersed in the ashy matrix, fine sand to millimetric sized. Minute shell fragments are rare, either highly burnt or calcined. Phytolith slags and burnt filamentous microfossils were also observed. Bioturbation of these sediments is evident by channel and chambers porosity locally disrupting articulated and cemented ashes (plate 6.12). | *In situ* complete combustion of vegetal material, later cemented by secondary micrite and phosphates. |
| 4 | Microgranular grey micrite preserving ash pseudomorphs. Well preserved, loose ash pseudomorphs are abundant, but ashes are very locally cemented and recrystallized to microsparitic crystals, or phosphatised and impregnated with manganese. Few instances of articulated ash pseudomorphs are still visible. The main coarse components are shells and dispersed reddish silty-clay aggregates. Shells (mainly limpets) are mostly fragmented, but some almost complete sections of limpets are visible, and are randomly distributed, being overall burnt and a few are calcined. Reddish silty-clay aggregates range from fine to coarse sand size and exhibit roundness to angular shapes, overall presenting cracks from heating. Some charcoal is preserved, coarse sand sized up to 1 cm., dispersed in the ashy matrix, along with rare instances of articulated phytoliths, phytolith slag and char aggregates. Red algae fragments, some of them possibly burnt, calcareous foraminifera and siliceous sponge | *In situ* combustion of mixed debris. |

| | | | |
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| | | spicules and filamentous microfossils were also observed and appear to be burnt. Bioturbation is intense, mainly in the form of chamber voids (plate 6.13). | |
| | 5 | Fine and fibrous organic matter, charred and strongly humified, is the distinctive and main component. The fibrous plant material in some areas is chaotically arranged, but in others is organised in parallel stringers, in a microagranular matrix composed by dispersed ash, clay, and charcoal, all finely mixed, with micritic microaggregates. Coarser (fine gravel size) silty-clayey aggregates are rounded, dark-reddish, isotropic, and present abundant cracks, probably result of combustion. Calcareous foraminifera (example in plate 6.7f), filamentous microfossils, microbial carbonate aggregates, here slightly decalcified and phosphatised (brownish colour instead of grey and loss of birefringence), as well as siliceous sponge spicules and rare diatoms were observed. Bone is present and seem optically heated (example in plate 6.2a). Large limpet shell fragments and echinoid spines are present and optically burnt (micritized). Some channel and chamber voids indicate post-depositional biological disturbance (plate 6.14). | Grassy plant material accumulation, *in situ* charred by incomplete combustion. |
| 3 | 6 | Microgranular microstructure dominated by carbonate mud micromass and phosphatic components. Fibrous, granular and laminated phosphatic crusts are abundant, and an overall stronger orange colour, otherwise the composition is equivalent to mF domain 1. Coarser pieces of wood charcoal start to appear in the sequence in this mF type (plate 6.15). | Exposed surface of a deposit of exogenous sedimentary material originally from mudflats surrounding the cave, affected human trampling and burning. |

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| 7 | Dominant micritic pale-brownish micromass with strong calcitic crystallitic b-fabric (carbonate mud) (plate 6.16). Shell fragments are common (10%), and most of them probably correspond to terrestrial gastropods, giving their millimetric regular shapes and aragonitic composition (confirmed by µ-FTIR). A single, gravel sized fragment of a calcitic (marine) shell (confirmed by FTIR) was identified (see mF type 7a below). Small mammal bones are abundant and frequently weathered (plate 6.2: c, d). Charcoal occurs rarely as very fine particles (silt or fine sand size), generally fibrous and humified, finely mixed with the micromass. 5% of quartz and few muscovite silt and 3% of fine/medium sand composed of quartz, few calcite and glauconite. Phosphates are present in the form of nodules, infillings and fragmented crusts. Carbonate clasts are abundant, and comprise concentrically laminated, dendritic and clotted microfabrics.<br>Two sub-types are distinguished by the voids pattern, mF types 7a and 7b. | Exogenous sedimentary material originally from mudflats surrounding the cave, possibly affected by human trampling. |
| 7a | Two porosity patterns superimposed: the principal one is an intricate network of plane voids (20-30% of void space) ranging from discrete to millimetric lengths, sub-horizontal and contorted shapes. The second void pattern is composed by vesicles (10% of void space), often sub-horizontal too, up to a few mm long. Components with planar morphologies, such as shells and chert exhibit a preferential horizontal orientation. Some shells are crushed *in situ*. Some of the planar voids present organic, Iron and manganese staining (like hypocoatings) along planes and impregnations of the adjacent matrix are present (plate 6.17). | Planar horizontal porosity could be the effect of: 1) structural compaction, possibly by trampling, which could cause also the *in situ* crushed components; 2) dehydration if the sediment was wet, as the vesicles and iron/manganese impregnation indicate; or 3) hollows left by decay of plant material (moldic voids), as suggested by their morphology and humified organic remains. |

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| | 7b | Substantial concentration of fine-sand sized rounded micrite aggregates that gives to the deposit a microgranular texture. Tubular microfossils are particularly abundant, more than geogenic silt, as well as other clastic microbial carbonates (plate 6.18). Interstitial granular microstructures, also micritic, can be observed in these areas of the thin sections. | Temporal surface affected by trampling (?) |
| 4 | n/a | Coarse granular microstructure well-rounded to subangular silty-clay aggregates, ranging from sand to a few mm size, mostly interconnected, which generates a dominat porosity of polyconcave vughs. Aggregates have a massive micromass composed by brown clay in PPL with two differential b-fabrics: 1) undifferentiated to weakly speckled and 2) crystallitic, resembling dense and dark micrite. The distribution pattern of the zones with different b-fabrics does not follow any perceptible pattern, i.e., a same aggregate can exhibit one or both. The aggregates contain common opaque organic impurities and heterogeneous inclusions of little quartz silt (2-5%) and fine to medium sand (2%) grains of quartz and calcite. The silty-clay aggregates also incorporate fine sand sized, amber coloured phosphate grains (1-2%). The aggregates are often bounded by a fissured and cracked void patterning, also expressed around pebbles. A chamber porosity is superimposed to this microstructure, with large round void chambers, commonly up to a few mm, filled with excrement features and chaotic fine granular microstructure. With local variations, globally the porosity comprises about 30% of the total space in thin section. | Polygenetic deposit accumulated by cryoclasty, cryogeny, outside surface creep of eroded local soils, birds visiting the cave and bioturbation. |

Microvertebrates' bones (%) often exhibit alterations such as strongly orange zones possibly heat-induced, weathering, corroded edges and loss of birefringence and are commonly associated to pale, isotropic phosphatic masses.

Very thin shells (possibly of land snail), most of them comminute to sand-sized grains up to few millimetres.

Earthworm calcitic granules, coarse sand size, are common, as well as charcoal fragments, very deteriorated and appearing humified, up to several mm sizes.

Calcite and fossiliferous limestone pebbles (from the local bedrock) are common (30% of the thin section) angular and subangular shapes, ranging from small gravel to centimetric sizes.

Tufa crusts, with stromatolitic and feather-like microfabrics are common, horizontally oriented.

Manganese hypocoatings on aggregates surfaces and matrix impregnations.

The aspects above described can be observed in figure 6.23.

There is a clear difference between the microfacies present in Units 1, dominated by ashes, and 3, where those are absent, although the continuity of some key elements, namely marine bioclasts, in the lower deposits of Unit 1 seem to indicate that there is some relation between them.

Unit 3 has an extremely heterogeneous composition, rich in all carbonate, phosphate and clastic and organic components listed in table 6.2, except those related to combustion (ashes, phytolith slag and rubefied aggregates, and charcoal is extremely rare). The upper millimetres (1 cm at most) of Unit 3 was discriminated as a different mF type, called 6, visible both in thin section and in the field, where it displays a reddish colour (plate 6.3c; 6.19: a, b; 6.20: a, b), because of a combination of heat-induced rubefaction and the enrichment in reddened phosphatic features, especially coprolites, fibrous and laminated crusts (discussed below), otherwise the composition is equivalent to the underlying sediments of mF type 7. The lower contact is very gradual and the upper contact, with Unit 1, is sharp.

The contact between Unit 3 and Unit 1, or mF type 6 and mF type 5 respectively, is extremely significant because despite the groundmass differences (carbonate-phosphatic in 6; charred organic matter and ash in 5), there are key elements present in both. Is the case of, charcoal, absent in Unit 3, but starts to appear in the sequence in mF type 6, and mudflatd grains and filamentous microfossils, major components of mF type 6, that are observed finely mixed with the charred organic material in mF type 5 (plate 6.14: c, d). These aspects probably mean that there is a relation of continuity between both Units. Unit 1 corresponds to the Mesolithic sequence of ashy deposits with abundant mollusc shells and charcoal. It was subdivided in several sub-units during the 2015 multi-sampling works (see table 6.1).

### 6.3.3 Post-depositional alterations

Bioturbation affects the whole sequence and is ubiquitous in thin sections, in the form of channel and chamber porosity and well delimited areas where the groundmass is visibly rearranged by the action of animal burrowing. The latter is represented in considerable areas of the thin sections in Unit 3, where the original fabric is structurally disrupted (plate 6.20). These domains show a heterogeneous crumby and spongy microstructure with micromass composed of diffuse areas of micrite, little clay and organic impurities. All types of calcitic, phosphatic and terrigenous aggregates are present and loosely packed and chaotically distributed. Pebbles (up to 0,5 cm) are as diverse as angular clasts of calcite to well-rounded limestone and quartz. An aspect considered decisive to assess the intense degree of bioturbation is that in Unit 3, the bioturbated domains systematically present loose aggregates from Unit 4 (plate 6.20: a, c), identified by the dense and dark micrite with heterogenous inclusions (comminute bones, phosphatic grains, land snail shells, and geogenic silt and sand).

## 6.4 Discussion

### 6.6.1 Unit 4: Late Pleistocene

#### *6.4.1.1 Formation processes and climatic implications*

The overall microstructure of La Fragua's Unit 4 sediment, well-rounded to subangular silty-clay aggregates (plate 6.19), might indicate transport of whether eroded soils from the steep slope outside of the cave or endokarstic sediments if there was water circulation. The fissure and crack porosity pattern (plate 6.9c; 6.23: e, g.) bounding the aggregates may be the effect of shrink and swell due to periodic wet-dry cycles of the sediment, as observed by Courty and Vallverdú (2001) and Goldberg et al. (2003). The presence of *éboulis*-like clasts composed of heterogenous and angular limestone, calcite and tufa (plate 6.19: a, b) suggests a transport from the mouth into this inner part of the of the cave.

In thin section it is possible to differentiate two different patterns in the upper and lower halves concerning the coarse fraction. The main difference is that in the upper half, centimetric limestone pebbles with rounded edges (despite low sphericity) dominate, whereas the tufa and calcite fragments with angular shapes are dominant coarse component in the lower half (plate 6.19: a, b). This might be regarded as a factor of differentiation between to different moments of sedimentation. In the lower portion of the thin section, tufa crusts and small clasts of more easily detachable calcite would have fall from the cave wall, being rapidly incorporated in the sedimentation of the cave floor. The upper portion contains larger limestone pebbles which rounded edges with "festoon-like" morphologies (plate 6.19: a, b) that might lead to think in some transport history, but, according to Courty and Vallverdú (2001), these features can result from intense dripping by carbonate-saturated water and associated colonization of the cave walls by plants.

The chamber porosity associated to fine granular microstructures (plate 6.19h), plus the abundance of calcite biospheroids (plate 6.9: c, d; 6.23: a, b) from worms reveals that the sediments were subjected to biological activity that promoted the homogenisation of the deposit, which must have contributed to obliterate the original microstructure.

The presence of coprolitic material and the compaction of aggregates, expressed by the closed polyconcave vughs patterns, and the abundance of microvertebrate bones and their degree of alteration and comminution, suggests that carnivores, or birds, visited the cave, and their biological fluids have promoted the phosphatisation of the matrix, hence the phosphatic grains incorporated in the aggregates (plate 6.19). This would have caused localised acidification of the sediments, a possible explanation for the decalcified patches in the groundmass, as suggested by Goldberg et al. (2003) for the similar features in Hohle Fels (Germany).

Some of the aspects addressed above point to a very slow sedimentation rate of Unit 4, such as vughy porosity and cryoclastic fragmentation of products from the cave walls and biological colonisation. Courty and Vallverdú (2001) observed similar features under cold and wet conditions with less severe frost and high moister content of the soils during freezing season at layer 11b of El Mirón, more recent than Unit 4 of La Fragua. Previous works remarked the influence of local conditions and cave configurations in the degree of expression of outside climate in the interior of caves (Courty and Vallverdú, 2001; Karkanas, 2001), and probably the protected position of La Fragua cave entrance, oriented to south, might also contribute for the lack of more striking cryogenic features such as a platy porosity or lenticular microstructure (Van Vliet-Lanoë, 2010, Van Vliet-Lanoë, 1998). This explains why the cryogenic signatures of Unit 4 are not straightforwardly identified, apart from homogenisation by biological activity. The local topography and position of the cave certainly as influence also in the low sedimentation rate, which is revealed also by the radiocarbon dating (table 6.1) that spans from 23 087 cal BP at the bottom to 19 339 cal BP at the top, that is about 4000 years concentrated in little more than 30 cm. However, with micromorphology it was possible to discern some variations on the type of coarse components incorporated in the deposit, which might reflect different environmental conditions. This difference could represent climate variations through the Upper Palaeolithic and seems to corroborate the hypothesis of low sedimentation rate.

The tufa fragments reveal different water flow regimes through the cave walls and plant species involved in the formation of the tufa deposits, but overall, they point a moment of colonization of the cave wall by algae, under wet and less cold conditions (Courty et al., 1989). These biogenic carbonates eventually became detached and incorporated in the cave floor together with small *éboulis*, indicating erosion and transport by water.

#### *6.4.1.2 The origin of tufa clasts of Unit 4*

La Fragua is a fairly dry cave, as suggested by the general lack of speleothem formations today. The exception is a tufa deposit hanging from a fissure on the cliff in the cave entrance, which lower part is missed (fig. 6.25). This very localised deposit, that looks like flowstone, might be a small cascade tufa according to Pentecost (2005) and Chafetz and Folk (1984) tufa categories. The centimetric-scale lamination indicates seasonal growth of bryophytes combined with changes in species as response to variations in flow regimes (Pentecost, 2005). The morphology of the deposit also offers some correspondence with the tufa category that Pentecost (1995, 2005) calls "remora", developed in slow or intermittent water flow over steep surfaces, common at the entrance of caves and characterised by strong adhesion, density and hardness, often forming below bedding plane seepages, partly through evaporation of thin water films and photosynthesis, which cause the resemblance with spelean flowstone (Chafezt and Folk, 1984, Pentecost, 2005).

This peculiar and eroded deposit is thus a possible source of the tufa clasts in Unit 4, meaning a transport of the fragments after detachment towards the interior of the cave, which corroborates the idea of the sediment source being the colluvial deposits and soils outside that until some point had direct access to the cave, possibly by creep processes. A detailed sampling and study of this tufa deposit in the future, and perhaps its dating, could help in a better formation processes of the site as well as a more accurate paleoevironmental reconstruction. The important thing to retain is that the carbonate crusts found in the sediment of Unit 4 are not spelean carbonates, but tufas related to an ephemeral, very localised water flow at the cave entrance, thus authocthonous materials, which contrasts with the biogenic carbonate clasts in Unit 3 and supports the idea of those being allochtonous.

#### *6.4.1.3 Anthropogenic activity during the Late Pleistocene*

In thin section, the only possible indicators of anthropogenic activities are charcoals and burnt bone. These elements, resulting from the seasonal visits to the cave through the Upper Paleolithic (Marín Arroyo and González Morales, 2007, González Morales, 1998), are mixed with groundmass, thus probably are reworked by the slow process of accumulation of sediments in the cave. Animals that occupied the cave might eventually also remobilized

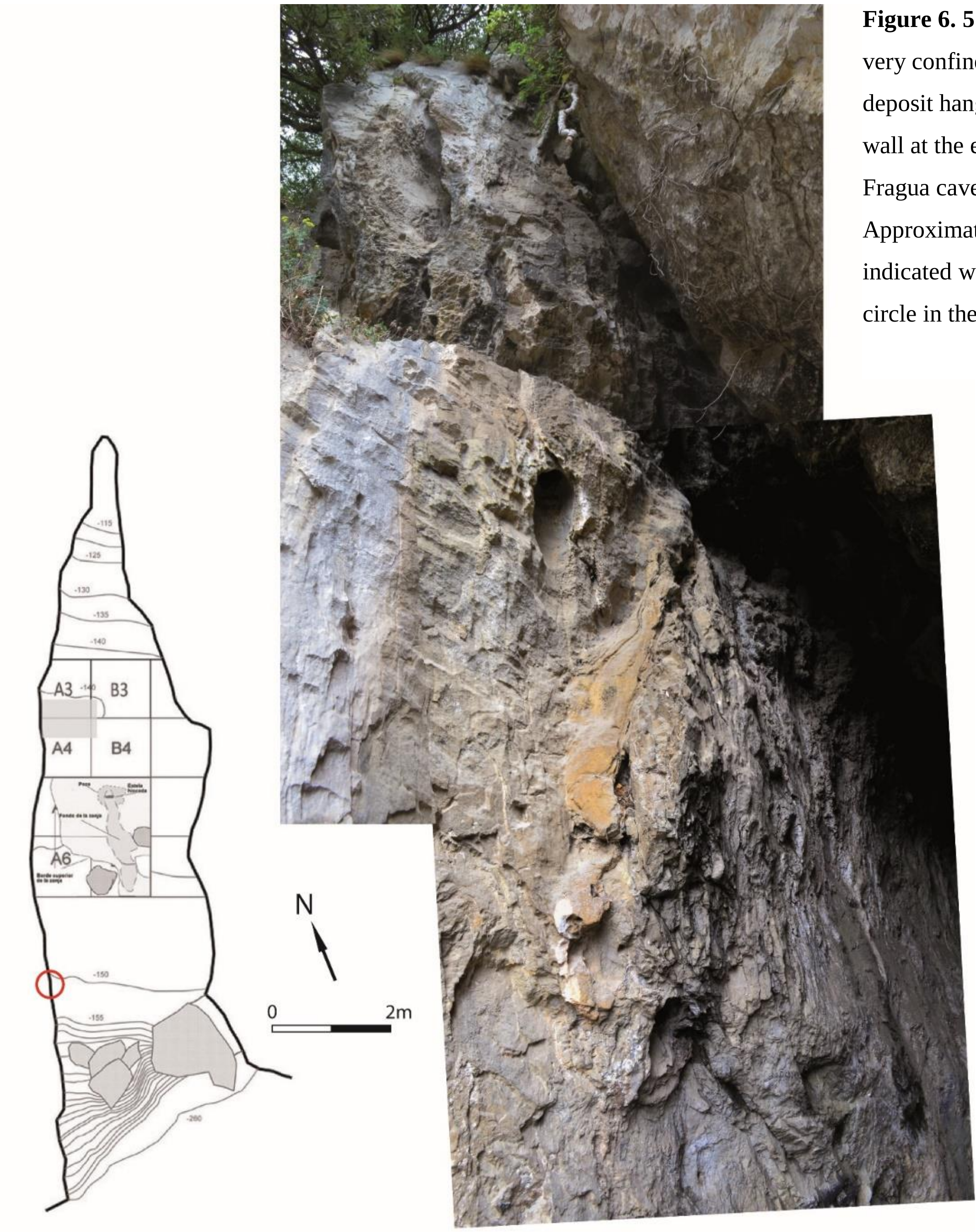



**Figure 6. 5** Aspect of the very confined tufa deposit hanging in the wall at the entrance of La Fragua cave. Approximate location is indicated with the red circle in the cave plan**.**

anthropogenic remains. Therefore, the occupations must have been located more towards the cave entrance. We can hypothesise that the cave mouth might have been located a few metres ahead of the present, if the large blocks we see today did not have collapsed from the ceiling yet. This hypothesis agrees with the idea that the strong deepness of the rockfall deposit we see today is effect of early Holocene sea-level rise erosion as proposed by González Morales (1998). If so, the central areas of occupation in the Paleolithic might have been eroded today.

### 6.4.2 Unit 3: Holocene

Unit 3 is completely different from Unit 4. Unfortunately, the micromorphological sampling of the contact between both was unsuccessful because of the presence of large blocks and the sediments were excessively loose and highly affected by burrows (plate 6.3b) of medium mammals, likely rabbits. The high heterogeneity of the sedimentary components of Unit 3 make it extremely informative. Many of the components are allochthonous, such as bioclasts, the group with the bigger diversity within the sediments, most of them being skeletal grains of marine organisms (see table 6.2). The high position of the cave above the sea level make impossible that marine incursions are the reason of the presence of these grains. This is the first aspect to have in mind regarding the origin of Unit 3 sediments. Secondly, clasts with fine-grained micritic fabrics (laminations, clots) and microfossils of filamentous green algae or cyanobacteria, are strong evidence of microbial carbonates, that thrive in sub-aqueous shallow environments. The question raised by such mixing of components is, how do we untangle these two natures (marine skeletal grains and microbial carbonates) and how can we use it to track the sediment source and infer the reason of their presence in the cave? Answering this question is fundamental to address the anthropogenic implications and contextualise the archaeological materials embedded in this deposit.

The hypothesis proposed here is that the sediments must have a marginal marine origin, more exactly intertidal mudflats, based mainly on the whole set of components of marine and microbial origin, since intertidal zones are the more susceptible to the mixing of both organisms. In the next sections, we will go through the microscopic data in detail to support our hypothesis, dividing the lines of argumentation in the analysis of bioclasts, microbial carbonates and phosphates.

#### *6.4.2.1 Tracking the bioclasts*

Focusing first on the bioclasts, it becomes evident at first that they correspond to skeletal grains of marine organisms (plate 6.7, 6.11). A crucial question is thus how did they arrive to the cave? If all the components of marine origin were already in the same sedimentary environment before being incorporated to the cave, we will first investigate the circumstances under which these specific components occur together, that is, sedimentary settings where their skeletal grains had accumulated already as bioclasts. Skeletal grains of sponge spicules, echinoid spines, foraminifera, calcareous red algae and molluscs are very likely to form part of relatively young sands in temperate-cool intertidal environments (Flügel, 2004, James and Jones, 2016). In temperate-cool outer shelf platforms, such sediments undergo permanent reworking, leading to the mix of relict carbonates and modern particles (Flügel, 2004). In the Bay of Biscay, as in the North Atlantic in general, there are two carbonate producing marine ecosystems of interest to regard as possible source of carbonate particles. One is kelp forests, ecosystems that host a great number of carbonate sediment-producing organisms and typically occur in wave-exposed flanks of rocky costal platforms (Flügel, 2004). Other source of carbonate particles to consider is the so called 'maerl', one of the most common shallow-water carbonate deposits of cool-temperate latitudes, which are gravel deposits consisting on unattached coralline red algae, widely documented in more protected parts of the platforms (Flügel, 2004, James and Jones, 2016), and abundant in the platform of the Bay of Biscay (Peña et al., 2014, Wehrmann, 1998). Calcareous red algae seen in thin section could have come from such subtidal carbonate deposits, close enough to the shore for being reworking into intertidal settings around Mount Buciero. The local intertidal environments comprise rocky pools and estuarine mudflats. Coralline algae and sponges can encrust rocky substrates in intertidal zones, while mudflats, are subjected to incorporation of all types of skeletal grains that the high tides or storms bring from subtidal zones (James and Jones, 2016). For these reasons, we believe that the whole set of marine bioclasts in the sediments of Unit 3 come from intertidal settings.

#### *6.4.2.2 Tracking the glauconite*

Apart from skeletal particles, the presence of glauconite grains is also highly significant because this mineral is formed exclusively in marine environments (Scholle and Ulmer-Scholle, 2003; Flügel, 2004). It is a common mineral in many old limestones, however, it is not present in the limestone bedrock of La Fragua (Olivé Davó et al., 1982). Glauconite grains could be reworked from the ocean to intertidal settings, together with other sand grains and bioclasts. An alternative explanation arises when looking to the broader regional geology influenced by the hydrographic basin of the River Asón. There is a restricted area adjacent to the present day mudfalts composed by sandstone containing glauconite (Olivé Davó et al., 1982). This outcrop (plate 6.2b) could be a source of glauconite grains giving it is located within the catchment of the estuarine system, thus the mudflats are still the most plausible final depositional environment for the grains before their incorporation in the sediments of La Fragua alongside marine bioclasts.

#### 6.4.2.3 Tracking the microbial carbonates

Again, environmental implications of microbial carbonates are very significant and important to understand. If not analysed carefully, one could consider these clasts as tufa formations from the cave itself, but the fact that these clasts have completely different micro-fabrics form the tufas at Unit 4, makes it important to try to understand its source.

Microbial carbonates are “carbonate deposits produced or localized by benthic microbial communities [Riding, 1990] living in marine, marginal-marine, freshwater and terrestrial environments” (Flügel, 2004:370). These communities are formed by micro-organisms such as bacteria, cyanobacteria and algae, as well as encrusting invertebrates such as sponges, foraminifera or ostracods that can be trapped in them (Flügel, 2004). In Unit 3, there are several types of carbonates that have microbial origin, namely filamentous microfossils, several microbially-induced fine-grained structures like calcified filaments and an array of micrite structures such as spherical bodies, laminated crusts, concentric stromatolites, clotted and finger-like structures. Microbial carbonate sediments vary with environmental conditions (Scholle and Ulmer-Scholle, 2003) where they are formed, thus have a great informative potential. The analysis of microbial carbonates will be divided according to specific information they provide: micritic micromass, filamentous microfossils, tufa fabrics and microbial/algal mats associated to microboring.

- *The miritic micromass*

  Micritic micromass here refers to the dominant miromass in mF 7 (see table 6.4), pale-brown with strong calcitic crystallitic b-fabric. Micritic micromass occurs as rounded aggregates resembling carbonate peloids (plate 6.21: a-d). The term “peloid” is applied in carbonate petrology to grains composed of micro and cryptocrytalline carbonate, regardless their origin, precisely because it is difficult to determine in most of the cases, although a microbial origin seem to be widely accepted (Riding, 1991b, Riding, 2000, Riding and Awramik, 2000, Pedley, 2000, Jones, 2001, Pentecost, 2005, James and Jones, 2015). The recurrent association of the micritic micromass in mF 7 with filamentous microfossils (plate 6.19: a, b) and other possible bacterial features (e.g. spherulites) (plate 6.19: e, f) led us to consider the hypothesis of this micrite corresponding to microbially induced carbonate.

Another significant aspect in several micritic aggregates in Unit 3 is the relatively common presence of calcareous spherulites. Spherulites are generally associated to bacterial calcification (Riding, 1991) and, in stromatolites, their presence has been interpreted as calcified cyanobacteria as well (Flügel, 2004). The presence of "fresh" coccoid cells in Unit 3, highly fluorescent, (plate 6.21: g-i), and the occurrence of some spherulites in clumps (plate 6.21: e-f), like coccoid cells usually are arranged, seem to point to the same origin, and the fact that they did not calcify might be indicating different species, since calcification of cyanobacteria seem to be species-dependent (Golubic et al., 2000).

- *The filamentous microfossils*

The filamentous microfossils, probably calcified cyanobacteria or green algae sheaths (table 6.2; plate 6.6; 6.19e; 6.26: a, b), by their overwhelming abundance, constitutes strong evidence that carbonated microbial sediments are one of the main sedimentary sources of Unit 3 sediments. From shallow-marine to terrestrial environments, cyanobacteria, some green algae and diatoms occur in close association in a specific type of microbial communities, called microbial mat or biofilm (Riding, 2000). Microbial mats are composed by phototrophic organisms organised into distinct layers that result in microstratification, which development demand submersion, however, once developed, they can support periodical desiccation (Stolz, 2000). These structures are known in the fossil record from a wide variety of environments, ranging from marine intertidal, hypersaline coastal settings to freshwater terrestrial settings, such as lakes or springs (Riding, 2000, Flügel, 2004). Giving this range of possible substrates, it is difficult to attribute a specific origin to the filamentous microfossils at La Fragua and the associated micrite only based on their appearance, especially considering their unusual calcification as a hyaline crystal (plate 6.6), instead of micrite, which is how cyanobacteria usually calcify (Merz-Preiß, 2000, Riding, 2000, Riding, 1991a).

One of the possible environments to consider for the formation of algal/microbial mats is the cave itself. Jones (2001) reported well-developed microbial mats partially calcified covering walls at the twilight zone of caves, whereas Golubic et al. (2000) noticed that calcified species can co-habit with uncalcified ones in periodically wetted limestone cliffs. The large majority of filamentous microfossils occur as loose bodies, tangled masses and incorporating micritic aggregates, which suggests they are fragments of disrupted calcified algal/microbial communities, or microbial mats, undergoing continuous reworking and diagenesis, evolving to peloids (plate 6.6: a, b). This suggests that they are reworked elements from tufa systems that would have functioned at the entrance of the cave and were transported by water to inner parts of the cave.

In regard of cyanobacterial calcification, Unit 3 also contains aggregates resembling *Girvanella*-group fossils. Fossils of the *Grivanella*-group, typically occurring in peloids composed of tangled micritic recognisable pseudomorphs of cyanobacterial filaments (Riding, 2000), thinner and more intricate than the one we here distinguish as filamentous microfossils (plate 6.21: c, d). Anyway, cyanobacteria are the main constituents of microbial mats from intertidal to terrestrial sedimentary deposits in the Present (Turner et al., 2000, Pentecost, 1991, Pedley, 2000). Likewise, calcification of modern cyanobacteria is mainly a freshwater or intertidal phenomenon, rare in subtidal and deeper marine environments (Riding, 2000).

- *Tufa*

Gravel-size carbonate clasts with clotted and stromatolitic microfabrics in Unit 3 constitute strong evidence of microbially induced sedimentary structures. Clotted microfabrics are one of the most common micro- and meso-fabrics in tufas (Pedley, 1992, Pedley, 1990, Pedley, 2000, Pentecost, 2005). Clotted microfabric is a common feature in lake, pond and marsh tufa deposits, according to Pedley's (1990) classification. A clast with clotted microfabric in Unit 3 also exhibits mamillated and irregular branching protuberances (plate 6.13: d, e) that could be microbial (Riding, pers. com. 2017) and might correspond to "free-form growth-forms" that Pedley (1990) associates to static water conditions.

The concentrically laminated stromatolitic features in Unit 3 (see table 6.3; plate 6.13f) closely resemble oncoids associated to fluvial tufa and tufa deposits often formed in streams, rivers and lakes, but also in marshes and marine inter- and subtidal conditions (Flügel, 2004, Pentecost, 2005, Riding, 1991b, Pedley, 1992). Riding (2000) classifies oncoids as "unattached spherical stromatolites", within the "tufa stromatolite" category in his classification of stromatolites, assuming biogenic origin for them. The author also states that “modern marine examples are scarce, but heavily calcified cyanobacterial oncoids are common in calcareous lakes and streams” (Ridding 2000:196). Oncoids are formed by a combination of calcium carbonate precipitation by algae and cyanobacteria during photosynthesis and adhesion of fine grains of sediment to the mucilaginous surface of microbial mats and subsequent overturning controlled by waves, tidal currents and stream flow (Flügel, 2004, Pentecost, 2005). According to Pedley (1990), the oblate shapes, such as those observed at Unit 3, are typical of sluggish flow regimes, contrarily to highly spherical ones that form in rivers. The gravel size of sub-spherical stromatolites of Unit 3 lies within the typical diameters of 1-5 cm, enhanced by periodic overturning controlled by the flow regime (Pedley, 1990). A critical aspect regarding the concentric stromatolites of La Fragua is that they lack clear evidence of microbes within the laminae, and morphologically resemble also “soil glaebule” that occur in calcrete pedogenic horizons where there is evidence of microbial activity (Pentecost, 2005, Ridding, 2000). This aspect will be discussed later.

- *A synthetizing limpet*

A crucial element that turns out to constitute a good synthesis of all the interpretations made above regarding microbial carbonates in Unit 3 is a single calcitic shell fragment in mF type 7a, probably a limpet, with very rounded edges suggesting intense reworking as a bioclastic fragment (fig. 6.27a). The surface of this shell is incrusted by a layer of dense micrite of microbial origin, as indicated by both clotted and laminated micrite, some prostrate and erect calcified cyanobacterial filaments and even a dome structure (fig. 6.27: c, d), a typically microbial construction (Flügel, 2004). This layer is overlaid by a layer of tangled filamentous microfossils (fig. 6.27: c, d). Crusts like these over the surface of bioclasts are very common in shallow marine carbonates, corresponding to calcified microbial mats (Riding, 2000, Flügel, 2004, Scholle and Ulmer-Scholle 2003). A closer look at the same shell fragment reveals that it is densely invaded by microboring structures in the contact with the micritic layer (fig. 6.27: c, d). This suggests a direct relation of the latter with the microborings and that the limpet was incorporated as a bioclast in Unit 3 sediments already with a lithified microbial mat on its surface. A well-rounded geogenic calcite clast close to the shell in thin section, is also heavily bored and developing a micrite envelope (fig. 6.27: e, f), a diagenetic process typical of shallow-marine environments (Golubic et al., 2000) that eventually lead to formation of peloids (i.e. a completely micriticized clast) (Flügel, 2004). The evidence of intense microboring with a calcified biofilm in a marine gastropod shell constitutes strong argument to infer that these structures in Unit 3 were formed under marine influence, thus providing a source for this bioclast, as well of the rest of marine bioclasts. It must be carried in mind that the mudfats were beginning to form around Mount Buciero, bringing marine components with the tides.

One last note regarding some pedogenic features related with the carbonate sediments. One of the aspects to note is that calcifying microbial tubules from terrestrial cyanobacteria, algae and lichens are reported on calcrete horizons, as well as clotted microfabrics (Scholle and Ulmer-Scholle 2003; Flügel, 2004; James and Jones, 2015). The other aspect to note is that the concentric stromatolites, because of the absence of visible microbes, could be regarded as soil glaebules, also typical of calcrete horizons, instead of subaqueous oncoids. These alternative interpretations suggest a calcrete crust as a source for these components. However, the karstic surface right over La Fragua cave is dominated by typical exokarst *karren* features (fig. 6.1b) where the incipient soil cover does not seem to offer conditions for calcrete formation, now or in the past, that could have had direct influence over the cave. In fact, most of the soils in the area are developed on rockfall and slope deposits and are very dark and organic. For these reasons this alternative interpretation does not seem a likely hypothesis. Another pedogenic related feature observed are needle fibre and alveolar septal calcite cements, typical from fungal activity in calcium-rich soils (Verrecchia and Verrecchia, 1994, Durand et al., 2010). These features affecting a single gravel size tufa aggregate might be the result of fungi colonisation of the original tufa deposit, eventually promoted by pedogenesis as result of water table lowering, as reported by Pedley (1990).

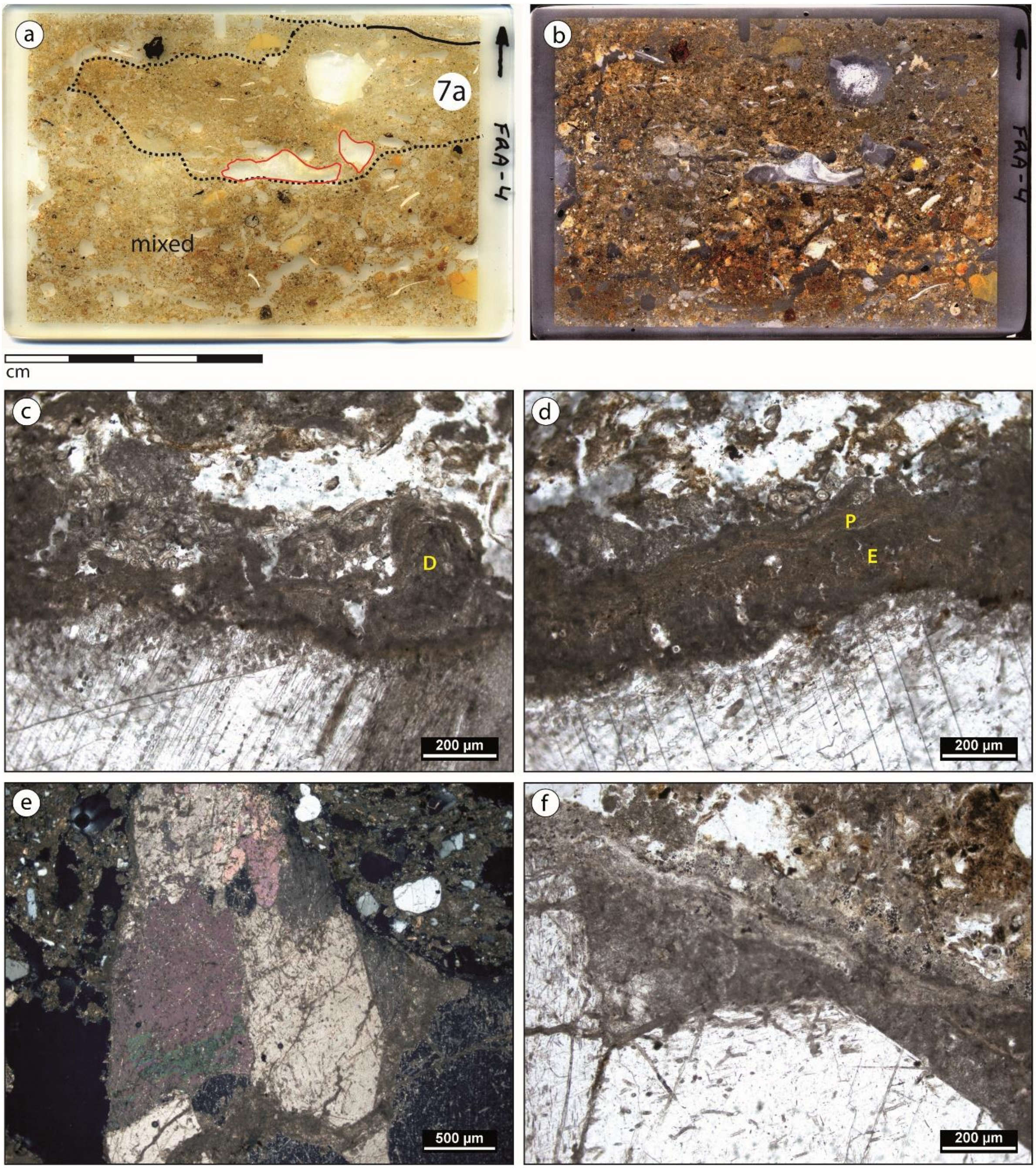



**Figure 6. 6** Lithified microbial mat and associated microboring on limpet in mF type 7: a) annotated scan of thin section from Unit 3: dark line: mF type contact; dashed line: bioturbation limit; number within white circle: mF type; red contours indicate the limpet fragment and the calcite clast referred to next. b) dark-field scan of the same thin section in a. c) and d) two different aspect of the calcified microbial mat colonising the limpet surface; note microbial dome structure (D) in c; note superimposed layers of erect (E) and prostate (P) lithified microbial forms in d; note the microbores (B) associated to subaquatic microbial perforation into the interior of the shell, some of them filled with micrite; PPL. e) calcite clast heavily affected by microboring and micritisation; XPL. f) detail of the same calcite clast in e, showing micritisation of the rim with traces of microbial filaments and microbores filled with micrite; PPL

#### 6.4.2.4 Phosphatic features

The phosphates, together with bones and the lithic artefacts, are components of Unit 3 that are considered authochtonous, i.e., incorporated to the carbonate sediments when these were already in the cave. This assumption is based in the particularly high concentration of phosphatic crusts (plate 6.22) in the upper millimetres of Unit 3 (mF type 6, see plate 6.14), that suggests a separate event of accretion of phosphatic materials over the surface of the deposit. Such event might have resulted from animal occupations in the cave and a sedimentary hiatus that allowed the concentration of phosphates at the surface. This event might be related with the Unit 2 identified in the 1990's excavations at La Fragua (González Morales, 1998, Marín Arroyo and González Morales 2007), not recognised in 2015.

Some strongly fluorescent coprolites with bone fragments (plate 6.23) could be related to the presence of carnivores. As mentioned before, birds are a likely candidate to have intensely inhabiting the cave (González Morales, 1998). All these animals were contributing to the phosphate-rich groundmass throughout Unit 3, like the nodules and void fillings (plate 6.23) that might correspond to secondary apatite from bone dissolution (Karkanas and Goldberg, 2010a), but the similar features have been related to bird guano (Mallol and Goldberg, 2017). Furthermore, the granular and fibrous phosphatic crusts (plate 6.22), by its strong colours in PPL, spongy texture and association to plant material, amorphous and humified organic matter (plate 6.22: a-d), also appears to be similar to bird guano deposits described in previous works (Karkanas and Goldberg, 2010b, Karkanas and Goldberg, 2010a, Mallol and Goldberg, 2.17).

#### 6.4.2.5 The formation of Unit 3: synthesis

Based on the evidences discussed above on Unit 3 sediments and their micromorphological aspects, it can be concluded that Unit 3 is a polygenetic deposit that went through an intense history. The groundmass is utterly different from the sediments that accumulate mainly by natural processes in Unit 4, and yield polygenetic material like marine bioclasts, glauconite, carbonate algal mud and relict fragments of tufa, all probably mixed in the cave, given the different sedimentary environmental origins. The striking abundance of phosphatic features associate to bird guano raises the hypothesis of birds having played a major role in the accumulation of estuarine components in the cave, in particular swallows, that use considerable amounts of mud to build nests. As recently noted by Mallol and Goldberg (2017), swallow nests once abandoned fall from the cave roof/walls where they were built and become incorporated in the cave sediments. It remains questioning this hypothesis the fact that swallows' nests are composed by mud pellets considerably coarser than any sand-size peloids observed in thin section. It would be expectable to find remains of such pellets, which was not verified in thin section nor during excavation. Another factor hampering a straightforward interpretation of the origin of this layer in bird nesting is the absence of eggshell fragments, which should be expected to observe in thin section.

Apart from birds, we could hypothesise humans as responsible for the transport of bioclastic mud to the cave. There is no apparent purpose for bringing such amounts of mud from the salt marshes up to the cave, or at least there is insufficient data to advance such a purpose. But there is the hypothesis of estuarine components being a by-product of some other activity, for instance, gathering of molluscs or wetland plants that would have been processed in the cave. Estuarine molluscs consumption does not seem to be a major activity during this phase in the cave, considering that most molluscs are comminute fragments of land snails or small non-edible small specimens of gastropods (Gutiérrez-Zugasti, 2009). The only marine mollusc clearly identified in thin section is the well-rounded fragment of limpet that most probably came as a sandy bioclast along with the rest of marine bioclasts, as seem to indicate the microbial mat growing on its surface, mentioned above (section 6.4.2.3) The gathering of wetland plants (reeds or sedges) could also explain the presence of estuarine seidments, transported to the cave attached to the roots of such plants, and this hypothesis seems to be supported by some of the porosity of the sediments in thin section that resembles moldic pores that mimic the shape of grassy plants after its decay (table 6.3, plate 6.16: c, d; 6.21: b-e;) Some articulated phytoliths embedded in the carbonate mud (plate 6.17h) also indicated the presence of grassy plants. This hypothesis will be addressed again regarding the combustion features of Unit 1. Overall, human influence in the transport of carbonate mud from the mudflats to the cave is on the table and needs further investigations.

Despite the groundmass of Unit 3 indicating different sources (reworked tufas and probably estuarine environments) , it contains components like limestone clasts, lithics, bones and charcoal. These components should have been mixed with the carbonate groundmass once it was already in the cave floor, while humans promoted its dispersion together with anthropic components. The horizontal plane voids and some *in-situ* crushing of components of mF domain 7a (plate 6.17) suggests structural compaction of the deposit as effect of repeated trampling (Rentzel et al., 2017, Aldeias and Bicho, 2016), reinforcing the hypothesis of humans being involved on the dispersal of the carbonate-phosphatic mud, modifying it.

The fact that the granular phosphates with abundant humified plant fibres, and phosphatic crusts are concentrated at the upper millimetres of Unit 3 is a major factor of differentiation of mF type 6 in relation to mF type 7. It suggests that this layer was an exposed surface where guano accumulated during occupations of the cave by birds. Some previous works report that the upper millimetres of trampled surfaces tend to be microgranular (Miller et al., 2013, Rentzel et al., 2017), which is the case of mF type 6, which would explain the disrupted phosphatic crusts from possible ephemeral stable surfaces nearby and subjected to posterior modification by the humans that came after the birds occupy the cave. However, this “surface” is also the combustion substrate of a hearth that was lit over it, (see section 6.4.3 below), resulting in visible reddening (fig 6.20: a, b; 6.22: a, b). This combustion feature reveals some interesting aspects of continuity with Unit 3, that will be discussed below.

### 6.4.3 Unit 1: The Mesolithic Shel Midden and Combustion Features

Unit 1 is a succession of stacked combustion features, rich in shells, that were not homogenously distributed in the excavated area for the multidisciplinary sampling in 2015. The micromorphological block was collected where the bigger number of lenses was preserved, corresponding to the border of more discrete and well delimited layers, usually not thicker than about 1 cm (plate 6.3c). The central area of these deposits and main area of activity would develop toward the area where a trench dated to the Chalcolithic was opened (plate 6.3a), that must have destructed that record. Following Mallol et al. (2017), the study of this succession of combustion layers will combine the microfacies concept with specific observations regarding the evolution of the combustion to reconstruct their formation and functionality.

#### *6.4.3.1 Products of combustion*

The combustion products present in all microfacies of Unit 1 are rubified soil aggregates, burnt bones, char, phytolith slag, ashes, burnt mollusc and echinoid shells. Burnt calcareous bioclasts inherited from the carbonate mud (filamentous microfossils, foraminifera and red algae) are also present in all layers in lesser amounts, except in those corresponding to mF type 5, where their presence is significative, associated to charred fibrous plant material.

This carbonised plant material responds to different patterns. It is the main component of mF type 5, and wood charcoal is overall rare, except in mF type 2. Ashes also show differential characteristics. In mF types 1 and 4 they preserve few aggregates with articulated pseudomorphs, but in general the fine-grain microstructure is open (plate 6.10, 6.17). In mF type 2, there are no articulated ashes, whereas in mF type 3, large pieces of completely ashed plant tissue are still preserved (plate 6.11, 6.16).

The distribution of shells in relation to their burning degree is also different between layers (table 6.4). Complete shells have a significant presence only in mF types 1 and 2 and show little signs of heating alteration (almost no alteration or only with some patches or bands micritised), whereas only small (up to 1 cm) fragments of shells are present in all mF types, and those systematically present evidence of burning at higher temperatures (cracks between growth bands, micritization and calcination) (Villagran, 2014a, Villagran et al., 2011a, Aldeias et al., 2016). The reason or this systematic pattern might be significant. Experiments have demonstrated that shellfish cooking demands very low temperature (refs). Such low temperatures (i.e., between 100 and 200 ºC) generally do not promote any optically visible changes in the shells (Aldeias et al., 2016, Villagran, 2014a). The fact that complete shells at La Fragua do not show alteration by heating could be indicating they were discarded right after cooked (and left empty) and did not underwent any further significant re-heating or fragmentation. On the other hand, smaller shell fragments that systematically show heating at higher temperatures (from 200 ºC up to 700 ºC (calcination threshold) at least – see (Aldeias et al., 2016 and Villagran, 2014 for temperature values references) probably are remnants of shells that underwent successive re-heating and became fragmented over time and incorporated in successive combustion substrates. Regarding this inference, the shell distribution in relation to its fragmentation and heating degree constitutes a highly significant aspect in the interpretation of these combustion features.

Burnt soil aggregates are ubiquitous although heterogenous, and despite rubified, the difference between the original b-fabrics (undifferentiated or striated), the same observed in not-heated soil aggregates in Unit 3, is still recognisable in some cases (plate 6.1: e, f). The burnt soil aggregates present some sorting in some layers. In mF type 1 there are many gravelly examples (plate 6.10: a, b), while in mF type 3 there is a higher concentration of silty/fine sand rubified grains (plate 6.12: a, b). Concerning phytolith slag, its presence evidences high temperatures of combustion (Mentzer, 2014), but its distribution in Unit 1 layers seems random. Bone is overall rare, but the fragments observed are generally heated.

#### 6.4.3.2 Microstratigraphy, fabric and structure of combustion

The open microstructure of the ashy groundmass mF types 1, 2 and 4 and the mixing of burnt and unburnt shells suggest that those materials are in secondary position. However, different degrees and agents of reworking can be inferred.

For the case of mF type 1, the elements pointing to reworking of the material are shell are, for instance, articulated plant pseudomorphs confined to a closed space inside a gastropod shell (plate 6.10: d, e), a capping of not burnet organic sediment around a limpet (see fig. 6.30a, mF 1), and a large worm biospheroid embedded in the groundmass (with internal cracks and recrystallizations, suggesting it was burnt; plate 6.9a). The matrix is almost pure ash, which could be indicating that these materials came from features where combustion was complete. This layer corresponds to the most surficial ashy layer in the sequence of Unit 1, with about 5 cm of average thickness. The heterogeneity and wide range of grain size of inclusions, general high inter-particle porosity and absence of rubified substrate points to an anthropogenic ash dump deposit (Mallol et al., 2017).

The discriminating factors of mF type 2 are the inclusion of coarse pebbles and abundant wood charcoal and the dusty appearance of the ashy matrix, due to the enrichment in fine organic matter (plate 6.11; 6.30, mF 2). These aspects and the mixing of burnt and unburnt components (plate 6.11: c-e) suggest the dumped material came from reworking of combustion features where the combustion was not complete and produced essentially charcoal.

Regarding mF type 4, it differs from mF types 1 and 2 for the absence of the coarser components such as complete shells, pebbles, charcoals and soil aggregates. The shells are millimetric fragments and exhibit varying degree of burning, being only a few of them calcined and charcoal is rare and comminute. Carbonised plant tissues are very rare, although poorly preserved articulated phytoliths and pseudomorphs occur (plate 6.4: a, b). The preservation of such fragile components makes us think that mF type 4 is more likely result of little reworking of combustion products, perhaps by rake-out from the centre to the periphery of the combustion structure. According to experiments (Miller et al., 2010) raking of combustion features result in particle sorting, which might explain the absence of coarser objects in this deposit, that remained in the central part of the hearth. The rubified substrate underlying the deposit (fig.

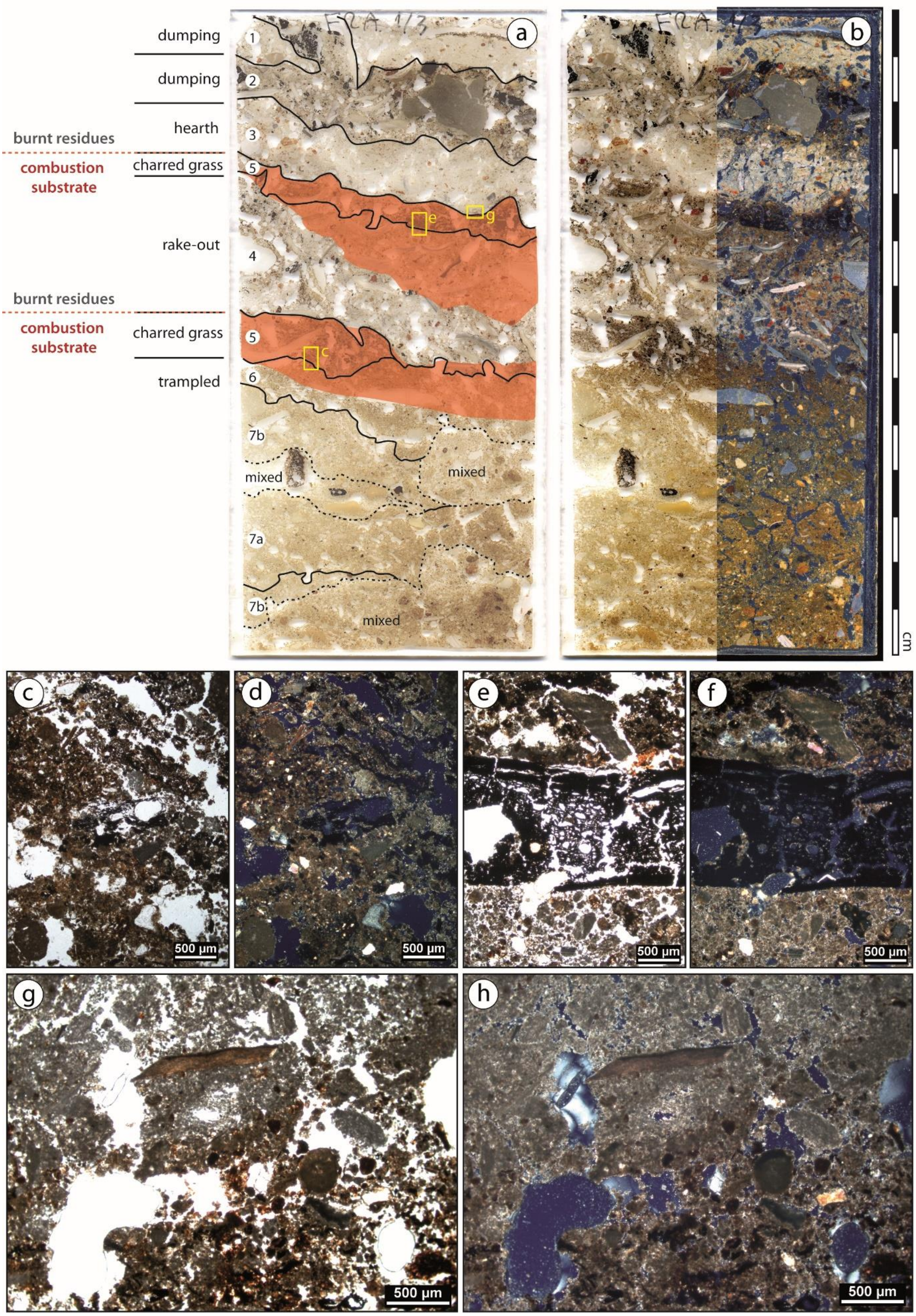

dumping
dumping
hearth
burnt residues
combustion substrate
charred grass
rake-out
burnt residues
combustion substrate
charred grass
trampled
1
2
3
5
4
5
6
7b
mixed
mixed
7a
7b
mixed
a
b
c
d
e
f
g
h
cm
500 µm

**Figure 6. 7 (previous page).** Synthetic reconstruction of the formation processes of units 1 based on the microfacies approach combined with the combustion substrates delimitation: a) annotated scan of thin section comprising units 1 and 3: dark lines: mF types contacts; dashed lines: bioturbation limits; numbers within white circle: mF types; red shade: combustion substrate extension; yellow rectangles: areas represented in the indicated next images. b) same thin section as a, in normal and dark-field scans; note high contrast produced by ashy layers. c) and d) contact between mF6 (below) and mF 5 (above) showing the strong difference between the phosphatic matrix of the former and ashy matrix of the latter, where fibrous charred organic matter is also visible; PPL and XPL, respectively. e) and f) contact between mF 4 (below) and 5 (above); a small woody charcoal is visible, separating the ashy matrix of mF 4 from the organic-rich matrix of mF 5; PPL and XPL, respectively. g) and h) contact between the rubified combustion substrate in mF 5 (below) with the combustion residues of the *in-situ* hearth mF 3; PPL and XPL, respectively.

6.7) corresponding to mF type 4 also points to little reworking, possibly by rake-out rather than dumping (Mallol et al., 2017).

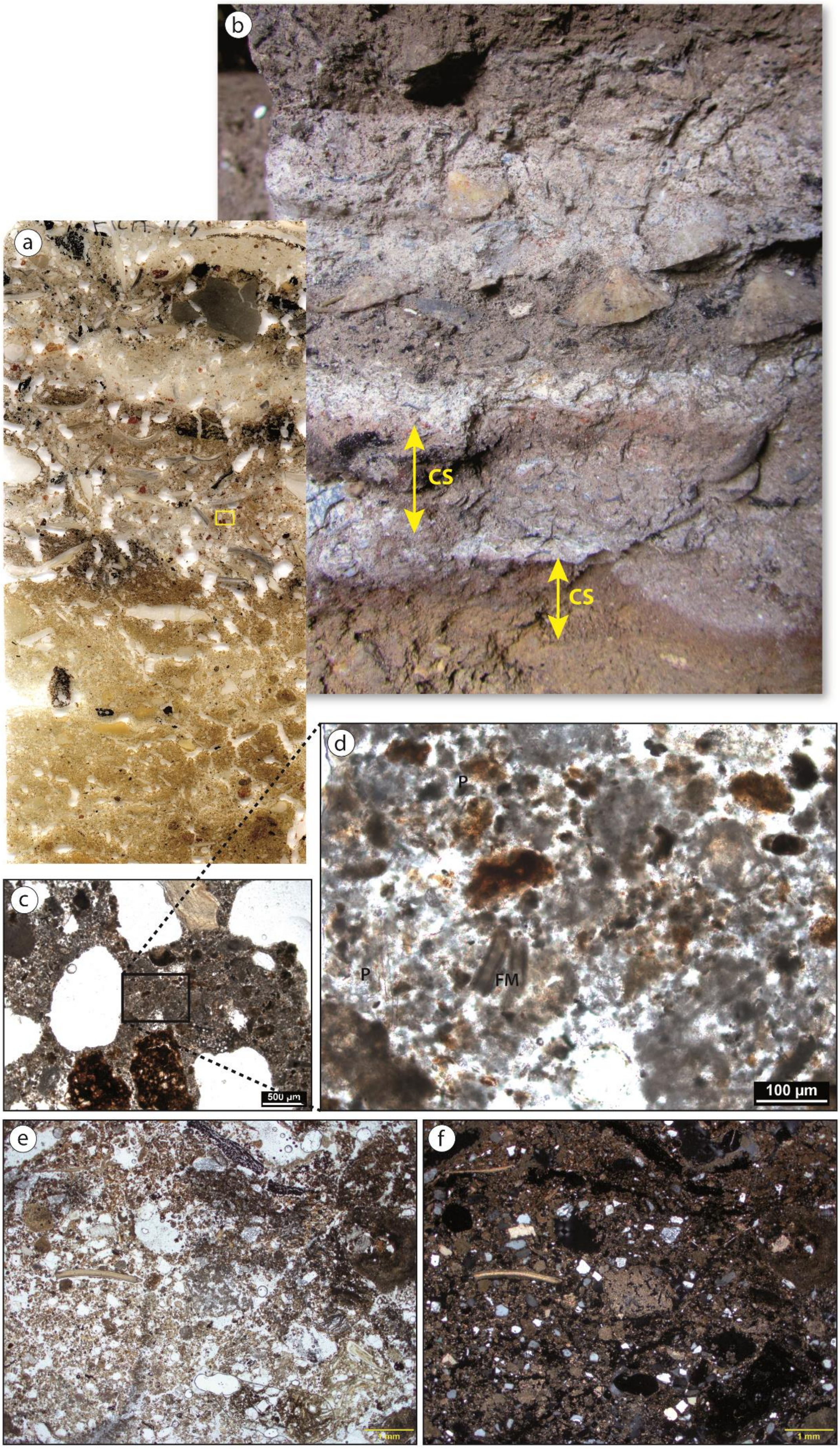
The mF type 3 is distinctive because of the particularly good preservation of ashes, showing lamination of ash pseudomorphs and large plant tissues preserving anatomical structure replaced by micritised pseudomorphs (plate 6.12), which suggest they are burnt residues in primary positions (Mentzer, 2014, Mallol et al., 2017). Furthermore, in mF type 3 all shell fragments are totally calcined, which suggest that temperatures above 700º C homogenously affected the layer (plate 6.12: a, b).

Lastly in what concerns to individual layers in Unit 1, is mF type 5, corresponding to the black layers in this sequence of stacked combustion features. The laminated stringers of organic matter that composed mF type 5 point to the existence of grassy material subjected to humification, as indicated by its reddish colour, similarly to those reported by Goldberg et al. (2009) and to burning, since it is charred and given the presence of some ash rhombs and few charcoals in these layers (plate 6.14). This fibrous charred organic matter is closely mixed with potentially estuarine components (filamentous microfossils, foraminifera, sponge spicules and red algae) and all present micritization or recrystallization, indicating they also were subjected to burning along with the grassy material (plate 6.14). The association to estuarine sedimentary components might suggest the ignition of mats formed by grass gathered from the wetlands, i.e., reed or sedges, similarly to the interpretation of Goldberg et al. (2009) in concern to the presence of aggregates from the river valley next to the site of Sibudu in the layers of fibrous organic matter. This aspect leads us again to the hypothesis of collection of wetland grasses as a possible reason for the presence of such exogenous components in the Mesolithic sediments.

Significant elements for interpretation of combustion at La Fragua are those expressing rubefaction. The coarser rubified soil aggregates (plate 6.1: e, f) are thought to have been reworked into the combustion features (Mentzer, 2014, Mallol et al., 2017) and the silty and fine sandy reddish particles are interpreted as iron oxides formed in-situ (fig. 6.31d), possibly hematite (which needs future confirmation), and mark *in-situ* combustion substrates (Mallol et al., 2017). In the thin sections of Unit 1, it becomes clear mF type 5 is systematically associated to rubified substrates (fig. 6.30). In turn, rubified substrates systematically underlie ash layers that present evidence of being intact (mF type 3) or almost intact (mF type 4) but in bot cases are intercalated by a black layer, corresponding to mF type 5 (fig. 6.30, 6.31). This rubefaction process affects substrates of different nature. The lowermost one is affecting the upper centimetre of the carbonate-phosphatic sediment of Unit 3, in the contact with Unit 1, with a layer of mF type 5 (fibrous charcoal) in the middl e (fig. 6.30: a-f). The other instance of rubified substrate is underlying mF type 3 (in-situ ash) and affects mF type 4 (little reworked ash) that macroscopically has a pinkish-white colour (fig. 6.30: g and h).

As said above, mF type 5 (black layer) is always associated with the contact between rubified substrates and ash layers, which at this point might have two interpretations. One possible interpretation is that the grasses belong to the to the burnt residues, and in this case the fibrous organic matter would constitute the fuel (Mentzer, 2014, Mallol et al., 2017). This hypothesis would imply one of (at least) two situations: i) the black layer and overlying ash layer result from the same combustion event but reducing conditions were maintained in

**Figure 6. 8 (next page).** Documentation of two in-situ combustion features judging by the presence of combustion substrates: a) scan of thin section comprising units 1 and 3, placed and scaled to fit the profile detail in b. b) field photograph of detail of the sampled profile where the microstratigraphy can be observed; the thickness of the combustion substrates (CS) is indicated with double arrows; for further reference see fig. 30a. c) microphotograph corresponding to the yellow rectangle in a, showing the bioturbated channel microstructure with two rubified soil aggregates at the bottom, in mF type 4, that is this area is rubified; PPL. d) close-up on the central area represented in c, where the fine-grained iron oxides possibly formed during combustion are finely mixed with the ash that served as combustion substrate; note the presence of articulated phytoliths (P) and micritisized filamentous microfossils (FM); PPL. e) and f) combustion substrate affecting the surface of the carbonate-rich sediments of Unit 3, in mF type 6 and 7; note the material becomes increasingly reddish towards the top, as phosphates and charcoal appear, and abundance of quartz grains decreases; PPL and XPL, respectively


b
a
CS
CS
c
500 µm
d
P
P
FM
100 µm
e
f
1 mm

the lower part causing only charring of the organic matter and few ash, while oxidizing conditions were reached in the complete combustion of the upper part of the fuel accumulation; or ii) the black layer and the ash layer belong to different overlapped fires where different combustion temperatures were reached.

Another hypothesis is that the black layers correspond to organic material that was in the surface before the combustion, belonging then to the combustion substrate, that became charred as effect of the fire over it. In this case, mF type 5 reflect previous activities predating the combustion event (Mallol et al., 2013), that would the imply the accumulation of grasses. Phytoliths and charcoal analysis would help in corroborating or not this hypothesis. From a microstratigraphic point of view, this is reasonable to admit as the most likely hypothesis, because the mF type 5 is in fact not only underlied, but also overlied by rubified sediment, as is it can be clearly observed both in the field and in thin section (fig. 6.31). Mallol et al. (2013) already observed this phenomenon in an experimental fire on wet ground that resulted in a substrate with reddened and blackened patches. Their observations on that pattern furthermore indicate that the organic matter "*contained in the black patches is fire-altered while that in the reddened patches is not. A possible explanation for this pattern is that the soil moisture content was not homogeneous*" (Mallol et al. 2013, p. 2536-2527).

#### *6.4.3.3 Diagenesis*

Diagenetic effects are generalised in Unit 1 ashy deposits and consist in cementation and recrystallisation and decalcification of ashes, as well as locally phosphatised ashes, identified by patches of cloudy appearance and replacement of the carbonate by isotropic, amorphous brownish material (plate 6.5; 6.24: e, f). A well representative example of varying conditions of carbonate depletion and reprecipitation is a highly altered phytolith slag in mF type 1, that shows an inner hollow of secondary carbonate precipitation, and organic staining in the outer rim (plate 6.9: a-b), which denounces several phases of carbonate precipitation and dissolution for which it went through.

#### *6.6.3.4 Synthesis: reconstruction of the combustion functionality in thin section*

The earliest combustion event is documented by the rubefaction of the surface of Unit 3, a deposit that despite composed of polygenetic microbial/algal carbonate accumulated naturally, that was subjected to trampling by humans, according to the reasons described in detail above (section 6.6.2.5). That combustion seems to be related with the burning of grassy material in the surface, which is hypothesised to belong to reeds or sedges collected in the surrounding estuary giving the incorporation of sedimentary components originally from such environment that are observed in these specific contexts. This activity could be related to site maintenance purposes, based on similar features previously reported (Miller et al., 2013, Goldberg et al., 2009). Some remnants of the ash layer overlying these charred grasses might be preserved in the form of the poorly preserved articulated pseudomorphs and phytoliths, but the overall ash deposit on top of it seems to correspond to reworked combustion products from nearby hearth, possibly by rake out. A new accumulation of grasses was placed over the disturbed ash layer and together they undergone carbonisation and rubefaction as substrate of a new combustion feature, an open hearth that reached temperatures above 700 ºC that cause calcination of all shell’s fragments within it. The burnt residues of this hearth (basically ash) remained intact and its good preservation might indicate it was exposed for short period of time, being buried by a dumped deposit of several combustion products in secondary position, rich in charcoal, pebbles and other heterogenous coarse components. A new ash dump would be placed over the sequence.

## 6.5 Conclusion

The micromorphological study of La Fragua allowed to reconstruct formation processes of an important Pleistocene-Holocene transition sequence. Despite the transitional contact was impossible to sample, the study of the Pleistocene deposit revealed essentially natural dynamics in the sedimentation, dictated by cycles of climatic freezing and amelioration, homogenised by post-depositional biological activity. The embedding of both animal (particularly birds) and human inputs in the sedimentary matrix reinforce that these is an accretionary palimpsest of low sedimentation rate reworking materials located towards the cave mouth, that was possibly a few meters ahead of its current position.

The Holocene deposits revealed, on the other hand, an essentially anthropogenic origin marked by stacked combustion features. A hypothetical reconstruction of the formation of the overlapped combustion features was possible based on the micromorphological observations that allow to infer the functionality of each deposit. The analysis of the distribution of the combustion products of Unit 1 allowed for the establishment of layers corresponding to burnt residues and combustion substrates, and therefore which layers are in primary or secondary positions.

The combustion substrates revealed to be rich in fibrous charred organic matter with intertidal microscopic components finely mixed, which suggest the presence of wetland grasses in the surface where the combustion took place. Wetland grasses could be brought to La Fragua cave for multiple purposes, for instance, the making of fishing nets or other fabrics (see, e.g., (Robson et al., 2016). Intentional grass beds are unlikely because there is little evidence to support such constructions, for instance, layers of articulated phytoliths are lacking. It seems more plausible that grasses were accumulated in the occupation surface as result of other activities. This hypothesis could be tested with the anthracological analysis of the fibrous charcoal and for instance by applying use-wear analysis to the shells and lithics associated to the respective layers, that could reveal or not its use to work grasses. The confirmation of this hypothesis would help in understanding the reasons the seasonal visits to the cave, according to Marin Arroyo and González Morales 2007, and the site functionality in the framework of the regional Mesolithic. Finally, the results from La Fragua indicate that extending micromorphological studies to other finely stratified shell midden sites in the Asón estuary (e.g., Peña del Perro, La Chora cave) has great potential in understanding regional settlement dynamics during the Mesolithic.

Chapter 7

# El Mazo

## 7.1 Introduction

The main purpose of the application of this methodology at El Mazo was to unravel the microstratigraphic organisation of this intricately stratified shell midden, the only one of the few in the Asturian context presently object of excavations. At the same time, a cemented shell midden remnant hanging from the rockshelter ceiling was also sampled for micromorphological analysis to establish a microcontextual approach in the correlation between both contexts.

### 7.1.1 Geological and Archaeological Context

El Mazo rockshelter is at 900 m. southeast of the village of Andrín, administratively located in the council of Llanes. The site was discovered in 2006 by M. R. González Morales and I. Gutiérrez Zugasti, who launched a project that has allowed archaeological fieldwork at the site since 2009 (Gutiérrez Zugasti et al., 2014, Gutiérrez-Zugasti and González-Morales, 2014, Gutiérrez Zugasti et al., 2013).

El Mazo is a large rockshelter, approximately 18 m. long and 7 m. at the deepest point from the dripline, oriented to East. The site has an altitude of 38 m. above the sea level and lies at 1 km. from the nearest point of the coast, at the Andrín beach, and at only 600 m. west from the small brackish inlet where the the Purón river drains to (fig. 7.1). The neighbouring

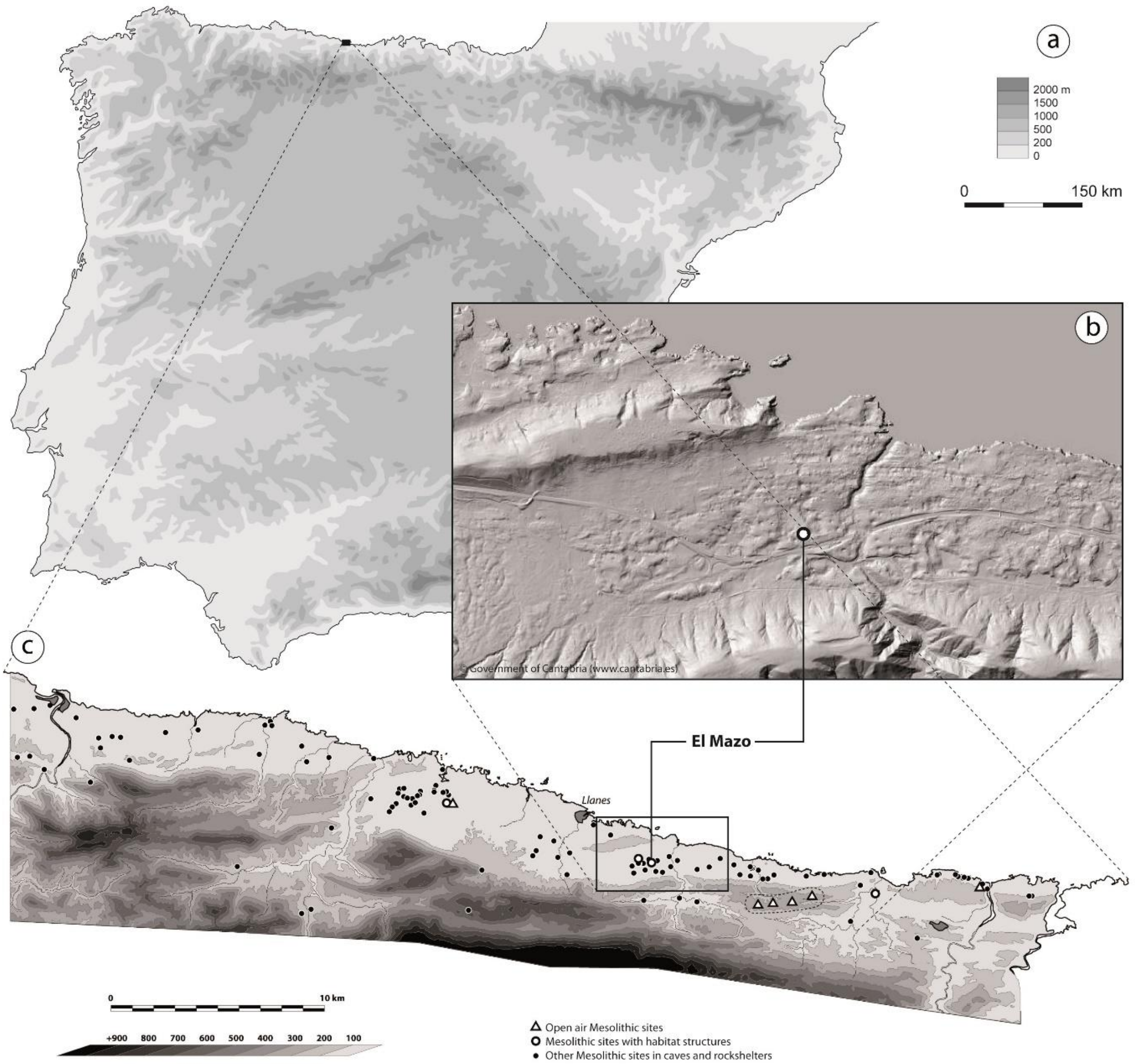



**Figure 7. 1** Geographical and geological setting of El Mazo rockshelter: a) location in eastern Asturias in the in the northern coast of Iberia. b) location of EL Mazo (circle) and surrounding topography; note the accentuated karstic features in the limestone massif where the site is located and the small canyon of the Purón river; map source: Gobierno de Cantabria. c) The topographic environment of the coastal area of the territory of Llanes municipality; map source: Mapa Geológico Continuo Digital de Asturias 1:50.000 (GEODE), IGM and Principado de Asturias.

coastline is very irregular, characterised by rocky coves and sand beaches and the littoral platform is marked by karstic geomorphological features such as abundant karren fields and sinkholes (fig. 7.1). In fact, the rockshelter itself is located on the northwest border of a large sinkhole, with approxima tely 80 m. of diameter and 15 m. deep.

Presently, the surface of the rockshelter describes a steep slope going down from the dripline toward the shelter’s wall (fig. 7.2), and at the deepest point there is the exiguous entrance to a small cave. The excavation of the six square metres (fig. 7.2) in the north area of

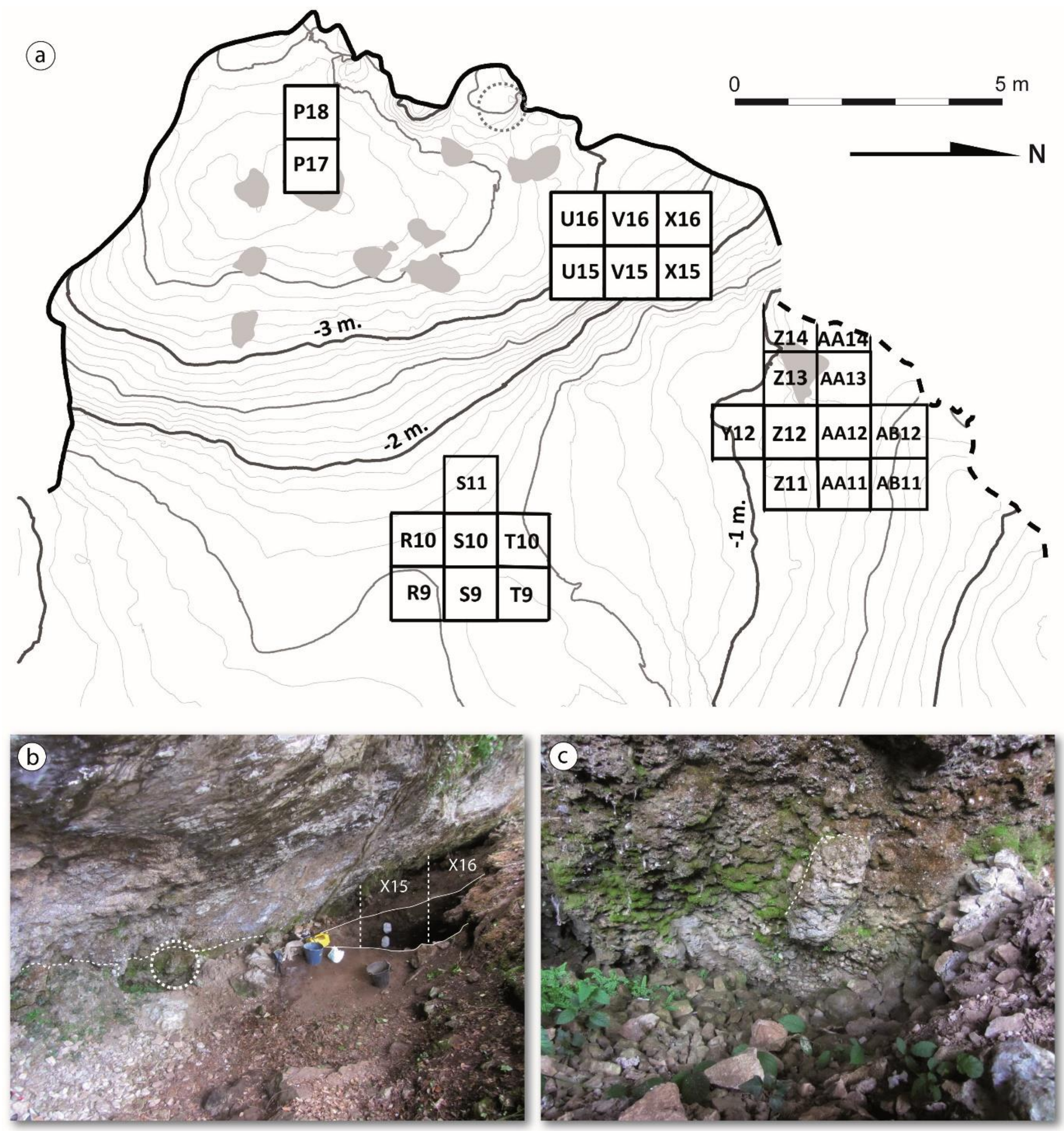



**Figure 7. 2** El Mazo rockshelter: a) plan with indication of the excavation areas; b) view from southeast towards the squares X15 and X16, where the micromorphological samples where collected; dashed circle, as in a, indicated the location of the cemented shell midden remnant that was sampled for micromorphology; c) detail of the cemented shell midden protuberance (dashes line) that was collected, hanging from the rockshelter ceiling.

the rockshelter revealed that the slope corresponds to the Mesolithic shell midden that yielded an intricate stratigraphy plenty of interfingering shell-rich lenses and discordant contacts between layers (fig 7.3). The shelter's wall, in fact more a ceiling giving its inclination, also preserves typically Asturian hanging shell-rich cemented remains (fig. 7.2). It is not possible to observe a physical connection between the stratified shell midden and the cemented remains in the shelter ceiling, but its presence has been suggested to allow envisioning the original volume of the shell midden (Gutiérrez-Zugasti and González-Morales, 2014).

The fact that El Mazo preserves such a fine record of a stratified Mesolithic shell midden makes it the only site offering such conditions presently available for archaeological excavation in the current investigation on the Asturian Mesolithic. Nonetheless, other stratified and not cemented shell middens have been documented in past investigations, namely Mazaculos II (González Morales, 1982), Poza L'Égua (Arias et al., 2007) and El Toral III (Noval, 2007). None of them, however, revealed such a complex stratigraphic record as El Mazo. Therefore, this is a prime context for conduct micromorphological analysis to address the questions that remain unanswered regarding the formation processes of the Asturian sites, namely to assess the integrity of layers that appear to be combustion features or to understand the nature of the different sedimentary matrixes observed in the lenses and what could they mean in terms of formation processes and use of space.

### 7.1.2 Stratigraphy and chronology

The excavation of a 2 m. wide area in the shell midden of El Mazo exposed another two metres deep archaeological deposit. This deposit is composed by eigth major shell midden stratigraphic units (100/101, 102, 103, 103.1, 104, 105, 106 and 107) and some of them revealed lateral variations of sedimentological character or very discrete and localised depositional events that lead to the discrimination of further sub-units as the excavation areas was being enlarged.

Remarkable elements in this complex stratified shell midden deposits are carbonate crusts (102 and 106), a stone-structured fireplace (104) and rubified clay and charcoal lenses (103), possibly corresponding to combustion features, always with a predominance of shells over the matrix. Only unit 105 revealed the opposite, i.e., a predominance of sediment over the shells. Finally, a basal, unit 108 constitutes the base of the shell midden and still contains archaeological material including abundant shells (García-Escárzaga et al., 2015).

Radiocarbon dating from several samples revealed a Mesolithic chronology for the whole deposit, coherently distributed throughout the sequence, with dates of the end of the seventh millennium cal BC at the base (unit 107, sub-unit 114) and progressively younger towards the mid-sixth millennium cal BC at the surface (Gutiérrez-Zugasti et al., 2016).

## 7.2 Sampling strategy and analysis

The stratified shell midden at the East profile of the squares X15 and X16 (fig. 7.2, 7.3), was object of a selective micromorphological sampling, targeting interesting stratigraphic contacts and covering the entire diachronic sequence (fig. 7.3). From this profile, seven samples were collected (MAZ.1 to MAZ.7) with pre-plastered bandages. Two large (13.9 x 6.7 cm) thin sections partially overlapping were obtained from each block sample, except for the sample MAZ.5, which impregnation was complicated and was not possible to thin section at the time. The thin sections were numbered sequentially from bottom to top, so the upper thin section from sample MAZ.3 was called MAZ.31 and the lower thin section MAZ.32 and so on. For the analysis of the profile X15/16 samples, a microfacies approach was applied (Golberg et al., 2009).

The optical study of thin sections was carried out under polarizing petrographic microscopes at the DCIYTM and at the Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany, which allowed magnifications between 400x and 20x. The micromorphological analysis followed the criteria established by Courty et al. (1989) and Macphail & Goldberg (2017) recurring also to Stoops (2003) and Bullock et al. (1987) terminology and Goldberg and Aldeias (2016) recommendations. The microfacies approach was applied as preconised by Goldberg et al. (2009) and largely based on Flügel (2004) for carbonate materials, for which terminology of Pentecost (2005) was also followed.

## 7.3 Results

The clastic components and fine fabric sedimentary materials identified at El Mazo thin section from profile X15/16 are combined in such a variety of ways, that yielded a high number of microfacies (twenty-five). For managing the information provided by such array of possible combinations and frequencies of the sedimentary materials, the microfacies (mF in the text) were divided in broad groups based on general geometric arrangements.

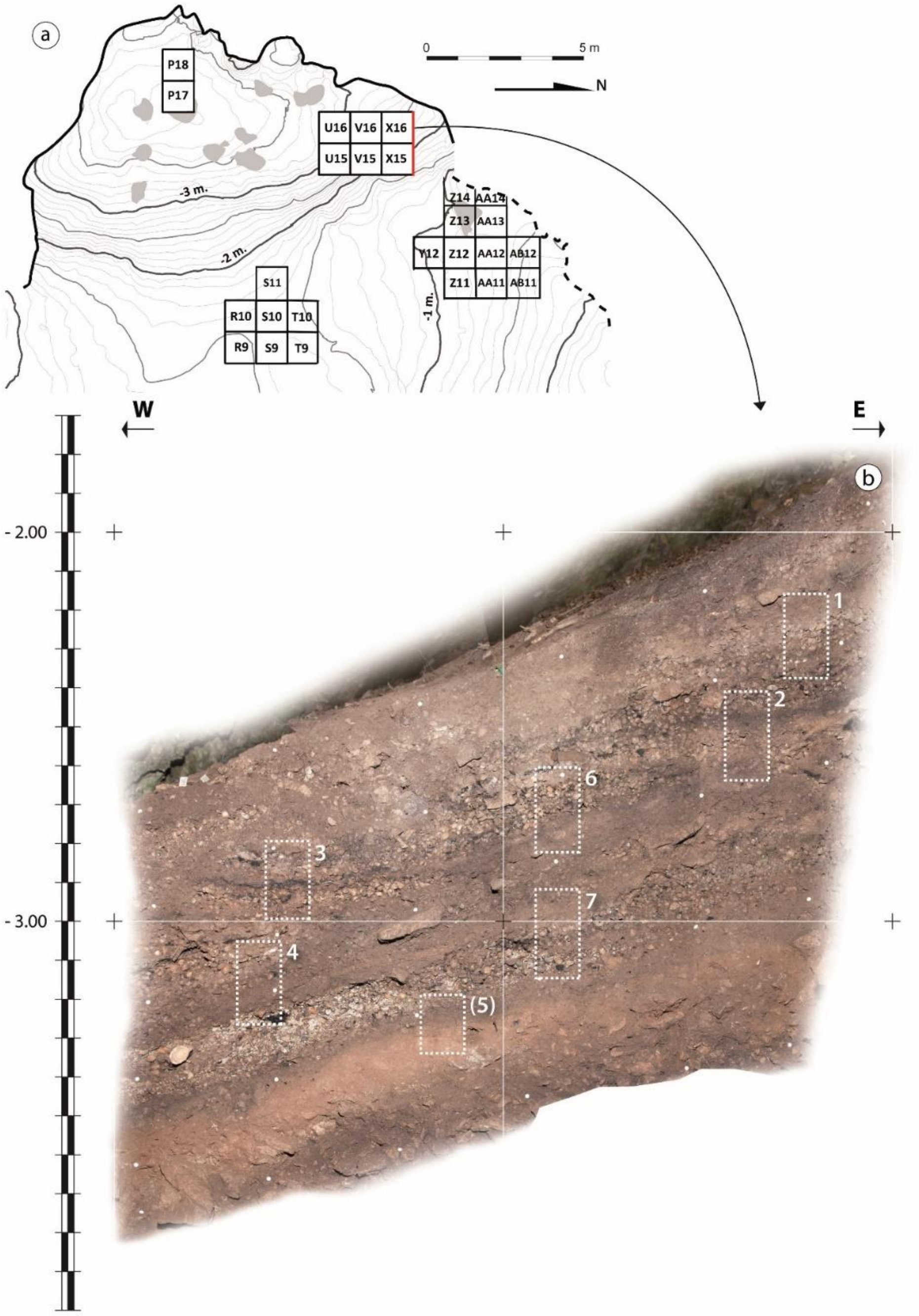



**Figure 7. 3** Micromorphological sampling at El Mazo shell midden: a) location of the sampled profile in the site plan (red line); b) stratigraphic profile of squares X15/X15 with location of the 7 collected samples; note the slope dominating in the deposits and the interfingering of shell-rich lenticular layers**.**

The following sections will focus on the micromorphological description of clastic and fine sedimentary components, the thin sections following a microfacies approach. Finally, the microfacies were grouped into categories for helping in infer the processes responsible for the formation of each one.

### 7.3.1 Clastic Sedimentary Components

The main sedimentary components identified at El Mazo thin sections are listed and described in table 7.1, where genetic interpretation and representative microfacies are also indicated. The main sedimentary component are top shells (genus *Phorcus*), limpets (genus *Patella*) and sea urchins, or echinoids. Other anthropogenic components are charcoal, bones and fishbones, usually not above 5% frequent in thin section. Ash is common and main micromass constituent of some microfacies. Components like rubified soil aggregates, foraminifera (as well as other less common marine microfossils) and serpulids are considered non-intentional products of anthropogenic activities. Seaweed, specifically coralinaceae (calcareous red algae, or rhodophytes), are commonly observed, specially concentrated in sample MAZ.2. Natural inputs to the sediments are biogenic material, being the most common calcitic biospheroids, and geogenic material from the rockshelter wall and ceiling, namely limestone pebbles and tufa fragments.

**Table 7. 1** Main sedimentary clastic components identified in thin sections from El Mazo.

| Component | Description | Main mF | Interpretation |
|---|---|---|---|
| Gastropods – *Phorcus sp.* | Top shells are dominant at the site, self-supported in some microfacies. Complete sections are usually unburnt whereas fragments are usually burnt or calcined. | Self-supported: 2, 5, 24. Other: 8, 10, 11, 14, 15, 16, 18, 19, 20, 21, 22, 23. Fragments: all. | Human consumption of shellfish |
| Gastropods – *Patella sp.* | Limpets are dominant at the site, self-supported in some microfacies. Complete sections are usually unburnt whereas fragments are usually burnt or calcined. Some limpets present incrusting seaweeds, serpulids and foramifera. | Self-supported: 4, 10, 16, 18. Other: 2, 5, 8, 11, 14, 15, 20, 21, 22, 24, 25. Fragments: all. | Human consumption of shellfish |
| Echinoids (sea urchin) | Sea urchins have heavily calcified, globular to discoidal, hollow, endoskeletal tests that are composed of individual sutured, interlocking or | Self-supported: 7, 9. Other: all. | Human consumption of shellfish |

| | | | |
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| | imbricated calcite plates. Each plate behaves optically as a single, extensively perforated, calcite crystal and displays unit extinction. Echinoid spines have pores arranged with radial symmetry that in cross-sections, have a distinctive lobate or flower-like appearance. (Scholle and Ulmer-Scholle, 2003). All echinoid shells are fragmented plates. Many echinoid shells and spines are burnt or calcined (micritized). | | |
| Rubified soil aggregates | Silt to fine gravel size aggregates with reddish dark clay, low birefringence, sometimes with plain voids (cracks) with 2% quartz silt and fine sand grains, angular to rounded. | 1, 2, 3, 10, 13, 18, 19, 20, 22, 23, 24, 25. | Silty clay aggregates from the surroundings of the rockshelter more or less heated due to exposure to fire. |
| Charcoal (wood) | Sand to gravel size pieces which woody cellular structure is generally well preserved. | 1, 2, 3, 6, 8, 9, 10, 11, 12 13, 14, 16, 18, 19, 20, 21, 22, 23, 24. | Anthopogenic combustion activities |
| Ash | Ashes in the form of rhombic, micritic pseudomorphs of calcium oxalate crystals (Mentzer, 2014). Depending of the microfacies, their preservation varies from very-well preserved, articulated ash rhombs, to locally decalcified or phosphatised, to cemented. | 1, 4, 10, 11, 12, 14, 16, 18, 19, 20, 21, 23, 24 | Anthropogenic combustion activities locally affected by diagenetic dissolution and reprecipitation of carbonate and phosphates. |
| Bone | Usually comminute fragments in very small amounts. Occasionally weathered (loss of material and birefringence) and burnt (reddened) | 3, 12, 13, 14, 18, 19, 23 | Micromammals present at the site or fragments of animals processed at the site for human consumption. |
| Fishbone | Small vertebra and other extremely thin and long fishbones, and characteristic crescent-moon shaped fish tale bones, sometimes burnt | 3(?), 4, 5, 7, 8, 9, 10, 11, 14, 17, 18, 19, 20, 21. | Human processing of fish at the site. |

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| | (reddened) and many of them crushed in-situ. | | |
| Limestone pebbles | Micritic and sparry pebbles from fine gravel to centimetric sizes, sub-rounded to angular. | 3, 11, 19, 23 | Rockshelter bedrock |
| Quartz silt and fine sand | Poorly sorted particles in little amounts (>5%). | All | Sediments in the surroundings of the rockshelter. |
| Tufa | Rounded to flat fragments with porous clotted and stromatolitic microfabrics, formed by micrite and microsparite calcite crystals. | 9, 10, 13. | Detached from tufa deposits in the rockshelter walls. |
| Seaweeds (Rhodophyta / red algae) | Coralline algae are easily identified by their very fine-scale reticulate, cellular internal structure that reflects the filamentous fabric of these organisms (Scholle and Ulmer-Scholle, 2003). There are two types in thin section:<br>Encrusting *corallinaceae*:<br>These Rodophytes, such as *Lithophylum* sp., have a reticulate cellular structure with an exterior layer (perithallus) that is differentiated from the interior (hypothallus). They occur either encrusting limpets and binding foraminifera, or loose fragments.<br>Articulated *corallinaceae*:<br>Disarticulated segments of articulated species, such as the *Corallina* sp., are very frequent. Their calcified segments, held together by soft tissue, disarticulate upon death (Scholle and Ulmer-Scholle, 2003). Many segments are burnt (micritized) | 8, 9, 10, 11, 12, 13, 17, 18, 19, 20, 21, 22, 23, 24. | Presence of seaweed is ambiguous. The calcareous red algae identified are abundant in the same intertidal rocky environments where shellfish were gathered. Its presence could be regarded whether as by-product of shellfish gathering or fishing techniques, or intentional gathering of seaweed. |
| Foraminifera | Dispersed between aggregates, calcareous foraminifera, multichambered planspiral and biserial morphologies, are common, | 3, 10, 11, 13, 14, 20, 21, 22. | Non-intentional by-product of intertidal resources gathering. |

| | | | |
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| | and sometimes they are burnt. Some specimen are incrusted in seaweeds and serpulids. | | |
| Serpulids | These annelid worms' constructions exhibit smoothly circular to elliptical interior tubes and smooth or ornamented exterior surfaces. Tubes are found as encrustations on limpet shells. Tubes may be isolated or form intergrown clusters. Distinctive tubular external and internal shape. One or two-layer walls with a type of foliated microstructure. Wall consists of concentric, very fine (0.005 mm or less in thickness) laminations, sometimes with thin, lenticular gaps between layers (Scholle and Ulmer-Scholle, 2003). | 10, 20. | By-product of limpet gathering. |
| Biospheroids | Round aggregates of biogenic calcite crystals radially arranged. | 8, 20. | Colonisation of the subsurface by earthworms. |

Regarding the shells (gastropods and echinoids) a pattern related to burning degree was systematically noted at El Mazo thin sections. In general, complete shells of *Patella* and *Phorcus* in thin section are not burnt, whereas the millimetric and comminute shell fragments are burnt. This pattern applies also when both, complete shells and fragmented shells, coexist in the same mF (above mentioned mF 23 is an example of an exception for this pattern). Burning degree of the shells and its homogeneity or heterogeneity turn out to be a crutial criteria in microfacies discrimination.

A direct way to observe it is by observing the dark field scanning of the thin section at 1:1 scale  (Goldberg and Aldeias, 2016). In these scans, unburnt shells, or burnt only below 200 ºC, as these low temperatures do not cause mineralogical alteration of the calcite (Aldeias et al., 2016, Villagran, 2014a), will appear translucid in the dark field scan (fig. 7.4a). Burnt shells will appear bright grey or white (fig. 7.4b), due to the reflectance effect of the micritic crystals replacing the original shell crystals habit after combustion. The homogenous burning of shells was determinant in some microfacies discrimination when shell size or matrix

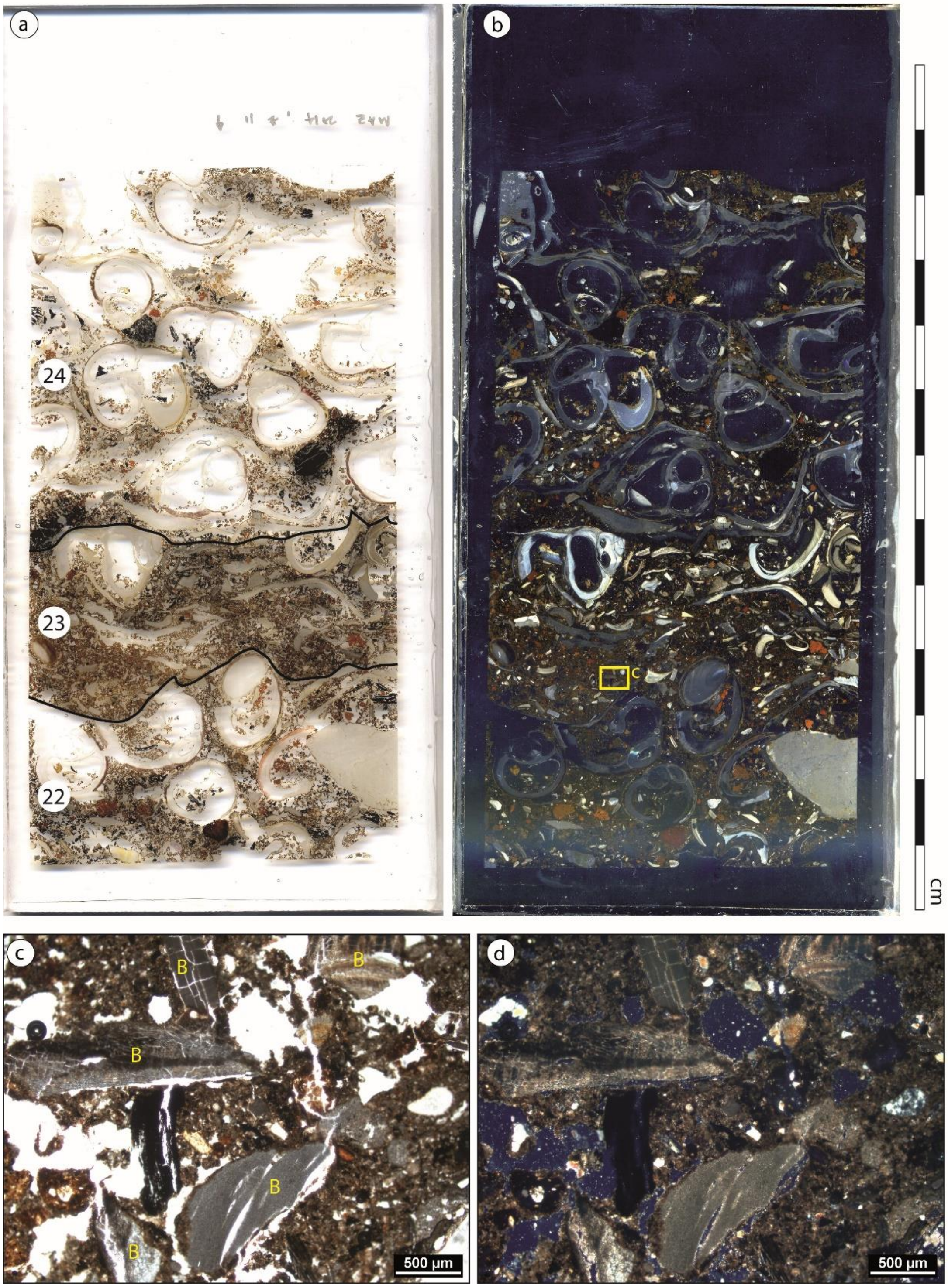



**Figure 7. 4** Shell burning in relation to fragmentation in thin sections from El Mazo: a) thin section scan of MAZ11; numbers within white circle: mF; dark lines: mF contacts; b) Dark-field scan o the same sample in a; most shells in mF 23, fragmented and complete, are burnt, as seen by their high reflectance in this scan mode; the unburnt shells, also complete, in mFs 22 and 24 remain translucid; note that in the latter mF the small shell fragmenst are systematically burnt; note in a and b that mG 23 shows positive grading; c) microphotograph of the rectangle marked in b; note the high degree of burning/calcinantion of the shell fragments, revealed by general micritization and intense cracking (B); PPL; d) same as c; XPL

composition was not so straightforwardly isolated, as it became clear, for instance, for mF 23 (fig. 7.4).

### 7.3.2 Fine Fabric Components and Microstructures

The coarse and fine clastic components listed above are generally supported by or contain different amounts of interstitial fine material (micromass), which constitutes the matrix of most microfacies. The matrix nature varies a ccording to its composition and can be divided in four sedimentary microfabric types (SMT) (Golberg and Macphail, 2006, Macphail and Goldberg, 2017), that are combined with the clastic components in ways as diverse as the microfacies. The SMT isolated in thin section are the ones described and interpreted in table 7.2 and represented in plate 7.1.

**Table 7. 2** Main sedimentary microfabric types (SMT) identified in thin sections from El Mazo, with indication of representative microfacies (mF) and genetic interpretation.

| **SMT** | Description | mF | Interpretation |
|---|---|---|---|
| Combustion residues | Ashy matrix, with articulated pseudomorphs, common rubified silty-clay aggregates, few fine charcoal and burnt shell fragments. | 1, 5, 15, 21, 22. | Anthropogenic combustion residues, either in-situ, when forming a continuous matrix of a microfacies, or reworked, when preserved in aggregates, isolated or attached to other coarse components. |
| Calcitic clay | Pale brown to orange clay with calitic crystallitic b-fabric, usually with dispersed ash pseudomorphs, and organic punctuations and fine organic tissue. | 3, 6, 19, 20, 22, 23, 24, | Micritic calcite and clay particles, finely mixed, as result of natural or anthropogenic reworking of ash from combustion residues and surrounding sedimentary clayey material and rockshelter limestone dissolution. |
| Organic clay | Dark to dark-brown, sometimes reddish, undifferentiated b-fabric, with very abundant organic inclusions (punctuations and tissue) | 8, 9, 10, 13, 16, 25, | Decomposed or coalescent organic matter, natural (exposed surface) or anthropogenically (organic matter processing)-induced. |
| Organo-mineral clay | Dark- or ligh-brown clay with stipple-speckled b-fabric and | 1, 2, 18, 19, | Mineral clay from the surrounding of the rockshelter, with calcite crystals from dissolution of the limestone outcrop. |

| | | | |
|---|---|---|---|
| | organic inclusions (punctuations and tissue) | 20, 22, 23 | |

The different SMT occur indiscriminately in several mF, combined with different clastic components assemblages, but exhibit almost always spongy or crumby microstructures (Bullock, 1985, Stoops 2003). The microstructure is called spongy when the solid material is overall continuous, broken by many, often interconnected voids (plate 7.2a). Crumby microstructures are those consisting in irregular aggregates not accommodated, more or less interconnected (plate 7.2b). Occasionally, specific mF exhibit other micromass microstructures, such as massive, normally restrained to in nondescript zones within an mF, combined with one of the former two types.

### 7.3.3 Microfacies of the stratified shell midden

Throughout the stratigraphic profile X15/16, the sedimentary clastic components and SMT are combined in a wide variety of ways in terms of abundance or presence/absence, making it possible to individualise specific events involved in the formation of the shell midden. Each mF identified is unique, since there was no strict repetition of the same exact characteristics, and when there was, a ratio of abundance between certain components make its interpretation differ, so the option was to maintain it as separate microfacies. Table 7.3 presents a list of all the mF identified, from the bottom to the top, and a very succinct description highlighting only the main general aspects of each one, the thin section where they occur and a genetic interpretation, which criteria are explained in detail in the following sections. The detailed microfacies description can be found at this chapter's supplementary material (see Appendix).

**Table 7. 3** Microfacies (mF) synthetic description and interpretation from El Mazo

| mF | Brief description | TS | Interpretation |
|---|---|---|---|
| 1 | Compound packed rounded aggregates of organo-mineral and biogenic clay (with filamentous algae or cyanobacteria) with common rubified soil aggregates | MAZ.72 | Naturally, colluvial-like, reworked material of different origins: anthropogenic shellfish roasting refuse and sediments from the rockshelter surroundings as well |

| | | | |
|---|---|---|---|
| | and ashy aggregates. Shell fragments are unburnt and burnt at several degrees. | | as from an exogenous source, possibly estuarine (microbial aggregates). Post-depositionally bioturbated. |
| 2 | Interconnected *Phorcus* and few *Patella*, unburnt, with 20% crumby micromass composed by calcitic and organo-mineral clay, abundant echinoids and shell fragments burnt and unburnt, and rare charcoal. Discrete secondary carbonate cementation. | MAZ.72 | Quick deposition of reworked deposit of selected shellfish roasting refuse by dumping. Post-depositionally partial water logging. |
| 3 | Calcitic brownish, ash-rich clay with few marine microfossils and spongy ms. Shell fragemnts and fishbone are unburnt and burnt at several intensities. | MAZ.72 | Colluvial-like, reworked material of different origins: anthropogenic shellfish roasting refuse and sediments from the rockshelter surroundings as well as from an exogenous source, possibly estuarine (microbial aggregates). |
| 3a | Same as 3, with crumby ms and more void space. | MAZ.72; MAZ.71 | Disruption and microaggregation, possibly by trampling, of the previous deposit (mF 3), thus possible temporal exposed surface. Possible combustion substrate of hearth. |
| 4 | Interconnected *Patella* with 10% interstitial fine material, namely fibrous charred organic matter, fine ashy aggregates and fishbone. | MAZ.71 | Anthropogenic direct tossing of limpets. Later, heated substrate of combustion feature placed above. |
| 5 | Interconnected *Phorcus* and *Patella*, unburnt, with 40% micromass of combustion assemblage SMT. Frequent (15-30%) calcitic coatings and hypocoatings in voids. Rare (2%) rhizoliths. | MAZ.71 | Burnt residues layer of combustion feature. Post-depositional partial water logging and bioturbation. |
| 6 | Calcitic, pale brown clay with spongy and massive ms, with abundant ash. Abundant comminute shell fragments are burnt and unburnt. Abundant (<30%) rhizoliths and secondary carbonate cementation. | MAZ.71 | Naturally reworked, colluvial-like deposit of combustion activities fine debris. Post-depositional partial water logging and bioturbation. |
| 7 | Interconnected echinoids. | MAZ.42 | Anthropogenic direct tossing of echinoids. |

| | | | |
|---|---|---|---|
| 8 | Organic clay with spongy ms with abundant Phorcus and very abundant shell fragments, charcoal and fishbone. Very abundant (20%) rhizoliths and secondary carbonate cementation. | MAZ.42 | Colluvial deposit of reworked soil material and shells. Post-depositional partial water logging and bioturbation. |
| 9 | Interconnected and fabric-oriented echinoids, some crushed in-situ, with common tufa fragments and abundant micromass of organic clay, charcoal and fishbone, with discrete gefuric c/f rd. | MAZ.42 | Water-laid or mass-movement deposit of selected material (echinoids), in organic matrix, probably from a former echinoid-rich deposit located upper in the slope and eroded. |
| 10 | Interconnected and fabric-oriented *Patella* and few *Phorcus*, frequent bone, tufa and shell fragments, and occasional fishbone, seaweed, serpulids, rubified aggregates and charcoal. Abundant micromass of organic and ash-rich clay, with discrete gefuric c/f rd. Very discrete (5%) secondary carbonate cementation. | MAZ.42; MAZ.41 | Water-laid or mass-movement deposit of reworked anthropic domestic activities debris. Post-depositional incipient water logging. |
| 11 | Interconnected *Patella* and *Phorcus* and pebbles, with abundant coarse charcoal and calcitic clay and ash, occasionally articulated. Discrete secondary carbonate cementation. | MAZ.41 | Anthropogenic dumping of burnt residues. |
| 12 | Organic and calcitic clay with crumby ms, with very abundant shell fragment and few scattered Patella (oblique-oriented), occasionally crushed in-situ, and rare charcoal, fishbone and seaweed. Occasional secondary carbonate cementation. | MAZ.62 | Colluvial mass-movement deposit of reworked anthropogenic debris. Post-depositional incipient water logging. |
| 13 | Calcitic brownish clay with spongy ms, with very abundant shell fragment and few scattered *Patella* and *Phorcus* (oblique-oriented), frequent tufa and rubified soil aggregates, and rare charcoal, fishbone and seaweed. Abundant secondary carbonate cementation. | MAZ.62 | Colluvial mass-movement deposit of reworked anthropogenic and cave-wall debris. Possible intense erosion of the cave walls due to wetting and drying conditions alternations. Post-depositional partial water logging and bioturbation. |

| | | | |
|---|---|---|---|
| 14 | Interconnected *Phorcus* and *Patella*, with abundant coarse charcoal and crumby calcitic clay and ash, with abundant void space. Common secondary carbonate cementation. | MAZ.61 | Anthropogenically unsorted combustion residues, in secondary position by dumping. |
| 15 | Interconnected *Phorcus* and *Patella*, partially burnt, with abundant calcitic clay and combustion assemblage SMT. Common secondary carbonate cementation. | MAZ.61 | Burnt residues layer of combustion feature. |
| 16 | Interconnected *Patella* and few *Phorcus*, partially burnt, with abundant crumby reddish and organic clay, shell fragments, rare ash aggregates and charcoal. Common interaggregate clay coatings of dusty, oriented reddish clay. | MAZ.32 | Dumping deposit, used as combustion substrate of combustion feature, post-depositionally affected by water circulation. |
| 17 | Charred, structureless organic matter with spongy ms and few calcined and organic-stained shell fragments | MAZ.32 | Combustion substrate of combustion feature, post-depositionally affected by water circulation. |
| 18 | Interconnected *Patella*, partially burnt, with organic and calcitic, ash-rich clay and combustion assemblage SMT aggregates. Contains pockets of weathered bone and phosphatic grains. Few interaggregate clay coatings of dusty, oriented reddish clay. | MAZ.32; MAZ.31 | Burnt residues layer of combustion feature, post-depositionally affected by water circulation and bone diagenesis. |
| 19 | Shell fragments are all burnt and display inverse grading, with smaller fragments, most burnt at the bottom and progressively larger toward the top, culminating with a line of complete Phorcus shells. Very abundant of organio-mineral clay and ash. | MAZ.32; MAZ.31 | Anthropogenic debris reworked by granularflow/debris-flow. Post-depositional water percolated downwards through the underlying combustion feature (mF's 16-17-18). |
| 19a | Shell fragments closely packed, burnt to calcined, with matric of calcitic clay and ash and abundant rubified soil aggregates | MAZ.31 | Anthropogenic deposit of reworked fine combustion residues probably result of a size-sorting process, such as sweeping or rake-out. |
| 20 | Calcitic brown and organic clay with occasional ash and spongy ms. Contains abundant scattered *Pattella* | MAZ.22; MAZ.21 | Anthropogenic reworked deposit of reworked combustion, shellfish, organic matter and seaweed (?) processing, and |

| | | | |
|---|---|---|---|
| | and *Phorcus*, very abundant shell fragments, rubified soil aggregates, many charcoal, seaweed, serpulids and foraminifera, and rare charcoal and fishbone. Very abundant secondary carbonate cementation. | | other varied domestic and soil debris. Slow rate sedimentary accretion and temporally exposed. Post-depositional partial water logging and bioturbation. |
| 21 | Combustion assemblage SMT with abundant *Patella* and *Phorcus* and shell fragments, burned seaweed and very few charcoal. Very abundant secondary carbonate cementation. | MAZ.21 | Combustion residues layer of combustion feature. Post-depositional partial water logging and bioturbation. |
| 22 | Amorphous, dark organic matter (marine origin?) with spongy ms and highly bioturbated. Contains abundant Patella and *Phorcus*, shell fragments, many of which calcined, aggreagtes of combustion assemblage SMT attached to shells, abundant seaweed and foraminifera. | MAZ.21; MAZ.12 | Anthopogenic reworking, possibly by sweeping or rake-out, of highly organic and material in advanced decomposition, whith debris from shellfish and seaweed (?) processing. Post-depositional intense bioturnation. |
| 23 | Shell fragments are all burnt and display inverse grading, with smaller fragments, most burnt at the bottom and progressively larger toward the top. Very abundant of organio-mineral clay and ash, abundant seaweed, rare charcoal, bone and limestone pebbles. | MAZ.12 | Water-laid deposit of reworked fine anthropogenic debris by growing energy water flow. |
| 24 | Interconnected *Phorcus* and *Patella*, with abundant calcitic clay and ash with crumby to spongy ms, abundant shell fragments and seaweed and very abundant charcoal. | MAZ.12; MAZ.11 | Anthropogenic dumped deposit of reworked combustion, shellfish, organic matter and seaweed (?) processing. |
| 25 | Organic clay with spongy ms with abundant *Patella* and shell fragments and rubified soil aggregates. Very abundant secondary carbonate cementation. | MAZ.11 | Naturally reworked, colluvial-like, anthropogenic debris, possible temporally exposed surface. Post-depositional partial water logging and bioturbation. |

Legend: mF: microfacies; TS: thin section; ms: microstructure; c/f rd = coarse/fine related distribution

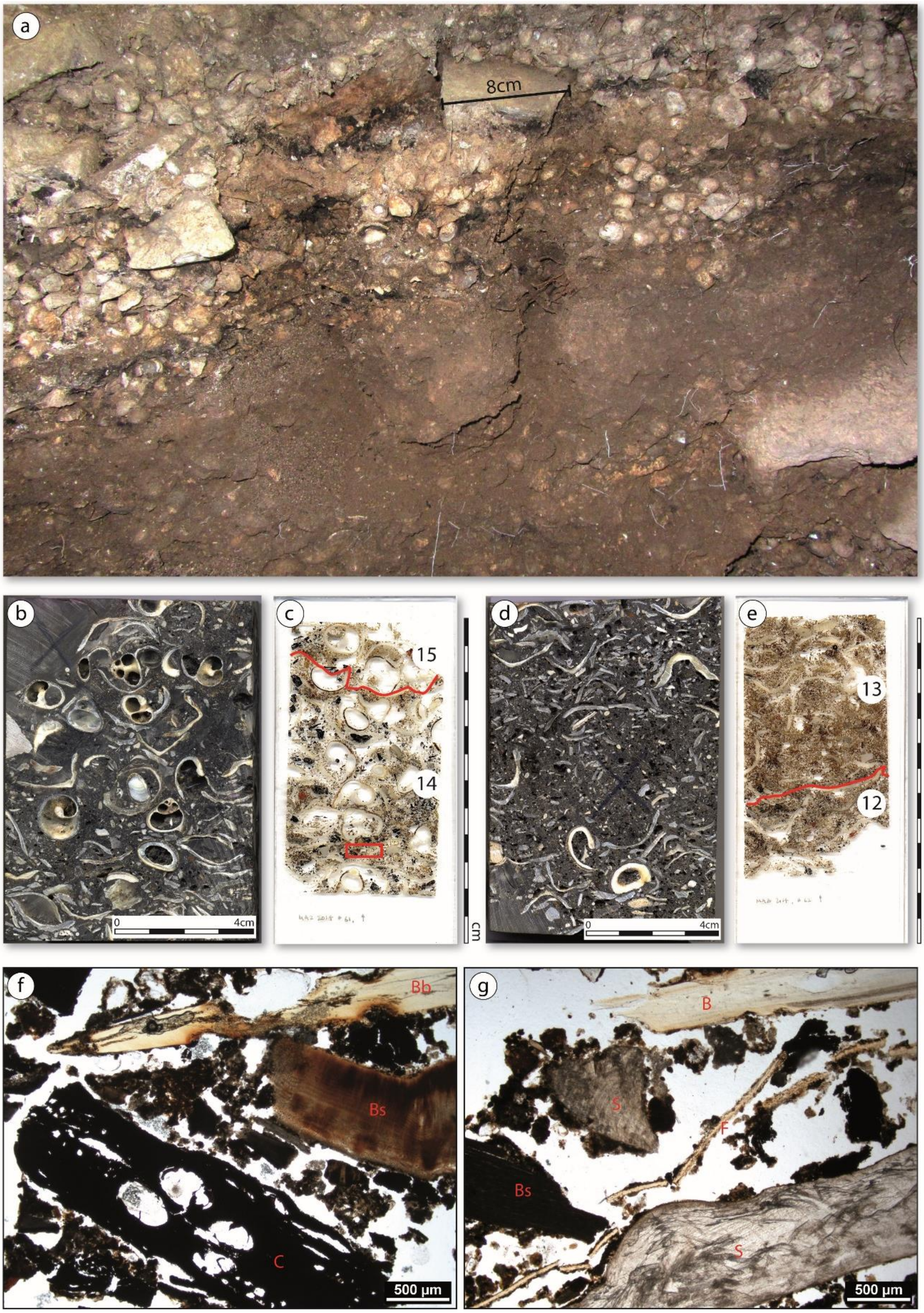
### 7.3.4 Coarse/fine ratios and sedimentary fabrics

Although it was not observed the repetition of any microfacies during the thin section analysis, which generated an elevated number of them, their interpretation was easier if grouped in general types that are attributed to a same generic process. Further aspects concerning the origin of those processes is furthermore inferred by the type and abundance of components and constitute the basis of the mF discrimination. The microfacies were grouped into sets established according to the coarse/fine ratio for interpretation of generic formations processes. The groups are shell-supported sediments, matrix-suported sediments, and fabric structures, each one explained next.

#### *7.3.4.1 Shell-supported sediments*

Under the scope of this set are those sediments dominated by complete *and* interconnected shells (fig. 7.7: a-c). These deposits can be composed by one or more of the three main shell types identified (*Patella*, *Phorcus* and echinoids), although in general one of them is dominant. These deposits might contain different amounts of interstitial micromass aggregates (fig. 7.7: f, g) and some shells might contain a fine-fabric infill, equivalent to the

**Figure 7. 5** (next page) Examples of the coarse/fine ratios groups in thin section: a) field photograph of the sample MAZ6 in process of collection; note the difference seen in the field between shell-supported sediments and matrix-supported sediments, in the upper and lower half of the sample, respectively; for scale use the 8cm long cobble marked in the figure; the upper part of the sample corresponds to a stone-structured hearth that was sectioned during excavation; b) impregnated and cutted slab of the upper half offers a good perception of the degree of interconnection of the complete shells; c) thin section MAZ61 resulting from the slab in b; note the composition dominated interconnected coarse elements, including shells and charcoals; the red line indicates the contact between mF 14 and 15, corresponding 15 possibly to a layer of combustion residues associated to the combustion feature identified during excavation; numbers within circles: mF; red lines: mf contacts; d) impregnated and cutted slab of the lower half of the sample, showing that complete shells are rare and supported by a matrix of fine material, where small shell fragments are abundant; e) thin section MAZ62, resulting from the slab in d, where the predominance of fine-grained matrix becomes evident; numbers within circles: mF; red lines: mf contacts; f) and g) microphotograph from mF 14 (both from red rectangle in c) where it is possible to observe the simple packing of heterogenous components and ashy/organic micromass derived from mixing, probably by dumping, of previously deposited anthropic activities; B: bone; Bb: burnt bone; S: shell; Bs: burnt shell; F: fishbone, crushed in situ; C: charcoal; PPL


a
8cm
b
0
4cm
c
15
14
cm
d
0
4cm
e
13
12
cm
f
Bb
Bs
C
500 µm
g
B
S
F
Bs
S
500 µm

general matrix, or different of it, which indicates that it is a relict from a previous deposit. Inside this set of microfacies there are two subgroups that revealed different processes:

- *Shell-supported sediments with matrix*

These are shell-supported sediments that contain more than 10% interstitial fine-fabric material (plate 7.2: b, c) (composed of any of the STM) or fine clastic components. In these sediments, the abundance degree of the matrix makes it possible to distinguish between enaulic, porphyric and gefuric coarse/fine related distribution patterns (plate 7.1 c-e) (Stoops, 2003) or more specifically, whole shell/micromass related distribution (henceforth c/f), regardless the internal microstructure of the micromass. The enaulic c/f pattern refers to finer material occurring as distinct aggregates in the interstitial space between coarser components; in a porphyric c/f pattern, the fine material fills all space between coarse components homogenously, with or without internal porosity; finally, the gefuric c/f pattern correspond to fine material occurring as bridges linking coarse components and, in the case of El Mazo, those components might be coarse material or fine material aggregates.

- *Shell-supported sediments without matrix*

The shell-supported sediment with less than 10% fine fabric are interpreted as being in overall in primary position. The only clear examples of this instance are mF 4 and 7 (plate 7.2f).

#### *7.3.4.2 Matrix-supported sediments*

The set of deposits concerning to matrix-supported sediments are those supported by a more or less aggregated fine-fabric that contains few or occasional (> 10%) complete shells and dispersed (i.e., not interconnected) shell fragments (fig 7.7: a, d, e). In these deposits, it is the nature of the micromass, constitute by one, or a combination of two SMT, together with coarse clastic components, that indicates the process, that can be natural or anthropogenic (see table 7.4).

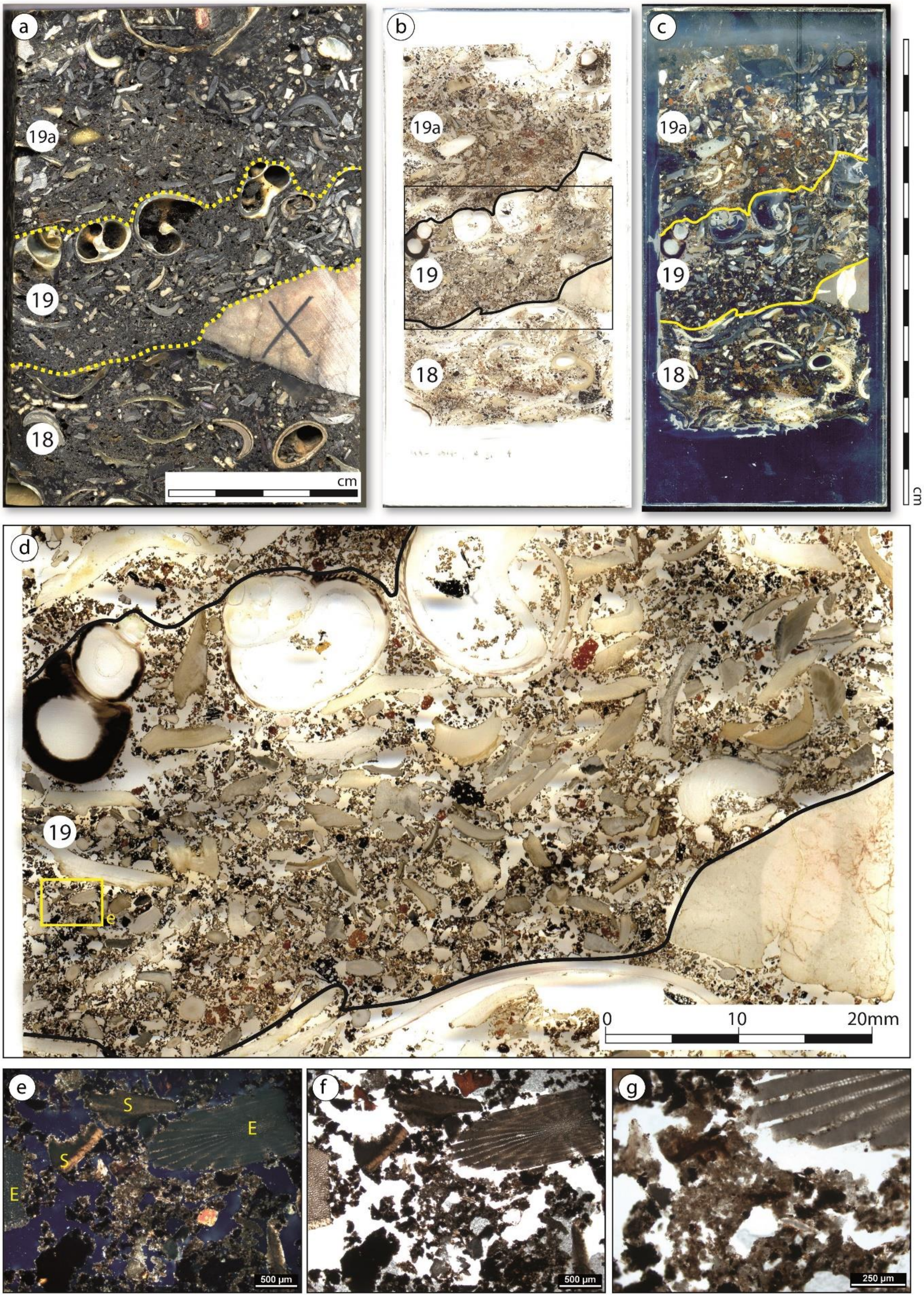
#### *7.3.4.3 Sedimentary Fabric Features*

Two significant features regarding sedimentary fabric were identified. One is inverse grading of shell fragments within a same mF, with smaller fragments deposited at the bottom and coarser ones at the top, increasing size gradually (Goldberg and Macphail, 2006). This pattern is observed in mF 19 and 23 (fig. 7.4: a, b; 7.6: a-d). The other is a same orientation of the long-axis of the shells within a given deposit, similar to imbrication.

**Table 7. 4** Correlation between groups based of c/f ratios and matrix as determination of processes, with indication of correspondent microfacies

| **c/f ratio group** | Subgroup | SMT, ms or fine component | Process | mF in thin section |
|---|---|---|---|---|
| Shell-supported sediments | With matrix: enaulic c/f | Calcitic clay + charcoal | Dumping | 2, 11, 14, 24 |
| | | Charcoal | In-situ fire | 4, 18 |
| | | Rubified aggregates | In-situ fire | 16, 18 |
| | | Ash aggregates | In-situ fire | 18 |
| | With matrix: porphyric c/f | Calcitic clay + charcoal | Dumping | 20 |
| | | Combustion assemblage | In-situ fire | 5, 15 |
| | With matrix: gefuric c/f | Organic clay | Waterlain or solifluction | 9, 10 |
| | Without matrix | | Single tossing | 7, 4 |
| Matrix-supported sediments | Function of SMT + clastic components (see Table 7.3) | | Colluvial | 1, 3, 6, 8, 12, 13, 25 |
| | | | Trampling | 3a |
| | | | In-situ-fire | 17, 21 |
| | | | Anthropogenic reworking | 19a, 22 |
| Fabric features | Inverse grading | | Granular flow/debris flow | 19, 23 |
| | Long axis orientation | | Water-laid or solifluction | 9, 10 |

Legend: c/f = coarse/fine related distribution; SMT = sedimentary microfabric type; ms = microstructure; mF = microfacies


a
19a
19
18
cm
b
19a
19
18
c
19a
19
18
cm
d
19
e
0
10
20mm
e
S
E
S
E
500 µm
f
500 µm
g
250 µm

### 7.3.5 Post-depositional processes in the stratified shell midden

Features resulting from post-depositional alteration observed in thin section are in general rare and weakly expressed, although its record helps in some interpretations. The most common feature is secondary weak cementation by micrite and micro-spar around aggregates' surfaces (plate 7.3a). Occasionally, this cement completely fills voids when the components are closely packed (plate 7.3b). This feature reveals essentially a partial and ephemeral water logging in the deposits. The same contexts are usually associated to incipient root activity that result in weak micritic hypocoatings and rhizoliths (plate 7.3: c, d). These features are more common in the thin sections of sample MAZ.6, which might be related with the existence of a preferential dripping point in the ceiling above this area. Another poorly represented, and very localised secondary carbonate precipitate is the needle fibre cement (plate 7.3: e, f) that occurs in mF 13, also in sample MAZ.6. Needle fibre calcite is usually associated with fungal colonisation of the surface, which in this case points to an exposed surface for some time.

Apart from secondary precipitation features mentioned above, carbonate dissolution features are also observed, but affecting almost exclusively calcined echinoids plates in mF 18 and 19, thus a very localised and selective process. Those echinoids tests plates in these two successive microfacies that are calcined (micritisized) appear to be going through some diagenetic process, presenting strong depletion features and structural deformation, which gives a melted-like appearance to the affected areas (plate 7.4).

In mF 16 and 18, complex clay textural features consisting of very dark and red clay were observed (plate 7.5). Mostly unoriented and with undifferentiated b-fabric, although some well oriented clay coatings occur, with sweeping extinction (plate 7.5: a, b). The geometry of the features does not resemble typical illuvial clay coatings, being more similar to muddy splashes (plate 7.5). Giving the microstratigraphic association of these textural features and the weathering process affecting echinoids mentioned before, it is arguable that the origin of such

**Figure 7. 6** (previous page). Fabric features: a) slab from upper part of sample MAZ3; numbers within white circle: mF; dashed lines: mF contacts; note the grading of the shell fragments in mF 19; b) scan of thin section MAZ31 with indication of mF; c) dark-field scan of thin section MAZ31 with indication of mF; in mF 19 it is perceptible that most shells are burnt; d) close-up on mF 19 in the thin section MAZ31; the grading of the components is clear; e) microphotograph of the rectangle marked in d, showing the calcitic clay SMT; note the crystallitic b-fabrics, also rich in fine organic matter and calcined components - E: calcined echinoid spine, S: calcined shell fragments; XPL f) same as e; PPL; g) close-up in the micromass of the e and f, where ash rhombs mixed with the clay are visible; PPL.

features might be related with the anthropogenic activity involved in the formation of these microstratified deposit, that correspond to a combustion feature, but it remains enigmatic where the clay comes from, which complicates even more the interpretation of this localised process.

### 7.3.6 Micromorpholy of the cemented shell midden

The block of the cemented shell midden hanging from the ceiling of El Mazo rockshelter (fig. 7.2 and 7.12a) has a basic structure consisting of interconnected complete shells and occasional angular limestone pebbles (fig. 7.12: b, c). Concerning the distribution of coarse components, it is noteworthy that the lower half of the block consists mainly of *Phorcus* topshells and large echinoids tests, whereas the upper part is dominated by limpets and very rare examples of the former two (fig. 7.12: b, c). Further components are as diverse as in the stratified deposit and present quite the same characteristics as listed and described in table 7.3. Echinoids spines are the most abundant, almost as a matrixial component, followed by bones, charcoal and seaweeds, homogenously distributed and presenting several degrees of burning (plate 7.6).

Regarding the micromass, the most abundant type are calcitic faecal pellets that are ubiquitous in both thin sections presenting a fine enaulic c/f related distribution pattern. Heterometric clayey aggregates are also present (plate 7.6), composed by combustion residues and calcitic clay SMTs (see table 7.2).

#### *7.3.6.1 Carbonate cement*

The most striking characteristic of the cement at El Mazo cemented block are isopachous fringes of uneven sparry crystals of dogtooth calcite that regularly circumscribe all clastic components and aggregates, forming curious sunflower-like effects in thin section when the components are round pellets or cross sections of echinoid spines (plate 7.6: g-i; 7.14: a, b, g). The crystals growth weld together the components, creating closed vughs. Commonly, in some of these vughs the dogtooth crystals have their terminations regularised instead of pointy, creating smooth, vesicle-like pores (plate 7.7: c, d). Vughs surrounded by irregular, pointy terminations and voids with smooth walls are many times next to each other. If the isopachous cements are typical form in phreatic conditions (James and Jones, 2015, Scholle and Ulmer-


**Figure 7. 7** Sample of the cemented shell midden remnant hanging from El Mazo rockshelter: a) field photograph of the protuberant remnant of cemented shell-rich deposit hnging from a leaning wall that was collected for micromorphological analysis; note that the neighbouring wall/ceiling is replete of cemented shellfish remains; b) scan view of the two slabs obtained after impregnation of the block; c) combined normal and dark-field scan of the thin sections from the cemented shell midden block; mF C2 corresponds to the areas in b where the cement is more dense and bright; numbers within white circle: mF; red lines: microfacies contacts.

Scholle, 2003, Flügel, 2004), the smooth voids indicated that some air was present in some pores, which impeded the complete growth of the calcite crystals (James and Jones, 2015), revealing partially vadose conditions. However, clear signatures of predominantly vadose conditions such as pendants and meniscus are absent. This observation suggest that the deposits were affected by water table oscillations, alternating periodically between inundating and draining waters. Such variations should have occurred quickly enough to prevent the development of more expressive vadose cements, but also without leading to more advanced stages of phreatic cementation, since there was no time for drusy calcite complete fillings, for instance.

Another type of cement identified in thin section are dendritic crystals, considerably larger than dogtooth, with stick-like ramifications and arranged in radiating fans (plate 7.7: e, f), a calcite morphology that forms via rapid precipitation from fast-flowing, supersaturated waters in spring system s (James and Jones, 2015). The dendritic crystals only occur in a layer restricted to the central part of the block, called microfacies C2 (fig. 7.12: b, c), placed between the two deposits with the difference in the shell composition registered above (limpets in the upper half and topshels in the lower half). In the dendritic crusts, the abundance of faecal pellets decreases being mostly absent.

A last type of carbonate cement registered at El Mazo was needle fibre calcite (plate 7.7h), particularly frequent in the lower half. Needle-fibre calcite is cement formed by thin (0.5-2 µm wide) and very long (up to 100 µm), randomly oriented crystals forming a meshwork pattern partially filling voids usually superimposed to previous cements. Needle fibre calcite is a carbonate precipitate typically associated with fungal activity (Verrecchia and Verrecchia, 1994, Durand et al., 2010).

## 7.4 Discussion

In this section the aspects presented above will be analysed from a microstratigraphic point of view, correlating the different microfacies and their inferred processes. Firstly, a general comment on the implications of shell burning in relation to shell fragmentation pattern will be made, since it is a constant throughout the whole deposit, remarking the significance of the few exceptions to the pattern. Some of the microfacies associations reveal inter-dependant processes, that are vital for the identification of anthropogenic actions responsible for the accretion of shell-rich sediments. Natural processes were also identified as more likely factors controlling the deposition of some layers. Some microscopic aspects also allowed for a few climatic inferences. Finally, micromorphological analysis of the cemented shell midden block also revealed significant depositional an environmental data.

### 7.4.1 Shell burning in relation to fabric and processes

The division in shell-supported and matrix-supported sediments yielded a significant observation, stated before, concerning the burning degree of the calcitic shells of *Phorcus* and *Patella*. When complete, the shells usually do not exhibit optical signs of burning, which means they were not exposed to temperatures above 200º, the threshold for optically visible heat alteration in the shell calcite crystalline structure (Villagran, 2014a) (Villagrán). For brevity, the term “unburnt”, since it is how the shells are seen in thin section, will be used onwards to refer to burnt below 200 ºC, while the term “burnt” will refer to the optical signs of temperatures higher them 200 ºC.

Shellfish roasting for human consumption demands very low temperatures, i.e., around 100 ºC, and above that value the shellfish becomes charred and inedible. With this is mind, the shell burning pattern offers evidence that most complete shells were probably subjected to burning only once, probably just for roasting, and were not reheated, at least to temperatures higher than the demanded for cooking shellfish. In turn, the burnt and calcined shells were subjected either to periodic reheating or to higher temperatures, maybe related to combustion for other purposes different from cooking.

On the other hand, the millimetric shell fragments are usually burnt and calcined. This might be explained because once the fragments became incorporated in the sediments, they are more likely to be reheated by exposure to consecutive combustion events, which also favours shell fragmentation, but as sedimentary components and not necessarily the object that was being cooked, since those are likely to be preserved complete if not reheated. Most mF rich in shell fragments mix both burnt and unburnt fragments, which is interpreted as mixing of fragments with different pre-depositional reworking histories. Therefore, when all complete shells and fragments are homogenously burnt in a given mF (e.g., mf 17), this was considered significant and that those shells were burning at high temperatures together and probably *in-situ*.

From these inferences, it is possible to discern that all burnt fragmented shell reflect intense history of burning and reworking, so the fragments become incorporated to the sediments that will serve as matrix for unburnt complete shells in naturally-reworked deposits, generating mainly matrix-supported sediments. The unburnt complete shells, by oposition, would be less reworked, probably tossed or dumped immediately after the first combustion for cooking to their final position in the archaeological record, and thus indicate that were mainly human-driven processes behind most of the shell-supported sediments. A few exceptions for this pattern were, however, noticed, judging by combinations of components and matrix, and will be discussed in the following sections.

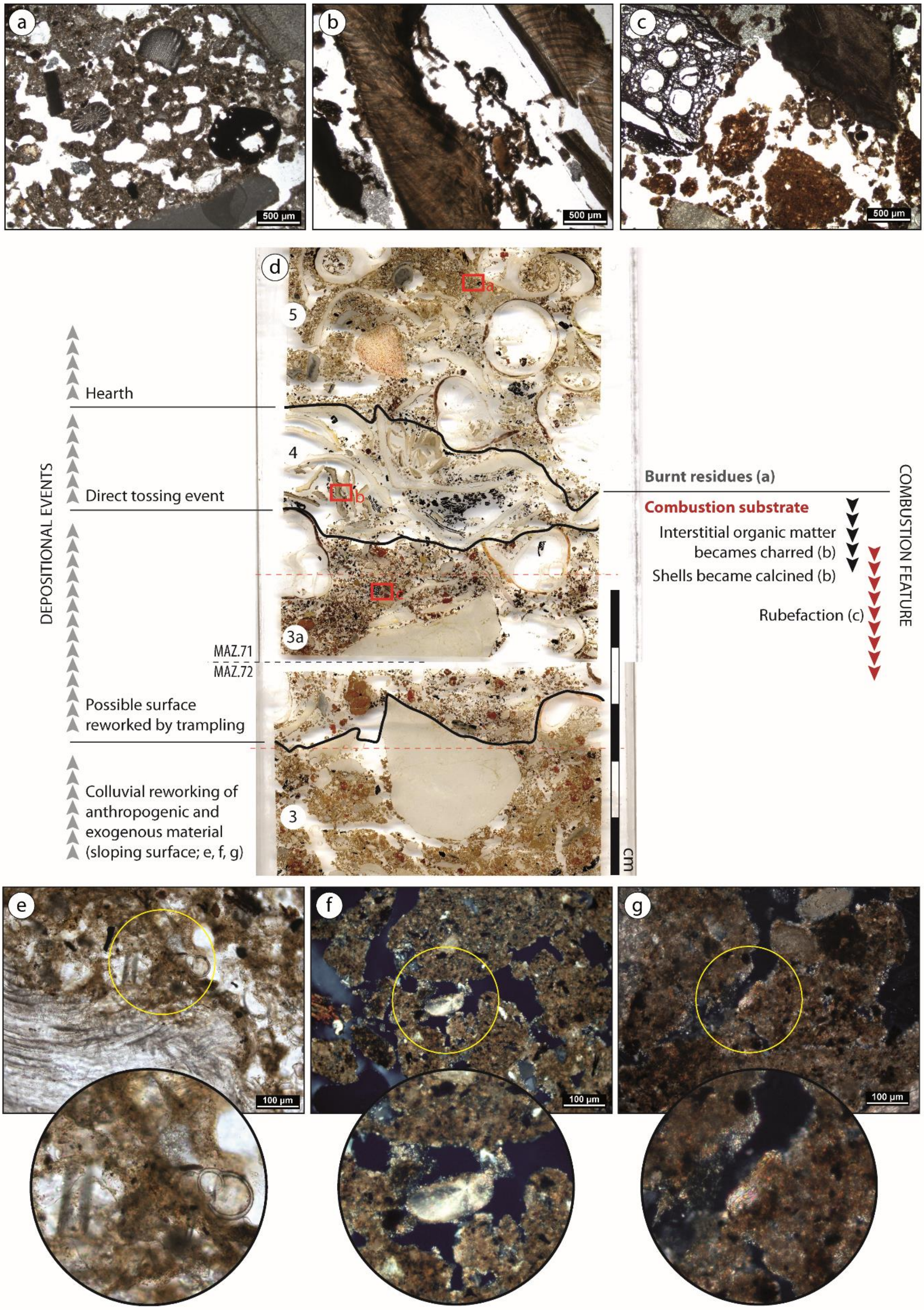
### 7.4.2 Anthropogenic activities

The anthropogenic activities inferred from the microfacies comprise those deposits considered *in-situ* like combustion features, and reworked deposits, either intentionally or unintentionally transformed by human actions.

#### *7.4.2.1 Combustion features*

Three *in-situ* combustion features were identified in thin sections from the profile X15/16. The main characteristic for their identification is the micro-stratigraphic doublet composed by the layer of burnt residues derived from the fuel overlying a combustion substrate

**Figure 7. 8** (next page) Microstratigraphy of overlapping depositional and post-depositional processes overlapping at El Mazo. Example from sample MAZ7: a) ash matrix from mF 5, corresponding to the burnt residues layer of the combustion feature; PPL; b) Charred fibrous organic matter and shells from the superficial combustion substrate, corresponding to a previously deposit of directly tossed limpets; PPL; c) charcoal and rubified clay aggregates embedded in an also slightly rubified ash matrix from the lower combustion substrate of the combustion features, corresponding to a colluvial-like deposit of reworked debris down slope; PPL; d) annotated scan of two overlapping thin sections, MAZ071 and MAZ.72, from sample MAZ7; the overlapping area is indicated between the dashed red lines; numbers within white circles: mF; dark lines: mF contacts; note the lack of supporting matrix in mF 4 and the transition from densely packed structure of mF 3 towards loose, crumby microstructure of mF 3a, despite the compositions remains identical, only with a few coarser shells in 3a; e), f) and g) examples of aquatic skeletal grains embedded in aggregates from mF 3, respectively a foraminifer and possible sponge spicule (out of focus), a bacterial calcareous spherulite and a cyanobacterial/algal filamentous microfossil, together with ash rhombs that compose the calcitic clay, that attest both exogenous and anthropogenic origin of these reworked sediments; these aquatic components were identified only in colluvial-like deposits of the base of the shell midden.



a
b
c
500 µm
d
5
4
3a
3
MAZ.71
MAZ.72
cm
DEPOSITIONAL EVENTS
Hearth
Direct tossing event
Possible surface reworked by trampling
Colluvial reworking of anthropogenic and exogenous material (sloping surface; e, f, g)
Burnt residues (a)
Combustion substrate
Interstitial organic matter becames charred (b)
Shells became calcined (b)
Rubefaction (c)
COMBUSTION FEATURE
e
f
g
100 µm

that is rubified and its components charred (Mallol et al., 2017). The burnt residues layer is indicated in thin sections of El Mazo by combustion residue SMT with massive or spongy microstructure, or a porphyric c/f in shell-supported sediments.

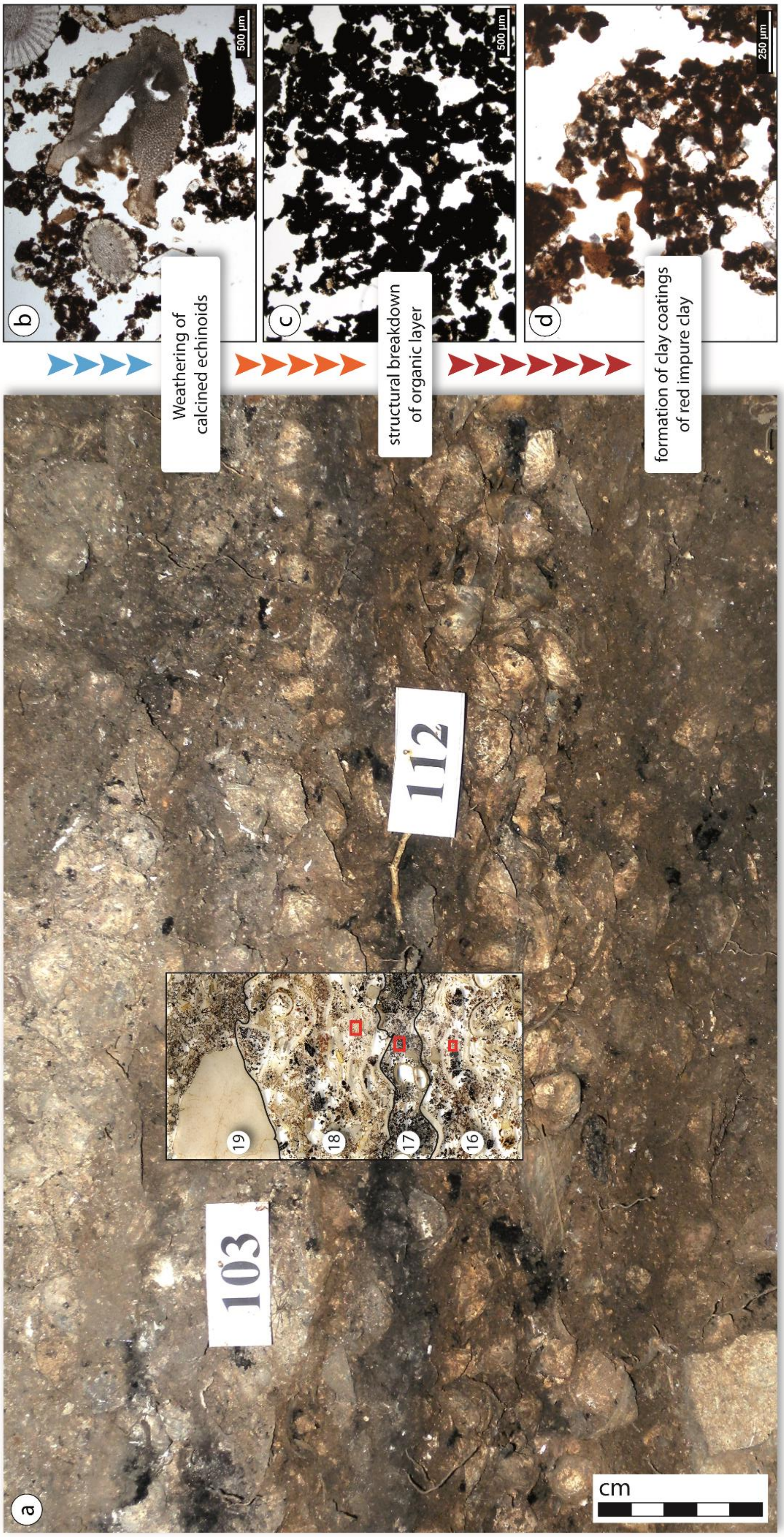
- *Combustion feature in MAZ.7*

Chronologically, the oldest combustion feature was recorded in sample MAZ.7, composed by mF 3, 4 and 5 (fig. 7.3; 7.15: a-d, table 7.3). In this combustion feature, mF 5 represents burnt residues, rich in articulated ash. The rest of components are unburnt complete shells and charcoal and fishbones were also rarely observed. Microfacies 4 represents the upper combustion substrate, a thin accumulation of limpets, accumulated probably by direct tossing giving the virtually lacking sedimentary matrix. In this mF, the rare interstitial material and infillings of the limpets composed by fibrous organic matter and shell fragments (possibly inherited from the original deposit they came from) are charred, probably due to the combustion on top of them (fig. 7.15d). In the underlying mF 3, the calcitic clay sediment is rubified, which can be an also an effect of the same combustion (fig. 7.15: c, d). Note that both mF 3 and 4 have their own independent formation processes that are not related to the combustion (see below).

- *Combustion feature in MAZ.3*

In sample MAZ.3, another possible *in-situ* combustion feature was detected in thin section, formed by the mF 16, 17 and 18 (fig. 7.3, 7.16, table 7.3). This combustion feature present the same microstratigraphic layers of the one above described in MAZ.7.

**Figure 7. 9** (next page). Combustion feature and post-depositional processes in sample MAZ.3: a) field photograph of the profile of the combustion feature in square X15, with superimposed scan of the thin section MAZ31 in the corresponding sample location; note the yellowish composition of mF 18 due to presence of ash, the black layer corresponding to the superficial charred substrate (mF 17) and the rubified substrate (mF 16); numbers within circles: mF; dark lines: mF contacts; red rectangles: location of the microphotographs, in same order from top to bottom; b) one of the echinoid test plates in mF 18 showing intense weathering after being calcined as its micritic pseudomorphic structure suggests, PPL; c) black layer of the combustion feature, an accumulation of coalescing organic material due to structural collapse; note in a all coarse shells appearing calcined; PPL; d) mF 16 showing rubified aggregates and discrete coatings of red dusty clay, forming connecting bridges between aggregates.


a
b
c
d
500 µm
500 µm
250 µm
Weathering of calcined echinoids
structural breakdown of organic layer
formation of clay coatings of red impure clay
103
112
19
18
17
16
cm

Microfacies 18 corresponds to the burnt residues layer (plate 7.8a), rich in articulated and dispersed ashes and carbonized seaweed and charcoal (plate 7.8: a-c), from the fuel and materials added to the combustion. This burnt residue layer contains an interesting record of phosphates. The phosphates are preserved in a horizontal lens no more than 5 mm thick within the ashy layer (plate 7.8a). The phosphates are pale to strong yellow isotropic grains finely mix with organic material, closely associated to bones and comminute bone particles (plate 7.8: d, g). A suspected carnivore coprolite is also present (plate 7.8: e, f) with phosphatic material adhered. The presence of these phosphatic lens with coprolites and bones is difficult to interpret. It could correspond to plant material used as fuel for the combustion that already contained inclusions such as coprolites. The upper contact of this combustion feature reveal a drastic change in the site dynamics, shown by curious features such as the moment of crushing of a shell by a limestone pebble (plate 7.8h) associated with the naturally deposited graded sediments of mF 19 (plate

Microfacies 17 is interpreted as the superficial combustion substrate, rich in an organic material lacking any geogenic mineral grains, that possibly became completely black because of charring (plate 7.9: a-f). All shell fragments and complete shells in this mF are homogenously calcined and stained black (plate 7.9: c, d). This reinforces the idea that this layer constitutes a combustion substrate rather than burnt residues, and the shells had been heated before, thus became burned when reheated by the combustion on top of them. Moreover, the shells in the burnt residue layer (mF 18) are not burnt.

The interpretation is that the  temperature of the hearth did not exceed 200 ºC, but the shells in the superficial combustion substrate (mF 17), became optically burnt because they had been heated before. Finally, at the base, the organic clay of mF 16 is rich in rubified and charred components (fig. 7.16a).

All three mF corresponding to this combustion feature present the post-depositional clay textural features. This red clay is more abundant in the basal layer, the combustion substrate mF 16, where the coatings are more abundant and composed of well oriented dusty clay (plate 7.5; 7.17d). In mF 17 the coatings are not as visible, because the entire fine material is completely stained black, but the coalescent character of the amorphous organic matter in this layer (fig. 7.16c; plate 7.9: e, f) seem to correspond to the same type of feature. In the combustion residues layer, mF 18, the clay coatings are less frequent and composed of unoriented, very dusty red clay (plate 7.5). These post-depositional feature evidences that the combustion feature was affected by surficial splashing water that cause translocation of the clay particles. The origin of this clay is uncertain, but the colours suggest an enrichment in organic matter and probably rubefaction. Similar features have been identified in Prehistoric domestic contexts, and it was suggested that very dusty red clay coatings result from ash weathering that promotes potassium-rich clay translocation, triggered also by trampling and rain-splash on bare surfaces (Macphail and Cruise, 2001, Macphail and Golberg, 2017). This is a possible origin for these features, giving that we are in a context corresponding to a combustion feature, but more detailed analysis is needed for its better understanding. Further evidence of intense water circulation in this context is provided by expressive, though unusual dissolution features exhibited by the echinoids shell fragments, that seem to be undergoing dissolution process  Giving that these weathered echinoids occur in mF 18, a layer above mF 16, the one where the red clay coatings formed, it seem likely that the origin of both processes is related. This percolation process seems to agree with the spongy microsctucture of the amorphous organic matter accumulation of mF 17, the intermediate layer through which the percolating substances went, possibly explaining the dusty character of the clay coatings further below (fig. 7.16). Micro-elemental and mineralogical analysis in the future, such as µ-FITR, would help in corroborate or not this hypothesis. Overall it is notable the highly localised occurrence of this process, affecting this combustion feature.

- *Combustion feature in MAZ.6*

The younger combustion feature was recorded in sample MAZ.6, and it is inferred only from the burnt residues layer, corresponding to mF 15, with well-preserves articulated ashes and charcoal. The lack of visible combustion substrate might be due to the absence of sedimentary material susceptible to charring or rubefaction with heating in the underlying layer, such as organic matter or clay. This combustion feature was the only that was structured with stones and inferred from field excavation (fig. 7.7).

- *Possible combustion feature in MAZ.2*

Microfacies 21 has a complicated geometry of this mF in thin section that makes it difficult to interpret. It is not a horizontal layer but more properly a domain in thin section (plate 7.10: a, k), of matrix-supported sediment rich well-preserved combustion residues and some complete shells. It resembles mF 15 from the combustion feature in sample MAZ.6, and observations on the profile seem to indicate a lateral continuity of the deposit (fig. 7.3). Therefore, it is tentatively interpreted also as a combustion residues layer of a peripheral area of a combustion feature.

#### *7.4.2.2 Single tossing events*

Shell-supported sediments without matrix are overall interpreted as being in primary position, because humans are the only likely agent for accumulation of shells through such a process that does not imply the addition of sedimentary matrix. Therefore, anthropogenic deposits of interconnected shells in primary position are interpreted as corresponding to single events of direct tossing of shells, as suggested by Aldeias and Bicho (2016). This instance occurs only in two mF, 4 and 7. In the case of mF 4, the deposit consists of interconnected limpets (fig. 7.15d), thus result of anthropogenic selection of this specific species. Microfacies 4 has been mentioned before regarding the oldest combustion feature, because it functioned as combustion substrate for a hearth (see section 7.4.2.1), that cause calcination of the limpets and charring of the few interstitial fibrous plant materials (fig. 7.15b). Concerning mF 7, it corresponds to a rather thick deposition of echinoids almost exclusively (plate 7.2f), which seem to indicate, again, the selected tossing of this species.

#### *7.4.2.3 Trampling*

A possible evidence of trampling appears to be recorded by mF 3a. This mF has the same composition of mF 3 (table 7.3), which has a spongy microstructure and lower porosity (30%) (fig. 7.15d). In turn, 3a has higher porosity (50%) and a crumby microstructure consisted of small, sand-sizes aggregates (fig. 7.15d). The disruption of a microstructure into small aggregates at the top of a layer has been interpreted as effect of trampling over that surface, which has been attested also by experimental tests. (Rentzel et al., 2017, Goldberg et al., 2009) Once again, mF 3/3a were mentioned before regarding the oldest combustion feature in sample MAZ.7, as it was affected by the heating that cause the rubefaction of the matrix. But before that, the exposed surface was covered by the tossing of limpets that constitutes mF 4. Because of this association, we might picture the occupants of the site making tools from limpets over an exposed occupation surface (mF 3a), and tossing the discarded limpets in that surface (mF 4). Later, a hearth was made and both layers served as combustion substrate below the hearth fuel (reduced to combustion residues mF 5) (fig. 7.15).

#### *7.4.2.4 Anthropogenic reworking of sediments*

Deposits with enaulic c/f present variable amounts of matrix with crumby microstructure and are interpreted as anthropogenically reworked, thus in secondary position, generated by dispersion of shells and some domestic debris, possibly by actions like dumping of sediment loads, rake-out or sweeping of debris accumulated in an occupation surface, actions that might have promoted the incorporation of loose crumby aggregates of fine sediment alongside shells. Potential examples of this type of sediment dispersion are mF 20 and 22, which highly organic matrix contains abundant and diverse components related to plants, animal and shellfish processing (bones, organic matter, seaweeds, serpulids, foraminifera) (plate 7.10: a-j). This organic-rich matrixes in shell middens have been associated to reworked sediments from a nearby original deposit where these activities took place (Aldeias and Bicho, 2016).

When these reworked deposits incorporate further coarse components besides the complete shells (e.g., coarse charcoal), a possible action inferred is intentional dumping of such selected items from one place to another, generating thick deposits like mF 24. Dumping experimental tests have demonstrated that this deposits potentially preserve the coarser components, whereas sweeping and rake-out deposits are more likely to promote some grain-size sorting (Miller et al., 2010). The latter may be applied to the fine-grained mF 19a, which closely packed small shell fragments and absence of complete shells and further coarse components. Dumping to further distances might reflect intention of flatten out or create/renew surfaces, as suggested by similar features in shell midden contexts by Aldeias and Bicho (2016). The high number of mF in secondary position (mF 2, 11, 14, 20 and 24), interpreted as anthropogenically reworked, particularly by dumping, and the residential character of the site as suggested by the abundance of combustion features, suggests that there were constant efforts in maintain the shell midden surface suitable for occupation.

### 7.4.3 Naturally Reworked Deposits

Some of the geometric and fabric attributes in a few mF are better explained as result from natural reworking, namely by slope processes and water circulation, which will be addressed in this section.

#### *7.4.3.1 Slope deposits*

Most matrix-supported microfacies in thin section have stratigraphic correspondence with archaeological layers that exhibit considerable sloping (fig. 7.1). This association should make us consider the occurrence of slope processes, either surficial, such as creep, or down movements of sediment in mass, like sliding. Slope deposits are typically rich in fine-fabric matrix that supports coarser components incorporated in the gravitational transport, and exhibit massive structures with coarser components chaotically oriented and scattered in the matrix (Bertran and Texier, 1999).

- *Lower slope*

The most basal microfacies recorded in thin section is mF 1 and corresponds to layer 108, in the sample MAZ.7 (fig. 7.20). This mF has not a spongy or crumby microstructure like most anthropogenic deposits. It presents instead packed aggregates with massive microstructure of many natures, including microbial aggregates (fig. 7.15g) and organo-mineral SMT, which has not been identified in anthropogenic deposits. It does contain few aggregates of ash, and one limpet with an ash infilling. These aspects all together suggest natural reworking of several materials available in the surroundings downslope, i.e., from outside of the rockshelter. By association, the earliest occupations must have been located outwards and, when eroded, transported towards the rockshelter wall, since there was a slope in that direction. This process involves the incorporation of anthropogenic activities debris in the form of reworked aggregates.

In the same sample, the already mentioned mF 3, shares some characteristics: biogenic aggregates with marine microfossils (filaments, spherulites, foraminifera and sponge spicules), one shell infilled with ash and even angular pebbles, in a matrix-supported sloping deposit, although with more abundant dispersed ash pseudomorphs (fig. 7.15: d-g). This is the deposit which surface was trampled (mF3a), covered with anthropogenically tossed limpets (mF4), and an hearth placed on top (mF5).

Both mF 1 and 3 have aggregates with marine microfossils, which origin is uncertain, but above all it suggests they shar the same sediment source, located elsewhere outwards the rock shelter. In between bot layers, lies the deposit corresponded to shell-supported mF 2, interpreted as an anthropogenic dumping deposit, possibly placed here in an earlier attempt to flatten out the slope, intercalated between two colluvial deposits (fig. 7.10).

- *Mid slope*

The deposits considered in this group correspond to archaeological layer 105, which exhibits a striking stratigraphic angular discordance in the profile (plate 7.11a). All mF in this layer are matrix-supported, which in the absence of anthropogenic markers in the correspondent SMT, are attributed to natural processes, particularly slope processes (table 7.4).

Microfacies 6, 8, 12 and 13 are those attributed to slope processes such as sliding or creep because of being matrix-supported, with the coarse components not organised nor oriented, which also characterises colluvial deposits (Courty et al., 1989, Bertran and Texier, 1999). They are distinguished from each other because of the different natures of the micromass, that reflect the nature of original deposit that was eroded. In sample MAZ.7, mF 6 has a calcitic clay SMT and charcoal, resembling the two slope deposits of the lower slope, being all three vertically coincident, so it is assumable that mF 6 shares the same sediment source with mF 3 and 1 (plate 7.11: b-d). Microfacies 8, in sample MAZ.4, at the base of layer 105, has an organic clay SMT (plate 7.12: a, h, i). Microfacies 12 has dark organic clay with some aggregates of calcitic clay, whereas mF 13 has brown-reddish, ashy calcitic clay. All these mF share the same set of anthropogenic coarse components: shell fragments, fishbone, charcoal, seaweed and rubified aggregates, chaotically distributed.

- *Upper slope*

In the contact with the superficial layer of the shell midden, that is disrupted by recent bioturbation, lies mF 25, matrix-supported organic clay with chaotically distributed shells, angular pebbles and rubified aggregates.

Fabric features such as sedimentary structures are another an indication of slope processes. An important structure identified in thin section was inverse grading of coarse components, namely shells. In mF 19 and 23, the shell fragments are inversely graded, which means at the bottom the fragments are smaller and their size increases towards the top culminating with aligned complete shells (fig. 7.4: a, b; 7.8: a-d). Inverse grading within a same mF is attributed to debris flow or granular flow processes and/or water laying promoted by increasing energy flow (Goldberg and Macphail, 2006). Microfacies 23 is particular because all shells, complete and fragmented, are burnt (fig. 7.4). This aspect indicates that these shells belong to a same original context where they were homogenously burnt. Therefore, the flow process that affected the original deposit must have took place shortly after its formation.

#### *7.4.3.2 Water-lain deposits*

The deposits with gefuric c/f, which generally have moderate amounts of matrix (>10 <20%) with massive/spongy microstructures, are interpreted as result of natural reworking of previously deposited shell-rich sediments that were mixed with the respective matrix by action

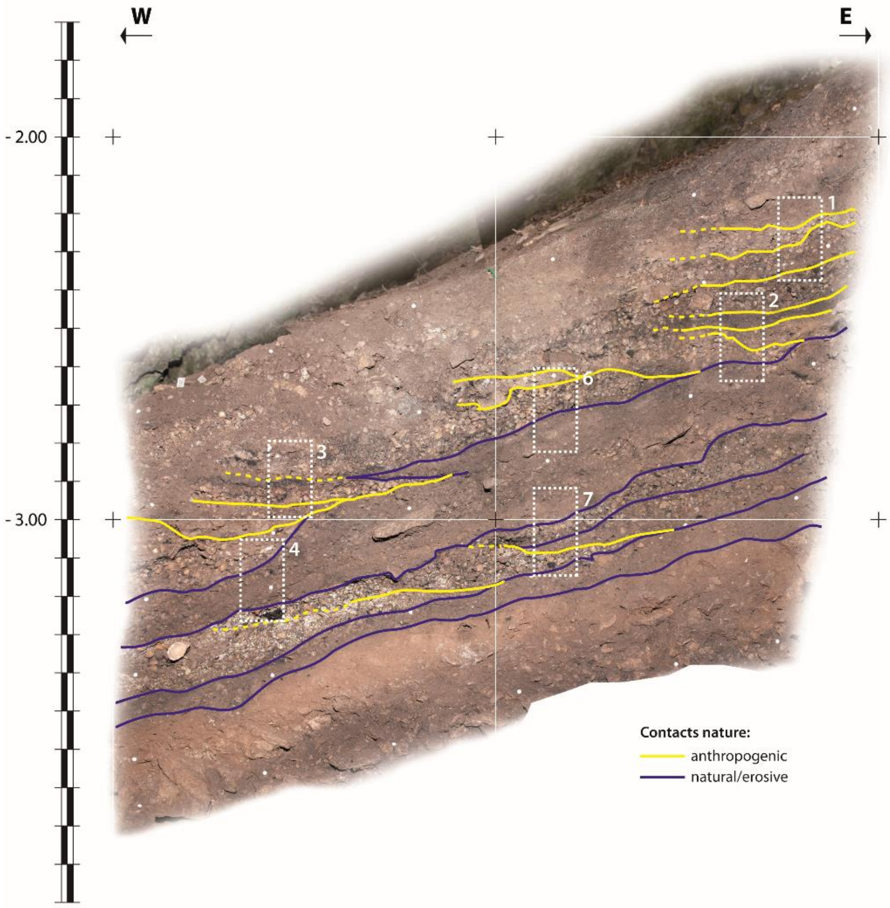



**Figure 7. 10** Annotated sampled profile X15/16 of El Mazo with the micromorphological sampling areas indicated (dashed rectangles); note the angular discordances formed between naturally and anthropogenically induced contacts, with the anthropogenic ones tending to horizontality.

of water. Water saturation and transport would have been responsible for the gefuric c/f. Microfacies 9 and 10 of sample MAZ.4, correspond to sloping deposist that exhibit gefuric c/f. (plate 7.2e) Furthermore, the coarse components of both mF are well-oriented, parallel to the sloping (plate 7.12a). In both mF, discrete bridges of highly organic clay, isotropic, frequently coat and connect coarse components or aggregates, isolating voids (fig 7.22: a, f, g). The fact that this bridges and coating are of the same material of the groundmass, seems to indicate that the gefuric c/f is syn-depositional, otherwise the coatings and bridges would consist of exogenous material illuviated from elsewhere above, which is not the case.

Another type of fabric that is intuited from two mF is consistent long-axis orientation of closely packed components, which is somehow difficult to discern in two-dimensions of the thin section, being better observed in the profile. However, the discretion of the mF complicates its identification also in the field. In thin section, the way the shells are packed against each other in mF 9 and 10, oriented parallel to the slope (plate 7.12a) as already mentioned, makes us think of running water in their deposition. Even being shell-supported, they exhibit high amounts of organic micromass that is better explained as naturally than human-induced, namely if the shells were being transported in a clay-rich flow. The already mentioned gefuric c/f seem to support the hypothesis. Microfacies 9, within archaeological unit 105, is a discrete lens c. 1 cm thick which coarse composition is almost exclusively echinoids spines and shells, unburnt and closely packed (plate 7.2f, 7.22a). This aspect makes us hypothesizes if these echinoids come from the same original deposit of mF 7, the one with self-supported echinoids without matrix, located further up in the slope. This implied that the lower part of these hypothetical same deposit, preserved as mF 7, has been partially covered by slope deposits (namely mF 8).

### 7.4.4 Environmental considerations

Clastic components not related to human inputs, being independent from human actions, are susceptible to bear information regarding local environment conditions. This is the case of tufa clasts identified in deposits naturally reworked, specifically mF 9, 10 and 13, all within the sloping archaeological unit 105 (plate 7.11: g, h; 7.22f).

These stromatolitic tufa clasts probably became detached from the rockshelter wall, where the original deposit must have developed. Tufa formation in karstic environments is normally considered to take place under humid conditions by phreatic waters, pointing also to spring activity in the rockshelter (Jones and Renaut, 2010). On the other hand, the systematic detachment of fragments, as seems to be the case given its abundance in these mF, has been pointed out as consequence of erosional effect of colder conditions or wetting and drying processes over the rockshelter and cave walls (Courty and Vallverdu, 2001) post-dating the tufa formation.

Water circulation is susceptible to promote mass movements downslope, as well as the in-situ fragmentation of components during the transport (Bertran and Texier, 1999). In mF 9, 10 and 13, a systematic feature are shells and other components cracked in-situ (plate 7.2e; 7.21: e, f). The sloping of this deposits makes it unlikely for the cracking to result from crushing due to surface pressure, but wetting and drying, promoting shrink and swell movements in the sediment, is a possible explanation, however this hypothesis needs for further investigation to be confirmed.

### 7.4.5 Syntehsis: depositional history of El Mazo shell midden.

The lower set of anthropogenic deposits, mainly represented by sample MAZ.7, marks the onset of systematic human occupations of the site, that are intercalated with probable periods of abandonment represented by colluviated archaeological materials (fig. 7.11). Specifically, the lowermost deposit, layer 108, seems to correspond to a colluvium containing shells and materials from different sources, from combustion features to carbonate mud. It was covered by layer 107, a shell dump. A new deposit of colluviated materials similar to 108, layer 111, partially overlaps 107, which surface possibly suffered trampling and finally both are covered by anthropogenic shell-rich deposits corresponding to a combustion feature, part of layer 110. Another anthropogenic deposit of direct tossing, mostly of echinoids, but also other shells and bones, took place towards the rockshelter wall. The sequence could possibly have had more deposits superimposed, but a high-impact erosional event caused the truncation of the deposits mentioned above, creating a sloping surface toward the shelter’s wall that was filled with the deposits corresponding too layer 105 (fig. 7.10, 7.11).

Such process was likely of natural origin, giving the evidence of subsequent predominantly naturally-driven processes as responsible for the accumulation of the successive sloping deposits of layer 105. This suggests that this area of the site was not occupied, and probably in the whole rockshelter the occupation was not as intense as during the accumulation of the anthropogenic deposits below and above. The evidence of downslope mass-movement

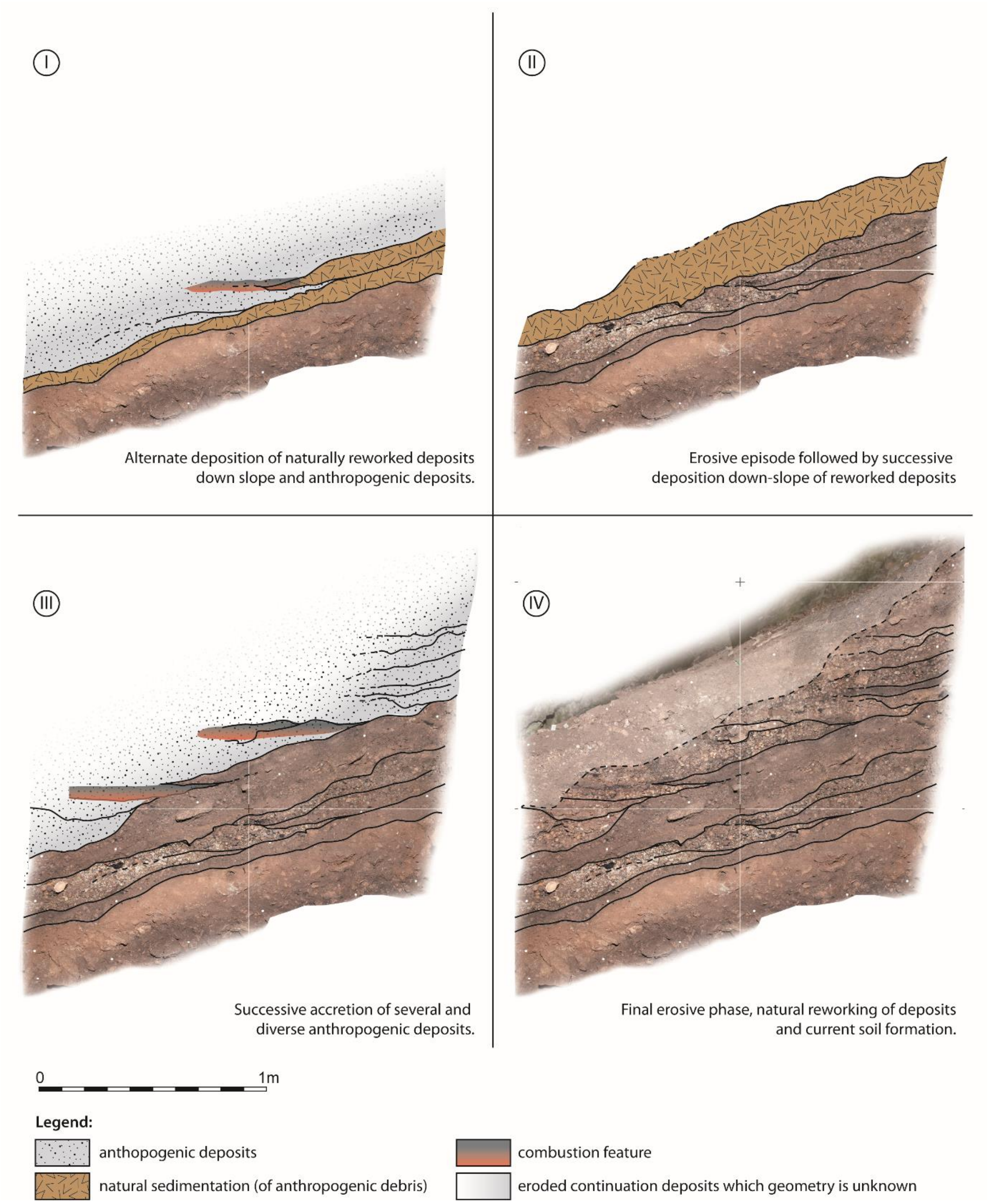



**Figure 7. 11** Hypothetical schematic synthesis of the main depositional phases of the stratified shell midden of El Mazo.

of anthropogenic deposits highly significant when related with the lower intensity of human occupations at the site, since it seems to correspond to an erosional period, which is a significant contribution for the understanding of mobility patterns of the Mesolithic groups in the region.

The upper set of mainly shell-supported deposits represents the reestablishment of systematic human occupation of the site, marked by accretion of overlapping lenticular anthropogenic deposits (fig. 7.23). The basal one documented micromorphologically, in the lower part of the sloping surface of 105, is a dumped deposit of combustion residues, that could hypothetically represent an attempt of regularisation of the surface, according with the interpretation of such deposits proposed in earlier works (Aldeias and Bicho, 2016). These lenticular deposits include successive combustion features and anthropogenically reworked deposits by raking out and dumping, that tend to retrieve the horizontality, more suitable for human occupation, compensating the slope as they are superimposing to the previous. The water-lain deposits and dispersion of materials, sometimes promoting sediments grading, perhaps represent strom events, although the hypothesis of intentional use of water loads to disperse sediments or extinct fires could be considered.

The uppermost layers (unit 101 and internal subdivisions) seem to correspond to bare surfaces immediately surrounding an occupation area, where successive reworked domestic activities debris was accumulating (fig. 7.23). Microfacies 20 and specially 22 have a distinct micromass composed by very dark, isotropic organic material, mixed with ashy sediments (plate 7.10). These deposits are interpreted as little reworked material from a nearby domestic activity area, perhaps accumulated as result of occasional cleaning of the central area. The presence of biospheroids, absent in other deposits, provide evidence of earthworm colonisation, thus supporting an organic-rich surface as source of the materials. It is relevant the striking amount of seaweeds, foraminifera and serpulids registered in thin section form samples MAZ.2 (plate 7.10) suggest the processing of seaweed and further organic materials took place.

### 7.4.6 Formation processes of the cemented shell midden

The aspects described in section section concerning the components and cement types in the cemented shell midden block present enough evidence for distinction of three possible moments of shell-rich sediments accumulation, intercalated with different moments of post-depositional cementation. The earlier moment involved the accumulation of *Phorcus* shells and common large plates of echinoids tests', and fewer *Patella* shells. In a later moment, primarily *Patella* limpets were deposited, alongside fewer *Phorcus* shells. Since the shells are of anthropogenic origin, it is likely that this differential deposition of species reflects human influence in the deposition process. However, the general chaotic distribution of components and absence of fine organic matter and total excremental microstructure points to high degree of reworking of these materials, possibly in different phases and affecting different deposits, explaining the differences in shell's sorting.

The isopachous cements combined with smooth voids in the cement indicates alternating phreatic and vadose conditions, which suggest that this area of the site was periodically inundated after each moment of deposition. This process certainly modified the geometric configuration and distribution of the archaeologic material, having it been either anthropogenically or naturally originally accumulated.

The reason for inundation could be a resurgence of spring activity in the limestone massif, as it is suggested by a moment of crystalline tufa formation by large calcite dendrites. Dendritic crystals usually nucleate in fast-flowing waters characterised by high driving force (James and Jones, 2016), which suggest a period some turbulent waters flowing between the two main depositional events.

The total excremental microstructure and the very rounded relict aggregates also points to strong reworking of the micromass, hardly corresponding to an anthropogenic accumulation, lacking signatures of human activity as found in the stratified shell midden. These aspects highlight that the cemented shell midden remnants at El Mazo has its own accumulation dynamics more likely to by naturally-driven, thus independent from the largely anthropogenic processes at the stratified shell midden.

## 7.5 Conclusions

The micromorphological analysis of El Mazo provided a high-resolution microstratigraphic reconstruction of the deposit, individualising deposits correspondent to different events, to which the recognition of micro-contextual fabrics and compositions were vital. With the microfacies approach and the establishment of microfacies associations was possible to infer specific human activities behind the formation of the shell midden.

Another significant implication of this study is that the different deposits are composed by naturally-reworking archaeological materials. The distinct microscopic characteristic of these deposits suggests some anthropogenic influence in the sourcing, although since the process of the current deposit is mainly natural, it most likely provoked mixing of archaeological material from several occupations in some other part of the site, probably beyond the dripping line. This aspect must be considered when interpreting other data from the materials within this layer, and the microfacies helps in achieve a higher definition of the microstratigraphy present in the layer, in order to have a more accurate dating of these events and therefore of the occupation's dynamics in the site. The evidence erosive events followed by successive slope deposits that correspond to natural reworking of anthropogenic material suggests periodic abandonment and provides sedimentological data to future debates regarding settlement patterns' adjustments during the Mesolithic.

The study of a block extracted from a cemented hanging shell midden remnant revealed that this deposit, also stratified, has its own sedimentation dynamics that do not seem to offer a clear correspondence with the processes identified in the stratified deposit. The cementation process was caused by water table fluctuations, and an episode of fast-flowing water that seems to have origin in increasing water circulation or, perhaps, a resurgence of spring activity at the site. Future research directions regarding the cemented testimonies, such as dating of the tufa crust formed by torrential waters, would possibly clarify the age of this episode and its implication of the site-scale formation processes.

Chapter 8

# El Alloru

## 8.1 Introduction

This chapter addresses two distinct loci of the site of El Alloru, one located in the interior of the karstic rockshelter and another in the exterior. In the exterior location, the objective of the study was a geoarchaeological characterisation of the stratigraphic sequence excavated to contextualise the archaeological findings related to the Mesolithic occupation and the reconstruction of the formation processes. In the interior of the rockshelter, the object of study was a cemented typical Asturian shell midden preserved there, seeking to unravel the internal organisation and stratigraphy of a well representative case of this type of contexts.

### 8.1.1 Geological and Archaeological Context

El Alloru is a rockshelter in a small limestone outcrop corresponding to a Carboniferous, dark and laminated limestone (fig. 8.1). The outcrop itself is limited by a contact joint by north and surrounded by a system of coalescent sinkholes filled with sandy-clayey materials, which surface is nowadays flattened by recent anthropogenic activity. The outcrop is thus a small remaining limestone relief conforming a spur with north-south orientation, densely vegetated and strongly affected by karstic processes (fig. 8.1), presenting well-developed *karren* morphologies at the top platform, although very eroded. The main rockshelter is located at the southwest border of the outcrop, at 25 m. above the sea level, and the ground at the bottom is 1 m. below oh that of the outside surface. Other small cavities exist along the outcrop border, some of them with remnants of cemented shell middens (fig. 8.2). In

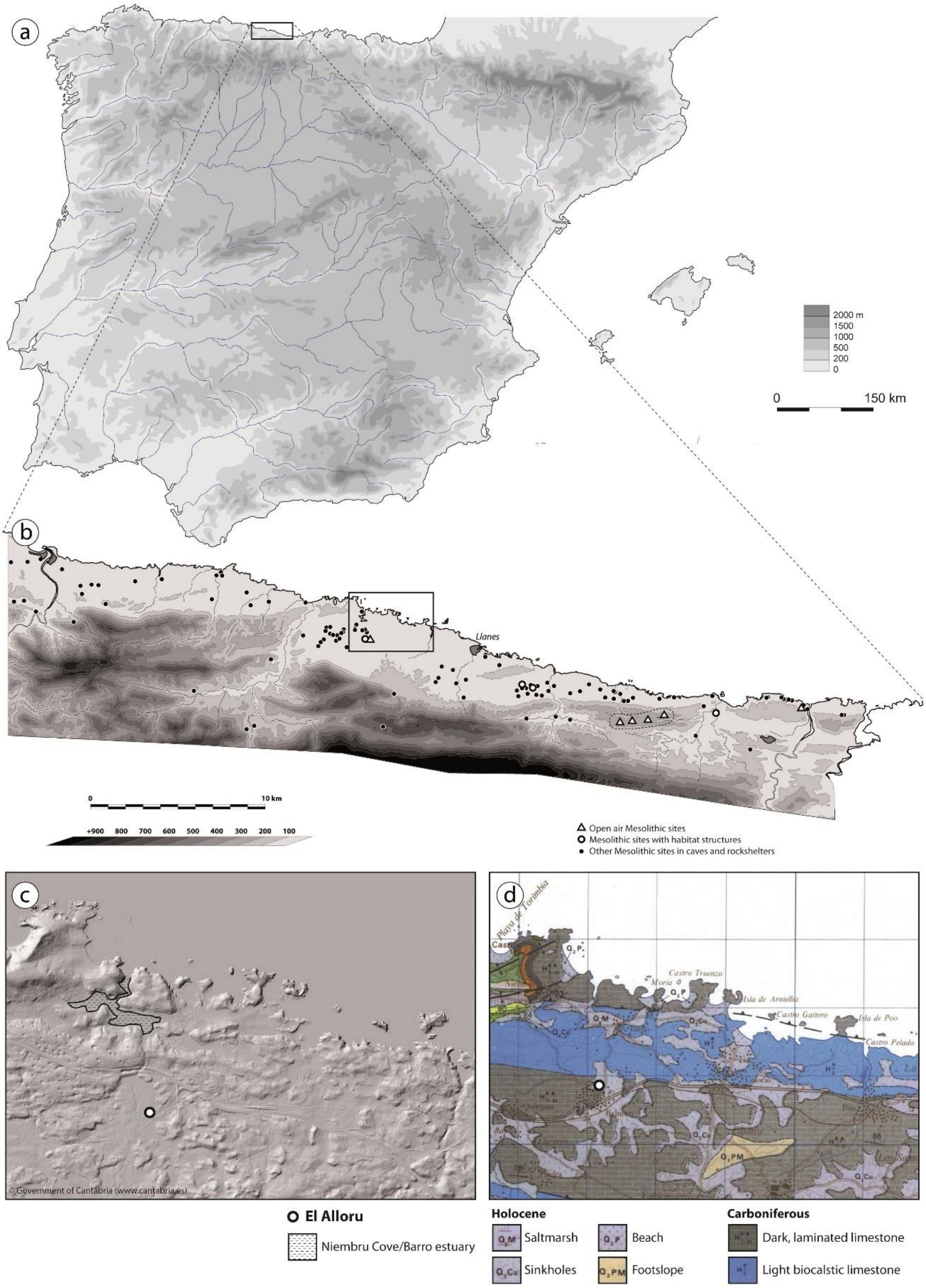



**Figure 8. 1** Geographical and geological setting of El Alloru rockshelter: a) location of eastern Asturias in the in the northern coast of Iberia. b) close-up on Easter Asturias with Mesolithic sites. c) location of El Alloru (circle) and surrounding topography; note the accentuated karstic features and the Barro/Niembru saltmarsh area delimited by black line. d) geological environment of the coastal are of the territory of Llanes municipality.

the main rockshelter, a thick shell midden is cemented at its innermost point (fig. 8.2), accumulated over a clayey sterile substrate, as well as a cornice of hanging remains are visible along the shelters walls to its most external part.

The cemented shell midden is known since Vega del Sella's (1923) prospections. It is in the core area of highest concentration of Asturian shell middens, neighbouring important sites such as Balmori Cave and the sites of La Llera karstic massif (Bricia, La Riera, Cueto de la Mina, etc). It was visited and described by Clark (1976) and González Morales (1982), who did not undertake any fieldwork at the site.

### 8.1.2 Stratigraphy and chronology

The fieldwork at El Alloru in 2013 was organised in 4 tests, 1 and 2 outside the rockshelter and 3 and 4 inside of it (fig. 8.2). The location of the outside tests, of 2 $m^2$ each, was guided by the results of previous geomagnetic survey carried out at the site (Arias et al., 2015a, Arias et al., 2016).

Test 1, located 3 m. away from the rockshelter dripline, revealed the most complete stratigraphy. It starts at the top with grassy soil developing on a thick and homogenous silty-loam deposit corresponding to recent anthropogenic activities. The first prehistoric mixed material (including manual pottery as well as Asturian picks), appeared in Unit 103, with frequent small limestone clasts. The underlying layer corresponds to intact Mesolithic occupation remains, with some lateral differences in terms of materials and sediments composition, discriminated into different units (see table 8.1) (Arias et al., 2016). It contained moderate amount of shells in a dark brownish silty-loam matrix. At the base of this layer, two small negative structures penetrating the underlying clay, filled with darker sediment, were identified. Arias et al. (2015a and 2016) suggest they could correspond to post-holes, therefore associated to a Mesolithic dwelling structure. The basal orange-brown clay where the structures were dug contained very few interstitial archaeological materials between limestone cobbles and boulders, that could not be removed entirely.

Test 2 was located further away, 9 m., from the dripline, did not yield any intact Mesolithic layer, although reworked prehistoric material was recovered. Test 3 was 1 $m^2$ in the slope going down toward the interior of the rockshelter and revealed only a sterile stony deposit with a clayey matrix overlying basal silty-clays. In a dark sandy-clay pocket within the basal

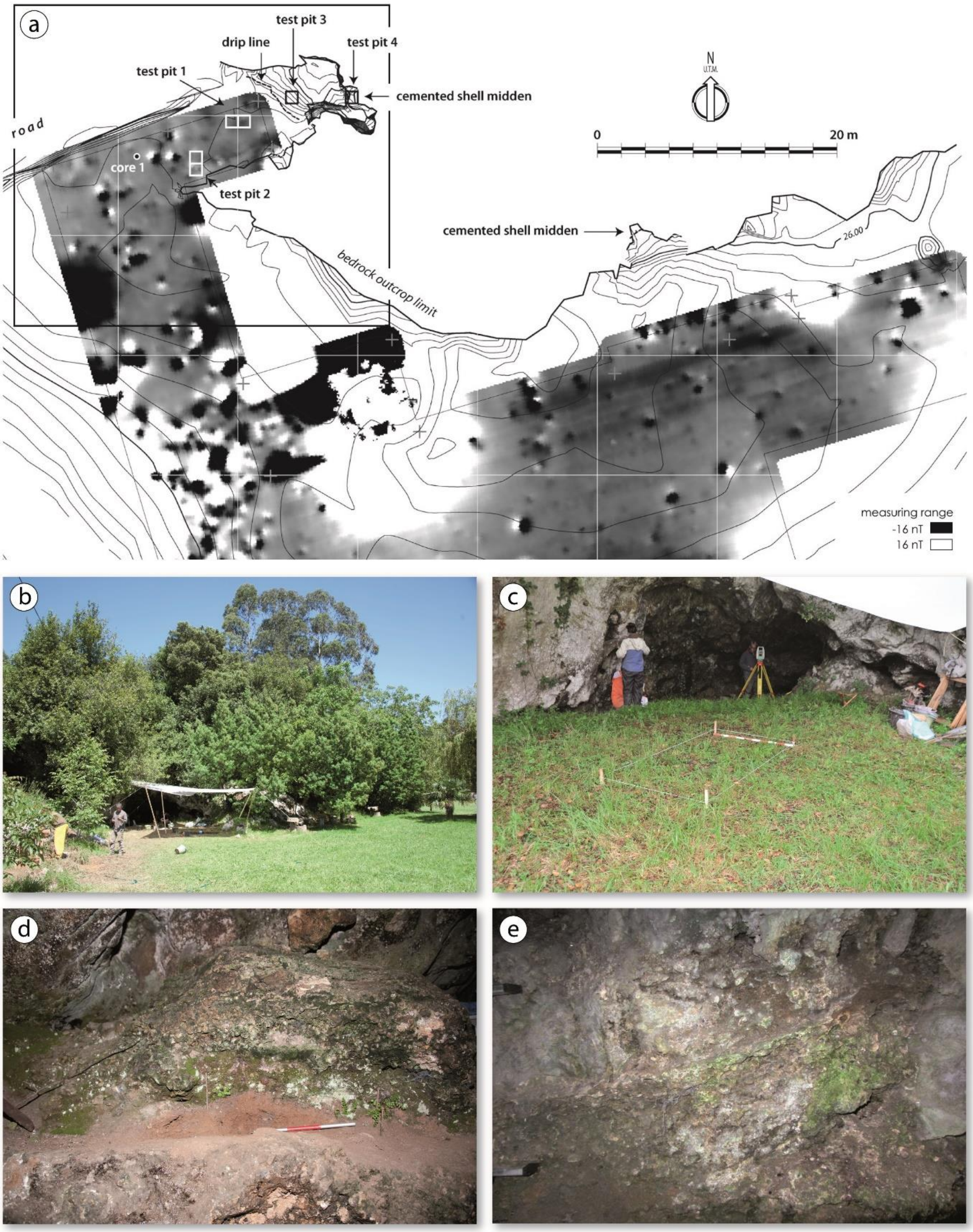



**Figure 8. 2** El Alloru site: a) plan of the limestone massif of El Alloru, where the main rockshelter is located, facing west, with indication of the excavation areas; b) view from west towards the small limestone outcrop, hide by dense vegetation, and excavation area; c) location of Test 1 in front of the rockshelter before excavation; d) detail of the studied cemented shell midden that was sampled, located at the back of the rockshelter; e) detaill of further cemented shell midden remnants adhered to the rockshelter's walls.

silty-clays a few limpets and topshells were recovered and radiocarbon dated to the seventh millennium cal BC (table 8.1).

Test 4 was located at the rear of the rockshelter, adjacent to the cemented shell midden, in the carbonate deposit over which it rests (fig. 8.2). The shell midden exhibited an artificial semi- vertical face, probably result of early excavations, prior to Clark's (1976) visit, of which we have no notice (Arias et al., 2016). In table 4, a list of the stratigraphic units and respective radiocarbon dates is presented.

**Table 8. 1** Descriptive list of stratigraphic units and radiocarbon dates of Tests 1, 3 and 4 at El Alloru

| Stratigraphic unit field description | | Chronology | | | |
|---|---|---|---|---|---|
| | | **Material** | **Ref.** | **Result** | **Cal BC 2σ** |
| **Test 1 (exterior)** | | | | | |
| 101 | Surficial vegetal and humic soil | - | - | - | - |
| 102 | Clayey-silt of pale brown colour, with lithic industry and some shells alongside recent material (modern pottery, roof) | - | - | - | - |
| 103 | Dark brown clayey-silts with many limestone clasts, with Mesolithic artefacts and some recent pottery. | - | - | - | - |
| 105 | Dark-greyish sandy-silts with little manual pottery | - | - | - | - |
| 104/ 107/ 112 | Dark brown clayey-silt with lateral variations and small negative structures at its base (S.U. 109 and 111, filled by darker sediment, S.U. 108 and 110, respectively), possibly corresponding to post-holes. This layer contained a moderate amount of shellfish and Asturian lithics, including five picks. | Charcoal (Unit 112) | OxA-29835 | 1937 ± 25 | AD 9-127 |
| | | *Rupicapra pyrenaica* (Unit 104) | OxA-29115* | 7979 ± 38 | 7049-6708 |
| | | *R. pyrenaica* (Unit 104) | OxA-29116* | 7979 ± 38 | 7049-6708 |
| 106 | Reddish and compact clayey-silty sand, with much little archaeological material than upper layers. | - | - | - | - |
| Boulders | Limestone block, probably collapsed frmom the kartic gallery in the Pleistocene | - | - | - | - |
| **Test 3 (interior)** | | | | | |
| 301 | Surficial vegetal and humic soil | - | - | - | - |

| | | | | | |
|---|---|---|---|---|---|
| 302 | Greyish clayey with many limestone clasts | - | - | - | - |
| 303 | Yellowish silt, with a pocket (305) filled with darker sand (304) | *Phorcus lineatus* | OxA-29080 | 8249 ± 37 | 6704-6393 |
| **Test 4 (shell midden)** | | | | | |
| 401 | Cemented shell midden, roughly stratified, with horizontal carbonate laminated crusts, bones and charcoals | *Patella vulgata* (top layer) | OxA-29082 | 7714 ± 34 | 6082-5912 |
| | | *P. lineatus* (middle layer) | OxA-29083 | 7342 ± 32 | 5716-5578 |
| | | *P. lineatus* shells | UBAR-781 | 8360 ± 70 | 6931-6477 |
| 402 | Yellowish clay with limpest and topshells | *P. lineatus* | OxA-29081 | 7761 ± 37 | 6161-5972 |
| 403 | Pebbly layer strongly cemented | - | - | - | - |
| 404 | Salmo-coloured silts | - | - | - | - |
| 405 | Yellowish silts | - | - | - | - |

*Both dates are from the same sample

The radiocarbon dates on a chamois bone from the exterior Test 1 revealed an occupation from the end of the seventh millennium, whereas the most recent dates from the shell midden yielded an age from the last half of the sixth millennium, thus corresponding to a late phase of the Cantabrian Mesolithic (Arias, 2007). This implies that the exterior occupation is older than that associated to the shell midden in the interior of the rockshelter. However, a previous dating of an assemblage of shells (UBAR-781) from a sample collected at the base of the same deposit in the year 2000 (Arias Cabal et al., 2007) reveal an older date, that that of a shell from the underlying clayey deposit (OxA-29081) (table 8.1). There is no apparent explanation for this contradiction, but there is the chance of the sample OxA-29081 constitute intrusion from the overlying shell midden into the basal clays, which would push back its chronology to the second quarter of the seventh millennium.

The two dates from the shell midden were obtained from samples collected at the top () (OxA-29082) and at the middle (OxA-29083) of the layer, which revealed stratigraphically inverted chronologies (table 8.1), that could be reflecting instability of this type of deposits, prone to vertical migrations of the material (Arias et al., 2016). The dating of a charcoal with a result from the first century AD should be considered a contamination into the Mesolithic context 112.

## 8.2 Sampling strategy and analysis

In Test 1, the micromorphological sampling covered vertically all stratigraphic units represented in the east profile (fig. 8.3a), focusing in include the stratigraphic contacts in the sediment blocks, from 101 down to the Mesolithic unit 104 (fig. 8.3b). Further down, the intense concentration of cobblestones prevented the successful sampling, so the lower Mesolithic units 105, 112 and 106 were sampled in the west profile, where a more suitable surface was available (fig. 8.3c). The samples were name LV1 to LV7. The cemented shell midden was also sampled for micromorphological analysis. As it was extremely consolidated

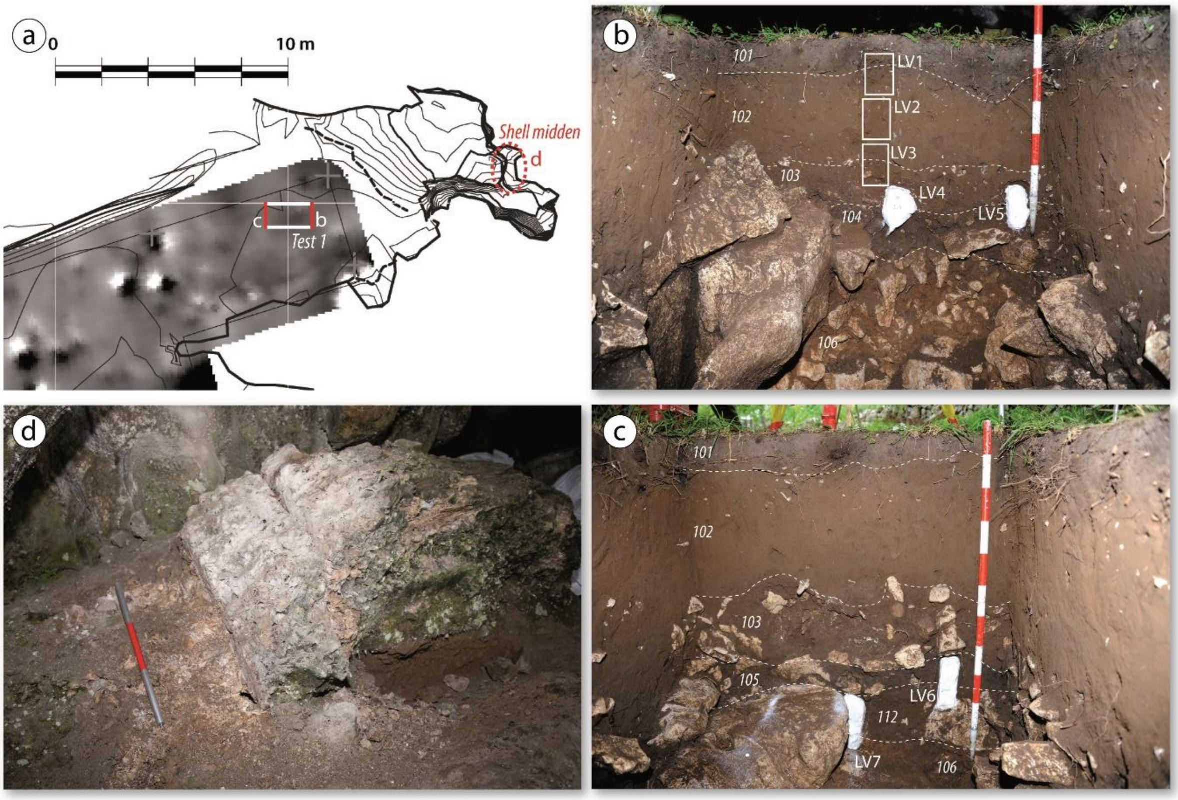



**Figure 8. 3** Plan of El Alloru rockshelter with indication of the sampled contexts in red; b) Annotated East profile of Test 1 with micromorphology samples location; note that samples LV4 and LV5 are still plastered in the profile, ready for extraction; c) Annotated Wast profile of Test 1 with micromorphology samples LV6 and LV7 plastered in the profile; d) Aspect of the cemented shell midden during the process of excavation to create a suitable surface for sampling the large block.

by calcium carbonate, it was sampled with an electric circular saw, which allowed the extraction of a block covering the whole layer from the bottom to the top in one large piece, sample ALL1 (fig. 8.3d), and a smaller block, ALL2. From ALL 1, five thin section were obtained, covering the entire block vertically; because of the long-time processing due to its large size, the smaller block ALL 2 was used for a quicker thin sectioning and preliminary observations.

The micromorphological analysis followed the criteria established by Courty et al. (1989) and Macphail & Goldberg (2017) recurring also to Stoops (2003) terminology and Goldberg and Aldeias (2016) recommendations. The microfacies approach was applied as preconised by Goldberg et al (2009) and largely based on Flugel (2004) for carbonate materials, for which terminology of Pentecost (2005) was also followed.

## 8.3 Results

In the next sections, the micromorphological observation are reported, starting with the results of Test 1 following the cemented shell midden. For Test 1, there was no microfacies recorded in thin section, so the micromorphological description follow the stratigraphic units (table 8.1). The cemented shell midden demanded a different approach organised in components and cement separately, and the microfacies concept was applied for the different contexts identified in thin section to reconstruct the formation processes.

### 8.3.1 Test 1 (exterior)

The deposit is globally composed of loamy silty-sand and it is homogenous throughout the sequence (fig. 8.3), as well as the sedimentary components, that present only slight distribution variations in some units (table 8.2, plate 8.1). The coarse fraction from a micromorphological point of view (> 63µm) is dominated by fine to medium sand grains composed mostly by quartz, although other minerals are residually observed, such as chlorite and biotite (plate 8.1: a, b). Coarser inclusions are limestone centimetric clasts with angular shapes (plate 8.1c). Anthropogenic inclusions comprise chert fragments, fine gravel sized charcoals and comminute bone fragments (plate 8.1: d-f). Shells of marine molluscs are concentrated in unit 104, and a single complete example is represented in thin section, corresponding most of the shell remains to comminute fragments showing advanced weathering (plate 8.1g). Biogenic components observed include fungal spores throughout the sequence and calcitic biospheroids in unit 104 (table 8.3) (plate 8.1h).

The fine fraction is composed by quartz silt and clay (plate 8.2). In the Mesolithic units 104 to 112, the silty fraction does not suffer any significant changes, but it increases in the basal unit 106 (plate 8.2). The same happens to clay fraction, or micromass, that presents a homogenous brownish colour, darker in the Mesolithic units due to higher presence of micro-charcoal. However, in unit 106 it present different texture and higher abundance (less void space) along with the silt increasing (plate 8.2). With exception of 106, the high porosity characterised by interconnected irregular vughs and some channels and chambers reveal intense biological activity throughout the formation of the whole deposit (plate 8.3b).

Unit 104 differs from the rest by the presence of shells, associated to the Mesolithic occupation of the site, calcite biospheroids alongside with abundant limestone clasts, all presenting advanced signs of carbonate dissolution (fig 8.6). Signatures of biological activity in the sediment structure are also incremented by the incipient development of a moderate pedality and sub-angular blocky structure better observed at meso-scale observation of thin sections (plate 8.3b). The abundance of fine organic matter gives it a darker colour.

Unit 106, at the base of the deposit, differs form the upper units in several significant aspects, apart from the fine fraction increment already mentioned. One of them is the porosity, which in unit 106 is lower than that of the upper units. The predominantly massive microstructure is broken by elongated vesicles (closed vughs with smooth, globular shape), closed polyconcave vughs and plane voids, as well as other irregular interconnected vughs. The micromass has a strong orange colour and a dominant stipple-speckeld b-fabric, although crystallitic (not calcitic, possibly sericitic?) and cross-striated b-fabrics are observed in some areas (plates 8.4 and 8.5). A significant aspect of unit 106 is the presence of textural clay features. The solid fraction present coatings of dusty, dark-brownish clay, well oriented, normally not laminated, though a few laminated ones occur (plate 8.6: a-d). These coatings might contain organic and charcoal micro-particles finely mixed with the clay particles, which makes them easily distinguishable from the surface where it was formed (Macphail and Goldberg, 2017). Other similar features are only visible in XPL and resemble clay coatings when good clay particles orientation around sand grains, differentiates it from the surrounding clay. These features are not considered clay coatings, but a result of rear rangements of the groundmass resulting in grano-striated b-fabrics (plate 8.6: e-h). Another very significant feature in unit 106 are discrete sedimentary structures. In some areas, the sand grains exhibit crude bedding and particle sorting (plate 8.7: a and b). Associated to these areas, horizontal clay intercalations and humified organic matter pans are observed (plate 8.7: c and d).

**Table 8. 2** Micromorphological description and formation processes interpretation for the stratigraphic units of Test 1 at El Alloru

| Unit | Sample | Description | Interpretation |
|---|---|---|---|
| 102 | LV3 | Microstructure and voids:<br>Unaggregated, simple packed fine loamy sand (30%) and silt (2%), both poorly sorted. Vughy microstructure, with irregular interconnected vughs. Void space 30%.<br>Micromass:<br>- Brown clay with stipple-speckled b-fabric (30%) and abundant microcharcoal and organic impurities.<br>C/f related distribution: close to single-spaced porphyric and enaulic.<br>Coarse components:<br>- Limestone clasts (10%), strongly weathered, micritic and fossiliferous.<br>- Common charcoal fragments, from medium to fine sand size;<br>- Fungal spores<br>- Mollusc shell (x1), strongly weathered (depletion of calcite)<br>- Bone fragments (2%)<br>- Flint fragments (2%).<br>Post depositional features:<br>- Fresh roots | Over-thickened, humic soil result from recent anthropogenic activities, reworking archaeological material from Late Prehistory. |
| 103 | LV3<br>LV4 | Microstructure and voids:<br>Unaggregated, simple packed fine loamy sand (30%) and silt (2%), both poorly sorted. Vughy microstructure, with irregular interconnected vughs. Channels and few chambers porosity superimposed. Void space 30%.<br>Micromass: | Base of the overlying soil, result of anthropogenic accretion of sediment post-dating the Mesolithic, result of intense reworking of surrounding material (archaeological an geogenic), later affected by intense leaching and dissolution of |

| | | | |
|---|---|---|---|
| | | - Brown clay with stipple-speckled b-fabric (20%)<br>C/f related distribution: close to single-spaced porphyric and enaulic.<br>Coarse components:<br>- Limestone clasts (30%), strongly weathered, micritic and fossiliferous.<br>- Charcoal fragments (5%), from medium to fine sand size;<br>- Comminute mollusc shell fragments (x1), strongly weathered (depletion of calcite)<br>- Cominute bone fragments (5%)<br>- Flint fragments (2%).<br>Post-depositional features:<br>- Very localized micritic calcite infillings in pores.<br>- Fresh roots, along channel voids | carbonates. Weak carbonate reprecipitation also occurred. |
| 104 | LV4 | Microstructure and voids:<br>Unaggregated, simple packed fine loamy sand (30%) and silt (2%), both poorly sorted. Vughy microstructure, with irregular interconnected vughs. Channels and few chambers porosity superimposed. Void space 30%.<br>Micromass:<br>- Dark-brown clay with stipple-speckled b-fabric with abundant microcharcoal particles (20%).<br>C/f related distribution: close to single-spaced porphyric.<br>Coarse components:<br>- Limestone clasts (30%), strongly weathered, micritic and fossiliferous.<br>- Charcoal fragments (2%), from medium to fine sand size;<br>- Comminute mollusc and echinoids shell fragments (10%), strongly weathered (depletion of calcite).<br>- Phorcus shell (x1)<br>- Cominute bone fragments (5%)<br>- Flint fragments (2%). | Possible Ah horizon of a Luvisol, developed over former Mesolithic occupation surface. |

| | | | |
|---|---|---|---|
| | | <u>Post-depositional features:</u><br>- Biogenic calcite worm granules.<br>- Very localized micritic calcite infillings in pores.<br>- Fresh roots, along channel voids | |
| 105 | LV6.1 | <u>Microstructure and voids</u>:<br>Unaggregated, simple packed fine loamy sand (30%) and silt (2%), both poorly sorted. Vughy microstructure, with irregular interconnected vughs. Channels and few chambers porosity superimposed. Void space 30%.<br><u>Micromass:</u><br>- Dark-brown clay with stipple-speckled b-fabric with abundant microcharcoal particles.<br>C/f related distribution: close to single-spaced porphyric.<br><u>Coarse components:</u><br>- Irregular, gravelly aggregates from underlying unit 106 (10%).<br>- Abundant charcoal fragments (20%), sand to gravel size;<br>- Bone fragments (2%) | Charcoal-rich sediments most probably of anthropogenic origin related to Mesolithic activities in the surroundings, responsible for the incorporation of aggregates from the underlying clayey substrate, possibly by trampling. Later affected by pedogenesis. |
| 106 | LV7 | <u>Microstructure and voids</u>:<br>Massive fine loamy sand (30%) and silt (20%), both poorly sorted.<br>Porosity: irregular polyconcave voids and elongated vesicles (10%); channels and few chambers porosity superimposed (10%)<br>Weakly expressed bedding of sand grains intercalated with horizontal clay infillings and organic material.<br><u>Micromass</u>:<br>- Orange-brown colour. Crytsallitic (not calcitic) to stipple-speckled and cross-striated b-fabric. In areas of wealky expressed bedding, the micromass has grano-striated and elongated-striated b-fabrics.<br><u>Coarse components</u>: | Deposit of fluvial/fluviokarstic origin and unsoluble materials from karstic dissolution. Weakly expressed bedding might be result of trampling or poaching during the Mesolithic occupation.<br>Humified organic matter probably anthropogenically induced, caused also Fe/Mn impregantions.<br>Dusty clay coating are likely to be caused by trampling over a slaking, not vegetated, sometimes ponded surface. Later affected by pedogenesis. |

| | | | |
|---|---|---|---|
| | | - Common charcoal fragments (10%), from medium to fine sand size<br>- Flint (subangular) fine sand size.<br>- Fungal spores (1%).<br>Post-depositional features:<br>- Dusty oriented clay coatings in voids; Sometimes they present some layering and inclusions of silty quartz and organic matter.<br>- Iron-manganese nodules, weakly to moderately impregnated. | |
| 112 | LV7<br>LV6.2 | Microstructure and voids:<br>Unaggregated, simple packed fine loamy sand (30%) and silt (2%), both poorly sorted. Vughy microstructure, with irregular interconnected vughs. Channels and few chambers porosity superimposed. Void space 30%.<br>Micromass:<br>- Dark-brown clay with stipple-speckled and weakly expressed grano-striated b-fabrics, with abundant microcharcoal particles.<br>C/f related distribution: close to single-spaced porphyric and gefuric.<br>Coarse components:<br>- Irregular, gravelly aggregates from underlying unit 106 (5%).<br>- Charcoal fragments (2%), sand to gravel size;<br>- Flint (2%). | Anthropogenic deposit, highly organic, affected by trampling, possibly corresponding to a slowly accretional occupation debris. Highly affected by biological reworking. |

### 8.3.2 Cemented shell midden

When observed in micromorphological sliced slabs or in thin section at natural scale, the sediments of El Alloru shell midden appear overall like chaotic jumble of very coarse components (molluscs, bones, centimetric pebbles…) all coated by thick carbonate crusts of creamy appearance (figs. 8.4 and 8.5). Overall, the shape of the clastic components determines


**Figure 8. 4** Block sample of the cemented shell midden: a) aspect of the block after extraction from the cemented deposit (see fig.8.2d); note the bigger coarseness of components in the lower half than in the upper one; b) slab for thin section corresponding to the upper half; note the differential coloration of the cement between the bottom and the top, and the chaotic distribution of components, most of them shellfish; scale in cm; c) slab for thin section from to the lower half of the sample; note the angularity of the limestone clasts and the presence of fine-grained aggregtaes between the coarse components, as well as infilling them; scale in cm

the shape of the pores, apparently packing voids, which space has been considerably reduced by the cement growing. However, some of these voids are filled with further carbonate cement, massive in some areas and more porous in others. One of the most interesting observations at first examination is that many shells contain organic clayey sediment infills (fig. 8.11 and 8.12) More careful observation reveals that the same sediments are sometimes adhered to clasts' surfaces and as aggregates of varying size. This is a significant occurrence, because the sediments trapped inside shells or preserved as relict aggregates have great informative potential about the original depositional contexts of the shells. In the next sections the constituents of the shell midden will be divided in three different groups: clastic components, clayey aggregates and carbonate cement.

#### *8.3.2.1 Clastic components*

The shell midden's main components, welded together by the cement, are generally coarse pebbly in size (figs. 8.4 and 8.5). This group comprises solid single objects, of geological and biological origin, including limestone pebbles, usually centimetric, mammal bones, limpets and top shells, sea urchin spines and tests fragments and wood charcoal, which are describe in detail in table 8.3. These components present varying distributions and abundance depending of the microfacies (see below).

Regarding the mollusc shells, it is noteworthy that almost all in thin section consist in complete shells, whereas shell fragments are virtually absent. Small shell fragments are present only within silty-clay aggregates, where they are burnt in most cases.

**Table 8. 3** Clastic components identified in thin section of the cemented shell midden of El Alloru

| **Component** | **Description** |
|---|---|
| Limestone pebbles | Coarse pebbles (up to 3.5 cm in thin section) in general angular and not spherical, of highly fossiliferous limestone from the local bedrock. |
| Marine gastropods shells | Complete specimens of limpets (*Patella sp.*) and top shells (*Phorcus sp.*) are dominant at the shell midden. Fragments are extremely rare as clastic material and occur almost exclusively as components of clayey aggregates (table 8.4). |
| Echinoids | Sea urchins have heavily calcified, globular to discoidal, hollow, endoskeletal tests that are composed of individual sutured, interlocking or imbricated calcite plates. Each plate behaves optically as a single, extensively perforated, calcite crystal and displays unit extinction. Echinoid spines have pores arranged with radial symmetry that in cross-sections, have a distinctive lobate or flower-like appearance (Scholle and Ulmer-Scholle, 2003). All echinoid shells at El Alloru shell midden are considerably large (up to 3 cm) test plates and numerous spines, neither with evidence of burning, except for those included in clayey aggregates (table 8.4). |
| Bone | Most of the bones in the shell midden are considerably coarse fragments, in many cases up to several cm and very well preserved, without burning marks. Comminute fragments are rare as clastic material but may occur within aggregates (table 8.4). |

| | |
|---|---|
| Charcoal | Overall rare, except in specific microfacies where it appears as coarse sand to gravel size pieces which woody cellular structure is moderately preserved. Finer pieces and dust charcoal is sometimes ca common components of clayey aggregates. |
| Silt and sand | Rare in general as clastic components, but in some contexts occur as overall angular quartz grains, in relative low amounts and scattered distribution. |

#### *8.3.2.2 Clayey aggregates*

Besides the components of clastic nature, the cemented shell midden also contains sedimentary fine-grained aggregates of different compositions. The aggregates were divided in three sedimentary microfabric types, or SMT (plate 8.8), according to its microscopic characteristics in terms of composition and internal arrangement, as described in table 8.4. The morphology of the aggregates varies depending on the microfacies.

**Table 8. 4** Sediment microfabric types (SMT) identified in reworked aggregates at El Alloru cemented shell midden in thin section

| SMT | Description | Interpretation |
|---|---|---|
| Carbonate mud | Dark- to greyish-brown, calcitic crystallitic clay with quartz silt (2%) and fine-medium quartz sand (10-15%), micritic nodules (5%), variable amount of tangled filamentous microfossils (10-40%) humified fine organic matter, and occasional phosphatic grains. | Carbonate mud, possibly of microbial origin. |
| Combustion residues | Greyish-brown clay, calcitic cristallitic b-fabric, with inclusions of micro-charcoal and charred organic tissues, ash pseudomorphic rhombs dispersed, burnt shells fragments, and rubified clayey aggregates as main components. Occasionally, foraminifera, filamentous microfossil, seaweeds (rodophyta) and phosphatic yellow, isotropic grains are also observed. | Combustion residues from domestic anthropogenic activities. |
| Faecal pellets | Clusters of pellety, granular microaggregates of brown calcitic clay. | Insect/worms faecal pellets |

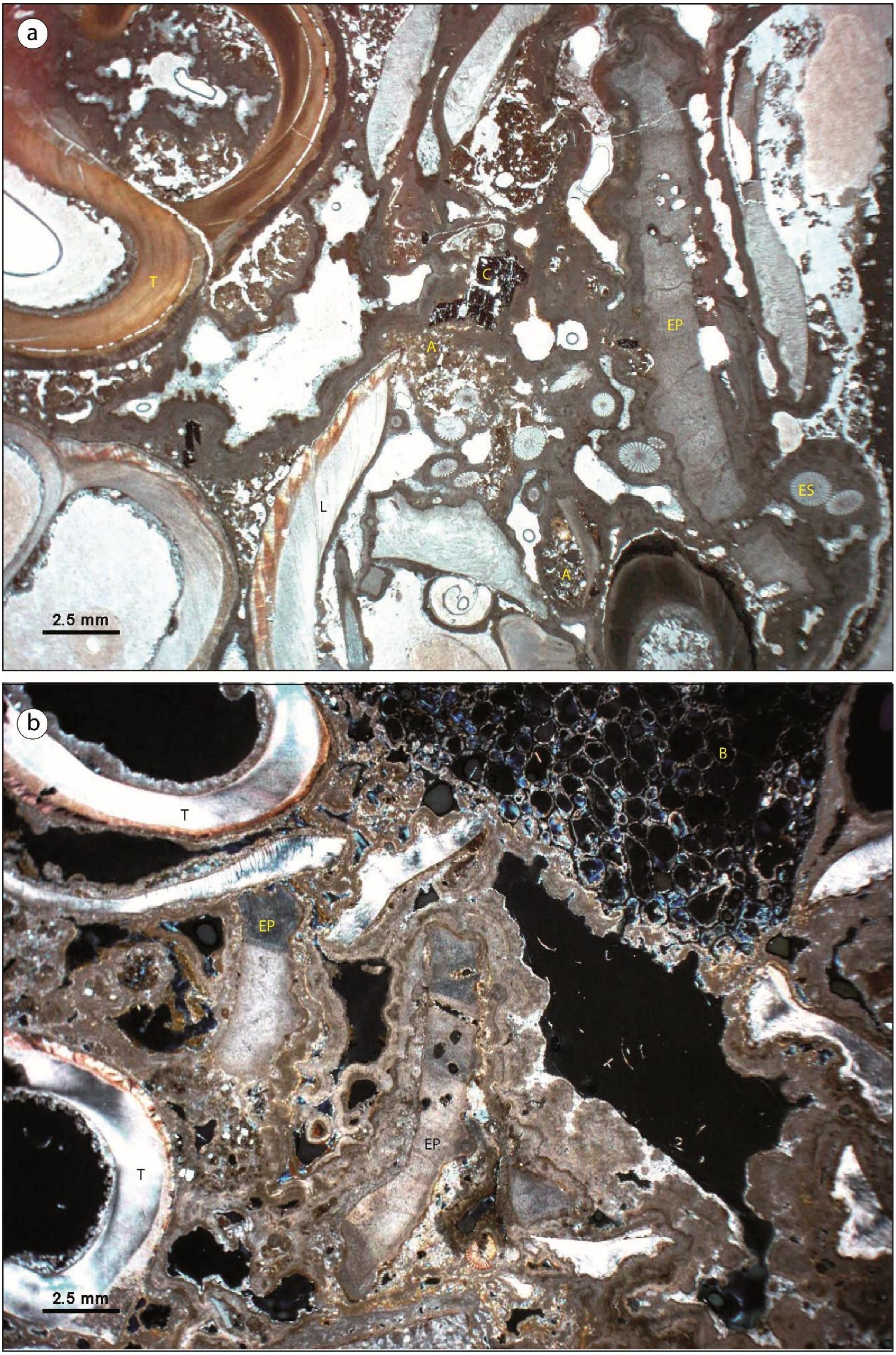
As said before, shells, mainly limpets, filled with any of the SMT are frequently observed in thin section. The fact that fine sediment is preserved only in well delimited aggregates and sheltered micro-contexts provided by shells, suggests that the aggregates are reworked relicts of deposits formed somewhere else in the surroundings, and thus their remains in the shell midden are in secondary position.

#### *8.3.2.3 Carbonate cement*

In thin section it became clear that the cement developed as quite regular crusts completely coating each aggregate and clast individually, until they became welded and the coatings progressively thickened by successive cementation (fig. 8.5). The carbonate cement morphology is thus determined by the morphology of the surface on where it grows. This suggests that fine sediment supporting the clastic material was already missing at the time of the beginning of the cementation, otherwise the cement would have formed horizontal crusts over the deposit and less probably growing so regularly as individual coats around each clastic component. In other words, if the cement formed such coatings, is because there was space available for it at the time and space it was formed.

The cement can be divided in two types: the stratigraphically older one, which is essentially formed by micrite and cloudy microspar that homogeously coats the clastic material surfaces, and a more recent one, mostly clear microspar and spar calcite, that forms fringes and fills voids spaces left by the first cement (plate 8.9). The former ones present all characteristics of biogenic carbonates, composed by an array of extensive and complex forms, from bacterial stromatolites to exuberant dendrites, thus not being strictly a cement, but essentially a tufa formation coating the clastic deposit (Pedley, 1990, Pentecost, 2005, Flügel, 2004), whereas the latter should be regarded as diagenetic, thus a true cement.

Within the tufa facies there are crystalline microfabrics that can be associated directly to microbial action, i.e., carbonate crusts which calcification was mediated by microbes (cyanobacteria and green algae) (Riding, 1991a, Pentecost, 1991, Merz-Preiß, 2000, Pedley, 1992, Pedley, 1990). Usually this is the case of the first generation of the cement in all samples and present great variability, from dense and massive micrite to crudely laminated to well recognisable microspar laminae, some rich in particles that gives them distinctive colorations such as orange when rich in iron oxides and darker/lighter grey varying with the amount of organic matter (plate 8.10a). This alternance in laminations following the clast surface' morphology happens when there is frequent biofilm damage (Pedley, 2000) that must have characterised the first moment of tufa formation in the deposit.


a
T
C
EP
A
L
A
ES
2.5 mm
b
B
T
EP
EP
T
2.5 mm

In later moments, increasing thickness the coatings becomes more irregular, forming stromatolitic structures (laminated columns and domal structures), finger-like protuberances and finally peloids as the outermost fabric type (figs. 8.14: a, b, e , f; 8.15: a, b). These characteristics strongly suggest a bacterial origin of this microfabric as records of successive calcified microbial mats which mucilaginous sheaths (when alive) tend to precipitate carbonate in the form of micrite (Ford and Pedley, 1996). Still concerning tufa facies, there are also abiotic crystalline structures, which formation relies on physico-chemical sparry precipitates (plate 8.11), rather than micritic (Pedley, 1992, Pedley, 1990)) that comprise essentially lithofacies of calcite morphologies such closely packed fibrous crystals forming palisades, ray/fan crystals and dendritic morphologies forming feather-like crystals, reflecting essentially different waterflow regimes (Gandin and Capezzuoli, 2014).

The diagenetic cements, superimposed to the tufa facies, are also common in carbonate tufas and correspond to later modifications occurring soon after the tufa has been deposited, giving origin to clotted microfabrics (Pentecost, 2005). In table 8.5, a list of all microfabrics identified in thin sections from El Alloru cemented shell midden, and used throughout the text, is provided, with theoretical interpretation concerning the depositional environment of each microfabric.

**Table 8. 5** List of tufa and diagenetic carbonates microfabrics identified in El Alloru cemented shell midden

| Carbonate microfabric | Description | Genetic interpretation |
|---|---|---|
| Microbial mats (plate 8.9, 8.15) | These cements are micritic crusts that invariably coat the clastic components of the shell midden. They consist in massive to laminated micrite crusts, sometimes more organic laminae and moldic porosity | These are typical facies from carbonate tufas (Pentecost, 2005, Flügel, 2004), that form from calcification of the mucilaginous substance that hold the living microbial or algal community together at the bottom of |

**Figure 8. 5** (previous page). Cemented shell midden at meso-scale; a and b) stereoscopic images of two different areas the cemented shell midden in thin section; PPL and XPL, respectively. Note that the cement coats each clastic component individually, until connected components merge as cementation increases. The main coarse components can be observed in both images: echinoid test plates (EP) and spines (ES), top shells of *Phorcus* Sp. (T), shell of limpets, or *Patella* sp. (L), charcoal (C), bone (B), and fine-grained aggregates (A). Note the top shell at the up left corner of presents cracks due to heating.

| | | |
|---|---|---|
| | corresponding to decomposed organic material, sometimes filled by posterior micro-spar. In the outer parts, they develop spongy (micro-thrombolitic) microfabrics and peloids, usually cemented by drusy calcite or isopachous dogtooth calcite (see below). They occasionally form incipient domes and micro-stromatolites. In some instances, both prostrate and erect forms of calcified cyanobacterial filaments are still visible | shallow water or small rafts at the water surface (Gandin and Capezzuoli, 2013). |
| Shrubs (plate 8.11) | Bacterial shrubs are a common and the most striking diagnostic feature in tufas (Pentecost, 2005, Chafetz and Folk, 1984). The shrubs at El Alloru present two distinct fabrics: 1) laminae of cloudy spar crystals organised in fan-like, radiating chains that corresponds to calcified bacterial clumps, developing arborescent structures, sometimes with a layer of clear micrite intercalated between layers of spar, and 2) intricate micritic and spar rhombs in organised in dendritic fabric. At El Alloru shell midden the bacterial shrubs are not ubiquitous but concentrated in a specific zones (see microfacies in section 8.3.2.5). | Shrubs are essentially produced by bacteria, other than cyanobacteria and algae (which produce different structures), and result from extracellular encrustation of the bacterial colonies by calcite crystals (Chafetz and Folk, 1984, Pentecost, 2005). They are reported from very shallow pools and sheets of still water in waterlogged flats, and small clusters of shrubs can develop in settings characterise be rapid evaporation of very thin films of hypersaturated water flowing on sub vertical surfaces of very shallow slow-running watercourses or micro-terraces (Gandin and Capezzuoli, 2013). The micritic layers intercalated with the radiating spar crystals have been interpreted as reduced carbonate precipitation during cold season (Chafetz and Folk, 1984). Other observation suggested that the shrubs (radiating spar) develop when the water flow level drops after evaporation, whereas the mud (micrite) is deposited during flooding periods (Gandin and Capezzuoli, 2013). |
| Fibrous crystals (plate 8.12) | The crystalline fabrics under this designation consist in fan-like radiating bundles of closely packed fibrous crystals with sweeping extinction under XPL, almost as if it was a single crystal. They form crusts ca. 200-500 µm thick that display regular | These crystals grow normal to the substrate and parallel to the direction of flowing water on subvertical surfaces forming laminar bands, whereas botryoids form in less steep surfaces. Fibrous crystal morphologies in particular appear to be related to |

| | | |
|---|---|---|
| | banding. These structures occur isolated and arranged in undulating fringes, forming palisades coating cavities. Sometimes their regularity resembles isopachous marine phreatic cements due to their fibrous nature (Flügel ,2004, James and Jones, 2015), and occasionally have botryoidal features and microbial mats associated. | hypersaturation of turbulent waters as a consequence of vaporization and rapid $CO_2$ degassing induced by the fast running, high-flux regime (Gandin and Capezzuoli, 2013). Banded fibrous crystals in tufas have been reported in hypogean phreatic environments within vent conduits (Gandin and Capezzuoli, 2013). |
| Dendritic crystals (plate 8.13) | Dendrites are calcite crystalls with ray or fan-like structures that form crusts up to 1 cm thick, with micritic clots and lenses intercalated, or more complex, irregular branching, but generally from a central, long crystal, resembling a stick. The dendritic calcite at El Alloru seems to correspond to what has been described as algal bushes (Pentecost, 2005), fan-like structures composed of long crystals radiating from a single point in the substrate upon which they develop. In hand sample, although the radiating patterns are not evident, they are readily identified in thin section at 1:1 scale. | According to Pentecost (2005), these structures are commonly called "algal bushes" where there is clear evidence of organisms influencing the fabric, as it seems the case of El Alloru block, because crystal growth seem to be controlled by the algal filaments. Feather-like crystalline crusts precipitate from very thin sheet of running water on irregularly steep surfaces (Gandin and Capezzuoli, 2013), being a common crystal morphology in tufa deposits associated to cascades (Pentecost, 2005, Chafetz and Folk, 1984). |
| Micro-layered Pendants (plate 19) | The pendant cements are discrete and generally very thin (<1 mm.) coatings around limestone pebbles and some shells. The coatings are formed by intercalated curled laminae of different compositions: brown calcitic clay, pale to dark micrite, sometimes with organic and quartz silt inclusions and in some cases, fibrous calcite fringes. The coatings cover the clasts entirely, but exhibit weakly expressed gravitational features, i. e., they are thicker in the underside of the clasts they coat, hence the classification as pendants (Flügel ,2004). | The gravitational features suggest these coatings formed by the capillary water hanging in the clasts (Flügel ,2004). |
| Isopachous cement (plate 8.15) | Isopachous cement are regular rims around cavities and grains (particularly peloids) formed by dogtooth and bladed calcite crystals. Dog tooth is a type of calcite clear | Isopachous rims of calcite crystals (bladed or dogtooth calcite) are typical of meteoric phreatic conditions (Flügel ,2004, James and Jones, 2015). |

| | | |
|---|---|---|
| | crystals up to hundreds of micrometres long, with uniform extinction, characterised by sharply pointed, sometimes blunted, terminations (Flügel ,2004). Bladed calcite rims have more regular thickness and are composed by smaller and elongated crystals (Flügel ,2004, Scholle and Ulmer-Scholle, 2003). | |
| Drusy cement (plate 8.16) | A void-filling cement composed of equant to elongated clear sparite crystals with uniform extinction, which size increase towards the centre of the void, creating a mosaic pattern. In El Alloru forms thick linings in irregular surfaces of earlier cements, but many times completely fills voids. | It is a common meteoric cement (Flugel 2004). In phreatic conditions, the pores were completely filled with water, the drusy crystals will have pyramidal terminations. Under vadose conditions (water/air interface) the crystals have smooth termination, caused by the air trapped in the cavity (James and Jones, 2015) |
| Meniscus cement (plate 8.16) | Extremely rare at the shell midden, these consist in micritic and drusy calcite cements confined to the contacts between older surfaces, exhibiting curved surfaces. | These forms are characteristic of meteoric vadose conditions, reflecting the existence of water and air in the pores (Flügel ,2004, James and Jones, 2015) |

#### *8.3.2.4 Non-carbonate post-depositional processes*

Despite the cementation itself being post-depositional, there are other features consisting of non-carbonate material. Some of these features are related to the cementation processes while others are not. Features that are related to the cementation process include cryptocrystalline coatings and reddish clay facies.

The cryptocrystalline coatings correspond to an early process in mF 6 (see below) consisting in a yellowish substance apparently amorphous with opaque impurities under PPL and a strongly birefringent crystallitic b-fabric in XPL. This feature coats and welds together coarse components, lack microbial-like constructions (domes, laminae, stromatolites) but merges itself with microbial micrite (plate 8.17: a-d). The nature of this feature is difficult to determine only petrographically. Hypothetically, either a mix of carbonates, phosphates and decomposed organic matter (e.g, a type of collophane material) or an alteration of an original carbonate cement are suggested, but further compositional analysis (e.g., µ-FTIR, µ-XRD, SEM-EDS) are required to state it securely. This feature is more common as the first post-depositional process affecting the shell midden components, but in the same mF there are layers of cryptocrystalline coating intercalated with microbial constructions as well.

Another non-carbonate features are laminae of impure and unoriented (undifferentiated b-fabric) red clay forming the outermost laminae of complex stromatolitic constructions, that exhibit gravitational geometry (plate 8.17: e, f). These features do not seem to correspond to illuvial clay giving the lack of sweeping extinction, but might correspond to decalcification or alteration of the originally carbonate material.

Features not related to the cementation process are typical illuvial clay coatings consisting in well oriented (sweeping extinction) dusty red-brown clay coatings (plate 8.17: g, h) that occasionally appear in some cavities, invariably as the most recent feature, i.e., without further deposits superimposed.

#### *8.3.2.5 Microfacies*

In thin section, it was possible to document that the course components exhibit variations in abundance and distribution, organised in superimposed layers (fig. 8.23: a, b). Furthermore, the carbonate microfabric and post-depositional processes also have different characteristics through the vertical sequence (fig. 8.23d). Combining both observations, it was possible to discriminate nine microfacies within the cemented shell midden, with stratigraphic meaning concerning the formation processes of the deposit. The microfacies identified based on different associations of components and cement microfabrics are described in table 8.6.

**Table 8. 6** List and description of microfacies from the from the cemented shell midden of El Alloru

| mF | Description |
|---|---|
| 1 | <u>Clastic components</u>:<br>- Large interconnected pebbles with angular shape and low sphericity (x2).<br>- Interconnected topshells (x2)<br><u>Micromass</u>:<br>- Rounded aggregates of dark-brown SMT 1 (5%).<br><u>Cement stratigraphy</u>:<br>Tufa:<br>1) Very thin (>1 mm.) micro-layered pendants around pebbles<br>2) Very thin and irregular microbial mats, usually not layered and developing domes<br>3) Few and weakly develop shrubs and fan/ray crystals |

| | |
|---|---|
| | Diagenetic:<br>4) Dogtooth fringes and drusy calcite pore fillings<br><u>Void space:</u> 40% |
| 2 | <u>Clastic components</u>:<br>- Large pebble (x1) with angular shape and low sphericity.<br>- Few interconnected limpets (10%)<br><u>Micromass</u>:<br>- Very few (5%) aggregates of SMT 3.<br><u>Cement stratigraphy</u>:<br>Tufa:<br>1) Very thin (>1 mm.) micro-layered pendants around pebbles<br>2) Thin microbial mats evolving to small stromatolitic columns and peloids.<br>3) Shrubs of dendritic micrite and spar rhombs.<br>4) Fan/ray fibrous crystals<br>5) Abundant large dendritic crystals (fan like).<br>Diagenetic:<br>6) Drusy fillings, rare and very localised.<br><u>Voids space</u>: 10% |
| 3 | <u>Clastic components</u>:<br>- Interconnected, unoriented limpets, dominant (50%)<br>- Bone (10%)<br>- Gravel size charcoal (2%)<br>- Limestone angular small pebbles (5%)<br>- Echinoids spines (10%)<br><u>Micromass</u>:<br>- SMT 2 sediment adhered to and trapped between limpets (10-20%)<br>- Few (5%) clusters of SMT 3 (faecal pellets)<br><u>Cement stratigraphy</u>:<br>Tufa:<br>1) Thick (5 mm.) micro-layered pendants around pebbles, bones and some limpets<br>2) Microbial mats evolving to small stromatolitic columns and small peloids with clotted microfabric<br>Diagenetic:<br>3) Isopachous rims of bladed calcite to uneven dogtooth arround clasts, peloids and pores' walls, with pointed terminations<br>4) Drusy fillings with pointed terminations<br><u>Void space</u>: 25% |
| 4 | <u>Clastic components</u>:<br>- Many (50%) very coarse bones, partially to completely filled with micrite and drusy calcite.<br>- Abundant (20%) small and comminute bone fragmnents |

- Limestone angular pebbles (40%)
- Limpets and topshells (20%)
- Echinoids (5%)

Micromass:

- Few (10%) aggregates of SMT 2

Cement stratigraphy:

Tufa:

1) Very thin (>1 mm.) micro-layered pendants around pebbles
2) Dense and laminated microbial mats, almost completely filling the inter-clast pore, forming fenestral voids

Diagenetic:

3) Fine to very coarse dogtooth crystals rims around clasts, peloids and pores' walls
4) Drusy pore fillings

Void space: 30%

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5 Clastic components:

- Interconnected limpets
- Bone (x1)

Micromass:

- Few (5%) clusters of SMT 4 (faecal pellets) as infilling of limpets

Cement stratigraphy:

Tufa:

1) Very thin (>1 mm.) micro-layered pendants around limpets
2) Thick and irregular dense microbial mats with large networks of calcified algal filaments
3) Weakly developed microspar and micritic fringes

Void space: 40%

---

6 Clastic components:

- Abundant (20%) echinoid spines and shells.
- Limpets (20%)
- Topshells (10%)
- Coarse charcoal (10%)
- Bone (10%)
- Limestone pebbles (10%)

Micromass:

- SMT 2, spongy aggregates adhered to and preserved inside shells, as well as occupying spaces between shells (10-15%).
- SMT 1, gravel size rounded massive aggregates superimposed to the cement, concentrated in a zone of thin section ALL2.

Cement stratigraphy:

Tufa:

1) Thin (ca 100 micromoeters) crudely laminated coatings of fine material (possibly clay) with strong yellow-orange colour and highly birefringent, welding coarse components together.
2) Thick dense microbial mats, massive to laminated, sometimes developing stromatolitic structures and peloids, and locally calcified filamentous cyanobacteria are visible. In thi mF, the laminated manicrobial mats have some laminae composed of impure clay poorly oriented, with calcitic crystallitic to undifferentiated b-fabric, exhibiting gravitational geometries, e.g., hanging from stromatolitic structures.
3) Abundant fibrous crystals in fan/ray crystals, isopachous rims and banded palisades, all more or less combined with micritic layers.
4) Abundant dendritic crystals, algal bushes and dendritic shrubs, forming crusts up to 1 cm. thick at the top of the mF, with micritic clots and layers intercalated.

Diagenetic:

5) Localised spar cements (dogtooth and drusy) usually in closed voids associated to fibrous fringes.
6) Dogtooth and bladed calcite rims around dendritic crystals of 4).
7) Discrete alveolar septal fabrics.

Post-depositional features:

- Coatings of reddish-brown, well-oriented (sweeping extinction) clay in voids.

Void space: 30-40%

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7 Clastic components:

- Bone (10%)
- Shell fragments (10%)
- Echinoids (20%)
- Charcoal, fine gravel size (2%)
- Limestone pebble, agular (x1)
- Sand and silt (1%)

Micromass:

- SMT 2 with micro-aggregated structure (15%) and locally microgranular (faecal pellets) (5%)

Cement stratigraphy:

Tufa:

1) Non-laminated thin microbial mats with micro-spar rims

Diagenetic:

2) Few and localised meniscus-like drusy cements

Non-carbonate:

3) In the lower part of the mF, in the contact with underlying mF6, the same poorly oriented reddish clay coatings occur.

Void space: 10%

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8 Clastic components:

- Imbricated limpets at the base (10%)
- Charcoal (1%)

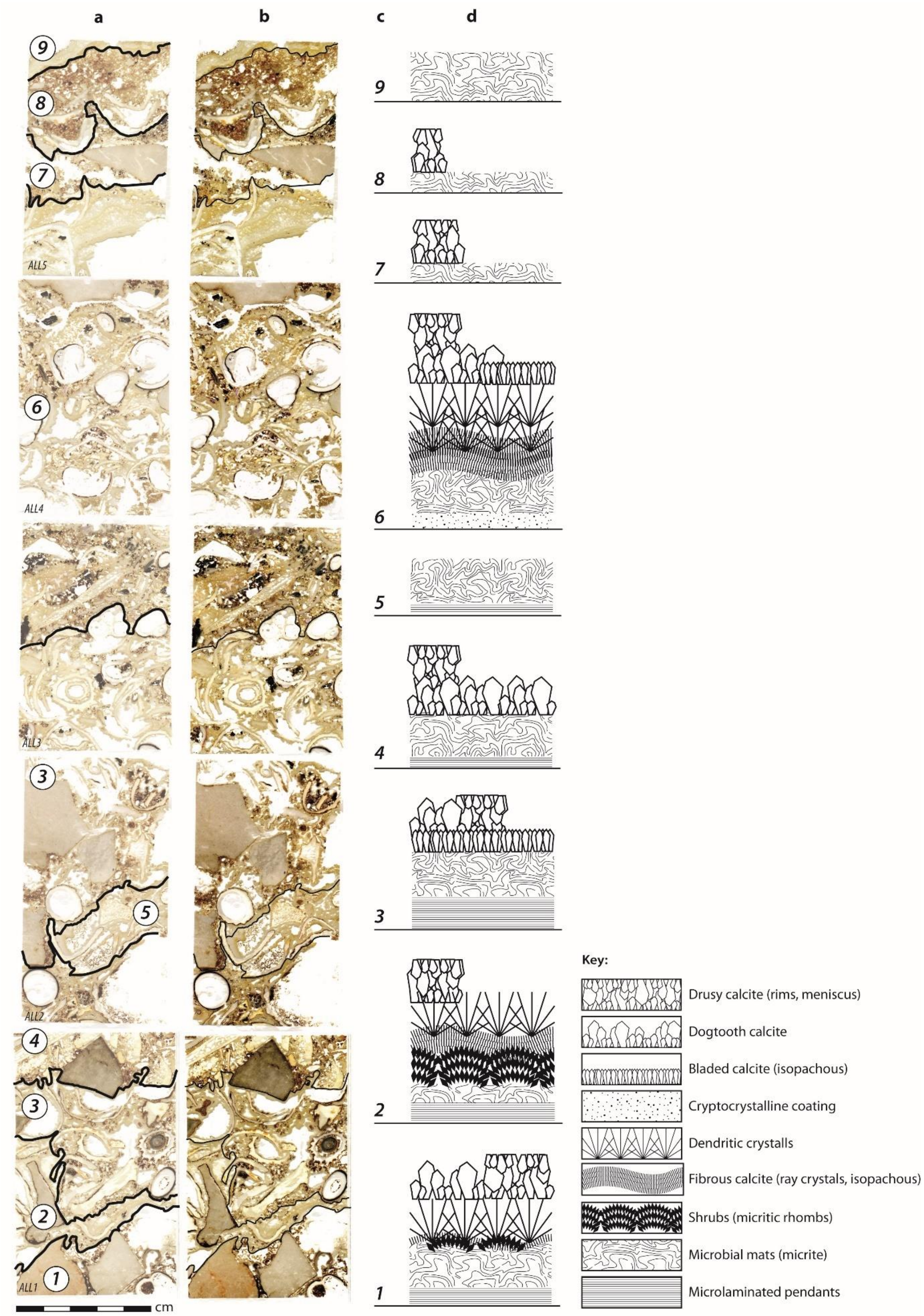
| | |
|---|---|
| | - Bones, comminute, rarely fine gravel size (2%)<br>- Silt and sand (5%)<br>Micromass:<br>- In this mF, the micromass prevails over the carbonate cement. It consists of SMT 1, more greyish than in other mF, possibly due to stronger micritic impregnations. It also contains rare bone, charcoal and seaweed. The porosity is characterised by not connected vughs and some channels, but it is modified by micritic hypocoatings, different from the tufa microbial mats.<br>Cement stratigraphy:<br>Tufa:<br>1) Incipient microbial mats forming some peloids<br>Diagenetic:<br>2) Microspar fringes<br>3) Rare drusy fillings<br>Void space: 10% |
| 9 | Tufa deposit, with typical fenestral prosity at mesoscale, formed by different layers.<br>1) Microbial mat with visible calcified filaments, cemented by microspar rims<br>2) Microbial mats forming layeres micrite with finger-like and stromatolitic structures<br>3) Cloudy, massive micrite<br>4) Impure reddish and poorly oriented clay coatings occur in all layers |

## 8.4 Discussion

This section will be dedicated to the interpretation of the micromorphological study, focusing fist on the stratigraphy of Test 1 and second on the cemented shell midden, to which a microfacies approach was applied.

### 8.4.1 Formation processes of the exterior deposit

The basal sediments of unit 106 contain key-elements to reconstruct the processes occurring at its surface, during the Mesolithic occupation. The geogenic loamy groundmass seems to correspond to background sedimentary environment of karstic dissolution activity, resulting in insoluble minerogenic silts and fine sands with clay. The crude bedding locally observed in the sand grains could suggest waterlain deposition (Courty et al., 1989). However, the massive basic microstructure and strong embedding of coarse anthropogenic material


a
b
c
d
ALL5
ALL4
ALL3
ALL2
ALL1
cm
Key:
Drusy calcite (rims, meniscus)
Dogtooth calcite
Bladed calcite (isopachous)
Cryptocrystalline coating
Dendritic crystalls
Fibrous calcite (ray crystals, isopachous)
Shrubs (micritic rhombs)
Microbial mats (micrite)
Microlaminated pendants

(chert, bone, charcoal), together with the association to striated b-fabrics suggest that this layer suffered compaction and fabric rearrangements, and these features might possibly be all related (Rentzel et al., 2018). Laboratory experiments by Rentzell et al. (2018) simulating trampling on a loamy sand luvisols, a type of soil similar to that of Unit 106 at El Alloru, generated grano- and elongated-striated b-fabrics and weakly expressed bedding of the sandy fraction when the soil was moist. Accordingly, giving that Mesolithic occupation debris and possible negative structures inserted on this unit's surface, human trampling might be one of the reason of structural compaction of Unit 106. The micro-laminated layers of silty clay intercalated with sand and organic matter might also reflect puddling in micro-depressions, that Rentzel et al. (2018) suggest being cause also by compaction that prevent drainage. The same experiments on moist loamy sand soils also revealed the formation of polyconcave voids and crusts parallel to the surface, both features observed in thin section of Unit 106 (fig 8.24a).

The polyconcave voids are perhaps directly related to compaction, but this association is not so clear concerning the elongated vesicles. Vesicles have also been interpreted as result of puddling (Courty et al., 1989, Deák et al., 2017). The clayey intercalations observed in Unit 103, associated with vesicles and polyconcave voids reflect a change in the sediment to slurry conditions, a process that is usually associated with impure clay coatings (Macphail and Golgberg, 2017), a common textural feature in Unit 106. In large voids where these clayey intercalations accumulate, slaking can also occur associated to trampling (Macphail and Golgberg, 2017, Rentzel et al., 2018), and some examples of shrinkage cracks in the clay coatings are visible in unit 106 (plate 8.5c; 8.24a). The humified organic matter or iron-rich micropan associated to the clay intercalations (plate 8.18a) is most likely also caused by trampling in wet surface (Macphail and Golgberg, 2017). The common iron nodules (plate 8.18: b-d), in several impregnative stages, and some of them possibly reworked, indicates waterlogged environments (Macphail and Golgberg, 2017).

**Figure 8. 6** (previous page). Schematic representation of the stratigraphy recognised in the cemented shell midden of El Alloru based on a microfacies (mF) apporach combining carbonate microfacies and clastic composition: column a) annotated scans of the thin sections obtained vertically through the block sample; dark lines = mF contacts; numbers within white circles = mF type; column b) thin section scans only with mF contacts indicated by thinner lines for better observation of components organisation; column c) mF types related to column d) schematic representation of the cement stratigraphy specific of each one (see side key for interpretation)

The experiments of Rentzel et al. (2018) showed that clay coatings originally present in the Luvisol disintegrate after trampling, becoming the clay dispersed in the groundmass. On light of this result, the clay coatings at unit 106 might correspond to a later moment of clay illuviation. The origin of dusty clay coating has been object of intense debate in soil micromorphology regarding their meaning, from initial stages of clay illuviation from the surface in recent cultivated soils (Jongerius, 1983, Kühn et al., 2010) to anthropogenic activities related to dumping and forest clearance by burning, cultivation or trampling (Macphail et al., 1987, Courty et al., 1989, French, 2003, Kemp, 2013, Kemp et al., 2006). It seems fair to exclude any search for cultivation-related explanation in the context of a seventh millennium BC occupation in Asturias, but there is an agreement that dusty clay coating indicate surface slaking (Courty et al., 1989), associated to intense trampling over a not vegetated moist surface that slakes after dissecation, allowing organic particles to percolate together with clay by action of rain water, together with micro-charcoal from human occupation activities (Courty el al. 1989).

The common presence of charcoal is possibly related with combustion activities carried out by the Meoslithic occupants of the site, that could be finely mixed in the sediments by trampling. Several coarse charcoal fragments in unit 106 show *in situ* diagenesis effects, such as clay invasion of the cellular structure (plate 8.18: e, f). The absence of ash could be caused by complete dissolution, a diagenetic effect well attested at the site by the poorly preservation condition of calcitic components in unit 104 (plate 8.1: c, d), and by the fact that carbonate fine material is virtually absent in the deposit in general. The existence in unit 106 of dusty clay coatings crudely layered (plate 8.6: a-d) suggest several phases of translocation (Macphail et al., 1987, Kühn et al., 2010), therefore, we can assume that the unit surface was a long-lasting surface subjected to constant trampling and moisture variations.

The contact of unit 106 with the overlying unit 112 (in the western part of Test 1) is quite sharp but irregular (figs. 8.7:a-c; 8.25: a, d). The contact with 104 (in the eastern side of the Test) could not be sampled but in the field, but is also quite sharp, marked by the concentration of limestone cobbles and blocks (figs. 8.3b, 8.6a). Unit 112 is adjacent to 104 and they differ by the concentration of shells in 104, whereas in 112 these are absent (plate 8.19a). These variations are related with different activities or moments of occupations of the site, but the large block might have also some influence in this lateral variation in terms of activities distribution. In thin section it was observed that unit 112 contains common scattered aggregates of unit 106 material (plate 8.19: c, d). This can be explained either by biological reworking or anthropogenic activities. Unit 112 was covering the small negative structures dug in unit 106 surface (Arias et al., 2015a, Arias et al., 2016). Very discrete grano-striated b-fabric is also visible along with incipient dusty clay coatings (plate 8.19e), together with incorporation of aggregates from the lower layer suggest that unit 112 might also have been affected by compaction processes and trampling (Courty et al., 1989). The sedimentary groundmass seems to be anthropogenic in origin, judging the be presence of abundant micro-charcoal in the micromass, as well as coarse charcoal, bones and chert, and correspond to some important sedimentation activity giving the substantial thickness of the deposit (over 10 cm). The slight gefuric c/f relation distribution (plate 8.19f) points could mean that the deposit was partially waterlogged. But overall the formation process is difficult to infer due to the intense biological reworking that promotes generalised homogenisation of the microstructure.

Unit 105 is a darker deposit overlying 112 in the western part of the archaeological test pit, which discriminating signature is the high abundance of fine gravelly sized wood charcoal dispersed in the groundmass (plate 8.19: a, c), probably related to specific human activities. Ashes and other combustion indicators are absent, which makes its interpretation difficult, together with generalised homogenisations by biological activity, like the rest of anthropogenic deposits. Pedogenetic porosity is also well represented by the formation of large channels (plate 8.19c).

The same applies to unit 104, directly above the basal unit 106, and where most shells are concentrated, poorly preserved. The shells and other carbonate components in 104 present strong evidence of carbonate depletion (plate 8.3: c, d). Giving that most shell fragments in thin section are comminute pieces, it reveals a possibly secondary position of those rather than intentionally accumulated. The shells in this context might result from a combination of reworking factors, namely pedogenesis involving bioturbation and human trampling over the underlying surface when the site was occupied bearing debris from other areas in the site. It is also remarkable the abundance of limestone clasts in the unit, probably falling from the top of the limestone outcrop.

The dominant channel and chamber porosity that forms incipient subangular blocky peds (plate 8.3b) from a pedogenic point of view, the presence abundant humified matter and calcitic biospheroids from worm colonisation, points to an exposed surface with occupation debris (shells) that went through pedogenesis after abandonment, developing an Ah1 horizon (Golberg and Macphail, 2006), that continue up into the base of unit 103. This paleosoil was later buried by the late Prehistory and Historic deposits that conform upper units (102 and the current surficial Ah2 horizon 101).

### 8.4.2 Depositional history of the cemented shell midden

The recognition of different microfacies within the cements shell midden deposit allows for tentative reconstructions of its formation processes. As seen above, the criteria for microfacies recognition (table 8.6) was a combination of differential distribution of coarse clastic components (table 8.3), of micromass sediment microfabric types (table 8.4) and carbonate microfabrics of the cement (table 8.4; fig. 8.23). The former two, clastic components and micromass, constitute the original coarse and fine fraction, respectively, reflecting the primary depositional events of the deposit. The variations in abundance and distribution throughout the deposit can thus be used to infer different events of accumulation. In turn, the cement records the post-depositional processes that affected these successive deposits, strongly marked by microbial and algal colonisation and subsequent formation of tufa.

Since tufa formation responds to different environments and forms stratigraphic deposits directly dependent on those (Chafetz and Folk, 1984, Pentecost, 2005, Ford and Pedley, 1996, Pedley, 1990, Pedley, 2000), it is possible to distinguish several depositional events intercalated in the shell midden deposit. Regarding this evidence, in the next lines it will be presented an evolutive hypothesis of the depositional and post-depositional history of the cemented shell midden of El Alloru based on the microfacies recognition.

In general, by observing the block sample and the thin sections (fig. 8.11), it is remarkable that the lower half is coarser than the upper half, having abundant centimetric pebbles and bones. At the base the deposit, mF 1 is distinct by the presence of carbonate mud SMT aggregates (plate 8.20a) that lack anthropogenic material (such as ash, burnt components, shells fragments…), although shells are also present. Carbonate mud aggregates is thus interpreted as result of reworking of an early carbonate-segregating environment (e.g. moss/lichen blankets) that was reorked together with pebbles and anthropogenic material that couls have been tossed or rolled.

Microfacies 2 is characterised by a general lack of clastic material, consisting in a tufa crust dominated by well-developed dendrites and, to a lesser extent, microbial shrub fabrics (plate 8.20b). This might be pointing to a sedimentary hiatus in terms of accumulation of anthropogenic material for enough time to allow the development of different algal vegetation communities, which crystalline variability seems to respond to the establishment of a fluctuating watertable sporadically submerging the deposit, that went through different energy flows, as seem to indicate the crystal variability (table 8.4).

In mF 3 the aggregates consist mostly of combustion residues SMT, which is a microfabric rich in anthropogenic, domestic debris plenty of ashes and other combustion-related products like rubified clay aggregates, burnt and calcined small fragments of bone, shell and seaweed, as well as non-intentional products related to the shellfish exploitation such as foraminifera (plate 8.20: c-f). These aggregates occur as rounded and isolated as well as infilling limpets or adhered to coarser anthropogenic components, which suggest they are not in primary position, but most likely result from reworking of previously deposited anthropogenic sediments. The clastic components and aggregates were homogenously affected by microbial colonisation that formed successive biofilm crusts over their surfaces, which means that they were exposed to good lighting conditions (as the deposit is today) and possibly still water. The deposit is fairly thick (over 10 cm. in thin section), which by the other hand seems to suggest that it was accumulated at a regular slow pace, so the microbial mats had conditions to form and calcify homogenously from the base to the top of the mF. This evidence seems to point to a syn-depositional relation between the addition of anthropogenic materials and the tufa formation, which suggest that human occupation took place in the proximity while the spring was active at a calm regime.

Microfacies 4 is distinct by the predominance of both large and comminute fragments of bone (plate 8.21: a, b). This microfacies is intercalated within mF 3, so it possibly corresponds to a very localised deposit. The sorting of an anthropogenic component like bones suggest that humans had some influence in the accumulation of the deposit. The microbial mats that formed around the components calcify in particularly thick micritic coatings (plate 8.21b).

Something similar must have occurred with the limpet-dominated mF 5 (fig. 8.23: a, b) regarding human influence in the material sorting. This mF is also placed between mF 3 sediments and is in contact with mF 4. The microbial communities developing in mF 5 however, must have known different environmental conditions, because here the algal filaments are still preserved (plate 8.21: c, d), and the abundance of pellety granular textures (SMT 3) in this mF seems to point to the presence of small invertebrates living in tufa depositional environments (Pentecost, 2005).

One aspect that is ubiquitous in mF 1 to 5 is the occurrence of micro-laminated pendants around limestone pebbles and some shells (plate 8.14), composed of fine laminae of calcitic clay and microspar with gravitational morphology, i.e., thicker at the base of the clast they coat, that has been interpreted as effect of water hanging from clasts (Courty et al., 1989). These micro-laminated pendants must correspond to an early moment of water saturation under vadose conditions.

The deposits corresponding to the microfacies described above comprise the lower half of the block-sample. The upper half is represented almost entirely by mF 6 (figs. 8.11a; 8.23: a, b), that has the biggest variety of components and outstanding amounts of echinoids compared to the other mF, which, again, strongly supports the idea that several deposition episodes are represented in the cemented shell midden. The tufa cements in mF 6 are also quite diverse. The non-carbonate cementing features (plates. 8.17; 8.22a) described before (section 8.3.2.4) were identified in this mF. A remarkable aspect of the tufa microfabrics in mF 6 is the development of isopachous fibrous rims and very abundant fan/ray crystals, occasionally associated to botryoidal crystals (plates 8.17; 8.22: b, d). These features, also present but not so expressive in other mF, point to running water under considerable turbulence, supersaturation and supercooling (Chafetz and Folk, 1984, Gandin and Capezzuoli, 2014, Pentecost, 2005, Jones and Renaut, 2010, James and Jones, 2015). In the case of mF 6 this is particularly significant because it is a thick accumulation of anthropogenic material. Giving this evidence, it must be considered that such high-energy spring regime must have had an effect in the erosion and transport of the anthropogenic components. Therefore, in this case, it seems that the accumulation of the material is more likely naturally-driven rather than anthropogenically although reworking a previous anthropogenic deposit. The deposit corresponding to mF 6 is covered by the thickest (1.5 cm.) crust documented in thin section (plates. 8.18: a-d; 8.28: e, f), composed by several generations of superimposed crystalline dendrites intercalated by micritic layers, possibly reflecting alternating periods of well-developed algal covers and microbial colonisation, thus varying flowing regimes, during which apparently no further material was being deposited. Typical dusty clay coatings on the surface of dendrites (plate 8.17: g, h) in the upper part of mF 6 reveals that clay illuviation occurred after the calcification. The origin of this clay is probably related to the overlying deposits, namely mF 7.

Microfacies 7 is a thin deposit in thin section that lack coarse shells and is composed mostly by small fragments of shells and echinoids, constituting an exception in this aspect, since small shell fragments are virtually absent in other microfacies (fig. 8.23). A small amount of interstitial quartz sand and silt is enough to mark presence, since it is also absent in other microfacies. These characteristics suggest that this thin layer is likely resulting from superficial reworking of debris from the surroundings. The faecal pellets SMT, dominant in the micromass (plate 8.8: g, h) suggest intense biological activity, possibly directly related to invertebrate fauna typically inhabits tufa-forming environments (Pentecost, 2005). The clay coatings in the immediate part of the underlying mF 6 deposit could hypothetically derive from eluviation of clay originally in mF 7 in a later stage of dripping water percolation.

Microfacies 8, accumulated over mF 7, constitutes another exception in the shell midden in the sense that a clayey matrix prevails over carbonate cement, consisting of carbonate mud particularly rich in filamentous microfossils (plate 8.23: a, b). However, this mF also contains components considered anthropogenic, namely limpets, bones, few charcoals and seaweeds, embedded in the carbonate mud (plate 8.23: c, d). Likewise, the reasons for the transport of carbonate mud to the site is uncertain, complicating its interpretation. The cementation of this mF (micrite and microspar hypocoatings) is more incipient than others, possibly because of the existence of a clayey matrix with more massive microstructure. This seems to support the idea that such matrix was already lacking in underlying deposits, where cementation occurred around the coarse components with plenty of interstitial space to grow. The last and upmost deposit, mF 9, is a layered tufa crust formed by successive microbial mats (plate 8.23: e, f), pointing to a last period of resurgence of the spring system but maybe in a protected situation propitious to the development of a horizontal biofilm (Ford and Pedley, 1996).

#### *8.4.2.1 Post-depositional diagenesis*

A major characteristic of the diagenetic cements is that they form isopachous rims around clasts and on voids surfaces. These isopachous rims present intense variability, sometimes even in neighbouring voids, in terms of the crystal morphology of the fringes, composed either by larger and pointy dogtooth calcite (plates 8.14d, 8.16b, 8.17d) or more finely packed bladed calcite (plate 8.8h, 8.14f, 8.20b). Overall these features reveal that phreatic conditions were dominating at the time of cementation, meaning that the pores were completely filled with saturated water (Flügel, 2004, Scholle and Ulmer-Scholle, 2003). The complete fillings of drusy calcite in some pores also points to phreatic meteoric water environments, although some cases of flat crystals terminations (plate 8.15d) forming smooth surfaces point to the presence of air in the voids that impede the typical pyramid-like crystal point to form. This evidence suggests that probably the deposit was inundated by meteoric waters that perched the water table for some time. These features are particularly expressive in mF 3 and 6, where it certainly had implications on the configuration of the shell midden accumulation and distribution of components. The rare cases drusy cements presenting meniscus morphology point to vadose conditions (Flügel, 2004, James and Jones, 2015) and are concentrated in mF 7 in the upper part of the deposit (plate 8.16: c-f). The variations that diagenetic cements present depending on the microfacies suggest that they reflect also different phases of water saturation instead of only one, and that these phases were intercalated with different events of the shell midden accumulation dynamic.

## 8.5 Conclusions

It results difficult to establish a relation between the Mesolithic contexts in the Test 1 and the cemented shell midden of El Alloru from the micromorphological analysis of both loci, because of the striking contextual differences between the exterior platform and the rockshelter. The result of the micromorphological study of the exterior contexts (Test 1) reveal intense occupation of the area during the Mesolithic occupation, reflected in trampled, occasionally puddled surfaces.

The micromorphological analysis reveals the existence of anthropogenic sediments in the form of combustion residues aggregates that are most probably in secondary position in the shell midden. These aggregates attest the existence of combustion features at the site that were completely eroded from the record. The spring activity in the rear of the rockshelter, where the cemented shell midden is located, seem to have known periods of some turbulence and elevated driving force judging for the some of the tufa microfabrics. Such events were possibly responsible for the destruction of the occupational contexts in the surroundings of the shell midden. This inference allow us to argue for a hypothetical location of these combustion features in the interior of the rockshelter.

The tufa microfabrics variations in the cemented shell midden, once characterised by vertical differences, constitute positive evidence of local past environmental change, namely in terms of different regimes of spring activity in the early-mid Holocene in El Alloru rockshelter. Such changing activity to which tufa deposition respond must have influenced the accumulation of the shell midden and above all it must have modified its configuration. However, human influence might be inferred in the accretion of some accumulations of components sorting such as bones, limpets or echinoids. This aspect could explain the inversion of $C^{14}$ dates obtained vertically in the shell midden (Arias et al., 2016, see also table 8.1).

The analysis of El Alloru cemented shell midden above all reveals that the cementation of Asturian sites needs for further investigation, and the fact that it is syndepositional reveals great potential for dating of the deposits to the construction of environmental reconstructions during the Mesolithic occupation of the coast of Asturias.

Chapter 9

# Poças de São Bento

## 9.1 Introduction

In this chapter the micromorphological analysis of Poças de São Bento shell midden is presented. Through micromorphological analysis, we aimed recognise of single events of human activities involved in shell midden formation. This approach intends to make a spatial correlation between different sampled areas of the site, in order to document if there are sedimentological differences between spatially disconnected shell midden accumulations, eventually associated with different function. Another objective was to clarify if there are any gaps in sedimentation related to absence of occupation. It was also a concern of this research to address de diagenetic processes that the shell midden undergone, in order to provide an integrative assessment, at high resolution, of preservation conditions of the human-derived deposits and the artefacts they embed.

### 9.1.1 Geomorphological context

Poças de São Bento is an open-air site on a gentle slope, limited to the SE by a brook belonging to a small subsidiary basin of the Sado River (Fig. 9.1). Nowadays, the site is 3 km south of Sado, on a Cenozoic platform, at an altitude of c. 80 m. above present mean sea level. The Sado basin is incised into this platform exposing successive layers of Miocene conglomerates and sandstones in quite steep slopes. The platform is covered by a Pleistocene/Holocene aeolian sand cover, on which the shell midden rests. The location of Poças de São Bento is substantially further inland, when compared to the other sites, which tend to follow a somewhat consistent location pattern close to the erosion edge of the platform,

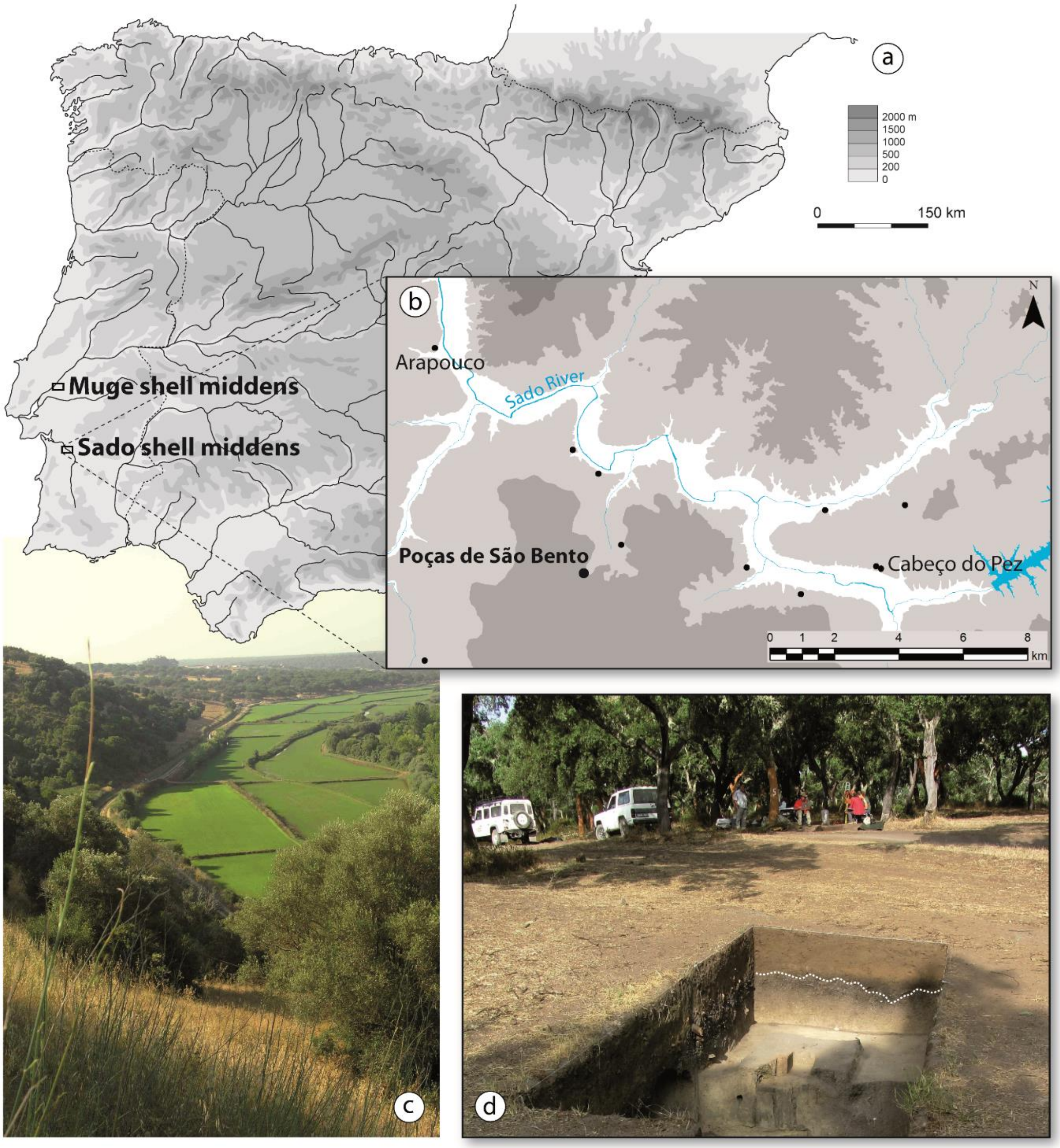



**Figure 9. 1** Location and surroundings of Poças de São Bento. a) Geographical location of the Sado and Muge shell middens in the Iberian Peninsula. b) close-up on the Sado valley with location of Poças de São Bento, the sites mentioned in the text of Arapouco and Cabeço do Pez, and the other known shell midden sites (black dots); note that Poças de São Bento is considerably away from the Sado in comparison to the other sites. c) View of the Sado alluvial plain, now extensive rice fields, from a typical location of most shell middens, close to the edge of the erosion platform; note the steepness of the slopes. d) General view of the site of Poças de São Bento, with Area 9 in first plan, from NE, during the 2015 excavation; the shell midden layer here is indicated by the darker sediments in the front profile.

usually with good overview of the Sado alluvial plain. The existence of estuarine marshland environments upstream of Arapouco during the Mesolithic, is an open question, and currently the object of ongoing investigations (see also section).

### 9.1.2 Stratigraphy and chronology

At Poças de São Bento shell midden, the stratigraphy is quite uniform in all excavated areas and test pits carried out by the current archaeological project, with some variations, mainly concerning the thickness and density of shells in the deposits. Arias et al. (2015b) classified the overall site stratigraphy in phases, combining the previous and new radiometric dates with macroscopic observations in the field, as summarized in Table 9.1.

**Table 9. 1** Summary of the chronological phases identified at Poças de São Bento and absolute chronology. For information about the contexts see Fig. 2. OSL date is in italics, $^{14}C$ dates in plaint text. The dates were obtained by the project currently investigating the Sado shell middens (P.I. PA and MD), except those for which the original publication reference is indicated. $^{14}C$ calibrations are as reported in Table 1 in López-Dóriga (2016).

| **Phase and field description after Arias *et al.* (2015)** | | **Absolute dates (OSL date in italics, radiocarbon dates in plain text)** | | | | **Stratigraphic unit (context of dated samples)** |
|---|---|---|---|---|---|---|
| | | Reference | Material | Result | cal BC (95.4 % probability) | |
| Geologic substrate: Cenozoic ferruginous reddish or yellowish sandstone and Pleistocene/Holocene sands. | | - | | - | - | - |
| **A** | Greyish sands with a low density of shells and lithics. | *GL14060* | | *12±1ka* | *12000-8000* | 912 (Area 9) |
| **B** | Dense accumulation of mollusc shells (mainly *Scrobicularia plana* and in a smaller proportion, *Cerastoderma edule*) in a sandy sediment with a low density of other | OxA-29113 | *Homo sapiens* bone | 7238 ± 35 | 6211–6031 | 613 (Area 6) |
| | | Lu-2769 (Larsson, 2010) | Shells | 7150 ± 70 | 6006-5653/ 5923-5281 | 45–50 cm (former projects) |
| | | OxA-29114 | *Scrobicularia plana* shell | 7121±35 BP | 5960-5666/ 5874-5275 | 403 (Area 5) |

| | | | | | | |
|---|---|---|---|---|---|---|
| | kinds of archaeological materials. | OxA-24652 | *Cerastoderma edule* shell | 7107±37 BP | 5951-5653/ 5861-5256 | 3/7 (Area 1) |
| | | OxA-24648 | *C. edule* shell | 7084±36 BP | 5917-5627/ 5830-5225 | |
| | | OxA-24650 (*C. edule* shell) | *C. edule* shell | 7070±35 BP | 5901-5620/ 5817-5212 | |
| | | OxA-24651 | *C. edule* shell | 7053±37 BP | 5890-5610/ 5806-5200 | |
| | | OxA-24649 | *C. edule* shell | 7052±35 BP | 5886-5611/ 5804-5200 | |
| | | Lu-2770 (Larsson, 2010) | Shells | 7050 ± 60 BP | 5921-5582/ 5831-5186 | 65–70 cm (former projects) |
| | | Q-2493 (Arnaud, 1989) | Shells | 7040 ± 70 BP | 5921-5556/ 5829-5160 | Lower layer (3) (former projects) |
| | | OxA-29235 | *Meles meles* bone | 6962±37 BP | 5974-5744 | 3/7 (Area 1) |
| | | Q-2494 (Arnaud, 1989) | Shells | 6780 ± 65 BP | 5807-5561 | Middle layer (2) (former projects) |
| | | Q-2495 (Arnaud, 1989) | Shells | 6850 ± 70 BP | 5724-5393/ 5622-4930 | |
| | | OxA-26094 | *Canis familiaris* bone | 6866±33 BP | 5837-5672 | 8 (dog burial - Area 1) |
| | | Ua-425 (Larsson, 2010) | *H. sapiens* bone | 5390 ± 110 BP | 4448-3984 | Burial 11 (former projects) |
| **C** | Blackish sand with some allochthonous sandstone blocks, a low density of shells and sparse archaeological material, including lithics, bones and scarce Neolithic pottery | OxA-29170 | Organic sediment | 5511±34 BP | 5048-4840 | 603 (Area 6) |
| | | OxA-29169 | Organic sediment | 6045±39 BP | 4453-4344 | |

| | | | | | |
|---|---|---|---|---|---|
| | sherds. It corresponds to the upper horizon of an A horizon of a palaeosol. | | | | |
| **D** | Yellowish sand with a low density of archaeological remains, including some modern pottery. | - | - | - | - |
| Surface: Modern soil. | | - | - | - | - |

The shell midden deposits rest on a cover of Pleistocene/Holocene aeolian sand. These sands are fairly homogeneous clast-supported and weakly compacted, except for the occurrence of post-depositional calcareous concretions related to root activity (Fig. 9.2c). An OSL age for Phase A sediments, in Area 9, associates the stabilization and burial of these basal sands slightly prior to the beginning of the Holocene (Table 9.1).

The set of $^{14}$C dates (Table 9.1) suggest that the earliest occupation at Poças de São Bento is that of Phase B, which corresponds to the shell midden layers, dated to between the late seventh millennium cal BC, and the sixth millennium cal BC. Broadly speaking, the shell midden deposits exhibit a greyish colour, a maximum thickness of around 80 cm and are sedimentologically quite homogeneous, loose sands with highly fragmented shells. These sediments enclose loosely-packed centimetric pebbles of allochthonous origin - some of them used as lithic raw material (see Table 9.2) - as well as lithics and bones, usually poorly preserved due to weathering and bioturbation. Spatially, however, each of the archaeological accumulations is quite sparse, with common lateral discontinuities, which result in patchy accumulations with gradual contacts with the under and overlying sediments; they are difficult to individualize topographically. Some sedimentological stratification within the shell midden layer is visible only in deposits in Areas 9 and 11 (Fig. 9.2). Here, the archaeological deposits present some internal stratification, with centimetre-thick lenses with sharp contacts, predominantly formed by quite complete shell valves.

In terms of habitat features, hearths and putative post-holes have been reported at the site (Arnaud, 2000, Arnaud, 1989, Larsson, 1996). Some negative structures, or pits, were identified dug into the Pleistocene/Holocene basal sands, usually under a layer of shell-rich Phase B sediments; the infilling seems to be sedimentologically equivalent to the same Phase

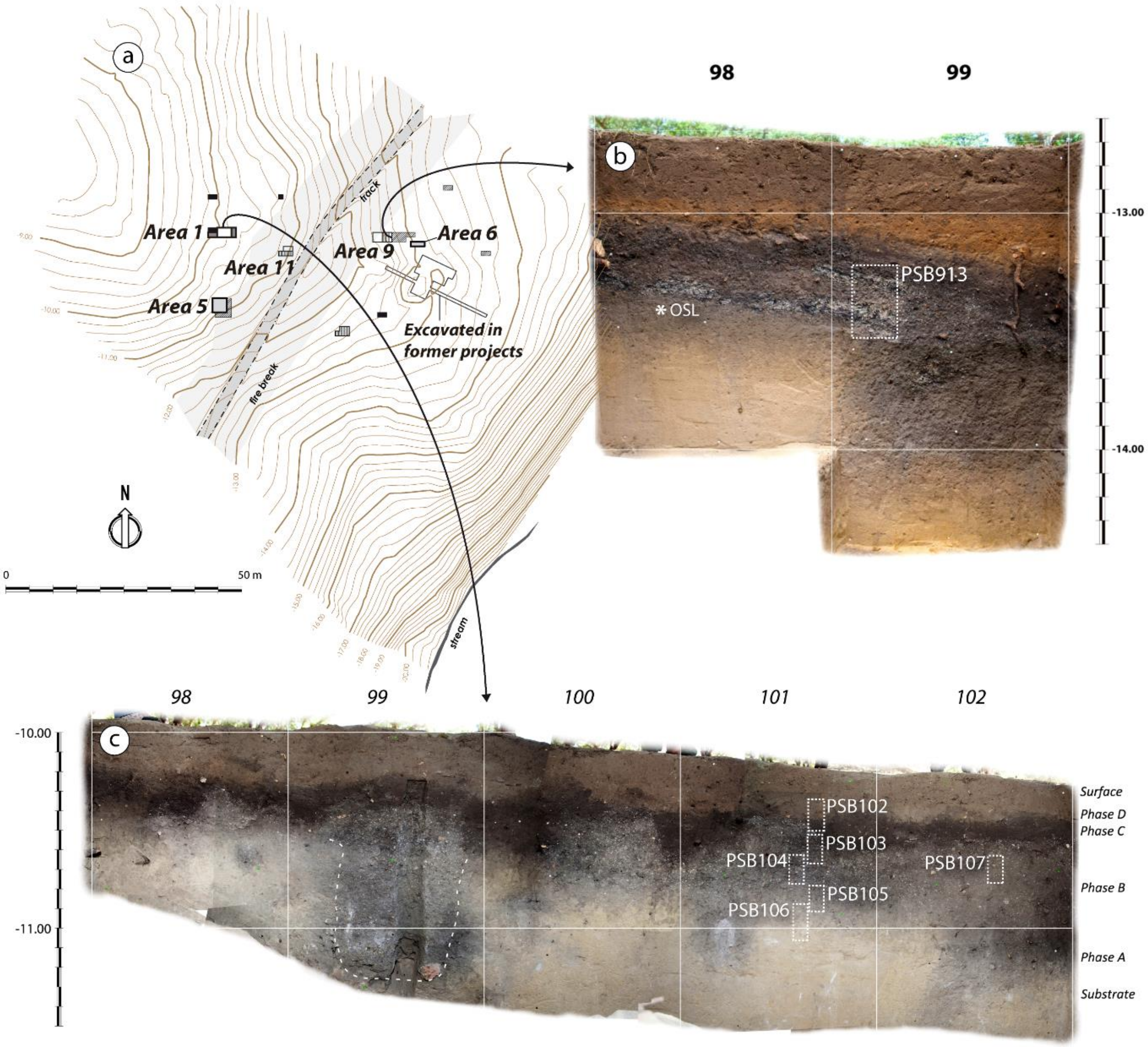



**Figure 9. 2** The site of Poças de São Bento. a) General site topography with indication of Areas mentioned on the text, 1, 5, 6, 9, and other excavated areas. b) Sampled profile in Area 9, with indication of the micromorphological block sample PSB913; note the oblique orientation, superposition and irregular upper contacts of the shell midden layers. c) Sampled profile in Area 1 with chronological phases after Arias *et al.* (2015), with indication of the micromorphological block samples PSB102 to PSB107; note the homogeneity of the shell midden layer (Phase B), the pit feature in square 99 and enigmatic, abrupt systematic features disturbing the top of the shell midden, filled with Phase C sediments

B sediments (Fig. 9.2c). In Area 1 these sediments included a dog burial (Arias et al., 2015). The human burials so far identified at Poças de São Bento were found in the basal sands below the lower contacts of the shell midden layer. They are concentrated in anarea of the site's estimated perimeter extensively excavated in former projects (Fig. 9.2).

Overlying the shell midden layers are the greasy, dark sediments of Phase C, which post-date the Mesolithic, a pedological horizon affecting the upper part of shell-rich sediments

(Fig. 9.2). The stratigraphic units corresponding to Phase C exhibit intense post-depositional bioturbation and admixture of pedogenic and anthropogenic materials. The radiocarbon result from Phase C sediments in Area 6), from a sample of total organic matter of sediment, revealed an early fifth millennium cal BC chronology, coherent with the scarce Neolithic pottery sherds dispersed in this layer (Arias et al., 2015). Finally, the uppermost sediments, Phase D, have a sharp lower contact with Phase C sediments, and correspond to the present-day soil surface.

## 9.2 Sampling strategy and analysis

The micromorphological samples presented here were collected in Areas 1, 5 and 9 (Fig. 9.2a), attending to specific stratigraphic features, highlighted below (see also Fig. 9.2: b, c). The sampling consisted of carving out the blocks from the profiles and using pre-plastered bandages to pack the exposed surface of the blocks and ensure their undisturbed extraction. After they were wrapped in plastic, the orientation was marked on each block.

The deposits in Area 1 are well representative of the overall site chronostratigraphic scheme explained above. Therefore, a vertical sampling strategy was undertaken (Courty and Fedoroff, 2002) covering the full sequence in the North profile (samples PSB102 to PSB106) (Fig. 9.2c). The shell midden here consists of one homogeneous layer ~35 cm thick (stratigraphic unit 3/7). Additionally, two lateral samples were taken: PSB107 was collected in the contact between stratigraphic units 3/7 and 12 (Fig. 9.2c), distinguished in the field by the relative lower abundance of shells in unit 12; and PSB108 was collected in the East profile in order to cover a zone of discontinuous calcareous concretions, which characterize the base of unit 12. From Area 5, one thin section (PSB510) was analysed, from a heavily and homogeneously concreted area at the base of the shell midden layer, which here is quite thick (50-60 cm). As mentioned above, Area 9 deposits revealed the most complex superposition of clearly different shell-rich deposits. One large block sample covering the full sequence of these shell midden layers was collected in the West profile (Fig. 9.2), and resulted in four thin sections (PSB913.B1, B2, D1 and D2). A total of 17 thin sections were produced and the systematic micromorphological descriptions followed the terminology established by Stoops (2003) and Courty *et al.* (1989).

## 9.3 Results

### 9.3.1 Sedimentary Components

The main sedimentary components of PSB observed in thin section are listed in Table 9.2, where detailed descriptions and brief genetic interpretations are also provided. Geogenic components are silt and sand mineral grains and fewer pebbles. Sand and silt grains, coming from the sand cover on which the shell middens rest, are mainly composed of quartz and feldspars, medium to well rounded. Some of the lithologies of pebbles, such as calcareous ones, are allochthonous, and are restricted to shell-rich anthropogenic sediments, therefore interpreted as deposited alongside with the anthropogenic components.

Anthropogenic components comprise shells of peppery furrow (*Scrobicularia plana*), widely dominant in abundance, and less frequent cockle (*Cerastoderma edule*). Other components directly associated to human occupation of the site are common in shell-rich sediments. These include bone, particularly fishbone, often with optical signs of burning, wood charcoal and char aggregates. Charred and calcified insect excrements and fungi anatomical parts are common. These elements are considered to be ancient, possibly as result of exploitation of conifer wood, namely dead wood (López-Dóriga, 2016). Our study corroborated this hypothesis, not only because of the mentioned taphonomical processes they undergone but also by the microcontext where they occur, that follows a different pattern from that where the recent, humified or fresh analogues occur (see bioturbation section below). The rare presence of small clay aggregates and isolated foraminifera and ostracods in shell-rich sediments is also explained as unintentional by-products of shellfish gathering in estuarine marshes of the River Sado.

**Table 9. 2** Description and genetic interpretation of the main components observed in PSB thin sections

| Component | Description | Genetic interpretation | Thin sections |
|---|---|---|---|
| Silt and sand mineral grains | Sand and silt sized minerals are the dominant component in all thin sections. Its composition consists of 80% quartz, 15% feldspar (microcline | The lithologies and general roundness of the grains reflect the Pleistocene/Holocene sand cover on which the shell | All |

| | | | |
|---|---|---|---|
| | and other K-feldspars and fewer plagiocalse) and 5% heavy minerals. Shapes vary from sub-angular to well-rounded. Very frequently, feldspars exhibit advenced alterarion to secondary clay minerals. | middens rest, continuously reworked by human and natural processes and incorporated into the archaeological sediments. | |
| Pebbles | Sub-rounded to rounded pebbles of quartz and rock-fragments such as arkose are ubiquitous in the shell midden related sediments, up to 1,5 cm in thin section and up to 7 cm in the field. Rounded calcareous* pebbles are common and in specific shell-rich sediments (MF3a) and exhibit optical signs of having been exposed to high temperatures (calcination and cracks). | The lithologies that are different from those present in the dune substrate and their association with shell-midden sediments indicates a transport to the site by humans (from somewhere else in the valley, where such materials outcrop), possibly as a by-product of shellfish gathering and other sediment bearing activities, but their intentional transport for combustion-related activities is also a possibility. | 103.2, 104.1, 104.2*, 105.1*, 105.2; 107, 108, 913.1 |
| Mollusc shells | Shell fragments of peppery furrow (*Scrobicularia plana*) are dominant in all shell-rich sediments of PSB. Cockle (*Cerastoderma edule*) shells are less frequent and less fragmented. Depending on the MF type, the degree of calcium depletion, fragmentation, orientation and organisation patterns and possible heating alteration is variable between MF types. | Anthropogenic input result of shellfish resources exploitation. | All, except 102 |
| Fishbones and mammal bones | Mammal bones fragments are extremely rare although existent in all thins sections and only in a couple of instances exceed sand size. Fishbones are present in all thin sections of shell-rich sediments, including vertebrae*. Bones exhibit some physical weathering, occasional calcium carbonate mineralisation and rarer signs of burning. | Animal/fish processing and consumption by humans at the site. | 103.1, 103.2, 104.1, 104.2*, 105.1, 105.2, 107*, 108, 913.1, 913.2, 913.3, 913.4 |

| | | | |
|---|---|---|---|
| Wood charcoal | Well-preserved fragments from fine sand size up to 1 cm are abundant, particularly in in shell-rich sediments. | Antrhopogenic combustion activities. | All, except 106.1 and 106.2 |
| Clay | Very little clay was observed in thin section. In shell midden layers, it occurs mostly as small amounts of clay attached to shells or coarser sand grains, sometimes forming connecting bridges between those (chitonic/gefuric c/f related distribuions). Also very few, isolated aggregates were identified, with optical signs of possible burning. Two different main compositions were distinguished in the shell midden layers:<br>1) Reddish brown, stiple speckled b-fabric, with organic matter inclusions.<br>2) Orange/yellow, crystallitic b-fabric, with silty mineral inclusions.<br>Both types of clay aggregates occur in MF type 5a (interconnected shells) deposits. | Origin uncertain, probably result of shell gathering in estuarine marshes, affected by post-depositional water percolation. | 913.1, 913.2, 913.3, 913.4 |
| Char | Char aggregates are present in shell-rich sediments, some exceeding sand size, with its characteristic amorphous shape with vesicles resulting from trapped air bubbles and dehydration cracks. In some cases, the charred mass is optically contiguous to wood charcoal. | Probably from charred plant-derived secretions (e.g. resin) result of combustion activities, giving the common association with wood charcoal. The macrobotanical assemblage evidences an important exploitation of pine (Lopéz-Doriga 2016). | 104.2, 105.1, 107, 913.1, |
| Foraminifera | Few and poorly preserved isolated foraminifera were observed in shell-rich sediments. | Anthropogenic, non-intentional input associated with shellfish gathering in the estuarine marshes. | 104.1, 913.2 |
| Calcified filaments | Very common in shell-rich and specially in cemented sediments, filaments (100 µm or more in length and | Charred and calcified fungi (*Cenococcum geophilum*) sclerotia – which taphonomic | All |

| | | | |
|---|---|---|---|
| | 5-10 µm wide) sometimes branching, reproducing the mycelial growth of fungal hyphae with (taphonomic) micritic nature and a characteristic inner hollow left after the fungi decomposition. | descriptions coincide with the characteristics identified in thin section – have been identified among the macrobotanical assemblage and associated to ancient wood exploitation, namely dead wood (López-Dóriga, 2016). These fungi also develop hyphae, too small to be recovered in flotation, but that can be related to the sclerotia species indentified in the archaeobotanical study. | |
| Insect faecal pellets | Very frequent, both humified and calcitic oblong to spherical granules are ubiquitous. | Charred and calcified termite excrements have been identified in the macrobotanical assemblage of PSB and associated to ancient wood exploitation (López-Dóriga 2016). Humic pellets (not charred or calcified), from other insects also occur frequently, associated with recent bioturbation. | All |
| Fresh plant material | Roots, plant tissue and plant cells are ubiquitous elements, often in close association with humic faecal pellets. | Recent bioturbation. | All |

Asterisk (*) indicate that the specific component occurs in the thin section it occurs also marked with asterisk in the correspondent line.

### 9.3.2 Microfacies

The most discriminating factor for microfacies (henceforth, mF) types identification at Poças de São Bento sediments were the relative abundance of shells and their organization and orientation patterns. The different mF types broadly coincide with the stratigraphic units visible in the field. However, different geometric patterns, only observed in thin section, can be clearly distinguished within the shell midden layers and associated with specific human activities. A total of seven main mF types were identified in the thin sections from Poças de São Bento, with several subtypes, as listed in table 9.3.

**Table 9. 3** Description of the microfacies types identified in Poças de São Bento thin sections

| **Microfacies type** | | **Description** |
|---|---|---|
| 1 | *Unsorted sand with clay* | These deposits are characterised by unsorted sand and micromass consisting in variable amounts of pale brown to brown clay, isotropic, with some micas and few organic punctuations, forming microaggregates of variable sizes between the grains (close fine to coarse enaulic c/f related distribution) as well as discrete, partial coatings in the coarser grains (chitonic c/f related distribution). Rarely, it also reveals some fine to coarse sand size bone and charcoal fragments, and fewer coarse sand size rounded clayey aggregates with massive microstructure. mF type 1 deposits are present only in the Phase D stratigraphic units, and correspond, mostly, to recent intensive agriculture practices that were carried out in the last several decades, that involved remobilisation of sediments from elsewhere by means of heavy machinery. Therefore, we will no further take mF type 1 into consideration regarding the prehistoric occupations of the site. |
| 2 | *Sand and polymorphic fom* | The distinctive characteristic of these deposits is the relatively high amounts of micromass (30-40%) composed by polymorphic fine organic matter (henceforth, polymorphic fom), composed of decayed plant material by action of soil fauna *in situ*, generating pellets, more or less coalescent into dark and isotropic aggregates (Buurman and Jongmans, 2005, Wilson and Righi, 2010). The presence of polymorphic fom decreases the porosity of these deposits (10-15%), compared to the other microfacies. Polymorphic fom in mF 2 forms welded aggregates (*sensu* Buurman *et al.* 2005) between and coating coarser grains of unsorted, tendentiously coarse sand (chitonic and close fine to coarse enaulic c/f related distribution), conforming a spongy microstructure (Plate 9.1b). We can distinguish a subtype of this mF: |
| 2a | *Sand and polymorphic fom with few shells* | This subtype has the same mineralogical and organic characteristics of type 2, slightly higher porosity (20%), but includes few shells (5-10%) that present strong dissolution features, as well as very rare fine sand sized charcoal and bone fragments. |
| 3 | *Matrix-supported shells* | In these deposits the shells are common (25%) to frequent (30%), but not the dominant component, not in contact between each other and lacking any orientation pattern. Another distinctive characteristic of this mF is a relative enrichment in secondary calcium carbonate in the form of micritic infillings and coatings. Interestingly, foraminifera specimens were spotted only from both subtypes of this mF type. |

| | | |
|---|---|---|
| 3a | *Coarse heterogeneous* | The deposits corresponding to this mF present frequent shell fragments (30%) ranging from few millimetres to not much more than 1 cm in length, fine to coarse sand size charcoal, bone, fishbone (including fish vertebra) and char aggregates, all chaotically distributed (Plate 9.1d). The porosity is variable, giving the also heterogeneous character of the micromass. Apart from moderate (PSB104 to 107 thin sections) to strong (PSB108) secondary micritic infillings, the micromass is composed of organic silt particles and micro-charcoal between coarse components (close fine enaulic c/f related distribution) and few amounts of porous crumbs with little clay and organic silt, overall coating the surface of coarser components (chitonic c/f related distribution). This micromass is rich in silt sized, highly birefringent microcrystals (stipple speckled b-fabric), presumably of calcite and sericite, resulting from secondary precipitation and feldspars alteration, respectively. In thin section, this mF present occasional rounded pebbles of calcareous rocks and quartz, up to 1.5 cm, and several centimetres bigger in the field. The pebbles were exposed to high temperatures (calcination and cracks). |
| 3b | *Coarse inorganic* | This subtype is characterised by slightly lower abundance of shell fragments (20%). Mineral sand and silt grains are the dominant coarse components and very rare, fine sand sized charcoal and fewer bone (>2%), have been observed. The micromass is rare (5-10%) and has a calcitic matrix (calcitic crystallitic b-fabric) and few organic silt, forming coatings and microaggregates between coarse components (chitonic and fine enaulic c/f related distributions). Secondary micritic post-depositional features, including localized cementations, coatings and hypocoatings increase in relation to mF type 3a. |
| 4 | *Horizontally oriented shells* | In this mF the shells are common to frequent (30-40%) and present a preferential sub-horizontal orientation pattern, organised in discrete stringers of interconnected shells, being overall still matrix-supported. In these stringers, the horizontally disposed shells recurrently present a brownish colour and loss of birefringence, as well as horizontal fissures following the lines of the shell growth (features associated with heating induced alteration according to archaeological and experimental evidence after Villagran (2014a), Aldeias et al. (2016). Together with these fissures, they also exhibit vertical fractures interpreted as *in situ* breakage, i.e., the shells were crushed but remained in its position. Some shells in this mF type present calcitic pendants (secondary calcite precipitations below the bottom surface of the shell). These millimetre-thick stringers were not identified in the field, and the total thickness of the mF in thin sections is < 2 cm. Charcoal, fishbone and char are also present in this mF, along with occasional medium sand size clay aggregates. The micromass and geogenic components are similar to those of mF type 3a. |
| 5 | *Shell-supported sediments.* | This microfacies corresponds to deposits where shells are the dominant component (50-60%), normally interconnected, both in sub-horizontal (60% of the shells) and sub-vertical (40% of the shells) positions. As a whole, mF type 5 deposits follow a |

| | | |
|---|---|---|
| | | slightly oblique general orientation in relation to the current soil surface, which is also perceptible in the field by the general geometry of the correspondent stratigraphic units (Fig. 9.2b, plate 9.3a). The deposits corresponding to this mF are ~10 cm thick, both in thin section and in the field, having been identified only in Area 9. Two subtypes can be distinguished. |
| 5a | *Interconnected shells* | In this mF practically all shells exhibit calcitic pendants. The porosity is high (20-30%), characterised by packing voids. Except for some restricted areas where the shells are virtually the only component (figs. 5a to 5e), this mF is rich in other anthropogenic materials, that follow distinct distribution patterns. Whilst fine sand sized charcoals are occasional (5-10%) and scattered throughout the mF, several fish bones were found concentrated in a cluster in thin section PSB913.D1 (Plate 9.3: e, k), although rarer isolated fragments also occur. Clayey aggregates tend to be concentrated at the bottom of the deposits corresponding to this mF (Plate 9.3b, g, h). The amounts of mineral sand and silt grains are low and generally interstitial, except in an instance when they form a 2-4 mm thick, regular and continuous concentration of well sorted, medium sized sand between the shells, as in thin section PSB913.B1 (Plate 9.3: b, f). This mF is highly affected by bioturbation, which is responsible for localized rearrangement of shells and common excrements and clayey granules (localized granular microstructure domains) that indiscriminately infiltrate the void space. A possible knapping residue is observed in thin section PSB913.4, among the interconnected shells (Plate 9.3: d, l). Micromass is extremely rare and consists mainly of microcharcoal and organic and micritic microaggregates (fine enaulic c/f related distribution). |
| 5b | *Coarse wood charcoal* | This mF is characterised by a striking dominance of wood charcoal. Charcoal fragments are medium to coarse sand and gravel sized. Together with shells, in ratio of 50/50, these are the main components of this mF, although few sand grains (5%) and phosphatic nodules (5%), the latter concentrated in clusters, embedded among the charcoals, also occur. These phosphatic nodules have granular and globular, irregular shapes, present a pale yellow or brownish-orange colour under PPL and are isotropic under XPL, and are probably result of decayed plant material. |
| 6 | *Silty sands* | This mF type consists of single grains of silty sand clast-supported (coarse monic c/f related distribution) associated to the Pleistocene/Holocene sand cover on which the shell midden lies. This mF type contains domains of complete micritic infillings of the space between sand grains (porphyric c/f related distribution). A subtype can be distinguished: |
| 6a | *Silty sands with few shells* | Differs from mF type 6 solely by the presence of few or very few shells (5-10%) and rarer fine-sand-sized charcoal, without any orientation pattern. |
| 7 | *Calcitic cement* | The distinctive characteristic of this mF is a strong cementation by secondary calcite that infills the void space between the components almost completely (10% void space), which, in the field, is reflected by localized concretions. This cementation |

| | |
|---|---|
| | is affecting, post-depositionally, deposits equivalent to mF types 3a, *coarse heterogeneous* (thin section PSB108) and 5a, *interconnected shells* (thin section PSB510), as the coarse and fine components, abundances and arrangement are the same. The deposits corresponding to mF type 7 are located in the base of shell midden layers, having the same situation been reported at Cabeço da Amoreira (Aldeias and Bicho, 2016). These deposits are fairly distinguishable in the field given their hardness, forming more or less sparse patches with irregular geometries, from ~2 cm nodules to several centimetres thick concretions. The cement is composed by infillings of calcitic fine crystals which characteristics are detailed in the post-depositional processes section of the main text. |

Interestingly, remarkable similarities were found with mF types identified at the site of Cabeço da Amoreia (Aldeias and Bicho, 2016). As this is an outcome with valuable broader implications explored later on in this work, Table 9.4 lists the mF types and respective brief interpretation at PSB, with correlation, when existent, to mF types at CAM.

**Table 9. 4** Interpretation of the microfacies types identified in Poças de São Bento thin sections and correspondence, when existent, with mF types at Cabeço da Amoreira (Aldeias and Bicho, 2016)

| **Microfacies type** | **Corresponding mF at Cabeço da Amoreira** | **Genetic interpretation** |
|---|---|---|
| 1, *Unsorted sand with clay* | - | Ap2-horizon. Recent ploughing activity |
| 2, *Sand and polymorphic fom* | - | A1-horizon. Middle Holocene Palaeosol |
| 2a, *Sand and polymorphic fom with few shells* | - | Surficial shell midden disturbed by pedogenic activity and post-Mesolithic admixture. |
| 3, *matrix-supported shells* - 3a, *Coarse heterogeneous* | 2, 4 | Anthropogenic reworking of activity debris (shellfish and other plant and animal processing refuse) by dumping or raking out. |
| 3 *matrix-supported shells*. Sub-type 3b, *Coarse inorganic* | - | Anthropogenic reworking of (mainly) shellfish refuse by dumping or rake out. |
| 4, *Horizontally oriented shells* | 3 | Trampled occupation surface. |
| 5, *shell-supported sediments.* | 1a | Shell and debris tossing activity |

| | | |
|---|---|---|
| Sub type 5a, *Interconnected shells* | | |
| 5, *shell-supported sediments.* Sub-type 5b, *Coarse wood charcoal* | - | Charcoal and shells tossing |
| 6, *Silty sands* | 5b | Pleistocene/Holocene sand cover |
| 6a, *Silty sands with few shells* | 5a | Dispersed shells in the sand by processes related to the active layer and reworked downwards by bioturbation |
| 7, *Calcitic cement* | 1b | Carbonate cementation by secondary calcite (micrite and needle fibre calcite) |

### 9.3.3 Post-depositional features

The archaeological stratigraphy at Poças de São Bento is badly affected by post-depositional alterations. Recent ploughing, small mammals' burrows, biological (root and soil fauna) channels and localised concretions are some of the most striking disturbances visible in the field (Fig. 2c). In the shell-rich sediments at Poças de São Bento, observing the micromorphological thin sections at 1:1 scale, it is possible to discern more accurately the extent to which these disturbances affect the stratigraphic record and track post-depositional movements of archaeological material. At the microscopic scale, post-depositional processes are readily identifiable, which allows the preservation conditions of the anthropogenic materials to be addressed, a fundamental aspect of archaeological interpretation (Goldberg and Berna, 2010). The post-depositional processes can be divided in two groups based on their implications for the integrity of the archaeological record at the site; these are crystallitic features and mechanical disturbance.

#### *9.3.3.1 Crystallitic features*

Crystallitic features result from calcium carbonate dissolution and reprecipitation. In the setting of the human settlement at Poças de São Bento, the presence of calcium is mostly due to the anthropogenic input of shells. Moreover, there are carbonated rocks in the broader geological environment (Miocene sediments that have undergone pedogenic carbonation) (Pimentel and Azevêdo, 1994), exposed in some points of the slopes of the Sado valley. Some of these rocks were also anthropogenically introduced to Poças de São Bento alongside the incorporation of shells.

Dissolution is an important process affecting the shells at the site. In mF 2a, *sand and polymorphic fom with few shells*, this process is observed in the majority of shells, which overall present intense carbonate loss. Microfacies type 7, *calcitic cement*, can be interpreted as the result, also post-depositional, of this process: the carbonates secondarily precipitated in certain zones, originating cemented areas of shell-rich deposits, normally at the bottom of the deposits. Cementation of basal shell midden deposits due to dissolution of the overlying shells by rainwater was noticed by Roche (1966) in Moita do Sebastião, another shell mound in the Muge valley, near Cabeço da Amoreira. Aldeias and Bicho (2016) also described the phenomenon at the latter. The cement in mF type 7, *calcitic cement*, is formed by several types of precipitates, of which micrite is most abundant (30%), coating irregularly the components' surfaces and forming closed vughs. Micritic infillings and hypocoatings are also abundant in mF type 3, *matrix-supported shells*, particularly 3b, *coarse inorganic*, (Plate 9.4: c, e) although without hardening these deposits, and constituting the very expressive, sometimes complete infillings of bioturbation features in the sandy mF types 6 and 6a (Plate 9.5e).

Needle-fibre calcite is exclusively seen and very common in mF type 7, *calcitic cement*, formed by thin (0.5-2 µm wide) and very long (up to 100 µm), randomly oriented crystals forming a meshwork pattern, superimposing surfaces of voids in the micritic infilling (Plate 9.6: a, b). Another common type of cement at mF type 7, is the so-called alveolar septal fabric (Scholle and Ulmer-Scholle, 2003) (Plate 9.6c), forming narrow, curved septa consisting of bundles of even finer calcite needles (>0.5 µm wide and <2µm long), barely perceptible under the petrographic microscope. Similar crystals have been interpreted as reproducing fungal mycelial shapes (Scholle and Ulmer-Scholle, 2003) and attesting to a significant fungal presence in the deposit. Another element both in the cemented layers and, to a lesser extent, overlying shell-rich deposits, are calcified filaments (Plate 9.2d), threadlike structures corresponding to fungal hyphae encrusted with minute calcium carbonate crystals (Durand et al., 2010). Calcified roots, or rhizoliths, occur in both cemented and non-cemented deposits (Plate 9.4e). These post-depositional, calcitic features reach centimetre-thick dimensions in the cover sand deposits underlying the shell midden (Plate 9.2c and 9.7f).

Another very common secondary calcite feature, unrelated to cemented deposits or biogenically induced calcite, is the aforementioned pendants. These structures are formed in meteoric vadose areas, i.e., above the water table, where there is enough void space for water drops to hang from the underside of the grains (Scholle and Ulmer-Scholle, 2003, Flügel, 2004). At Poças de São Bento, the pendants, reproducing the drop shape, consist of alternating laminae, roughly parallel to the bottom surface of shells on which they formed. The laminae exhibit differences in colour, from limpid to brownish, depending on the amount of organic matter (Durand et al., 2010). They can become quite irregular in the outermost surfaces, because of varying crystal morphologies of each laminae, ranging from micritic to microsparitic and acicular calcite crystals, and overall are quite fibrous. The aggradation of repeated pendant layers (fig 9.8: e, f) is common, forming fan-like structures, indicating several phases of partial water saturation of the deposits.  Practically all shells and some coarse sand/gravel grains in mF type 5a, *interconnected shells*, exhibit pendants (Plate 9.6d), and there are rare occurrences under some shells in mF type 4, *horizontally oriented shells* (fig. 9.9c).

#### *9.3.3.2 Physical disturbances*

In thin section, it is possible to delimitate, with remarkable precision, the areas mechanically disturbed by soil fauna (mainly arthropods) that, while burrowing, rearranged the shells in crescent/circular patterns, forming passage features, easily recognised at normal scale analysis of thin sections (Plate 9.3: a, c;  9.6a; 9.7b). Moreover, it is possible to affirm that shells in these areas have been disturbed because some of them exhibit shells with rotated pendants (Plate 9.6f), i.e. pendants not in the original gravitational position, meaning that the shell was disturbed after the pendant formation. The degree of bioturbation at Poças de São Bento in the remobilization of archaeological material is an important issue. For instance, the secondary position of a pottery fragment, consistent with ages of mF type 2 deposits, downwards into Mesolithic mF type 3a sediments was observed in thin section PSB104.1, inside one of these passage features (Plate 9.4: a, f). These features, easily recognisable for their two-dimensional geometry in thin section, are not always perceptible in the field.

## 9.4 Discussion

The recognition of microfacies enables the reconstruction of different human activities and behaviours behind the accumulation of shells and other anthropogenic debris at Poças de São Bento. Moreover, it provides precise information on natural processes during the site's occupation and how it might have been modified by post-depositional processes. Broader geological information available has provided relevant clues for the interpretation of human behaviour in the construction of shell middens at Poças de São Bento. In the next sections, we will address those questions, based on the geoarchaeological record studied with the mentioned methodologies.

### 9.4.1 The sand cover substrate

The interface between sterile dune sand and the first occupational deposits is difficult to pinpoint. There is no sharp contact from utterly “clean” sands, in terms of anthropogenic material, to shell-rich sediments. MF type 6, *silty sands*, corresponds to the lowermost and cleanest sands. The minute and extremely rare shell fragments in the mF appear to be post-depositionally displaced by root activity. This is supported by the microcontext of these fragments, characterised by micritic impregnations around roots (Plate 9.5: e, f).

In the overlying mF 6a, *silty sand with few shells*, the number of shells progressively increases towards the contact with shell midden layers, and reaches a relative abundance in thin section of 5-10%, in the immediate 10-20 cm below the shell midden, in both Areas 1 and 9. These sediments exhibit a grey colour in the field and the contact with the lowermost yellow sands is gradual and marked by macroscopically visible bioturbation features, such as root and insect channels. We attribute the grey colour to the precipitation of secondary carbonates, which are visible in thin section.

In sample PSB913 (Area 9), within 2-4 cm below the lower contact with the shell midden, mF 6a presents some remarkable aspects regarding shell positions. One is that the shell fragments are randomly oriented, many in vertical position, but not associated with bioturbation features that explain their presence as post-depositional. Thus, their presence here must have another origin (Plate 9.5: a, c, d, g). Aldeias and Bicho (2016) previously noted that shells in vertical position were most likely deposited together with the surrounding sediment, (otherwise, if not supported by the sandy matrix, the shells would tend to fall to a more natural horizontal position) which suggests that these are reworked sands that already contained shells. Another interesting aspect in thin section is the case of two nearly complete sections of *Scrobicularia plana* valves in sub-horizontal position; these were also perceptible in the field, where sometimes, several horizontal shells, crushed *in situ* and surrounded by sand were found. However, as noted above, these intact valves point to little transport. Given that the matrix is undoubtedly the same as the Pleistocene/Holocene cover sand, we interpret the first (upper) few cm of mF type 6a deposits, at least in Area 9, as an active layer, i.e., a rather unstable sand surface, susceptible to particle movements. The shells in these surficial sands may havearrived by dispersion. So far there is no field evidence of such deposits, so this remains open as a hypothesis for future work.

Dispersion of shells can result from many factors. Wind is an important natural agent in sandy settings, promoting surficial creep of silty-sand sized materials and rolling and saltation of coarser particles (French, 2003, Courty et al., 1989), where small shell fragments would be equally affected. Dispersion by human trampling is also a possibility that was taken into consideration for a similar mF type described at Cabeço da Amoreira (Aldeias and Bicho, 2016) The fact that some horizontally oriented shells in these sands display *in-situ* crushing (Plate 9.5d), resembling those in mF type 4, could mean that some trampling was reponsible for shell dispersion and incorporation in the surficial sand. Nevertheless, apart from the described microcontextual evidence of some shells in the surface having arrived with the sand by particle movements, in lower depths (from the first 2-4 cm downwards), bioturbation is considered the main agent for post-depositional migration of shells of mF 6a deposits. Bioturbation has long been considered a major factor in vertical displacements of archaeological material in sandy settings (Goudie, 2017). The OSL date of 12±1 ka seems to support this. The dated sample comes from the middle part of the ~20 cm thick stratigraphic unit 912 (Area 9, see Fig.1), containing shells, corresponding to mF type 6a. In sum, the date refers to a moment of sand accumulation and stabilization at the end of the Pleistocene (see Table 9.1), thus incompatible with any human occupation so far identified at Poças de São Bento. With micromorphology, however, we can track more precisely the extent of movements by at least roots and insects (those of larger animals like rodents, mustelids or rabbits are clearly visible macroscopically). The recognition of such movements and microcontextual observations like the those mentioned above (fragmented *versus* complete valves, organization pattern and association or not with rhizoliths), indicate that some of the shells, in the first few cm, were deposited with the matrix.

### 9.4.2 Anthropogenic formation processes: human activities at the site

The microfacies approach to the shell midden layers at Poças de São Bento allowed the discrimination of specific, intact characteristics of its internal microstratigraphy and the associatin of each one to anthropogenic actions, divided into three main types of activity. As already stated, very interesting and remarkable similarities were found with some of the mF types, corresponding to shell-rich deposits, described at the site of Cabeço da Amoreia (Aldeias and Bicho, 2016). This site is a larger shell mound, forming an artificial hill perceptible in the landscape. It is one of a group of Mesolithic shell mounds known in the Muge valley, part of the early Holocene palaeo-estuary of the Tagus River (for details, see Bicho et al. 2013, 2011), located approximately 100 km north of the Sado shell middens area (Fig. 2). Given the similarities in the mF between the two sites, an outcome with valuable broader implications, here we follow the nomenclature proposed by Aldeias and Bicho (2016) for anthropogenic activities (see also Villagran et al. 2011). For a correlation of the mF types and their respective brief interpretation at Poças de São Bento, linked to mF types at Cabeço da Amoreira, see table 9.3.

#### *9.4.2.1 Single tossing events*

Microfacies type 5, *shell supported sediments*, is thought to be the result of preserved single events of direct tossing of debris, mainly shells. These are often interconnected and parallel to each other, albeit not according to a single systematic orientation, and exhibit a low degree of fracturing. These deposits were identified in Area 9 and Area 5, although the latter was secondarily cemented. In thin section, features like fishbones maintained together (Plate 9.3: d, k) and 2-4 mm thick lens of well sorted medium-sand sized mineral grains (Plate 9.3: b, f) indicate little disturbance after deposition, thus possibly rapid burial. Clay coatings (pale yellow, stipple-speckled b-fabric) and interstitial clayey aggregates (Plate 9.3: g, h, j) contrast with the poorly sorted silt to coarse sand in the substrate, where clay is inexistent. For this reason, the well-sorted sand grains and the clay aggregates are interpreted as coming from a different source, possibly the estuarine marshes where shellfish was gathered using sediment-bearing techniques; it would suggest transport of the shellfish from the gathering place directly to the site of Poças de São Bento. This aspect reinforces the importance of the ongoing sedimentological research on the Sado valley infill, which is partially aimed at clarifying issues such as this. It is interesting to note that mF 5a is the only one where most of the shells exhibit well developed calcitic pendants, sometimes very elaborate, indicating several events of partial water saturation (Plate 9.6: d, e, f).

Like in the mF type at Cabeço da Amoreira also interpreted as single tossing events (see Table 9..3), the shells in Poças de São Bento's mF type 5a show some *in situ* cracks.

Although, at Poças de São Bento, these features are not as overwhelming as at Cabeço da Amoreira, where the shells follow only one consistent, sub-horizontal orientation pattern and *in situ* cracks are abundant (see figures 4 and 5a in Aldeias and Bicho, 2016), we argue that they similarly have suffered some trampling, but perhaps not repeatedly. A microfacies type at the recent shell midden of Túnel VII, Tierra del Fuego (Argentina), also with interconnected shells in sub-horizontal, oblique and sub-vertical orientation patterns, was interpreted as "tossing of discarded items on the hut outer perimeter where the Yamana used to deposit the waste of daily indoor activities." (Villagran et al., 2011). The characteristics of mF type 5a at Poças de São Bento  resemble more closely this organisation patternAside from the differences in thickness between Túnel VII (up to 50 cm) and Poças de São Bento (10 cm), and taking into account the evidence of the mentioned well preserved microcontextual arrangements, we may think of a similar deposit of discarded activity debris, in an area of the site not continuously occupied and probably covered shortly after deposition.

The interpretation of mF subtype 5b, *coarse charcoal and shells*, is revealed by the high porosity and the shells' orientation pattern, which suggests also a single tossing event, but of more selected material: only coarse charcoals and shells, in equal proportion, seem to have been tossed. We may tentatively think of different activities as the origin of the selection of components. Perhaps, mF 5a components were generated from the processing and consumption of shells and fish, whereas mF 5b could be the result of disposal of fire residues from a cooking structure, e.g., roasting with fire on top of the shellfish in a *cuvette* and later removal of the charcoal, as proposed in one of the experiments by Aldeias et al. (2016)., Furthermore, there are no micromorphological indicators that this is an *in situ* combustion event, such as heated substrate or ashes which should be preserved, given the basic pH provided by the shells). Microfacies 5b was identified clearly in thin section 913B1, with a thickness of 1.5 cm, between two deposits corresponding to mF 5a (Plate 9.2b and 9.5b), and there are other possible mF 5b domains in lower PSB913D1 thin section (Plate 9.3d).

Based on the above, we argue that the *shell supported sediments* of mF type 5 correspond to the superposition of single tossing events, in primary position. When excavated, these deposits exhibit a maximum thickness of ~10 cm and have irregular upper contacts (Fig. 2b), as well as irregular boundaries in plan view. Despite intense disturbance by roots, which complicates the visualisation of the original shape, this spatial geometry makes us think of extended deposits, although still spatially well delimited.

#### *9.4.2.2 Reworked anthropogenic deposits*

The microfacies approach allowed the recognition of anthropogenic shell-rich deposits that were not in primary position, but had been reworked. These correspond to mF type 3, *matrix-supported shells*, which had two subtypes. Subtype 3a, *coarse heterogeneous*, contains randomly orientated and distributed shells, including several in vertical position, which, together with a high degree of fragmentation, suggests they were deposited with the matrix that supports them. The randomly distributed charcoal and fishbones, indiscriminately burnt and unburnt (plates 9.5b and 9.8f), also supports this interpretation, in contrast with the concentrated distribution patterns of these type of remains in mF type 5a. The high abundance of organic components in both coarse and fine fractions is related to animal and plant processing for consumption, here in secondary position.

In mF type 3a, there are also geogenic components such as small calcareous pebbles, and these are equally interpreted as anthropogenic inputs, based on the fact that the lithologies do not occur in the local Pleistocene/Holocene basal sand, and that they are absent in other mF types. However, they occur in the broader geological region (Fig. 9.10) where calcareous rocks occur in Miocene outcrops in specific localities towards the bottom of the Sado valley, that is, downstream from the site. It does not seem likely that they could have been brought to the site by a natural agent given the relief and distance. The clasts are too small (0.5 up to ~5 cm) to be suitable for any recognisable activity, leading to the exclusion of an intentional transport to the site. Indeed, there is no evidence of using them as raw material for lithic tools production, as there are for other allochthonous rocks (Pimentel et al., 2015). Instead, it is more likely that they relate to sediment-bearing shellfish gathering techniques in the Sado estuarine marshes, where they would be naturally deposited by slope and fluvial processes. Miocene calcareous rocks occur at the bottom of the valley, on the banks of Arapouco (the most downstream shell midden) and at the confluence of the Alcáçovas brook with the Sado (Fig. 9.10), outside the shell middens area. Therefore, the areas of the valley adjacent to the mentioned outcrops, where calcareous rocks are more exposed and susceptible to erosion and reworking into the fluvial bed, could be the source of the calcareous pebbles. They show some evidence of exposure to fire, e.g., cracks and calcination (Fig. 9.9: a, e), eventually related to the combustion activities in which charcoal and burnt bones and shells of mF type 3a would have originated. Foraminifera (Plate 9.4: g, h) are another significant component, identified exclusively in mF types 3a and 3b, associated with an estuarine marsh environment and equally interpreted as a by-product of shellfish gathering. For all these reasons, we interpret the presence of calcareous pebbles as unintentional inputs brought with the shellfish by the Mesolithic occupants of Poças de São Bento. Furthermore, this hypothesis can indicate the preferential location of shellfish gathering, which might not have been carried out near the site, but ~8-12 km downstream in the river.

Overall, mF type 3a is interpreted as intentional anthropogenic displacement of previously deposited sediments, mixing remains from different activities, possibly by dumping or raking-out. The resulting deposits, according to experimental studies (Miller et al., 2010), also exhibit a high porosity and chaotic organization of poorly sorted, burnt and unburnt components. Given the considerable extension of mF type 3a deposits in Poças de São Bento, it seems that the occupants of the site proceeded to spread these sediments around, in more or less juxtaposed accumulations. Such accumulations exhibit gradual horizontal boundaries in the field. A possible cause for reworked anthropogenic deposits, proposed by Aldeias and Bicho (2016) at Cabeço da Amoreira, is that the occupants were attempting to level the area in order to create a more stable and flatter surface. Accordingly, we suggest a similar type of activity at Poças de São Bento.

Concerning mF type 3b, *coarse inorganic*, its main difference is a scarcity of organic components compared to mF 3a, and a predominance of silty sand matrix, abundant micritic impregnations and randomly distributed, fragmented shells. The micromass of mF type 3b is also less organic when compared to mF type 3a. The lesser abundance of anthropogenic components other than shells seems to indicate that this mF type might have resulted from reworking sediments that originally also did not contain such components. The origin of these sediments is for the moment unclear, but a possible explanation could be an older reworking history that could have progressively eliminated the organic components. Microfacies 3b was identified only in Area 9. The thickness of this deposit (~10 cm.) and lack of any internal sedimentary structures (e.g., graded or well sorted bedding), leads us to exclude a natural process as responsible for this deposit, since it would imply a localised high-energy event, which is difficult to envision. This deposit over- and underlies two different deposits of mF type 5a (fig. 9.2b and plate 9.11), thus indicating that the shell midden sequence at Area 9 was formed by alternatingly events of single tossing and mass loads of reworked sediments.

#### *9.4.2.3 Occupational surfaces*

Microfacies type 4, *horizontally oriented shells*, is individualised by the occurrence of discrete stringers of interconnected shells, in sub-horizontal position, with high degree of *in situ* crushing (Fig. 9.9: c, d). These attributes are interpreted as the result of intense trampling, pointing to possible remains of occupational surfaces, i.e., the exposed surface of an area of the site that people frequented more. It is not possible to individualise these sediments into field excavation units, but the unifying attribute of mF type 4 (stringers of interconnected shells crushed *in-situ*) display remarkable consistence in two thin sections. The corresponding samples, PSB104 and PSB107, were collected at similar elevations in the North profile of Area 1, and are separated from each other by c. 1 metre, suggesting that they are the same layer (Fig. 9.9: a, b; see also Fig. 9.2c for spatial correlation between the two samples). The sediments of mF type 4, *horizontally oriented shells*, overlie anthropogenically reworked mF type 3a sediments in both thin sections. This is one of the most interesting outcomes of the microstratigraphic approach at Poças de São Bento, since it reveals internal stratigraphic consistency within the quite extensive, apparently homogenous, (and only) shell midden layer in Area 1. Another valuable outcome is that this association of possible occupational surfaces overlying anthropogenically dumped sediments is also present at Cabeço da Amoreira shell midden, an association used by the authors to reinforce the inference that mF 3a sediments were dumped to flatten the surface (Aldeias and Bicho, 2016). More samples would have to be analysed from further mF type 3a deposits in other areas of the site to make site-scale extrapolations. In Area 1, mF type 4 is also overlaid by mF 3a, and thus it seems that a new load of reworked anthropogenic materials was dumped over an occupational surface.

In Area 9, the mF type 3b, *coarse inorganic*, also interpreted as an anthropogenically reworked deposit, is not overlaid by mF type 4, *horizontally oriented shells*. Further research on the differences between mF types 3a and 3b in other parts of the site would possibly clarify a probable difference also in the intentions behind the general dumping actions argued for on mF type 3, *matrix-supported shells* sediments.

### 9.4.3 Dune stabilization: the middle Holocene palaeosol

The Pleistocene/Holocene sand cover, and the shell midden resting over it, reached a period of stabilization, that allowed the development of a vegetated A horizon, which has been classified as palaeosol A1 (phase C of Arias et al. (2015); see Table 1). These sediments

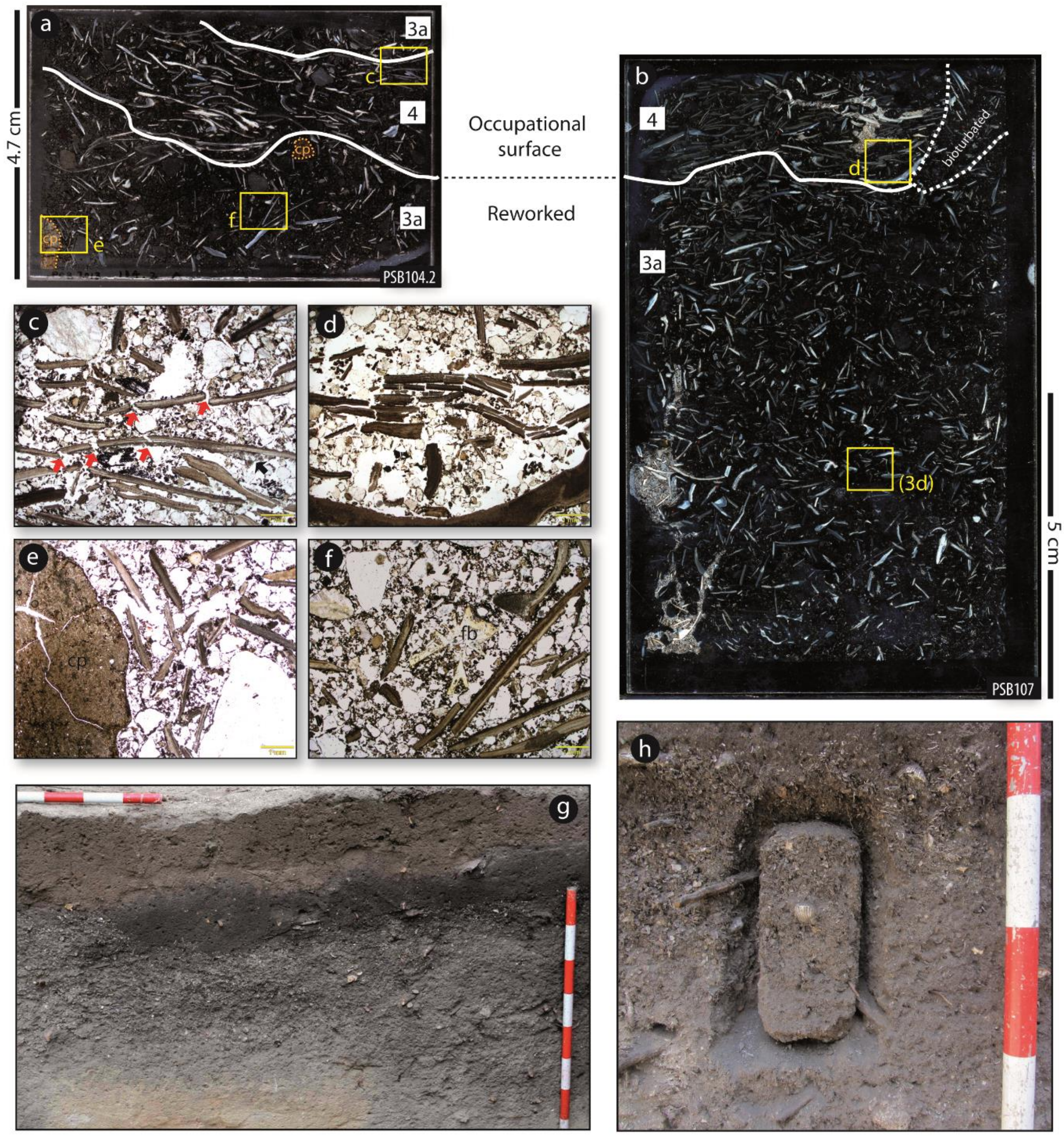



**Figure 9. 3** Superposition of microfacies of anthropogenic sediments; mF 4, *horizontally oriented shells*, overlying mF 3a, *coarse heterogeneous*. a) Dark field scan of thin section PSB104.2, with mF contacts marked (white lines); note the calcareous pebbles (cp) in mF 3a. The letters by the squares indicate the corresponding microphotograph below. b) Dark field scan of thin section PSB107, with mF contacts marked (white lines). The letters by the squares indicate the corresponding microphotograph below. c and d) Detail of horizontally oriented shells of mF 4; note in-situ cracking (red arrows), PPL, both scales: 1 mm. e) Detail of calcareous pebble; note the cracks, possibly due to exposition to heating, PPL, scale: 1mm. f) Detail of mf 3a, *coarse heterogeneous*; note the fish vertebra (fb), PPL, scale: 1mm. g) Aspect of the shell midden layer in Area 9 before the micromorphological sampling; note the homogeneity. h) Closer view of the same profile during collection of the sample PSB107; mf type 4 is not perceptible (compare with the resulting thin section above)

correspond, in thin section, to mF 2, *unsorted sand and polymorphic fine organic matter*. The sand grains in mF 2 are more poorly sorted than in underlying deposits, with higher abundance of coarse sand grains, especially when compared to the Pleistocene/Holocene sand cover. This suggests the onset of a different sediment source, which is somewhat difficult to identify. Elsewhere, Duarte et al. (2015) suggested that this phase represents a shift in the environmental conditions th at allowed the development of the palaeosol A1, which was inferred to represent more water availability from rainfall. The enrichment in polymorphic fine organic matter and the spongy microstructure are the key elements indicating that this deposit corresponded to a vegetated surficial soil. Polymorphic fom has been commonly found in spodic horizons (Buurman and Jongmans, 2005) (podzols have been reported in the area by Arnaud, 2000) but also in well-aerated, sandy soils. Curiously, it occurs in Brazilian "shellmounds with a sandy core" described by Villagran (2014b), although, here, polymorphic fom is related to anthropogenic inputs of organic carbon. In Poças de São Bento there is no clear indicator that this amount of organic matter could be anthropogenically introduced, given the general lack of anthropogenic structures in this layer. The action of microbial and mesofaunal transformation of plant material into degraded and more or less welded organic aggregates of polymorphic fom takes place in the A-horizon of vegetated soils, which can occur with spongy microstructures (Wilson and Righi, 2010), as in the case of mF 2.

The striking black colour of these sediments in the field (Fig. 9.2: b, c) is due to organic matter, and its maximum thickness (c. 40 cm), suggests that this soil was exposed for a considerably long time (e.g., centuries), which led to the development of a thick vegetation cover. Furthermore, the fifth millennium cal BC radiocarbon dates obtained for samples of total organic matter from palaeosol A1 at the top of this layer in Area 6 (see Table 9.1) are consistent with the archaeological content of this layer, including sparse pottery sherds. However, the nature of the Neolithic presence at Poças de São Bento (as in other shell midden sites of the Sado valley) remains an open question.

The palaeosol formation processes triggered some postdepositional alterations observed in the studied sediments. Soils are the dynamic product of chemical and physical weathering, and biological processes. Of particular interest at Poças de São Bento is the loss of material during periods of hydrologically effective precipitation, which leads to calcite dissolution and reprecipitation lower in the soil profile (Fairchild and Baker, 2012). The soil microbial community, inferred from the studied sediments, is a source of soil $CO_2$, along with root respiration (Witkamp and Frank, 1969); this $CO_2$ generates the soil water acidity that enhances

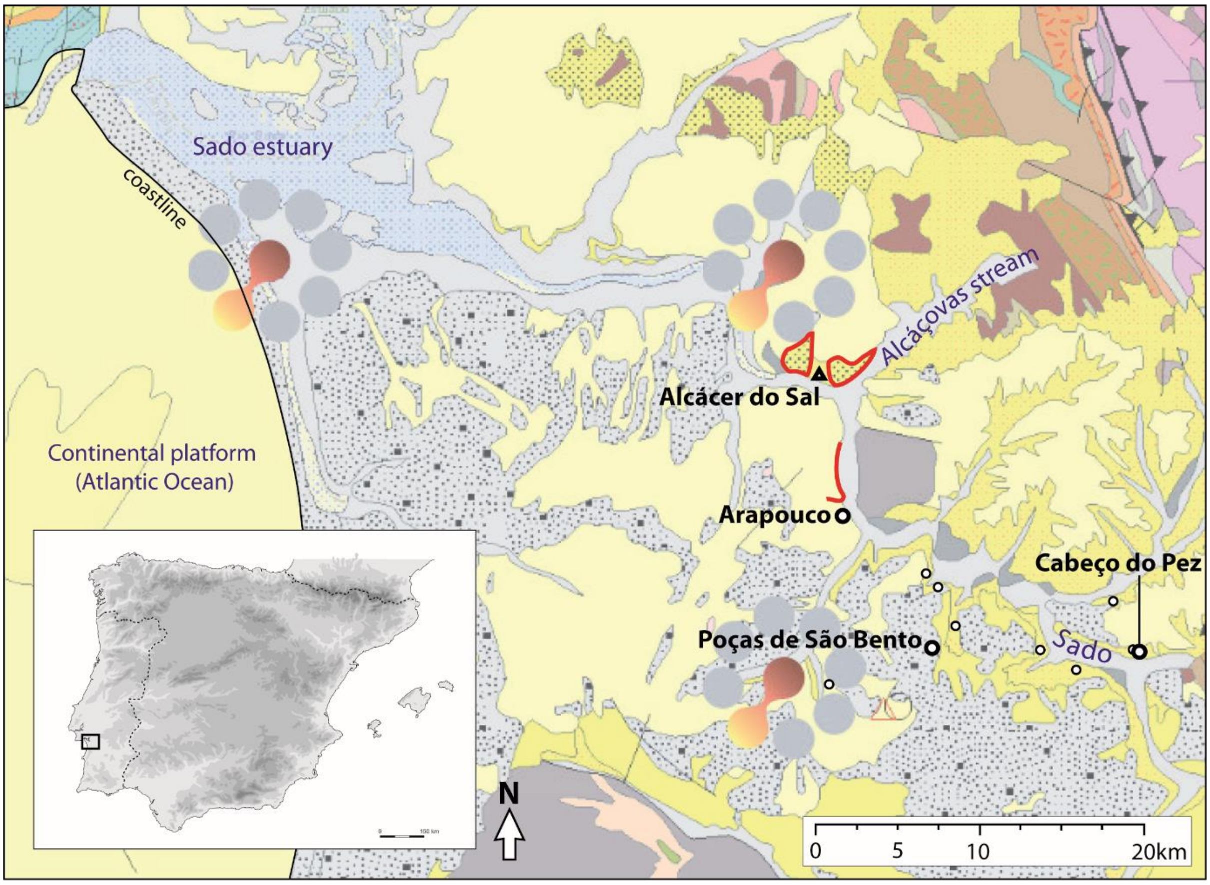



**Figure 9. 4** Geologic map of the Sado shell middens area, with location of the town of Alcácer do Sal, Poças de São Bento, Arapouco, Cabeço do Pez and the other known shell midden sites (white dots). Note the outcrops with calcareous rocks mentioned in the geological cartography delimitated in red. Note the present day estuary. Geologic map source: Laboratório Nacional de Engenharia e Geologia, Carta geológica de Portugal 1:500 000, version available online.

hydrolysis reactions, and the dissolution of carbonate clasts (shells). In our case, chemical weathering of Mesolithic sediments is evident by the hydrolysis of feldspars and their alteration to sericite (the main alteration mineral for feldspars and petrographically recognisable by small equidimensional crystal masses of grey to black interference colour replacing the feldspar crystal) and the partial dissolution of shell fragments in mF type 2a, the most surficial shell-rich sediments. The reprecipitation of these carbonates, lower in the soil profile, generates the pendants and the cemented areas in mF types 3, 6 and 7 (Fig. 9.6: c, e and 9.8).

### 9.4.4 Spatial organisation

The human activities inferred from the micromorphological observation of anthropogenic sediments at Poças de São Bento revealed a clear intra-site differential use of space.

In Area 1, the shell midden layers revealed an occupational surface with signs of intense trampling, overlying a dumping of reworked activity debris, suggesting that this area was intensively occupied. Furthermore, in Area 1, the shell midden layer filled a pit excavated in the sand cover (Fig. 9.2b), a type of feature normally associated with residential purposes. In the future, micromorphological analysis of this pit infill (shell-rich sediments macroscopically homogeneous and similar to the shell midden layer itself) can potentially provide more detailed data on this aspect. The shell midden layer in Area 1 also contained the dog burial, evidence of more symbolic behaviour, in an area of the site that was occupied intensively.

The overlapping of different types of anthropogenic deposits in Area 9 suggests that this location corresponded to a preferential area of refuse of food items (shells and fish). Several superimposed single tossing events, intercalated with at least one sediment dumping event, can be clearly distinguished in thin section (Fig. 9.2b and 9.11), suggesting that this specific location was used mainly for that effect. Little trampling and rapid burial indicators, seem to suggest that Area 9 was immediately adjacent to a location where food consumption activities, and subsequent tossing of the resulting debris repeatedly took place. This inference is interesting at the level of site-scale interpretations, given the proximity of Area 9 to the funerary area at Poças de São Bento.

### 9.4.5 Living in the dunes: a seasonal or sedentary option?

Settlement models have been proposed (e.g. Marchand, 2001, Marchand, 2005) in the framework of the hunter-gatherer economy of the Mesolithic groups in the Sado valley. In general lines, the site has been regarded as a semi-sedentary base-camp, articulated with Cabeço do Pez (see Fig. 9.10) in seasonal cycles (Arnaud, 1989, 2000). These hypotheses are based on their larger size and the relative significance of lithic industries and faunal records at these sites in comparison with other sites in the Sado Valley. The identification of residential structures (e.g., post-holes and fireplaces), and ecological characteristics of the area,

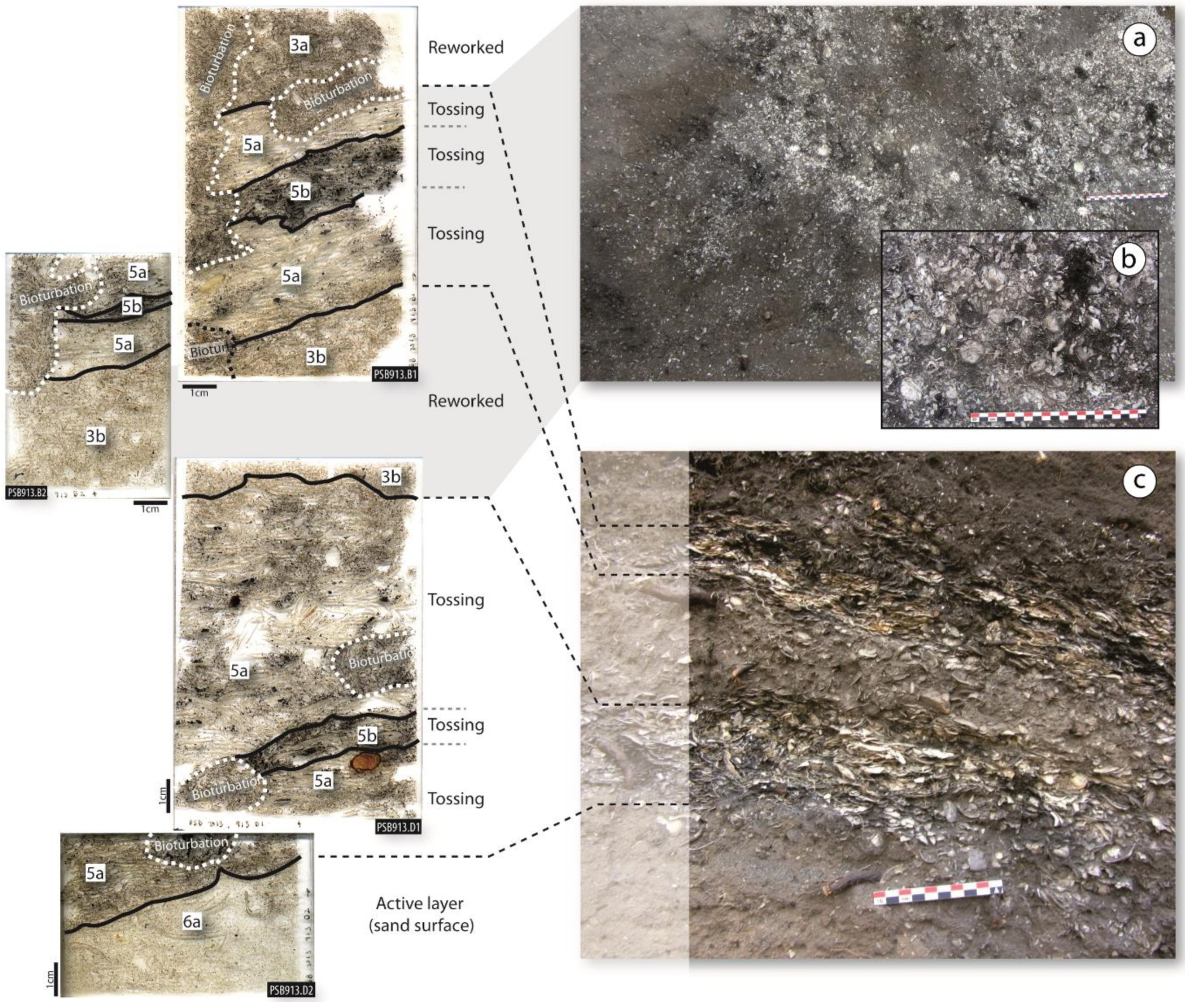



**Figure 9. 5** Hypothetical reconstruction of the events involved in the accumulation of the shell midden layers at Area 9, based on the four thin sections from sample PSB913, with indication of mF types limits and assigned activities at the right

particularly the existence of a freshwater source, were considered the mainstays supporting these hypotheses (Larsson, 1996, Arnaud, 2000).

The micromorphological analysis of the shell midden layers at Poças de São Bento can contribute to the temporal characterisation of, at least, the sampled contexts. The microstratigraphic record points to a rapid formation process characterised by quick and short events of anthropogenically deposited sediments. A possible exception is that of the few upper cm of mF type 6a, *silty sands with few shells*, at the base of the shell midden. This is the only microfacies where the presence of shells is not clearly intentional, but more likely explained by a non-intentional transport by humans (e.g., trampling).

Considering that aeolian processes might be active at the time of the shell midden formation and that there are topographically higher positions around the site, we can envision a very short time between each event in Area 9, at least, short enough to prevent natural wind-induced sedimentation to occur. The aforementioned indicators of rapid burial of mF type 5, *shell-supported sediments*, also point to this hypothesis. For these reasons, we argue for an accumulation of the vertical sequence in Area 9 during the same period of occupation, rather than the result of events belonging to occupations separated by large periods of total abandonment of the site.

Concerning Area 1, microfacies analysis also provided evidence of superimposed anthropogenic deposits. A deposit resulting from anthropogenic reworking was overlaid by an occupational surface affected by intense trampling. That surface was later covered by a new load of reworked debris, of short enough duration to prevent natural sedimentation occurring. For the same reason as for Area 9, we think that these events took place during the same 'occupation'. At Cabeço da Amoreira, thin lenses of crudely bedded silt to fine sand were sometimes found overlying occupational surfaces, and then a new dumping event covered the lenses. This was used by the authors to argue for a temporary abandonment of, at least, that area of the site (Aldeias and Bicho, 2016), which cannot be stated for the current sedimentary record of Poças de São Bento.

Overall, there are not enough data to distinguish sedimentologically different occupations in the vertical stratification at Poças de São Bento during the Mesolithic. One possible way to solve this question would be through isotopic analysis of the shells in order to establish seasonality patterns integrated with the microstratigraphic evidence for different episodes of shell accumulation while sampling.

## 9.5 Conclusion

The present study provided significant results for research on Mesolithic societies at Poças de São Bento, particularly regarding interpretation of the archaeological record. Concerning site-specific research questions, one of the most interesting outcomes of the micromorphological approach is that there *was* intentional superposition of shell-rich sediments, and not only lateral juxtaposition of anthropogenic deposits, as systematically assumed in previous studies on the Sado shell middens. Our approach revealed the distinction between dumped sediments and occupational surfaces within the shell midden layer at Area 1. This layer is actually macroscopically equivalent to most of the shell-rich deposits in all the excavated areas at the site, and very often the only one. Our analysis suggests a full internal dynamic in the formation of this apparently homogeneous shell midden layer. This evidence points to the need for further micromorphological approaches in similar deposits in other areas of the site, especially the pit infillings, in order to track the areas and activities complementary to those inferred microscopically.

At a broader, Sado valley scale, the remarkable occurrence of elements such as clay aggregates and foraminifera in anthropogenically reworked sediments, most probably indicate transport of marshland components directly from the gathering place to the site, as a consequence of shellfish gathering techniques. Calcareous pebbles in the same sediments, when related to the regional geology, provide sedimentological evidence suggesting that the shellfish gathering was not carried out in the vicinity of the site, but ~8-12 km downstream, where outcrops of Miocene formations with carbonates occur by the river. These aspects have major implications regarding future studies of logistical movements of the Mesolithic hunter-gatherers in the valley, and also the pending question of the extension of the palaeo-estuary during that period.

From macroscopically visible stratified accumulations, such as at Area 9, we were able to recognise human actions such as preferential discard of debris, single tossing events, and dumping of intentionally reworked sediments. The results show a lack of evidence of abandonment periods inside these deposits. This is an open question that could be investigated in the future. Particularly interesting for this issue are seasonality studies through isotopic analysis of the shells, based on the microstratigraphy of the different human-induced sedimentary events in order to prevent inadvertent mixing of materials from different events in the sampling of archaeological materials.

Tossing of debris, sediment dumping and spreading out, trampling, and preferential refuse areas, are some of the activities, inferred from the microstratigraphic record that Poças de São Bento has in common with Cabeço da Amoreira. These similarities appear to be revealing the same anthropogenic patterns in the activities involved in the formation of both sites. These observations open new research possibilities for other similar contexts regarding more general behavioural dynamics. The study of shell midden formation processes, through microcontextual approaches, has played a major role in our knowledge of Mesolithic societies at the two largest early Holocene estuarine ecological settings of the central/south Portuguese coast.

PART III

# DISCUSSION

Chapter 10

# Shell Midden Microfacies as Archives of Human Behaviour

The two sites studied in this dissertation that allow for more comprehensive microfacies approach regarding shell-matrix sediments are El Mazo and Poças de São Bento. At both sites, equivalent actions were identified due to similar aspects of sedimentary fabric recognizable at microscale. However, the extraordinarily different sedimentological environments of the Sado valley and the Cantabrian region (chapter 2) influences this pattern from the matrix type to the shell species. From the monographic sections it was possible to demonstrate how sometimes, due to geologic variety, similar activities have different expressions, like trampling, and, on the other way around, how similar features in thin section reflect different processes, like in-situ cracking motivated by surface pressure or climatic reasons.

In the next lines these aspects will be addressed to search for holistic interpretative characteristics in the studied shell middens, entailing a comparison with micromorphological data available from further shell-matrix sites, that comes essentially from Portugal, Tierra del Fuego (Argentina) and Santa Catarina (Brazil) (Aldeias and Bicho, 2016, Villagran et al., 2011b, Villagran, 2014b, Villagran et al., 2009, Balbo et al., 2010).

## 10.1 Shell midden construction

In the studied sites, the human activities involved in the accretion of shell-rich deposits through sedimentary microfacies analysis can be divided in three groups: shell-rich sediments in primary position, redeposited shell-rich sediments and occupational surfaces, that will be addressed separately.

### 10.1.1 Deposits in primary position and the significance of single tossing events.

The definition of “primary” in these deposits refers to the deposit itself, and not to the individual shells, since it is not certain that each shell is in the original position immediately after its first discarding. In other words, not all shells of a deposit necessarily went through the exact same pre-depositional history. Villagrán (2018) documented cases in which the distinction between deposits entirely primary and deposits mixing materials from different events was possible through micromorphological analysis. The action possible to infer from these deposits is the direct tossing, either through bucket loads of discarded shellfish (which is the most likely tossing modality for mixed components) or tossing of individual shells repeatedly in a same location during a single activity (e.g, while the shellfish is being consumed and immediately discarded). But overall, as tossed deposit and as an intentional anthropogenic accumulation, these deposits are in primary position in terms of shell midden growth.

Based on the studied sites, the general characteristics that allow to infer that this deposits are in primary position are: 1) large predominance of shells over matrix, since humans are the only agent that can cause it at the sites’ locations; 2) the shells are interconnected, preferably sub-horizontally oriented, which appears to be the most natural arrangement in its last moment of deposition if not containing a supporting matrix and 3) the shells are mostly complete (even if crushed *in situ*, as commonly reported, see Aldeias and Bicho, 2016, Villagran, 2014b, and this work, chapter 9), indicating little disturbance and a discarding shortly after its consumption.

In the case of the sample PSB913, where the only deposits in primary position were documented in Poças de São Bento (Area 9), elements such as the preservation of fishbones very close to each other (plate 7.1: d, k) suggest an at least partially articulated fish skeleton was tossed alongside the shells. These instantaneous frames allow to directly associate the items to the last action before its discarding and are exclusive of this type of deposits. In the same deposits of PSB913, the alternation of lenses of clean shells and shells and charcoal point to specific events in which such components were added to the action that directly formed the deposit. This reveals a certain dynamism in the formation of the deposit, instead of a single basket load of mixed materials being the cause of the deposit as a whole (plate 7.1). Shell-rich deposits in primary position seem to have a consistent characteristic: they are usually composed by a single shell species, as far as it is possible to infer from thin section. At Poças de São

Bento the species is the clamshell *Scrobicularia plana* and at El Mazo they are accumulations of *Patella* sp. (limpets) and echinoids, separately.

The primary deposits described in thin sections from Cabeço da Amoreira, in Muge (within the broad regional vicinity of the Sado valley) are like those in PSB913 concerning the composition (interconnected *S. plana* shells, interstitial quartz sand and rarer clay aggregates), but differs in the relevant aspect that they are homogenously burnt (Aldeias and Bicho, 2016: fig. 3a, 4). The shells in PSB913 do not seem to be burned, even those in the charcoal lenses, as suggested by their optical characteristics (plate 7.1: a, b, i). This does not mean they were not cooked, because, as said before, the necessary temperature to roast shellfish is below the aragonite-calcite transformation threshold (Villagran, 2014a, Aldeias et al., 2016). This rather means that probably the shells in PSB913 primary deposits were not repeatedly or intensely heated, while those in Cabeço da Amoreira were. The characteristics of the tossing events at Poças de São Bento, corresponding to mF type 5, show many similarities with the deposit corresponding to the homologous mF type 3 described at Tunel VII, an ethnohistoric shell midden in Tierra del Fuego (Argentina), including sub-horizontal orientation and areas where charcoal is also very common (Villagran et al., 2011b: figures 7 and 8). Balbo et al. (2010) and Villagran et al. (2011b) argue that the low fragmentation and subhorizontal distribution indicated the discarding of food items outside of the living space of the hut, observations that they contrasted with ethnographic sources referring to the *Yamana* communities that built the site (Villagran, 2018). For these reasons, adding the low compaction degree, it is considered that the primary deposits of from tossing event represented at PSB913 correspond to peripheral areas in terms of living spaces, rather than central domestic areas.

Further formal micromorphological characteristics of the microfacies corresponding to tossing event in both shell midden and monumental shellmounds in South America are an inter-grain microaggregate microstructure, enaulic c/f related distribution, high c:f ratios (70/30 or more) and sub-horizontal distribution of complete and fragmented shells (Villagran, 2014b). These characteristics can also be applied to the primary deposits of this thesis, reinforcing the unitarian character of this type of microfacies world-wide, as advanced by Villagrán (2018).

The stratigraphically older primary deposit at El Mazo (mF 4) has some original characteristics regarding the rest of tossing events in this thesis, namely the fact that it is a discrete lens (c. 1 cm thick) and the fact that it mixes burned and unburnt shells. The latter aspect reveals pre-depositional more complex history of individual components of the layer, suggesting that it mixes components from different actions. Tossing events in Brazilian shellmounds were exclusively documented at the site of Carniça-3, corresponding to mF type F, which is composed of shells of a single species (*Anomalocardia brasiliana*), few of each (3%) were heated at low temperatures (Villagran, 2018). However, mF type F is associated with combustion residues that were tossed alongside shells at the top of this shellmound with a constructed sandy core (Villagran, 2014b). In the case of El Mazo mF 4, besides the burning of some shells, also interstitial fibrous plant material is charred, and this is related with the fireplace that was made on top of the layer (section 7.4.2). Probably the homogenously burnt character of the shells at the tossing events of Cabeço da Amoreira must be reflecting some post-depositionally induced heating action as well.

The other deposit in primary position at El Mazo is composed largely by echinoids spines and tests, unburnt, but other components such as bones and gastropods are present, and it is a thick (10-15 cm) deposit, fitting in the general trend seen in other microfacies of this thesis sites and South-American ones, with the originality of the echinoids as predominating species. However, it is the only deposit with this characteristic along El Mazo intricate stratigraphy, which is interesting because it is telling us that direct tossing, the most basic action in shell midden accretion (Villagran, 2018), was not the main one in the accumulation of El Mazo shell midden. But what can we infer from these species-specific tossing events in terms of behaviour?

If one regards shells in the archaeological record from an exclusive subsistence perspective, and to shell middens as mere food waste mounds, a hypothesis for species-selection of tossing events could be that the events took place right after the consumption of specialized meals, i.e., one meal of limpets and another of echinoids. This inference would indicate that human groups visited the rockshelter for specialised meals, or that they were selective at the time of basket-tossing their waste.

But conceptualize shell midden stratigraphy from a broader perspective also implies the acknowledgment of use of shells for other purposes, such as tools and adornments. This aspect has been ignored until recently because it is not in the visible archaeological record (except for perforated shells), but now is well-documented in the archaeological research thanks to experimental and microscopic use-wear analysis, with incidence in the Cantabrian Region and Atlantic Europe (Cuenca-Solana, 2014, Cuenca Solana, 2013). According to this perspective, an alternative hypothesis is that these tossed materials are selected because they proceed from activities related to making tools or prepare shells for some function (e.g. adornments) to which a specific species are preferred or more suitable then others. Limpets were particularly suited to use as tools, namely, to work plant fibres (Cuenca Solana, 2013). Indeed, the few interstitial materials between the limpets of mF 4 are charred fibrous plant material. Regarding echinoids, its chests are still today very appreciated as adornments thanks to its ornamental morphologies. Use-wear analysis of limpets from the deposit corresponding to this mF would corroborate or not this hypothesis.

These aspects allow to suggest that these tossing events of selected species without sedimentary matrix can be better explained as resulting from discard of shells in the context of their use as tools or object making. Once the shells were selected and prepared, the remaining specimens were tossed. This possible micromorphological evidence provides context to what has been until recently an unknown, though important activity of the Mesolithic groups, the use of shell as tools, and that the preparation of those tools potentially was carried out in shell middens and contributed to shell midden formation.

The preservation of deposits of direct tossing events should imply that the area was rapidly buried, otherwise, if exposed for long enough, these deposits would tend to be reworked or eroded in the framework of shell midden redeposition of sediments or natural alterations (see below).

For these reasons, i.e., deposition directly related to a single moment and action, and possibly quick burying, these deposits are the most reliable for other studies regarding the artefacts they contain, isotopic studies based on shells and radiocarbon dating. These deposits constitute the finest record of archaeological formation processes intra-site occupation dynamics, and such analysis should be targeted to them. As advanced by Villagran (2018), and as illustrated by the primary deposits at Poças de São Bento and El Mazo, micromorphological analysis demonstrated that tossing events might reflect much more than mere shellfish discard after consumption, but when they do reflect *only* that, they constitute sealed time capsules, being the most reliable in terms of behavioural interpretations and multi-disciplinary analysis, therefore, an extra effort to physically individualising them in the field must be encouraged, with careful excavation techniques.

### 10.1.2 Redeposition of shell-rich sediments. How reworked is reworking?

Redeposited shell-rich sediments constitute most of the sediments in all the studied sites. This observation by itself already reveals that intentional accumulation of previously discarded shell-rich sediments is a major activity in shell midden accretion. But what is behind the action of taking already discarded debris and spread it around? The implications of this for dating and sclerochronology analysis interpretation are critical, therefore, it is important to know as detailed as possible the degree of reworking of these deposits.

The general characteristics of these deposits in the sites studied in this thesis are: 1) shells are fragmented and chaotically oriented, 2) presence of sedimentary matrix supporting shells and further coarse components, with heterogenous composition, 3) lack of sedimentary structures, and 4) presence of exogenous fine and coarse components besides shells that can only be explained as an anthropogenic input.

The actions that were possible to infer from the studied contexts were dumping of sediment loads away from the previous location, or less drastic sediment dispersion by sweeping or rake-out. Villagran (2018) recognised another action that forms deposits with very similar characteristics, that is the reorganisation of domestic debris due to continuous frequentation activities. This would be also a form of reworking of previously discarded items at minimal distance from the original deposit, thus is considered here under the same category, since it does not correspond to an undisturbed primary deposit.

Sediment dumping is perhaps the most commonly inferred formation process in Mesolithic shell middens in Iberia according to publications and reports and is directly related with the origin of the term "shell midden" and the interpretation of these deposits as waste refuse (Straus, 1991, Arnaud, 1987, Arnaud, 2000, Arnaud, 1989, Soares, 1996, Soares, 2013, Dupont and Araújo, 2010, Araújo, 2011, Valente et al., 2014). The successive accretion of dumped sediments might result in a homogenous deposit from which is impossible to distinguish the individual events, one of the biggest challenges in excavating and interpreting shell middens (Gutiérrez-Zugasti et al., 2011, Aldeias and Bicho, 2016). But as it was demonstrated, with micromorphology it is possible to differentiate such events by the identification of microscopic components, used to discriminate different deposits.

The micromorphological study of Poças de São Bento allowed to advance that most of shell-rich accumulation at the site correspond to redeposited sediments, based on the result from thin sections of Area 1. In Area 1, the only shell-rich layer is macroscopically equivalent to the laterally dispersed accumulations that also constitute the only shell-rich layer identified in most excavation areas at the site, with few exceptions such as the tossing events of Area 9. This reveals in turn that the site was mostly constructed by spreading of redeposited sediments throughout the occupied area, instead of primary deposits resulting from direct tossing. The reworked sediments correspond to mF type 3 at Poças de São Bento are divided in two mF sub-types, 3a and 3b, having the latter being identified only in Area 9 and object of discussion in a following section. Microfacies sub-type 3a is rich in organic coarse and fine components such as fishbone, charcoal and micro-charcoal (fig. 7.4: c, e, f, g). Coarse clastic components such as heated exogenous pebbles and other local lithologies are present, along fine components such as phytoliths and foraminifera. This set of components and its chaotic organisation overall matches the homologous deposits in Cabeço da Amoreira, and indicates intense reworking and remobilisation of domestic debris, including exogenous components derived from shellfish gathering (Aldeias and Bicho, 2016; this work, chapter 9).

In sample PSB108, entirely composed of mF type 3a, (with some domains of mF type 7, cemented by secondary calcite), collected from an adjacent area to the vertical sampling column of Area 1, revealed to be particularly rich in fungi, including charred fungal sclerotia, phytoliths and microcharcoal (fig. 7.4: c, d, e). This enrichment, not observed in the samples from the vertical column, could be revealing a separate accumulation event, related to the processing and burning of plants and fungi, as result of a possible exploitation of these resources, as suggested by the archaeobotanical study of the site (López-Dóriga, 2016). This localised enrichment in the area where sample PSB108 was collected certainly reveals differences within the homogenous shell midden layer, possibly corresponding to different accumulation events. The macroscopic limits between those are not possible to observe in the profile and are extremely difficult to track during excavation, but a more detailed sampling and more fine excavation methods would perhaps help in refine the identification of such events.

In this aspect, El Mazo anthropogenically redeposited sediments closely resemble the homologous microfacies described in Brazilian shellmounds, namely mF type A (Villagrán, 2018). However, the symbolic reasons for the accumulation of these deposits in the coast of Brazil, leading to massive reallocation of shell middens that, in turn, explains the absence of domestic areas in those sites (Villagran, 2014b, Villagran, 2018) seems farfetched to apply in El Mazo and the rest of Asturian sites. The anthropogenically redeposited sediments at El Mazo are invariably more or less rich in combustion residues, namely ash and shells heated at high temperatures, which implies that combustion features are one of the sediment sources of these deposits and part of their pre-depositional history. Some mF at El Mazo, e.g., 2, 11, 14, might even correspond exclusively to hearth dumps as defined by Mentzer (2014) and corresponding to mF type B in the Brazilian shellmounds (Villagran, 2018).

At Cabeço da Amoreira mF type 4 was distinguished by the great amounts of organic micromass and interpreted as food processing debris partially reworked for little distance from the activity area (Aldeias and Bicho, 2016). A similar interpretation was proposed in this work regarding highly organic deposits in younger layers of El Mazo corresponding to mF 19a and 22, possibly due to inherent dispersion of sedimentary components while processing organic materials, presumably fish, shellfish, plants, and seaweeds in a nearby location.

In formal terms, mF type 6 described at the domestic Fuegian shell midden of Tunel VII (Villagrán, 2018) shares a lot of characteristics with mF type 3 of Poças de São Bento (e.g., random distribution of matrix-supported burnt and unburnt components (shells and bone), charcoal and pebbles). But from the interpretative point of view, the mF type 6 of Tunel VII differs slightly from that proposed for the Mesolithic site. Microfacies type 6 of Tunel VII is not clearly interpreted as redeposited sediments, but as phases of frequentation and site maintenance activities that promotes reorganisation of components in the shell ring surrounding the central hut (Balbo et al, 2010; Villagrán, 2018). Acknowledging such interpretative difference, Villagrán (2018) proposes a correspondence between the mF type 3 of Poças de São Bento and mF type 2 at Cabeço da Amoreira with mF type 6 of Tunel VII, which establishes a conumdrum, since the mF type 3 at Poças de São Bento is formally composed of reworked debris components.

Probably the solution relies in the diversification of experimental and micromorphological work in shell-rich deposits to refine the concept of redeposition and reorganisation/frequentation. We may well be all talking about the same thing. When Aldeias and Bicho (2016:543) interpret mF type 4 of Cabeço da Amoreira as “partially reworked sediments” not far from the activity area, probably mean something very close to what Villagran (2018) calls frequentation phase and Balbo et al. (2010) reorganisation caused by site maintenance activities. In this direction point the fact that bot mF types present high amounts of organic matter. Villagran’s (2018) interpretation of mF type 6 at Tunel VII implies some level of reworking by the incorporation of burnt components from the hearths in central hut to the peripheral shell ring. In what concerns to this thesis’ sites, it is possible that the above-mentioned case of sample PSB108, where mF type 3a is particularly rich in fine organics, charred fungi and phytoliths, is perhaps a good candidate to correspond to Tunel VII frequentation phases, along with the highly organic mFs 19a and 22 from El Mazo, that are interpreted as little reworking derived from processing of organic materials. Concerning Cabeço da Amoreira, instead of mF type 2, as pointed out by Villagrán (2018), I suggest that mF type 4 corresponds more closely to the interpretation of Tunel VII mF type 6, relying in the high amounts of organic micromass. In respect to mF types 3 of Poças de São Bento (except maybe in the sample PSB108, as said before) and mF type 2 of Cabeço da Amoreira, I argue for a higher degree of reworking, resulting from intentional dumping of reworked debris, alleging as reason for it the absence of organic micromass in abundance.

All these aspects remark the need for further analysis on more shell midden layers that seem homogenous macroscopically, in order to refine the degree of reworking and eventually determine if a deposit is intentionally redeposited and composed of formerly discarded waste or if it derives of casual dispersion and reorganisation due to domestic activities nearby. It is highly probable that organic fines, and certainly integration of recent advances in organic chemistry and petrology (Ligouis et al., 2005, Villagran et al., 2018, Goldberg et al., 2009), play an important role in the solution of this conundrum.

Analysis and dating of materials from these deposits must take into account that they might be mixing materials from different occupational events, thus are less appropriate for high-resolution reconstruction of site diachronic patterns and chronology, hence the importance of knowing the formation process in depth. The micromorphological analysis allows to address the action and degree of reworking. Rake-out and sweeping seem to produce different signatures of dumped sediments, and furthermore, it was possible to infer if the sediments were redeposited close to occupation activity area or further away, which can be used to infer dynamic of site occupation and correlate radiocarbon dating. Considering the potential of micromorphology to determinate the degree of reworking, of course less reworked sediments are the most reliable to interpretation of multi-disciplinary analysis. Redeposited sediments in shell midden can result from a wide variety of circumstances and must be addressed one by one.

### 10.1.3 Occupation surfaces

The main evidence in the field for occupation surfaces in the Mesolithic shell middens of the Sado valley and Cantabrian region are combustion features and negative features like pits and post-holes (Arnaud, 2000, Arnaud, 1989, Bicho et al., 2013, Arias et al., 2015b, Arias et al., 2015a) or evidence from spatial distribution of artefacts at a same level (Gutiérrez Zugasti and Gozález Morles, 2010, Gonzalez Morales and Marquez Uria, 1978). In thin section, one of the ways to document a surface that was intensely occupied is structural compaction of the immediate sub-surface and evidence of repeated trampling (Rentzel et al., 2017, Karkanas, 2006, Miller et al., 2010).

In the studied sites, signatures of compaction overprint several types of sedimentary fabrics. In shell-rich sediments, the most characteristics diagnostic feature is the in-situ crushing of components, mainly shells, but also bones and fishbones are affected, that consists in vertical cracks and, depending on the shells/matrix ratio, a high degree of interconnection between shells. These features are clearly observed in the mF type 4 of Poças de São Bento, where the shell fragments are organised in crushed stringers, and apparently burned. At Poças de São Bento, this mF is 2 cm thick at most in thin section and was identified in two thin sections that are levelled and c. 1 m laterally distant in the stratigraphic North profile of Area 1, which gives it consistency as a continuous surface. However, the shells are still supported by the same sandy matrix of the under- and overlying layers of redeposited sediments, making it impossible to identify with regular excavation methods, but readily observed in the two-dimensional geometric arrangement of the components in thin section at meso-scale (plate 7.3: a, b), corroborated by microscopic evidence of intense crushing from surface pressure (plate 7.3: c, d). The implications for a site like Poças de São Bento are critical, and probably one of the most relevant contributions of micromorphology at the site: the shell midden that is composed by a widespread single homogenous and discontinuous layer through the site, developed not only by inferred lateral accretion of shell-rich sediments, but also by vertical superposition of intentionally redeposited sediments, separated by an occupational surface. Therefore, the apparently single layer represents more than one moment of occupation also vertically. Aldeias and Bicho (2016) observed the same association of microfacies (i.e. redeposited sediments overlaid by occupation surfaces) in Cabeço da Amoreira and advanced an interpretation for the reallocation of shells and other debris previously discarded as an attempt of flattening out the area or prepare new occupation surfaces. This hypothesis seems to be applicable to Poças de São Bento to explain the widespread action of redeposition of previously discarded debris, certainly combined with less reworked events that a more exhaustive micromorphological sampling should reveal. This hypothesis has implicit a significant behavioural aspect: the redefinition of waste, adopting Villagran (Villagran, 2014b) words, only perhaps not motivated by symbolic means as in the Brazilian monumental shellmounds, but as a resource for site maintenance, perhaps between different periods of occupation.

In Túnel VII, Balbo et al. (2010) described compaction/surface pressure based on the above-mentioned criteria, which Villagran (Villagran et al., 2011b) showed to be consistently associated to deposits resulting from direct tossing of shells and not to redeposited sediments, that is interpreted as intense trampling over the tossed material motivated by the domestic character of the site. One of the shell mounds in Brazil, Jabuticabeira-1, yielded compaction surfaces associated to redeposited sediments for the construction of the monumental structure, also consisting in thin layers of closely-packed shells horizontally oriented, that Villagrán (2018) associates with circulation areas.

In Cabeço da Amoreira, the thin compacted layers have an extra component, an organic-rich micromass, that contrasts with the underlying reworked deposits (see Aldeias and Bicho, 2016: fig. 7 and 9), reinforcing the character of these surfaces as individual layers formed in association with incorporation of fine organic debris from domestic activities of a moment of occupation. This micromass distinction is not noted in the case of Poças de São Bento, but a potentially homologous factor occurs: the fact that most shells in the occupational layer are burnt, unlike the reworked deposit it overlies (plate 7.3: a, d).

At El Mazo, strict occupation surfaces were not documented based on the criteria described above. In-situ cracking of components at El Mazo occur in not compacted, non-anthropogenic deposits, excluding anthropogenically-induced pressure. One instance of trampling was inferred from a different microstructural pattern in mF 3a, that consist in a structural change within the same layer which fine matrix has a dense, spongy microstructure and in the upper millimetres, it changes to a micro-granular organisation of the micromass. This pattern is possible to observe in the fine-grained character of the matrix at El Mazo, by comparison mostly with experimental trampling tests and other fine-grained sedimentary contexts (Rentzel et al., 2017, Miller et al., 2010). At El Alloru, without being directly related with a shell midden context, trampling is inferred with based on other signatures that form part of wide debate in micromorphology (dusty clay coatings and surface slaking) but seem to be supported by the identification of post-holes at the site, indicating an area that must have been intensely occupied. Similarly, at La Fragua, the compaction of Unit 3, a layer of reworked carbonate mud, over which the combustion and middening activities were superimposed, seems to point to a first moment of re-occupation of the cave in the Mesolithic after a hiatus in human occupation since the final Pleistocene.

In sum, the potential to identify surfaces – repeatedly trampled or occupied – of micromorphological analysis of shell midden is enormous and enhances the hypothesis of reconstruction of the site dynamics and formation processes, apart from providing base of distinction between areas of intense frequency and others that were peripheral.

## 10.2 Shell middens and combustion features

As said previously in this work, combustion features, aside with shell middens, are major anthropogenically-formed deposits in the Iberian prehistoric Archaeology, hence their importance to geoarchaeology. Combustion features are much widely studied in terms of micromorphology than shell middens, thanks to exhaustive work in archaeological, experimental and ethnographic contexts (Wattez, 1988, Shahack-Gross and Ayalon, 2012, Courty et al., 2012, Foucher et al., 2000, Karkanas et al., 2015, Mallol et al., 2013a, Aldeias et al., 2012, Mallol et al., 2007, Mallol et al., 2013b), from several practical and theoretical points of view (Goldberg et al., 2017, Mentzer, 2014, Aldeias, 2017). These and other works have demonstrated the potential of micromorphology to study and interpret the microstratigraphic record of combustion features to reconstruct the human uses of fire and associated behaviours.

From the analysis of previous geoarchaeological studies in shell middens undertook in Chapter 2 it becomes evident that combustion features are systematically associated with shell middens, especially in the case of the Portuguese Mesolithic. The few geoarchaeological studies carried out in shell middens in previous works did not focus such structures, with exception of Santa Catalina, Basque Country (section 4.1.6), that were not object of a specific geoarchaeological study, but a rather formal, macroscopically detailed study (Berganza Gochi and Arribas Pastor, 2014). However, examples of combustion features associated with shell-rich contexts are found in Tunel VII (Villagran et al., 2011b).

Combustion features were micromorphologically documented in all four sites analysed in this work, despite in one of them, El Alloru, they had completely disappeared, being preserved only in reworked microcontexts. At El Mazo, new combustion features were identified in thin section, and the ubiquity of combustion residues as sedimentary matrix reveals that most of the redeposited layers have a pre-depositional history strongly influenced by combustion and potentially cleaning of original features. At La Fragua, microstratigraphic analysis of the in-situ, stacked combustion features allowed a detail reconstruction of the combustion activity and reuse of structures, as well as possible functions for some of them (e.g. site maintenance), apart from the important distinction between fuel layers and charred organic material in the combustion substrate not related to the same combustion.

The study of intact combustion features related with shell-rich sediments, mainly those from La Fragua, was crucial in terms of regional correlation. The fabric of the well-preserved combustion residues and combustion substrates at La Fragua strengthens the interpretations of similar fabrics in secondary position on the other two Cantabrian sites. The resemblance of the in-situ combustion residues from La Fragua with the infills of reworked shells at El Alloru cemented shell midden is notable (fig. 10.1) and allowed a straightforward interpretation of the latter. Combustion substrates at El Mazo are tricky to follow, but similar correlations with the characteristic of the well-preserved ones at La Fragua offer a good point of reference to their classification.

At El Mazo, the observed pattern of small shell fragments being almost always burnt and calcined while complete shells were only burnt in specific contexts is highly informative in terms of formation processes and their relationship with combustion activities. Since most of the deposits of El Mazo contain a matrix rich in small burnt shell fragments, it means that those deposits are intensely reworked, incorporating components form several hearths located elsewhere in the rockshelter. This does not invalidate that at least four intact combustion features were documented in thin section. Two of them were evident in the field from the presence of microstratigraphic doublet of combustion residues layers overlying a combustion substrate (Mentzer, 2014, Mallol et al., 2017). The other two lack combustion substrates. Villagran (2018) refers that, according to experimental hearths, they do not necessarily undergo rubefaction, which is corroborated by the mF type 7 in Tunel VII, corresponding to Summer hearths (according to isotopic and zooarchaeological data) that lack rubified substrate, despite the occurrence of further consequences of fire, such as oxidised and fissured pebbles, burnt bone and coarse charcoal, but overall formed under low-moderate temperatures (200-500 ºC).

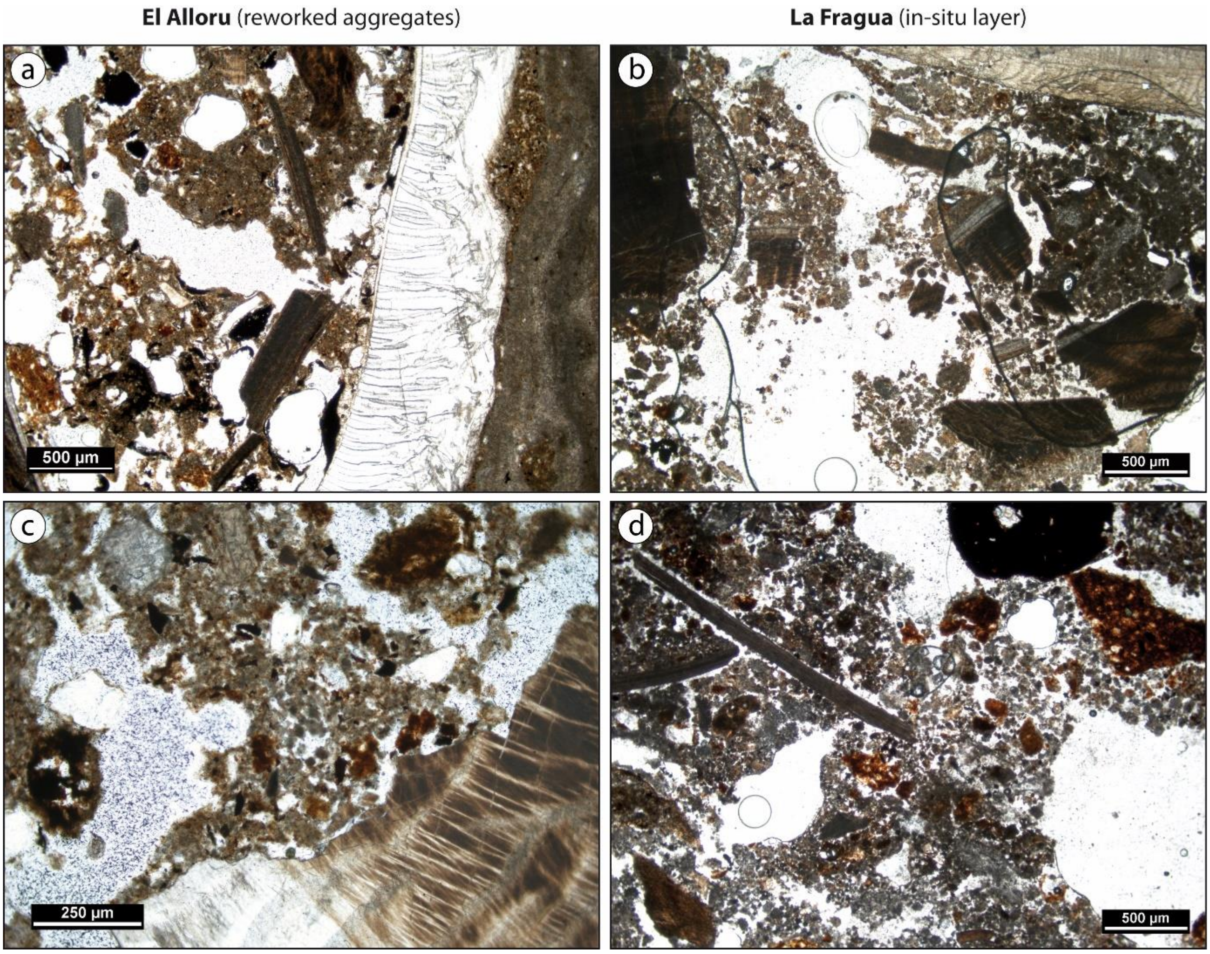



**Figure 10. 1** Combustion residues in secondary position; comparative examples from reworked aggregates at El Alloru and in-situ dumping layer at La Fragua: a) and b) ashy matrix with comminute burnt shell fragments; PPL; c) and d) ashy matrix rich in rubified grains; PPL

The data provided by Villagran (2018) reveals that mf type 7 of Tunel VII lacks ashes, the same being verified in general at Poças de São Bento, as well as in Cabeço da Amoreira (Aldeias and Bicho, 2016), and might lead the geoarcaheologist to wonder, what happen to them? Diagenesis could explain their absence from the record, an aspect that will be discussed in a later section. But this is also related with another challenge in shell midden archaeology: the most obvious function of combustion features in such sites – cooking shellfish – are not expectable to be preserved because the shells are removed to be consumed, leading to dispersion of further components like the wood charcoal resulting from combustion of the fuel.

I think the deposits of direct tossing in primary position documented in sample PSB913 from Area 9 in Poças de São Bento could have result from such event(s). The charcoal-rich lenses PSB913 (plate 7.1: a-d, i) were interpreted as not in-situ concerning the combustion feature where they were produced, because of the lack of both ashes and a direct association with combustion substrate. The charcoal lenses in PSB913 are thus considered as result of removal of the charcoal from a possibly nearby cooking feature, thus not representing the feature itself. The fact that the shells are not burnt, even those in the charcoal lenses, is perhaps because the same reason that Villagrán (2018) points out for the tossing-related mF type 3 at Tunel VII: “the method applied for opening the molluscs, which involved a short exposure to the embers and caused no thermal damage”.

Thus, mF type 5a (interconnected shells) and 5b (shells and charcoal) being intercalated in PSB913 seems to represent the action of opening shells using embers and immediately tossing them after consumption, as well as other item such as fish as suggested by the linearly packed fishbones in mF type 5a. The exact place of the heart should thus have been located very close to the tossing area, and both might actually merge in the broader contexts at field scale. It is the possibility of separating the lenses with micromorphology that allows further interpretations of these deposits at Poças de São Bento that are clearly related with combustion. The tossing contexts from Area 9 at Poças de São Bento might thus correspond to the closest as a combustion feature to cook shellfish can be preserved in the archaeological record, since such features are necessarily dismantled. On the other hand, this means that combustion features preserved intact in shell middens probably had other functions than cooking, reinforcing the habitation character in such cases, like El Mazo.

## 10.3 Shell middens, death and symbolism

As already mentioned, the association of shell midden and human burials is a key-aspect in the interpretation of these sites, but above all a crucial factor the understanding of the beginning and evolution of the ritual practices in Iberia (Arias and Alvarez-Fernandez, 2004). It has been pointed out that the Sado and Muge shell middens emergence is associated to burial grounds, as result of activities directly related with the funerary rituals (Peyroteo Stjerna, 2016). This seems to be corroborated by radiocarbon and stratigraphic evidence, considering that most burials are placed in the basal sands that constitute the natural substrate of both Sado and Muge shell middens.

Focusing on Poças de São Bento, as it can be seen in the site plan (fig. 10.2), the two studied Areas, 1 and 9, are 16 metres away from each other and micromorphology revealed different depositional narratives in each one. Area 1 is dominated by redeposited sediments, with an intensely trampled occupation surface mainly due to apparently different degrees of reworking of domestic debris, some of it intentional, and marked by compaction, suggesting more effective occupation (fig. 10.2b). In turn, Area 9, the accumulation of shell-rich deposits took place by the *in-situ* consumption and direct tossing of shellfish and fish (fig. 10.2c), and apparently was not as intensely frequented as Area 1, judging by the absence of deposits derived from occupation surfaces as seen in Area 1. It is dominated by single tossing events that show little compaction, intercalated by a sediment dump of quite clean (in terms of organic matter in comparison with those of Area 1) reworked shelly sediments (fig. 10.2: b, c).

The proximity of Area 9' tossing stratified deposits with the main burial ground of the site (fig. 10.2: d, e) could have relevant meaning. Accurate dating and study of the grave context could possibly corroborate one of the modalities of the funerary ritual in relation to site formation processes proposed by Peyroteo Stjerna (2016:475), according to which "Human and shell deposits were synchronous: the burial of the individual was followed by the deposit of heap(s) of shells freshly brought to the site. Shellfish was consumed in situ and deposited on top of the grave and/or at other areas of the site. In this case the shells are in primary position." The inference of the primary tossing of shells and charcoal immediately after consumption documented in Area 9, and the proximity to the burial ground (whereas in the rest of the site's area, these deposits were not identified), could hypothetically be linked to feasting behaviour of these groups related to the funerary practices. It is intriguing that both deposits of direct tossing are stratigraphically separated by redeposited sands and shells (mF type 3a), most likely anthropogenically dumped giving the lack of natural agents able to for such deposit. It can be interpreted as intentional burying of the "heaps of shells", over which a later episode of direct tossing took place. Unfortunately, the surface of the upper tossing deposit has been eroded, making it impossible to confirm if this was a repeated action with some ritualistic purpose.

Area 1 does not lack symbolic features though: less than one metre away from the micromorphological sampling column, a dog burial was documented, embedded in shelly sediments, macroscopically identical to those of mF type 3 (fig. 10.2: a, b), which corresponds to the only macroscopically homogenous shell midden layer of Area 1. In the same Area, as said before, a large pit structure was found filled with the same deposits, possibly associated to domestic functions. Peyroteo Stjerna (2016) admits other modality of depositional history of the funerary practices, according to which the shells deposits precede the human burial, and in

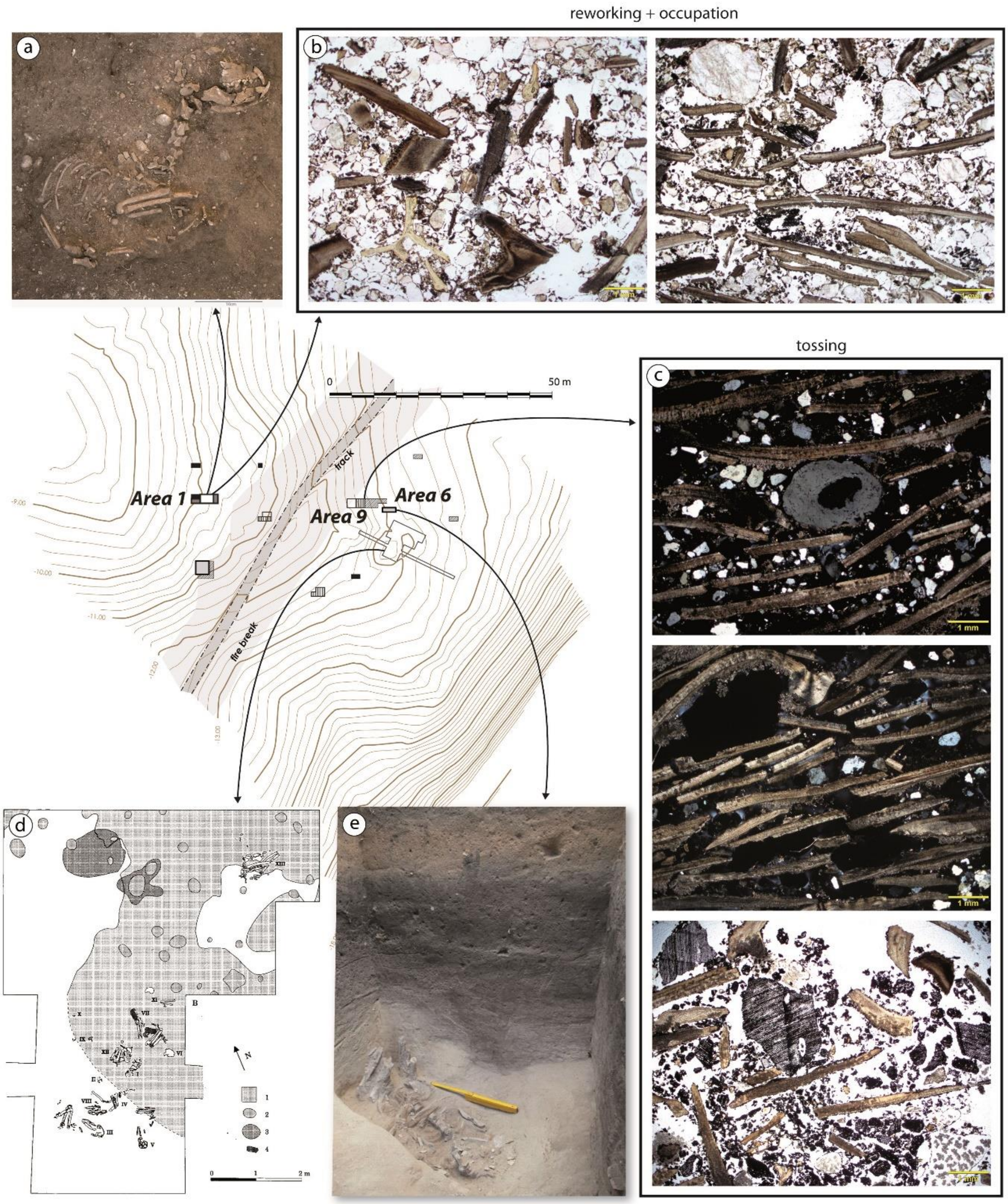



**Figure 10. 2** Schematic representation of spatial distribution of microfacies in association with symbolic features at Poças de São Bento: a) field photograph (by J. P. Ruas) of the dog burial found in Area 1; b) microphotographs of the main micromorphological features in Area 1, corresponding to anthropogenically reworked deposits and a trampled occupation surface; c) microphotographs of the main micromorphological features in Area 9, corresponding to superposition of direct tossing of shells in distinct events, hypothetically related to immediate discard of freshly roasted shellfish; d) field plan of the main burial area, after Larsson (1996); e) Aspect of the human burial found in Area 6 in 2013 by P. Arias and M. Diniz team; note the proximity of the burials to Area 9

this case the shells present in the interior or top of the grave were in secondary position. This case apparently matches the contextual evidence of the dog burial in Area 1, considering micromorphological data from the immediate surroundings, therefore, it appears that the dog was buried in a more intensely occupied area where domestic activities and more prolonged occupations were located.

The different meaning of the symbolic action of burying humans and the dog are attested not only by spatial differentiation, but also by the sedimentary record of formation processes in both areas. Further insights on these issues must be tested in the future, namely by the micromorphological study of burial contexts, in both Sado and Muge shell middens.

#### *10.3.1 To mound or not to mound?*

Mounds in Pre-History are often related with intentional monumentality and linked with symbolic behaviour and sense of community, and shell mounds are often included in this frame (Marquardt, 2010, Luby, 2004, Villagran, 2014b, Mehta and Chamberlain, 2018, Thompson et al., 2016, Gamble, 2017, Sherwood and Kidder, 2011). In the context of the Mesolithic of the early Holocene paleo-estuaries of central Portugal, the shell middens that emerged in the Sado valley and in the region of Muge in the beginning of the seventh millennium BC are primal examples of the coastal adaptations of the last hunter-gatherers, as stressed in a previous section of this work (chapter 2). Therefore, their anthropogenically-driven formation processes, if compared, constitute excellent archives of Mesolithic behaviour at regional level, as some previous works based on artefactual and paleoanthropological collections have demonstrated (Arnaud, 2000, Arnaud, 1989, Peyroteo Stjerna, 2016, Umbelino et al., 2015). Such works have also pointed out the most striking difference between both sites: the development of a vertical stratigraphy of the Muge shell middens, forming artificial mounds, over five metres high, prominent in the landscape, a phenomenon that is not observable in the Sado shell middens, which are unnoticeable in the local topography. The reasons for this dichotomy remain essentially unknown, and the key to understand it lies in the stratigraphic record and in the reconstruction of the formation processes, as stressed by Arnaud (1987).

Concerning shell-rich deposits accretion and shell-midden growth, one of the most interesting outcomes of the micromorphological analysis of Poças de São Bento (chapter 7), in the Sado valley, is the striking correspondence of microfacies with those previously documented in Cabeço da Amoreira, in Muge (Aldeias and Bicho, 2016), and, even more notably, the repetition at both sites of the microfacies association of occupational surfaces overlying anthropogenically redeposited sediments, that allowed to infer surface preparation. Based on the microfacies approach, carried out at both sites, renewed occupation over former occupation surfaces and alternated superposition of primary and redeposited sediments were documented.

The micromorphological data overall reinforce the resemblance in the formation processes at both sites instead of remarking any difference that explains the reason for the differential topographic expression. Therefore, the lack of development of Poças de São Bento shell midden in height does not seem to result directly from substantial differences in the modalities of accumulation, taking Cabeço da Amoreira as comparative example. Both Muge and Sado shell middens are also collective burial grounds, and if we notice the manifested similarities of microfacies of those Mesolithic sites with the Brazilian monumental shellmounds, also burials grounds, can we infer some intention of monumentality in the case of Muge to explain this its topographic expression? What is this telling us about symbolic behaviour and its relationship with mounding in the Mesolithic of central Portugal?

We are now in possession of relevant micro-stratigraphic information that allow us to deepen this open question, at regional level. In terms of microscopic sedimentary record, it became clear that shell-rich sediments accretion took place in the same modalities, with both superposition and juxtaposition of deposits, in Poças de São Bento and Cabeço da Amoreira. These observations constitute new evidence supporting that superposition of shell-rich deposits took place intentionally and in the same circumstances at both sites, therefore, the accumulation predominantly by juxtaposition or superposition does not seem to be a special concern of the occupants of either site.

What can we say, from the same source of information, i.e., the microscopic sedimentary record, that can explain this topographic difference between both sites? For this exercise, I looked for differences in thin section that could help explaining the phenomena. The aspect that is most marked in this aspect is the substantially highest abundance and variety of aquatic microscopic components (foraminifera, ooliths, diatomaceous clay) in Cabeço da Amoreira (Aldeias and Bicho, 2016: figure 5) than in Poças de São Bento, where only rare foraminifera were documented (plate 7.2: g, h). These components are strongly connected with the aquatic environment of the estuarine marshes where the shell beds exploited were located and were interpreted as non-intentional by-products of shellfish gathering. The existence of higher amounts of microscopic aquatic components in Cabeço da Amoreira might be indicating that the shellfish was being collected very close to the site and these components were accumulated and reworked in a same place, which lead to a more marked vertical development of the shell midden. On the other hand, in Poças de São Bento, the scarcity of aquatic microscopic components would be pointing to a bigger distance in the transport of shells between the shell beds and the site or its partial processing elsewhere before the accumulation at the site. Hypothetically, being the distance of transport larger, there was no practical purpose in occupying exactly the same place, causing a wider dispersion of deposits and not favouring vertical growth.

Based on the microscopic sedimentary record to address the topographic question related to shell middens, it results more acceptable that the highest degree on overlapping of deposits in Cabeço da Amoreira, creating an artificial mound, than in Poças de São Bento, where vertical development is much less evident, is the arbitrary result of other circumstances unrelated to the previously planned actions of the occupants, namely possible natural constraints of the immediate surrounding environments. Furthermore, geoarchaeological data from Poças de São Bento shows that the deposits in primary position in the development of the shell midden documented so far are spatially close to the burial ground, and further research on dating should be carried out to assess if there are also a chronological relationship or not. However, mounding does not seem to be a planned action among these hunter-gatherers, as inferred from an integrative formation processes perspective. As pointed out by Peyroteo Stjerna (2016) these likely genesis of the shell middens related to funerary practise did not invalidate the evolution of the sites to residential spaces. In the case of Poças de São Bento, it seems that this evolution happened as the reworked deposits were being dispersed further away from the primary tossing events close to the burial ground.

Micromorphological analysis in other sites in the Sado valley and Muge would allow to extrapolate this pattern to other sites and verify the hypothesis. Some sites at the Sado valley pointed out as logistical camps (Marchand, 2001) are of special interest to this issue, as well as the ongoing palaeoenvironmental studies in the Sado valey inflill (Costa, 2017, Costa, 2015), that are crucial to keep investigating this determining question of the regional Mesolithic.

## 10.4 N-transforms in Shell middens

Despite shell middens are anthropogenic in their genesis, as all archaeological sites, they are subjected to transformations driven by natural agents, or as Schiffer (Schiffer, 1987) designated it, n-transforms, that have great significance in the reconstruction of the formation of sites dominated by shell-rich deposits. At the studied sites, bioturbation was a significant factor and reflect the surrounding environments: in karstic rockshelter sites, bioturbation from soil invertebrates is more intense, whereas in open-air locations, root activity and soil formation are the main post-depositional transformation. Apart from pedogenesis and bioturbation, that reorganise the deposits, other agents were responsible from reworking of anthropogenic materials into new sedimentary deposits, a critical factor in the case of El Mazo.

### 10.4.1 Pedogenesis

The most obvious case of soil formation affecting shell midden layers was documented in Poças de São Bento, where the top of the shell midden is a well-developed, dark A2 horizon correspondent to a paleosoil (phase C in Arias et al., 2015, 2016). The geometry of this layer, with abrupt, and quite regular and rectilinear features cutting the surface of the shell midden layer, suggests it was affected by ploughing activity (fig. 7.2c). The scarce materials and radiocarbon dates obtained from this Ap2 horizon point to a Neolithic chronology, although it is possible that the ploughing marks are from historic periods, affecting both the paleosoil and the underlying shell midden at its surface. This corresponds to mF 2a, which contains few shells showing extreme weathering and advanced carbonate depletion, a direct effect of water percolation that promoted calcium dissolution. Such episode or episodes are possibly related with a period of intense rainfall allowing for a highly vegetated soil to form, generating high amounts of polymorphic organic matter. The fact that is affected directly the top of the shell midden possibly indicated that by the time it was abandoned, the aeolian activity occurring at the beginning of the formation of the site has ceased. This paleosoil has its own surface also truncated horizontally, by a very recent deposit of orange sands coming from elsewhere by means of heavy agricultural machinery.

In depth, the effects of the pedogenesis in the shell midden are well discernible in thin section, which allowed to individualise areas where the shells are reorganised, forming passage features. In the profile it is visible that root activity related with this paleosoil reaches the basal aeolian sands by the penetration of root channels (fig. 7.2: b, c; plate 7.2; fig. 7.7), which means that they cross the shell midden. Their correct identification in thin section is thus crucial to assess the integrity of the deposits.

The Fuegian shell midden of Tunel VII was also affected by soil formation after abandonment and is represented by mF type 2 (Villagran et al., 2011b). However, at Tunel VII this mF type was documented in three different stratigraphic layers, suggesting at least three phases of abandonment, where cold-climate conditions were the main factor in wind-blown sedimentation over the domestic deposits, posteriorly affected by pedogenesis controlled also by frost-action, origination calcium dissolution of the *Mytilus edulis* shells and reprecipitation in the same layer, in the form on needle fibre calcite (Villagran and Poch, 2014), which differs from both cases of El Alloru and Poças de São Bento, where the dissolved calcium by meteoric water was leached downwards in the profile.

At the *locus* of El Alloru outside of the rockshelter, the shells in Unit 104, also an A2 horizon with an incipient blocky structure (plate 6.3), present the same characteristics of advanced weathering as mF type 2a in Poças de São Bento (fig. 7.3c). These occurrences in completely different environments seem to establish a pattern of calcium dissolution due to water percolation of the shells in the upper layers when they are affected by soil formation.

The soil formation at Poças de São Bento is highly significant because it is telling us that the low amount of shells in corresponding layers is due to dissolution and does not correspond to the real amount prior to soil formation. The agriculture activity in historic times also must have dismantled part of the surface of the shell midden deposits. Therefore, the original surface geometry and even original volume of the deposits if extremely difficult to reconstruct since it was irremediably lost.

Other important post-depositional factor of remobilisation of the shell midden in Poças de São Bento are burrows made by medium mammals, such as rodents, that are well visible in some profiles. In the Cantabrian sites, burrowing is due mostly to colonisation by soil invertebrate fauna. The intensity of bioturbation in these cases is clearly visible in thin section, that allows to distinguish between those layers completely homogenised from those where the biological reworking is conscript to well-delimited passage channels outside of which the deposit is intact. Good examples of both cases are present at of La Fragua (plate 6.20) . Unit 3 is intensely affected by structural collapse and textural rearrangement in heterogeneous granules, leaving relatively small areas intact (mF type 7). These aspects agree with criteria proposed by earlier works regarding bioturbation (Courty et al., 1989, Courty and Vallverdu, 2001). At El Mazo, biological homogenisation by rearranging microstructures into microgranular textures seem to be generalised throughout the sequence.

### 10.4.2 Natural sedimentation and no-occupation periods

Natural processes of clastic sedimentation in shell middens, necessarily, involve shells that are the mains sedimentary component in the catchment environment. In the two Asturian sites studies in this thesis, El Alloru and El Mazo, this type of deposits was clearly identified by micromorphological analysis and are related with two main factors: spring activity and slope processes. If we exclude the former, that will be discussed in a later section, there is only El Mazo left, with several deposits related with slopes processes.

In the base of the stratigraphy, it is interesting to note the alternance between anthropogenic deposits and colluvial like deposits partially overlapping (fig. 7.23). The slope deposits seem to come from the exterior of the rockshelter, refelecting the probable direction from where the anthropogenic inclusions were reworked.

The thick layer 105 is a succession of several deposits accumulated over an eroded sloping surface created on earlier deposits, truncating them. Colluvial-like events as well as water circulation were involved in this successive accumulation of sloping deposits, eventually associated with the local spring resurgence. This would mean that during this period of adverse conditions the interior of the rockshelter was not occupied, therefore, the shells and other materials contained in these deposits are naturally reworked and can mix different primary or anthropogenically reworked deposits from elsewhere in the site, and this is vital to take into consideration in the interpretation of multidisciplinary analysis of these layers.

At Poças de São Bento, the only deposits with shells that are not clearly intentionally accumulated are those of mF type 6a, silty sands with few, random oriented shells and rare charcoal. This mF type was identified invariably at the base of the shell midden, in the top centimetres of the basal aeolian sands (plate 9.5). Most of the shell fragments in these deposits are associated with carbonate hypocoatings as past root penetration is clearly visible in the field, which explains the presence of shells in depth. However, in Area 9, within the first 5 cm immediately below the first direct tossing event, some shells are complete, horizontally oriented and crushed in-situ, embedded in the same aeolian sands as those of the substrate.

These microcontextual characteristics make me wonder if this upper centimetres of the basal sands corresponds to an unstable active layer where the sand was subjected to dispersion by wind or trampling, and shells were already present at the site and thus dispersed alongside the sandy matrix. If so, this would be the only hint on previously deposited shells that were unintentionally redeposited at Poças de São Bento, possibly because an anthropogenic deposit was left exposed. It does not constitute evidence of abandonment periods because the inferred previous deposits were not identified, but it is certainly an avenue for future research. At Cabeço da Amoreira, crudely bedded lenses of aeolian silt and sand were documented in the filling of a pit-like structure at the base of the shell midden, attesting a probable periodic abandonment of at least that area of the site (Aldeias and Bicho, 2016).

Chapter 11

# Shell middens, carbonates, and calcareous materials

Calcium carbonate features in shell midden goes well beyond the presence of shells. In prehistoric archaeological sites in general carbonates are widespread in a vast array of forms. Ashes, plant roots, speleothems and so on, are constant producers of calcium carbonate, and in shell midden the situation is not different. However, the fact that shells are the most obvious carbonate material in such sites is a factor of extra-caution when interpreting geochemical analysis of bulk sediment samples, because there is a common trend in attribute to the shells the presence of calcium, which might not be entirely true (e.g. Polo-Díaz and Eraso, 2010, Toffolo and Boaretto, 2014, Mallol et al., 2009, Canti, 2003, Durand et al., 2010). Another critical aspect of carbonates in the prehistoric archaeological record is the primary and secondary precipitates, a significant aspect to address site formation processes, and not always discernible by bulk analysis alone. Micromorphology provides an accurate tool to identify and differentiate between all these types of carbonates, as it will be discussed in the following sections.

## 11.1 Microbial carbonates

Like in the study of combustion features, the study of microbial carbonate materials in the Cantabrian sites was essential for interpretations at regional level. Carbonate microfacies identification in the sediments of La Fragua was crucial to distinguish between tufas of Unit 4 from the ones of Unit 3 (fig. 6.13). Interestingly, tufa crusts of Unit 4 are similar to the tufa cements of El Alloru, with stromatolites and dendritic calcite crystal forms. This is in accordance with the idea that the former might have originated in tufa deposits formed in the cave, such as the small cascade-like tufa existent at the current entrance of the cave (fig. 6.25).

In turn, the tufa carbonates occurring in Unit 3 of La Fragua, resembling unattached microbial sedimentary structures such as oncoids, peloids and microbial-rich micritic mud (plate 6.21, fig. 6.27), do not have correspondence in any of the in-situ carbonate tufa microfacies of the Asturian sites, but still are typical from open water running tufaceous environments and pooled tufaceous water masses, which could have existed in eroded distal parts of the cave.

More enigmatic are the filamentous microfossils, major components of specific anthropogenic contexts of La Fragua, but present in all Cantabrian sites, always reworked, unlike the tufa microfacies, that were studied in-situ in the two Asturian sites. To recapitulate, the filamentous microfossils (described in more detail in chapter 6), are a major component in La Fragua Unit 3 (mF 7) and mF 5 of Unit 1, here along with charred and humified fibrous plant material. At El Mazo, filamentous microfossils were documented uniquely in mF 1, very residually, and interestingly also one calcitic spherulite (fig. 7.15: f) identical to the bacterial ones very common in La Fragua's carbonate mud was observed (plate 6.21: e, f). Both are contained in aggregates of organo-mineral clay, in a naturally reworked deposit of Layer 108, that mixes diverse occupation debris in a slope, at the very base of the shell midden. At El Alloru, filamentous microfossils and other marine skeletal grains (foraminifera, calcareous red algae) are occasionally found in ashy clay aggregates in the protected infills of reworked shells. This resembles the case of the combustion residues layers from La Fragua where such elements were also present, allowing to consider that these elements were likely involved in the El Alloru shells' pre-depositional combustion process. Also at El Alloru, filamentous microfossils are common sedimentary components of the carbonate-rich muddy micromass of mF type 8, a particular layer in the cemented shell midden because it is supported by a clayey material prevailing over coarse shells and tufa cements.

Taking all these circumstances in consideration together, it seems that the presence of filamentous microfossils occurs in those deposits more strongly influenced by anthropogenic actions. The observation of filamentous microfossils forming a biofilm incrustation on a marine bioclast (a heavily microbored and rounded limpet shell) is the only hint on the pre-depositional original environment of the filamentous microfossils, i.e., marine, along with the rest of bioclast that appear in association to them in all mentiones contexts.

The identification of abundant bioclasts of marine origin in the same layers lead us to hypothesize that marine components were non-intentionally transported to the cave, and suggest the gathering of wetland grass, like reeds or sedges, to which local sedimentary components were attached and carried to the site, to explain how marine skeletal grains were incorporated in the anthropogenic sediments accumulated in the cave. This hypothesis is supported also by some of the porosity patters of mF 7 in la Fragua, that resemble plant fibres' mouldic voids. Perhaps something similar happened in the Asturian sites, since both El Mazo and El Alloru are close to estuarine environments, namely, the small Purón inlet (fig. 7.1b) and Niembro saltmarshes (fig. 8.1c), respectively. Use-wear studies have been reinforcing the importance of exploitation of plant material in Mesolithic coastal settings, including shell middens (Guéret et al., 2014, Cuenca Solana, 2013).

La Fragua offered also evidence of fibrous plant material present in the combustion substrates of the hearths (fig. 6.30 and 6.31), which point the possibility of they not being necessarily linked to fuel, thus their presence must have served other purposes like making fabrics or fishing nets, elements that are normally absent from the archaeological record, which identification must be tested with microarchaeological techniques in the future, namely use-wear and archaeobotanical analysis.

## 11.2. The identification of seaweeds and its possible meanings

The identification of seaweeds (rhodophytes or calcareous red algae, family *corallinaceae*) (plates 6.11, fig. 7.13, 7.19 and 8.29c) was a major contribution of the micromorphological study, since it is not common in the Prehistoric archaeological record. The few cases where it was systematically addressed, it was focused on the evidence of manuring techniques in Late Prehistory (Bell, 1981). Ainis et al. (2014) relied in the analysis of non-dietary gastropods in Californian shell middens to infer human harvesting of marine vegetation to which such small gastropods are associated, particularly kelp and brown algae which, according to the authors, have a nutritive value suitable for human consumption. Referring to ethnohistoric accounts, Ainis et al. (2014) also remark "the relative ease of drying and storing" that makes seaweeds "highly valuable as a storable nonmeat food item and potential fuel source" (p. 356).

At El Mazo, the preservation of seaweeds was possible because of the calcareous internal structure of the coralline species identified. Despite the whole sediment excavated from El Mazo was processed by flotation and hand-screening, these elements were not identified, being only found in thin section, in its sedimentary contexts, thanks to micromorphology.

Seaweed fragments are present in many mF (table), mostly as rare components and this cases it can be explained as unintentional by-product of shellfish collecting in the coastal rocky environments where both limpets and calcareous red algae live. The same can be said for the case of foraminifera, and the non-dietary gastropods in the study by Ainis et al. (2014). This should be also the reason for the occasional presence of the same type of calcareous red algae documented at La Fragua and El Alloru. The case of mF 20, 21 and 22 of El Mazo, however, is different because the shells/matrix ratio is balanced, and the abundance of seaweeds and foraminifera increases greatly, reaching dominant values in some areas of the thin sections (fig. 7.16).

As it was stressed in chapter 5, both incrusting type and unattached segments of branching type of red algae were identified in thin section (fig. 11.1). Based on petrographic characteristics and comparison with today's rhodophytes in the Cantabrian coast, namely in Mount Buciero, the incrusting type seems to correspond to the species *Lithophyllum incrustans* and the second to *Corallina* spp (fig. 11.1). The former is likely to incrust limpets, as it is seen also in thin section, but the second did not seem to correspond to the ones incrust limpets at the region today, which are not composed of articulated calcareous segments (fig. 11.1). The fish and molluscs record of these layers is particularly relevant for the interpretation of the presence of seaweed. It can be reflecting the exploitation of shellfish in the subtidal area, where seaweed is more abundant, leading to the carrying of higher amounts of seaweed colonising shells that were processed at the site. This could explain the incrusting seaweeds, but this hypothesis need confirmation through more careful analyses of biological order concerning the branching seaweeds species observed in thin section.

Some other hypothetical reasons for such amount of seaweeds in localised deposits lie in factors usually invisible in the archaeological record, such as the existence of different fishing techniques, involving nets or traps (Billard and Bernard, 2016) that promotes the collection of these elements and their transport to the site.

It remains intriguing the reason for the increasing amount of seaweeds in these specific layers of El Mazo, and if it was casual, why aren't they equally common in other deposits? Micro-contextual evidence points to little reworking of these deposits, corresponding to occupational activities debris, which micromass is a dense, fine grained organic matter of difficult identification but not resembling any plant, charcoal or woody-derived material. This suggests that such activities involved processing of substantial amounts of seaweed at the site.

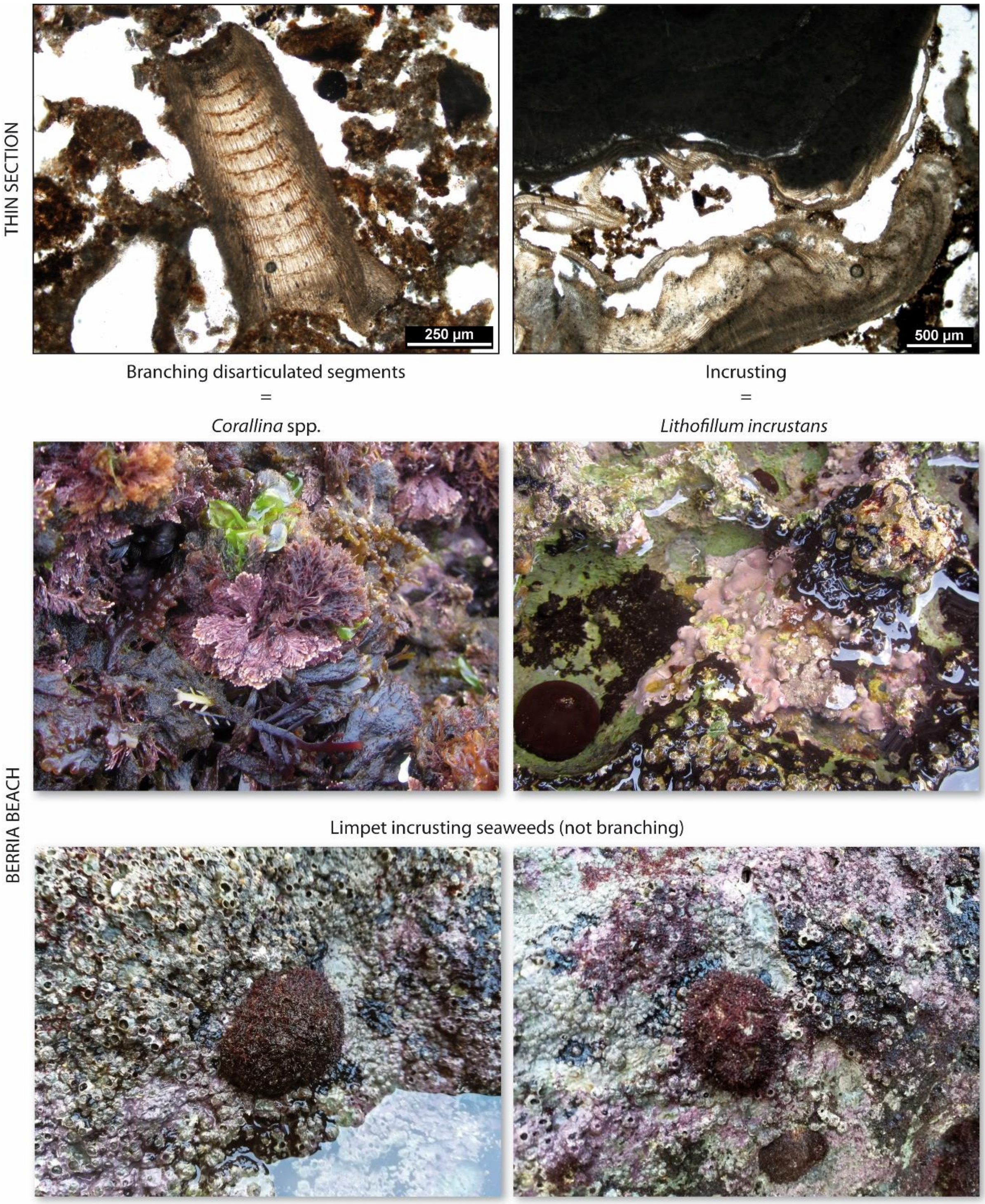



**Figure 11. 1** Identification of seaweeds (red algae, or *Rodophyta*) in thin section, and possible correspondence with living species of the Cantabrian coast in Berria beach; note the incrusted limpets at the bottom, which incrusting seaweed does not seem to correspond to the branching type seen in thin section.

The abundance of foraminifera and other unidentified skeletal probably marine grains embedded in this material makes me wonder if it is some sort of organic sediment also of marine origin. Organic petrology or organic chemistry analysis on this material, combined with study of further small marine organisms present in these deposits, are possibly convenient next steps in addressing this issue, helping in a better contextualisation of the human activities behind these deposits and the abundance of seaweeds, remaining open the hypothesis of intentional harvesting.

## 11.3 Carbonate diagenesis on shell middens (open-air)

As it turned out, carbonate diagenesis is a critical aspect in shell midden alteration processes. The carbonate diagenesis of the Cantabrian sites, particularly the Asturian case, will be discussed in a proper section. This section will focus the effects of carbonate diagenesis in the open-air, soil-forming environment of Poças de São Bento.

Poças de São Bento revealed two main cementation features resulting from calcium carbonate dissolution and reprecipitation: pendants below shells and clastic grains, and micritic fillings combined with needle fibre and alveolar septal calcite fabrics (plate 9.6: a-c), the latter associated to fungal biomineralization (Verrecchia and Verrecchia, 1994, Bajnóczi and Kovács-Kis, 2006, Flügel, 2004). The pendants were interpreted as result from partial saturation of the deposit by meteoric water drops hanging from the clasts promoting crystal nucleation in the form of pendants (Cou rty et al., 1989, Scholle and Ulmer-Scholle, 2003, Flügel, 2004). The fact that both shells and quartz grains exhibit exuberant, multi-layered pendants (plate 9.6: d-f) reveals that their source is from carbonate dissolved up in the profile for several consecutive phases. The cementation by micrite and fungi activity results in hardening of the basal deposits of the shell midden, a common feature in both Sado and Muge shell middens. For both types of cements, this most probable source of the carbonate are the highly depleted shells of the shell midden surface affected by intense pedogenesis.

These two types of cements present, however, a differential intra-site distribution pattern: pendents were identified only in the primary deposits of tossing events in Area 9, where hardened basal sediments are lacking, whereas the former occur in Area 1, where pendents were not observed in thin section. Both types of cementation seem to be mutually exclusive judging by the present record. Moreover, this seems to establish a direct relationship between primary deposits of shell tossing with the formation of pendents, possibly because the lack of sedimentary matrix between shells allowing for water to partially fill the void space. The reworked deposits have less voids space available, preventing retention of meteoric waters, which accumulated further below.

In terms of formation processes, this attests that these deposits are highly affected by water circulation and partial saturation, which certainly had an impact in the configuration and original geometry of the shelly heaps, transforming it for instance, reducing their original volume or promoting small particles migration.

Concerning the basal sediments cemented by root- and fungi-derived calcitic fabrics (micritic hypocoatings, needle fibre calcite and alveolar septal calcite), it is interesting to note that in Area 1 these cemented domains occur in patches, in the area where sample PSB108 was collected. This sample was mentioned earlier (section) due to the enrichment in organic matter, fungal elements (hyphae and sclerotia, some of it charred) and plant-derived tissue and phytoliths. This occurrence correlates well with the association of such cementation features with fungi activity. Furthermore, it provides a clue on a factor controlling the differential cementation of the shell midden basal sediments, that thus might have been influenced by the presence or not of fungi in the sediments. Further samples form Area 1, i.e., the vertical sampling in the North profile, are not as rich in fungal tissues and organic fines, and the basal sediments are not cemented, except in very localised areas corresponding to root channels (plate 9.5f). It is not the only evidence in this sense.

In sum, micromorphology and spatial analysis of hardened basal sediments strongly suggest that there is a connection between fungal activity and this type of cementation. The concentration of fungi in constrict areas might be related to human inputs related directly to individual events of site formation, as result of use of such material for residential or domestic purposes, as it seems to suggest the finding of charred sclerotia both in thin section and in the macrobotanical study (López-Dóriga, 2016). Recent analysis suggests the exploitation of fungal resources for tinder at the Neolithic site of La Draga (Berihuete-Azorín et al., 2018). The potential of this assumption is enormous, because, if accurately dated, these carbonate cements will contribute to individualisation of deposits and contribute to higher resolution of the site occupation dynamics.

Apart from shells, that seem to be the major carbonate source in Poças de São Bento, another aspect to consider in the calcium carbonate diagenesis concerns ashes, especially their absence. Since combustion activity is documented at the site, and combustion features partially preserved and micromorphologically documented in Area 9, diagenesis is a likely explanation for the absence of ashes. The fact that it is an open air, aeolian setting must have also contributed to an early ash deflation at the site. Dissolution of ashes by meteoric waters is also possibility, contributing for posterior cementation.

This conclusions regarding shell carbonate diagenesis have great implications on the interpretation of open-air setting affected by meteoric waters and attest the influence of the sedimentary characteristics of the deposits. Similar analysis on further Portuguese shell middens, since most are open-air sites, would help in built regional reference for the reconstruction of transformation processes of this deposits.

## 11.4 Shell middens and karstic sytems

Regarding the sedimentation processes, both cemented shell middens of the Asturian sites revealed a similar dynamic of several phases of accumulation of anthropogenic material reworked by natural agents, namely fluctuating waters with varying flow regimes, possibly related to the cementation process. However, the identification of internal stratification, provided by compositional and microstructural differences, was also an important aspect observed in thin section, that attest that this process did not happen homogenously affecting the deposits at the same time, but intercalated with sedimentation phases.

These are common traits between El Alloru and El Mazo, but some observed differences need to be highlighted. First, the evidence that the addition of reworked anthropogenic material at El Alloru deposit is syn-depositional to the tufa development. The depositional process of the anthropogenic material is difficult to define, although the material sorting of some microfacies, such as mF type 4, where bones are dominant, is more likely explained as being anthropogenically induced. But as mentioned in the correspondent chapter, these are very localised instances, that might had result from rolling down of such components from the original shell mound to deeper, inundated areas of the rockshelter that were in process of tufa formation. The syn-depositional relation allows to infer that the hydrological activity exerted an impact in the reworking of the anthropogenic materials, particularly in the washing out of the fine terrigenous matrix and redistribution of coarser anthropogenic components, specially in those moments of higher turbulence, as it seems to have occurred during the formation of the upper part of El Alloru shell midden. Above all, this reveals that the human occupation took place in the proximity of the active tufa forming location, that in turn went through regime and water table variations, recorded in examples of differential layering of the tufa facies. In the meanwhile, probably influenced by the pace of occupation and abandonment of the site, the anthropogenic materials were being reworked into the subaerial environment of the slurry, microbially colonised tufa-forming environment.

The case of El Mazo present some differences. Despite the recognition of at least two different superimposed deposits: a lower one dominated by topshells and echinoids and an upper one dominated by limpets. The clastic fraction is not dominated by coarse components like El Alloru. Small components such as seaweeds and smaller shell fragments are abundant at El Mazo as individual clasts, not only incorporated in aggregates. The cementation is more homogenous and dominated by diagenetic calcite precipitation by meteoric waters. This type of diagenetic cements is also common in tufa deposits (Pentecost, 2005), and influence of relatively high energy water flows *during* the formation of El Mazo cemented deposit is provided by an intercalated layer of exuberant dendritic calcite crystals, typical of tufa deposits formed in fast-flowing conditions in spring settings (Pentecost, 2005, Chafetz and Folk, 1984). In the case of El Mazo, the anthropogenic materials are also reworked, being difficult to advance a predominantly anthropogenic or natural agent of reworking. The cementation occurred mainly due to periodic inundations caused by meteoric phreatic waters, generating fluctuations in the water table and alternance between phreatic and vadose conditions. Considering that water flows of some turbulence occurred, the effects of such activity most likely impacted the original geometry of the shell midden, promoting structural rearrangements, reworking different anthropogenic deposits previously located elsewhere.

This process must have happened in several phases during the occupation of the sites, considering the compositional differences between layers of the cemented deposits, that probably means that different deposits were being eroded at different times. Furthermore, the total excremental microstructure of the fine fabric at the cemented shell midden of El Mazo strongly suggest that it was colonised by invertebrate fauna typically living in tufas (Pentecost, 2005), which suggets the influence of spring activity in the formation of the deposit. At El Alloru, the diagenetic cementation seems to have occurred in similar conditions, attesting a drastic change in the water circulation conditions in relation to the previous moment, dominated by still water.

Petrographically, the general characteristics of the carbonate cements observed in thin section are similar to those forming in spring settings (Chafetz and Folk, 1984; Sholle and Ulmer-Scholle, 2003; Flügel, 2004; Pentecost, 2005; Jones and Renaut, 2010; James and Jones, 2015). The cementation occurs in both sites as coatings around individual components instead of horizontal layers, which means that the deposits was already lacking a supporting matrix, possibly previously washed out by water circulation, and which enlarged porosity was filled with saturated meteoric waters that promoted the development of the quite regular (isopachous) cements (Flügel, 2004). Giving the syn-depositional processes that seems to dominate in the cementation of the different layers, it is plausible to assume that the cements are correlated with the reworking agent.  Therefore, spring activity could be considered one of the possible agents of reworking and posterior cementation. All these factors show that alternance in water flow regimes was coeval with the Mesolithic occupation of the sites. This constitutes a notable outcome in the research on the Asturian.

The variations in driving force recorded in the cements in thin section reveals the degree of detail that carbonate microfacies can offer in the formation processes reconstruction of the Asturian shell middens, and that they should not be regarded as a mere post-depositional process that caused a curious form of preservation. They bear relevant information for the human settlements in the Asturian area by providing accurate environmental characterisation of the sites like El Mazo and El Alloru, where today there are no signs of spring activity, apart from the cemented shell middens that mask actual tufa deposits. In the case of the stratified deposit of El Mazo, giving that layer 105 and other deposits correspond to mass movements downslope displacement of previously reworked anthropogenic material, probably also with influence of water, it would be extremely interesting to investigate the chronology of the cements, in order to address if the cementation phases coincide with periods of probable abandonment to establish a relation between both deposits.

Concerning archaeological spring settings, micromorphology has provided similar conclusions at the Pleistocene site of Obi-Rakhmat, in Uzbekistan (Mallol et al., 2009). The authors of the study found fine-grained micritic and algal features associated with spring subaerial conditions postdating the deposition of anthropogenic materials, during periods of no-occupation, where the anthropogenic materials were reworked by spring waters. Furthermore, Mallol et al. (2009:570) observed a phenomenon that can be applied to the Asturian shell middens: “the post-depositional processes documented in the carbonate-rich layers mark periods of sedimentary stasis and indicate that the upper part of the stratigraphic sequence is not a homogeneous deposit resulting from continuous accretion. Evidence for different sedimentary rates comes from the microstructural and compositional variability observed among the layers.”. Likewise, the cemented Asturian shell middens of El Mazo and

El Alloru are not homogenous deposits cemented all at once, but stratigraphic deposits which cementation occurred also in several phases between sedimentation events.

Like the conclusion of Mallol et al. (2009) at Obi-Rakhmat, the carbonate-cemented Asturian shell middens must correspond to peripheral areas during the Mesolithic, when the spring systems were active, while the main human occupation took place in their proximity. This means that the carbonate cements in the Asturian record are much more significant than a mere post-depositional alteration. They have relevant implications in site formation dynamics during the Mesolithic. As tufa deposits, these carbonate cements constitute excellent dating elements, also having the advantage of being fine archives of local changing environments, during which the human occupation does not seem to have ceased. Further analysis in the future on the cements, for instance cathodoluminescence, or chemical and mineralogical analysis, should contribute to a more detailed understanding of the environmental and diagenetic processes they undergone.

In this regard, the petrographic study of the cement raises some questions in respect to El Alloru. The isopachous fringes of fibrous crystals such as those observed on mF type 6 (plate 8.15), are not usually observed in tufas. Isopachous fringes in fluvial tufas were reported by Pedley (Pedley, 1987) who noted its resemblance with marine cements, but these seem to be composed by coarser sparry calcite and not fibrous crystals. Isopachous bladed crystals crusts (plate 8.15) are not common as meteoric cements as are dogtooth and drusy calcite (Flügel, 2004). Both features are more frequently reported as diagenetic cements in marine environments as well as typical speleothem formations in darker areas of caves (Flügel, 2004, Scholle and Ulmer-Scholle, 2003, James and Jones, 2015). This aspect that might lead to controversial interpretations of these features at this location need for further geochemical investigations especially of stable carbon and oxygen isotopic compositions (Scholle and Ulmer-Scholle, 2003), at the moment not possible to carry out in the slip-covered thin sections. New uncovered thin sections need to be produced from the remaining slabs in order to undertake analysis.

### 11.4.1 Rethinking the Asturian record

Overall, the differences pointed out above between El Mazo and El Alloru remark that Asturian shell middens should not be interpreted as resulting all from the same formation and cementation processes and must be carefully analysed case by case. This aspect questions the regional generality emphasised in the model proposed by Vega del Sella (1923) for the Asturian record. Vega del Sella argued that the shell middens constitute accumulations that completely obturated caves and rockshelter's entrances during the Mesolithic. Later, the parts of the deposit that were in contact with the cave walls and ceilings became cemented by carbonate precipitation related to water percolation though the walls and, once lithified, resisted to the erosion that cause the disappearance of most of the supposed pre-existing mound (fig. 11.2). González Morales (1982) added to the model the hypothesis that cementation process could have started already during the formation of the shell middens, which is now confirmed by geoarchaeological data. The author also pointed out hydrological activity as responsible for the erosion of the shell middens, which now can be elaborated.

Geoarchaeological data from El Mazo and El Alloru have revealed two important aspects that complicate the model. One is that the accumulation of shells in the cemented deposits at both sites is primarily due to natural agents, namely water table rise due to variations in local hidrological activity and meteoric water circulation under moderately turbulent flows, by reworking materials previously deposited elsewhere. Therefore, it seems questionable the generalised practice of using the cemented remnants to reconstruct original volumes and geometries of the shell middens. These deposits do not seem to correspond to entirely anthropogenic constructions and therefore do not reflect habitat activities and spatial organisation, as such interpretations suggest. Even if contemporary to the Mesolithic occupations, these deposits do not seem to have been accumulated within the framework of anthropogenic activities directly involved in shell midden construction, and such type of interpretations give an erroneous idea of a continuous mound resulting from anthropogenic actions. Based on result from El Mazo and El Alloru, the domestic space must have been organised in some other way in which spatial distribution of deposits was substantially influenced by natural reworking of previously deposited materials. When a group re-occupy a given site, the remaining shell-rich accumulations from previous occupations could have been already cemented, or eroded, and overall modified.

Another aspect that questions the model of Vega del Sella (1923) is that such model implies that the cementation of the supposed mounds occurred above the water table, thus under

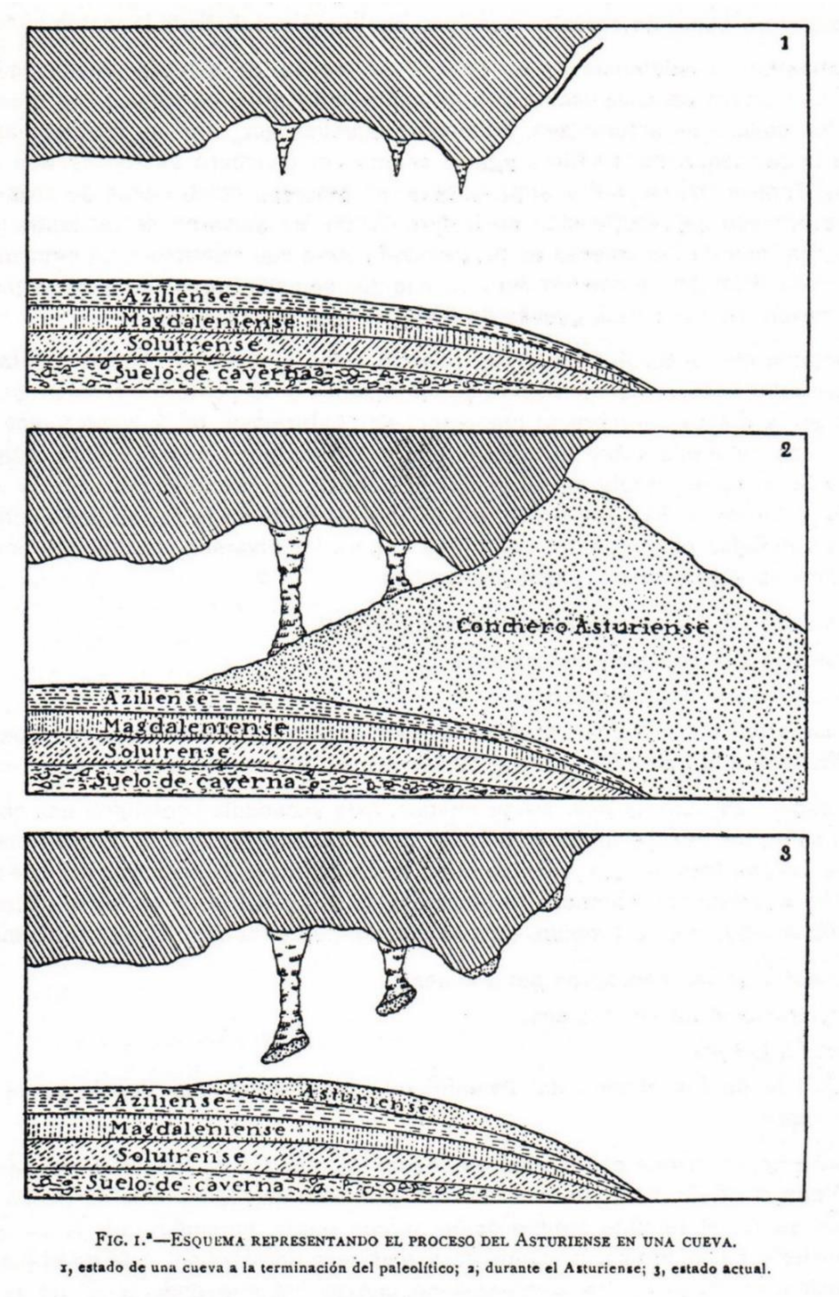



**Figure 11. 2** Reproduction of Vega del Sella (1923) schematic representation of the formation process of the Asturias shell middens. Legend: 1, situation at the end of the Palaeolithic; 2, during the Asturian; 3) Nowadays' situation

vadose conditions (fig. 11.2). The new micromorphological data from El Mazo and El Alloru clearly show that the porosity was filled with saturated water, actively involved in the accumulation of shells and other anthropogenic materials, while the sites where being occupied (fig. 11.3). This indicates that the deposits were at least periodically inundated and exposed to sub-aerial conditions and not only after their definitive abandonment when the suppose mounds had obturated the caves and reach the walls and ceilings.

Based on data from the two sites studied in this work, I think the key to propose an explanation for the hanging cemented remains of the Asturian region lies in the different water flow environments, from ponding and sluggish subaerial environments to relatively fast-

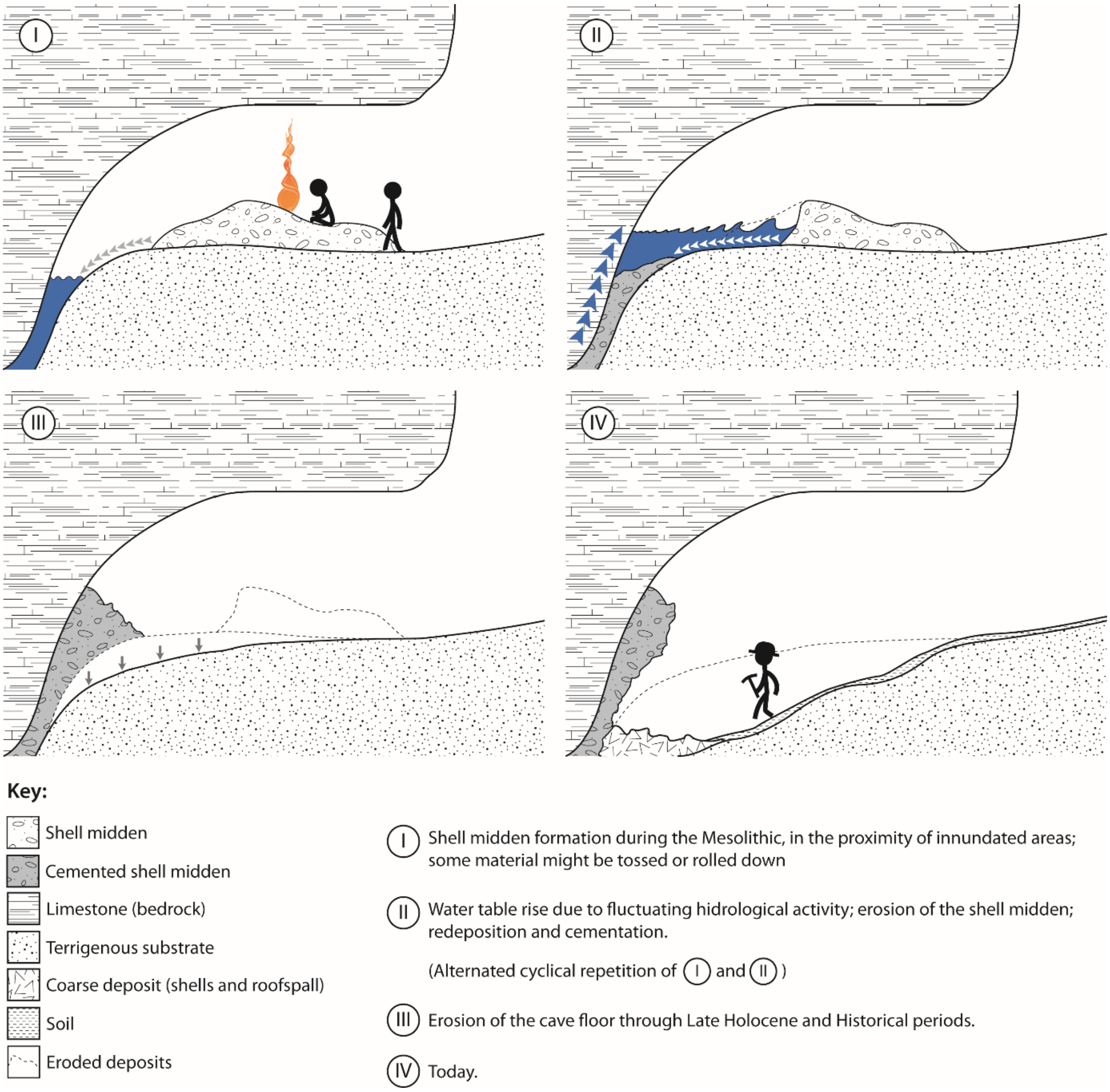



**Figure 11. 3** Schematic representation of the formation processes of the Asturian shell middens based on the micromorphological data from El Alloru and El Mazo

flowing meteoric waters and perhaps spring activity. Such hydrological activity might had contributed to wash out the fine matrix of the deposits and retained most of the coarse anthropogenic materials, reworking them in the process, that became accumulated in a changed configuration (fig. 11.3). The high position of some of the remains relatively to the current ground, hanging in rockshelters' walls, could be explained as resulting from different local topographic features in the Mesolithic that were eroded during later stages of the Holocene and Historical periods (fig. 11.3). This would explain how variations between phreatic and vadose conditions occurred to cement the shell middens, in contrary of massive accumulations envisioned with based on the current ground, that should prevent inundation of the deposit. But then again, a wider sampling in Asturian sites is needed to confirm if phreatic condition dominates in all cemented remains, or if vadose cementation also played a role in the Asturian record formation, corroborating Vega del Sella's theory in some cases.

The regional, and original, homogeneity of the Asturian record can only be explained by factors of climatic and geological order, such as the high rainfall rates that control hydrological and spring activity. The differences in local environment and higher or lesser direct influence of anthropogenic actions in the accumulation of the deposits between El Alloru and El Mazo, demonstrates that Asturian shell middens need to be addressed as individual cases in order to take the most of its informative potential, particularly when they constitute so many times the only remains of the intense Mesolithic occupation of the region. In the same way, such differences show that extending the observations of these two sites to the rest of over a hundred other sites must be cautious, as well as it also questions the general applicability of Vega del Sella model at regional level. With this work it becomes clear that, despite an apparent regional homogeneity, the Asturian formation processes are more complex than though until now, and the sites need to be analysed case by case to achieve more complete and accurate archaeological interpretations.

# CONCLUSION

With the methodology followed in this dissertation it was possible to identify sedimentary signatures associated to specific human actions, using micromorphology, in shell middens, that are complex archaeological palimpsests. This allows for the recognition of natural and anthropogenic individual events of shell-rich accretion and enhances the possibilities of reconstructing formation processes. The microfacies approach undertaken in the four sites studied allows to reconstruct the dynamics of shell midden formation through the observation of microscopic sedimentary record of the matrix of shell-rich deposits. The microscopic scale of observation bears relevant information that helps in distinguish different events of anthropogenic sediments accretion in shell midden growth.

The aspects of microstratification, so common in shell middens and difficult to individually characterise, some of them pointed out in early stages of investigation (Claasen, 1996), are possible to observe and study in thin section. Variability on the type and microstructure of different organic matrixes is also possible to discern in thin section and are an important indicator of reworking degree related to human intentional sediments moving. Likewise, it provides context and possible evidence for the exploitation and processing of less visible plant resources, such as fungi or seaweeds.

The combined study of shell midden and combustion features microfacies offered detailed insights on the functionality of the different contexts. Fires to roast and immediately discard shellfish after consumption are not expected to be preserved, although traces of this activity preserved in-situ were recognised through microfacies approach at Poças de São Bento. On the other hand, intact hearths were recognised in Cantabrian sites, containing shells, among other components, that were probably not being intentionally burnt, but already present in the sediments as result of previous activities.

Furthermore, the micromorphological study of microstratigraphic contexts allows to decipher what post-depositional effects are masking depositional sedimentation. This aspect significant in shell midden interpretation concerning, for instance, reconstruction of the volumes and geometries of the deposits associated to period of effective human occupation of the sites versus periods of natural reworking of the deposits, and how both contributed to the deposit we see today.

Contributions in the field of micromorphology regarding specific petrographic aspects were made, particularly in the field of microbial carbonates and calcareous algae, which record in archaeological context is generally difficult to identify. In the context of the Asturian Mesolithic, the study of the carbonate-cemented shell middens of El Alloru and El Mazo revealed essentially two aspects that are significant in the Asturian research: 1) the cementation and accumulation of the deposits is most likely syn-depositional and occurred predominantly in subaerial conditions, under the influence of saturated water, in which spring activity could have played a major role; 2) The cemented deposits are more likely to correspond to naturally reworked accumulations of archaeological materials, possibly also controlled by variations if water circulation and fluctuating spring activity, instead of result from actions of Mesolithic groups directly related to shell mound accretion. The study of these carbonate cements provided also extremely detailed knowledge about the type and environments of carbonate precipitations involved in the process thanks to carbonate microfacies identification. These results concern ultimately a revision of the interpretations in the Asturian occupation dynamics at regional level. The general preservation conditions (cementation) of the shell middens in the region might be masking the possibility that not all necessarily respond to the same processes. Additionally, even if most of them probably do not correspond the primary anthropogenic accumulations, they bear great informative potential of the deposits due to its formation during the Mesolithic. Perhaps, local topographic conditions might have controlled different habitation structures and spatial organisation site-by-site.

All these aspects regarding the Asturian shell middens are open to discussion and the Asturian Mesolithic surely would benefit from regional-scales analysis with important insight from karst science and neotectonics specifically designed to the understanding of the shell middens formation, with exploration of sites case by case.

All these inferences are possible only because of their integrative study in what concerns to the several scales of contextual analysis. With micromorphological data combined with spatial analysis and geomorphological analysis, it is possible to make thorough inferences on spatial organisation, symbolic behaviours regarding funerary practices, intentional monumentality through mounding, and the influence of natural constraints in the sites' formation. geoarchaeological broader aspects revealed close links to paleoenvironmental questions, which further development is crucial in the future for both Sado valley and Cantabrian region.

This work has also shown that comparison of microfacies confirms the worldwide character of shell midden archaeology, making it possible to make relevant interpretations regarding the completeness of the record based on accurate micromorphological descriptions in shell midden sites, therefore the application of the technique in similar contexts must be encouraged.

The implications for interpretations at site-scale involve critical aspect such as the undeniable contribution for providing context to multidisciplinary analyses, like isotope analysis techniques, radiocarbon dating, or the study of material culture and bioarchaeological remains. The knowledge of the degree of reworking and mixing, and if it is anthropogenically or naturally induced, are vital aspects to correctly interpret results from any samples taken form a given archaeological context, particularly in those susceptible to intense moving and materials redeposition such as shell middens. Taking micro-contextual resolution in consideration when sampling from multi-disciplinary analysis is probably the next step in many of those disciplines operating in shell midden research, and a challenge for the future of archaeological excavation, opening the way to more accurate integration and higher resolution of results. This is essential for the knowledge of the evolution of human relation and connection with coastal environments.

# REFERENCES


AINIS, A. F., VELLANOWETH, R. L., LAPEÑA, Q. G. & THORNBER, C. S. 2014. Using non-dietary gastropods in coastal shell middens to infer kelp and seagrass harvesting and paleoenvironmental conditions. *Journal of Archaeological Science,* 49**,** 343-360.

ALBERT, R. M. & WEINER, S. 2001. Study of phytoliths in prehistoric ash layers from Kebara and Tabun caves using a quantitative approach. *In:* MEUNIER, J. D. & COLLIN, F. (eds.) *Phytoliths: applications in earth sciences and human history.* Lisse: Balkema Publishers.

ALDAY, M., CEARRETA, A., CACHÃO, M., FREITAS, M. C., ANDRADE, C. & GAMA, C. 2006. Micropalaeontological record of Holocene estuarine and marine stages in the Corgo do Porto rivulet (Mira River, SW Portugal). *Estuarine, Coastal and Shelf Science,* 66**,** 532-543.

ALDEIAS, V. 2003. Estudos geoarqueológicos em Portugal: breve historial. *In:* MATEUS, J. E., MORENO-GARCÍA, M. & FARIA, A. M. D. (eds.) *Paleoecologia Humana e Arqueociências. Um programa Multidisciplinar para a Arqueologia sob a tutela da Cultura (Trabalhos de Arqueologia, 29).* Lisboa: Instituto Português de Arqueologia.

ALDEIAS, V. 2017. Experimental approaches to archaeological fire features and their behavioral relevance. *Current Anthropology,* 58**,** S191-S205.

ALDEIAS, V. & BICHO, N. 2016. Embedded Behavior: Human Activities and the Construction of the Mesolithic Shellmound of Cabeço da Amoreira, Muge, Portugal. *Geoarchaeology,* 31**,** 530-549.

ALDEIAS, V., GOLDBERG, P., DIBBLE, H. L. & EL-HAJRAOUI, M. 2014. Deciphering site formation processes through soil micromorphology at Contrebandiers Cave, Morocco. *Journal of Human Evolution,* 69**,** 8-30.

ALDEIAS, V., GOLDBERG, P., SANDGATHE, D., BERNA, F., DIBBLE, H. L., MCPHERRON, S. P., TURQ, A. & REZEK, Z. 2012. Evidence for Neandertal use of fire at Roc de Marsal (France). *Journal of Archaeological Science,* 39**,** 2414-2423.

ALDEIAS, V., GUR-ARIEH, S., MARIA, R., MONTEIRO, P. & CURA, P. 2016. Shell we cook it? An experimental approach to the microarchaeological record of shellfish roasting. *Archaeological and Anthropological Sciences***,** 1-19.

ALTUNA, J., CUENCA BESCÓS, G., ELORZA, M., GARCÍA PIMIENTA, J., MARIEZKURRENA, K., PEREZ RIPOLL, M., GONZÁLEZ MORALES, M. & STRAUS, L. Post-pleistocene faunas from the achaeological site of El Miron cave (Ramales de la Victoria, Cantabria, Spain): a preliminary summary. Miscelánea en homenaje a emiliano aguirre, 2004. Museo Arqueológico Regional, 40-49.

ÁLVAREZ-FERNÁNDEZ, E. 2015. Continuity of human-marine fauna interaction during the Holocene in Cantabrian Spain. *Quaternary International,* 364**,** 188-195.

ALVAREZ-FERNÁNDEZ, E. & ALTUNA, J. 2013. La cueva de Marizulo (Urnieta, Gipuzkoa), 50 anos después: Revisión de los restos arqueozoológicos de los niveles mesolıticos. *Kobie,* 32**,** 131-152.

ÁLVAREZ-FERNÁNDEZ, E., ÁLVAREZ-ALONSO, D., BÉCARES, J., CARRAL, P., CARRIOL, R.-P., CHAUVIN, A., CUBAS, M., CUETO, M., DOMINGO, R., DOUKA, K., ELORZA, M., JORDÁ-PARDO, J. F., MURELAGA, X., PORTERO, R., RIVERO, O., TAPIA, J., TARRIÑO, A. & TEIRA, L. C. 2016. Nouvelles données sur le Magdalénien inférieur de la Région Cantabrique : le Niveau F de la grotte de El Cierro (Ribadesella, Asturies, Espagne). *L'Anthropologie*.

ÁLVAREZ-FERNÁNDEZ, E., TERESA APARICIO-ALONSO, M., ARMENDARIZ, Á., ONTAÑON, R. & ARIAS, P. 2013. Étude archéomalacologique du gisement mésolithique de El Truchiro (Omoño, Ribamontán al Monte, Cantabrie). *Anthropozoologica,* 48**,** 153-170.

ÁLVAREZ, M., BRIZ GODINO, I., BALBO, A. & MADELLA, M. 2011. Shell middens as archives of past environments, human dispersal and specialized resource management. *Quaternary International,* 239**,** 1-7.

ANDERSEN, S. H. 'Køkkenmøddinger'(shell middens) in Denmark: a survey. Proceedings of the Prehistoric Society, 2000. Cambridge University Press, 361-384.

ANDRUS, C. F. T. 2011. Shell midden sclerochronology. *Quaternary Science Reviews,* 30**,** 2892-2905.

ANGELUCCI, D. E. 2003. A partir da terra: a contribuição da Geoarqueologia. *In:* MATEUS, J. E., MORENO-GARCÍA, M. & FARIA, A. M. D. (eds.) *Paleoecologia Humana e Arqueociências. Um programa multidisciplinar para a Arqueologia sob a tutela da cultura (Trabalhos de Arqueologia, 29).* Lisboa: Instituto Português de Arqueologia.

ANGELUCCI, D. E. 2006. Micromorphological observations on some samples from the prehistoric site of Barca do Xerez de Baixo. *Revista Portuguesa de Arqueologia,* 9**,** 5-19.

ANGELUCCI, D. E., ANESIN, D., SUSINI, D., VILLAVERDE, V., ZAPATA, J. & ZILHÃO, J. 2013. Formation processes at a high resolution Middle Paleolithic site: Cueva Antón (Murcia, Spain). *Quaternary International,* 315**,** 24-41.

ANGELUCCI, D. E., SOARES, A. M., ALMEIDA, L., BRITO, R. & LEITÃO, V. 2007. Neolithic occupation and mid-Holocene soil formation at Encosta de Sant'Ana (Lisbon, Portugal): a geoarchaeological approach. *Journal of Archaeological Science,* 34**,** 1641-1648.

ANTUNES, M. T., MEIN, P. & PAIS, J. 1986. Depósitos messinianos do sul de Portugal, mamíferos (incluindo Rodentia e Logomorpha) e idades K-Ar. *Ciências da Terra (UNL),* 8**,** 55-64.

APELLÁNIZ, J. M. 1971. El Mesolítico de la Cueva de Tarrerón y su datación por el C-14. *Munibe,* 23**,** 91-104.

APELLÁNIZ, J. M. 1975. El campamento mesolítico de pescadores de Kobeaga II (Ispaster). *Noticiario arqueológico hispánico***,** 229-240.

APELLÁNIZ, J. M. & ALTUNA, J. 1975. Memoria de la II. campana de excavaciones arqueologicas en la Cueva de Arenaza I (San Pedro de Galdames, Vizcaya). *Noticiaro Arqueologico Hispanico. Prehistoria***,** 155-181.

ARANBURU, A., ARRIOLABENGOA, M., IRIARTE, E., GIRALT, S., YUSTA, I., MARTÍNEZ-PILLADO, V., DEL VAL, M., MORENO, J. & JIMÉNEZ-SÁNCHEZ, M. 2015. Karst landscape evolution in the littoral area of the Bay of Biscay (north Iberian Peninsula). *Quaternary International,* 364**,** 217-230.

ARANZADI, T. D., BARANDIARÁN, J. M. D. & EGUREN, E. 1931. *Exploraciones en la Caverna de Santimamiñe (Basondo, Cortézubi), 2ª Memoria - Los niveles con cerámica y el conchero,* Bilbao, Diputación de Vizcaya.

ARANZADI, T. D., BARANDIARÁN, J. M. D. & EGUREN, E. 1935. *Exploraciones de la Caverna de Santimamiñe (Basondo: Cortézubi). 3ª Memoria - Yacimientos Azilienses y Paleolíticos.,* Bilbao, Diputación de Vizcaya.

ARAÚJO, A. C. 1995-1997. A indústria lítica do concheiro de Poças de S. Bento (Vale do Sado) no seu contexto regional. *O Arqueólogo Português, Serie IV,* 13-15**,** 87-159.

ARAÚJO, A. C. 2003. O Mesolítico inicial da Estremadura. *Muita gente, poucas antas***,** 101-114.

ARAÚJO, A. C. 2009. Hunter-gatherer adaptations during the Pleistocene/Holocene transition in Portugal: data and explanatory models. *In:* MCCARTAN, S., SCHULTING, R., WARREN, G. & WOODMAN, P. (eds.) *Mesolithic Horizons.* Oxford: Oxbow Books.

ARAÚJO, A. C. 2011. *O concheiro de Toledo no contexto do Mesolítico Inicial do litoral da Estremadura,* Lisboa, Instituto de Gestão do Património Arquitectónico e Arqueológico, IGESPAR.

ARAÚJO, A. C. 2016. Antes do afagar a terra: quando o território era então mesolítico. *In:* DINIZ, M., NEVES, C. & MARTINS, A. (eds.) *O Neolítico em Portugal antes do Horizonte 2020: perspectivas em debate.* Lisboa: Associação dos Arqueólogos Portugueses.

ARAÚJO, A. C. 2016b. The Significance of Marine Resources during the Early Mesolithic in Portugal. *In:* DUPONT, C. & MARCHAND, G. (eds.) *Archéologie des chasseurs-cueilleurs maritimes. De la fonction des habitats à l'organisation de l'espace littoral. Actes de la séance de la Société préhistorique française de Rennes, 10-11 avril 2014.* Société préhistorique française.

ARAÚJO, A. C. & ALMEIDA, F. 2003. Barca do Xerez de Baixo: balanço de quatro anos de trabalhos arqueológicos. *Revista portuguesa de arqueologia,* 6**,** 17-67.

ARAÚJO, A. C. & ALMEIDA, F. 2013. *Barca do Xerez de Baixo: um testemunho invulgar das últimas comunidades de caçadores-recolectores do Alentejo interior,* EDIA, Empresa de desenvolvimento e infra-estruturas do Alqueva.

ARAÚJO, A. C., GARCÍA, M. M. & GABRIEL, S. 2014. Para além de Toledo: outros dados, novas revisões e algumas reflexões sobre o Mesolitico Antigo do litoral da Estremadura. *Revista Portuguesa de Arqueologia,* 17**,** 5-34.

ARESO BARQUÍN, P. & URIZ GALARRAGA, A. 2014. Estudio sedimentológico del depósito arqueológico de la cueva de Santa Catalina (Lekeitio, Bizkaia). *In:* BERGANZA GOCHI, E. & ARRIBAS PASTOR, J. L. (eds.) *La Cueva de Santa Catalina (Lekeitio, Bizkaia): La intervención arqueológica. Restos vegetales, animales y humanos.* Bilbao: Diputación Foral de Bizkaia

ARESO, P. & URIZ, A. 1995. Estudio sedimentológico de la cueva sepulcral de Pico Ramos (Muskiz, Bizkaia) *Munibe (Antropologia-Arkeologia),* 47**,** 91-99.

ARESO, P. & URIZ, A. 2000. Estudio sedimentológico del yacimiento de Kobeaga II (Ispaster, Bizkaia). *Illunzar,* 4**,** 163-169.

ARIAS CABAL, P. 2005. Determinaciones de isótopos estables en restos humanos de la región Cantábrica: aportación al estudio de la dieta de las poblaciones del Mesolítico y el Neolítico. *Munibe Antropologia-Arkeologia***,** 359-374.

ARIAS CABAL, P., FANO MARTÍNEZ, M. A., ARMENDÁRIZ GUTIÉRREZ, Á., ÁLVAREZ FERNÁNDEZ, E., CUETO RAPADO, M., FERNÁNDEZ GARCÍA, R., GARRALDA, M. D., MENSUA CALZADO, C. & TEIRA MAYOLINI, L. C. 2007. Programa de sondeos en concheros holocenos del Oriente de Asturias. *Excavaciones arqueológicas en Asturias 1999-2002.* Oviedo: Consejería de Cultura, Comunicación Social y Turismo.

ARIAS, P. 1999. The origins of the Neolithic along the Atlantic coast of continental Europe: a survey. *Journal of world prehistory,* 13**,** 403-464.

ARIAS, P. 2007. Neighbours but diverse: social change in north-west Iberia during the transition from the Mesolithic to the Neolithic (5500-4000 cal BC). *In:* WHITTLE, A.

& CUMMINGS, V. (eds.) *Going over: the Mesolithic-Neolithic transition in north-west Europe.* . Oxford: Oxford University Press.

ARIAS, P. & ALTUNA, J. 1999. Nuevas dataciones absolutas para el Neolítico de la cueva de Arenaza (Bizkaia). *Munibe Antropologia-Arkeologia,* 51**,** 161-171.

ARIAS, P. & ALVAREZ-FERNANDEZ, E. Iberian foragers and funerary ritual–A review of Paleolithic and Mesolithic evidence on the Peninsula. The Mesolithic of the Atlantic Façade: Proceedings of the Santander Symposium, 2004. Arizona State University, 225-248.

ARIAS, P., CUBAS, M., FANO, M. Á., ÁLVAREZ FERNÁNDEZ, E., ARAÚJO, A. C., CUETO, M., DUARTE, C., FERNÁNDEZ SÁNCHEZ, P., IRIRTE, E., JORDÁ PARDO, J. F., LÓPEZ-DÓRIGA, I. L., NÚÑEZ, S., SALZMANN, C., TAPIA, J., TEICHNER, F., TEIRA, L. C., UZQUIANO, P. & VALLEJO, J. 2016. Une nouvelle approche pour l'étude de l'habitat mésolithique dans le nord de la Péninsule Ibérique : Recherches dans le site au plein air d'El Alloru (Asturies, Espagne). *In:* DUPONT, C. & MARCHAND, G. (eds.) *Archéologie des chasseurs-cueilleurs maritimes. De la fonction des habitats à l'organisation de l'espace littoral. Actes de la séance de la Société préhistorique française de Rennes, 10-11 avril 2014.* Société Préhistorique Française.

ARIAS, P., CUBAS, M., FANO, M. A., PARDO, J. F. J., SALZMANN, C., TEICHNER, F. & TEIRA, L. C. 2015a. Where are the 'Asturian'dwellings? An integrated survey programme on the Mesolithic of northern Spain. *Antiquity,* 89**,** 783-799.

ARIAS, P., DINIZ, M., ARAÚJO, A. C., ARMENDÁRIZ, Á. & TEIRA, L. C. 2015b. At the edge of the marshes: new approaches to the Sado valley Mesolithic (southern Portugal). *In:* BICHO, N., DETRY, C., PRICE, D. T. & CUNHA, E. (eds.) *Muge 150th: The 150th Anniversary of the Discovery of Mesolithic Shellmiddens. Volume 1.*: Cambridge Scholars Publishing.

ARIAS, P., DINIZ, M., CUBAS, M., DUARTE, C., IRIARTE, E., SALZMANN, C., TEICHNER, F. & TEIRA, L. 2017. Looking for the traces of the last hunter–gatherers: Geophysical survey in the Mesolithic shell middens of the Sado valley (southern Portugal). *Quaternary International,* 435, Part B**,** 61-70.

ARIAS, P., FERNÁNDEZ-TRESGUERRES, V., JUAN A. , ÁLVAREZ-FERNÁNDEZ, E., ARMENDÁRIZ-GUTIÉRREZ, Å., CUETO-RAPADO, M., FANO-MARTÍNEZ, M. A., FERNÁNDEZ-GARCÍA, R., GARRALDA-BENAJES, M. D., MENSUA-CALZADO, C. & TEIRA-MAYOLINI, L. C. 2007. Excavación arqueológica de urgencia en la Cueva de la Poza l'Égua (Lledías, Llanes). *Excavaciones arqueológicas en Asturias: 1999-2002.* Consejeria de Cultura, Comunicación Social y Turismo del Principado de Asturias.

ARIAS, P. & GARRALDA, M. D. 1996. Mesolithic burials in los Canes cave (asturias, spain). *Human Evolution,* 11**,** 129-138.

ARIAS, P. & SUAREZ, C. P. 1990. Investigaciones prehistóricas en la Sierra Plana de la Borbolla (1979-1986). *Excavaciones Arqueológicas en Asturias 1983-1986***,** 143-151.

ARNAUD, J. M. 1986. Cabeço das Amoreiras, S. Romão do Sado. *Informação Arqueológica,* 7**,** 80-82.

ARNAUD, J. M. 1987. Os concheiros mesolíticos dos vales do Tejo e Sado: semelhanças e diferenças. *Arqueologia,* 15**,** 53-64.

ARNAUD, J. M. The Mesolithic Communities of the Sado Valley, Portugal in their Ecological Setting. The Mesolithic in Europe. International Symposium. 3, 1989. 614-631.

ARNAUD, J. M. 1993. O Mesolítico e a neolitização: balanço e perspectivas. *In:* CARVALHO, G. S., FERREIRA, A. B. & C., S.-M. J. (eds.) *O Quaternário em Portugal: Balanços e Perspectivas.* Lisboa: APEQ, Ed. Colibri.

ARNAUD, J. M. 2000. Os concheiros mesolíticos do vale do Sado e a exploração dos recursos estuarinos (nos tempos pré-históricos e na actualidade). *Actas do Encontro sobre Arqueologia da Arrábida, Trabalhos de Arqueologia,* 4**,** 21-43.

ARNAUD, J. M. & LARSSON, L. 1994. Concheiro das Poças de S. Bento. *Informação arqueológica,* 9**,** 130-32.

ARPIN, T. L., MALLOL, C. & GOLDBERG, P. 2002. Short contribution: A new method of analyzing and documenting micromorphological thin sections using flatbed scanners: Applications in geoarchaeological studies. *Geoarchaeology,* 17**,** 305-313.

ARRIOLABENGOA, M., IRIARTE, E., ARANBURU, A., YUSTA, I. & ARRIZABALAGA, A. 2015. Provenance study of endokarst fine sediments through mineralogical and geochemical data (Lezetxiki II cave, northern Iberia). *Quaternary International,* 364**,** 231-243.

AYARZAGÜENA-SANZ, M. 2018. El papel desempeñado por geólogos e ingenieros de minas en la consolidación de la Arqueología prehistórica en España (1860-1970). *Boletín Geológico y Minero,* 129**,** 13-33.

BACCELLE, L. & BOSELLINI, A. 1965. *Diagrammi per la stima visiva: della composizione percentuale nelle rocce sedimentarie*, Università degli studi di Ferrara.

BAILEY, G. 1983. Problems of site formation and the interpretation of spatial and temporal discontinuities in the distribution of coastal middens. *In:* MASTERS, P. M. & FLEMMING, N. C. (eds.) *Quaternary coastlines and marine archaeology.* New York: Academic Press.

BAILEY, G. & MILNER, N. 2002. Coastal hunter-gatherers and social evolution: marginal or central? *Before farming,* 2002**,** 1-22.

BAILEY, G. & SPIKINS, P. 2008. *Mesolithic Europe,* Cambridge University Press.

BAILEY, G. N. & CRAIGHEAD, A. S. 2003. Late Pleistocene and Holocene coastal palaeoeconomies: A reconsideration of the molluscan evidence from northern Spain. *Geoarchaeology,* 18**,** 175-204.

BAJNÓCZI, B. & KOVÁCS-KIS, V. 2006. Origin of pedogenic needle-fiber calcite revealed by micromorphology and stable isotope composition—a case study of a Quaternary paleosol from Hungary. *Chemie der Erde - Geochemistry,* 66**,** 203-212.

BALBO, A., MADELLA, M., GODINO, I. B. & Ã• LVAREZ, M. 2011. Shell midden research: An interdisciplinary agenda for the Quaternary and Social Sciences. *Quaternary International,* 239**,** 147-152.

BALBO, A. L., MADELLA, M., VILA, A. & ESTÉVEZ, J. 2010. Micromorphological perspectives on the stratigraphical excavation of shell middens: a first approximation from the ethnohistorical site Tunel VII, Tierra del Fuego (Argentina). *Journal of Archaeological Science,* 37**,** 1252-1259.

BARRADAS, L. A. 1936. Concheiros do Vale do Sado. *Anais da Faculdade de Ciências do Porto,* 21 (3)**,** 175-179.

BARTOLOMÉ, M. P., UGARTE, P. M. C., GABILONDO, F. E., MUÑIZ, A. M., IZQUIERDO, E. R., GIL-GARCÍA, M. J., RUIZ, B., PRADA, A., SOLAR, M. & OLLERO, P. U. 2016. El Abrigo del Carabión (San Mamés de Aras-Cantabria, España) en el contexto mesolítico del Estuario del Asón y Marismas de Santoña: un depósito arqueológico con una secuencia de ocupación en el Holoceno inicial y medio en el oriente de la región cantábrica. *Munibe Antropologia-Arkeologia***,** 5-34.

BASTIDA, F. 2004. Zona Cantábrica. *In:* VERA, J. A. (ed.) *Geología de España.* Madrid: SGE-IGME.

BELL, M. 1981. Seaweed as a prehistoric resource. *Environmental Aspect of Coasts and Islands, British Archaeological Reports International Series,* 94**,** 117-26.

BELLO-ALONSO, P., OZKORTA-ESCRIBANO, L. & GUTIÉRREZ-ZUGASTI, I. 2015. Un acercamiento al aprovechamiento de los recursos litorales durante el Mesolítico: los invertebrados marinos del abrigo de El Toral III (Llanes, Asturias). *La Investigación Arqueomalacológica en la Península Ibérica: Nuevas Aportaciones***,** 91.

BENEDETTI, M. M., CORDOVA, C. E. & BEACH, T. 2011. Soils, sediments, and geoarchaeology: Introduction. *CATENA,* 85**,** 83-86.

BERGADÀ, M. M., VILLAVERDE, V. & ROMÁN, D. 2013. Microstratigraphy of the Magdalenian sequence at Cendres Cave (Teulada-Moraira, Alicante, Spain): Formation and diagenesis. *Quaternary International,* 315**,** 56-75.

BERGANZA GOCHI, E. & ARRIBAS PASTOR, J. L. 2014. Estructuras de combustión. *In:* BERGANZA GOCHI, E. & ARRIBAS PASTOR, J. L. (eds.) *La Cueva de Santa Catalina (Lekeitio, Bizkaia): La intervención arqueológica. Restos vegetales, animales y humanos.* Bilbao: Diputación Foral de Bizkaia

BERIHUETE-AZORÍN, M., GIRBAL, J., PIQUÉ, R., PALOMO, A. & TERRADAS, X. 2018. Punk's not dead. Fungi for tinder at the Neolithic site of La Draga (NE Iberia). *PLOS ONE,* 13**,** e0195846.

BERNA, F., GOLDBERG, P., HORWITZ, L. K., BRINK, J., HOLT, S., BAMFORD, M. & CHAZAN, M. 2012. Microstratigraphic evidence of in situ fire in the Acheulean strata of Wonderwerk Cave, Northern Cape province, South Africa. *Proceedings of the National Academy of Sciences,* 109**,** E1215–E1220.

BERTRAN, P. & TEXIER, J.-P. 1999. Facies and microfacies of slope deposits. *CATENA,* 35**,** 99-121.

BICHO, N. 2009. Sistemas de povoamento, subsistência e relações sociais dos últimos caçadores-recolectores do Vale do Tejo. *Estudos Arqueológicos de Oeiras,* 17**,** 133-156.

BICHO, N., CASCALHEIRA, J., MARREIROS, J., GONÇALVES, C., PEREIRA, T. & DIAS, R. 2013. Chronology of the Mesolithic occupation of the Muge valley, central Portugal: The case of Cabeço da Amoreira. *Quaternary International,* 308–309**,** 130-139.

BICHO, N., CASCALHEIRA, J., MARREIROS, J. & PEREIRA, T. 2011a. The 2008–2010 excavations of Cabeço da Amoreira, Muge, Portugal. *Mesolithic Miscellany,* 21**,** 3-13.

BICHO, N. & HAWS, J. 2008. At the land's end: marine resources and the importance of fluctuations in the coastline in the prehistoric hunter–gatherer economy of Portugal. *Quaternary Science Reviews,* 27**,** 2166-2175.

BICHO, N., HAWS, J. & ALMEIDA, F. 2011b. Hunter–gatherer adaptations and the Younger Dryas in central and southern Portugal. *Quaternary International,* 242**,** 336-347.

BICHO, N., UMBELINO, C., DETRY, C. & PEREIRA, T. 2010. The Emergence of Muge Mesolithic Shell Middens in Central Portugal and the 8200 cal yr BP Cold Event. *The Journal of Island and Coastal Archaeology,* 5**,** 86-104.

BICHO, N. F. 1994. The end of the Paleolithic and the Mesolithic in Portugal. *Current Anthropology,* 35**,** 664-674.

BICHO, N. F. 1999. A ocupação epipaleolítica do Abrigo Grande das Bocas, Rio Maior. *O Arqueólogo Português,* 13**,** 53-85.

BILLARD, C. & BERNARD, V. 2016. Les barrages à poissons au Mésolithique : une économie de prédation ou de production? *In:* DUPONT, C. & MARCHAND, G. (eds.) *Archéologie des chasseurs-cueilleurs maritimes. De la fonction des habitats à* *l'organisation de l'espace littoral. Actes de la séance de la Société préhistorique française de Rennes, 10-11 avril 2014, Société Préhistorique Française.*

BINFORD, L. R. 1968. Post-Pleistocene adaptations. *In:* BINFORD, S. R. & BINFORD, L. R. (eds.) *New Perspectives in Archaeology.* Aldine, Chicago.

BREUIL, H. & ZBYSZEWSKI, G. 1942. *Contribution à l'étude des industries paléolithiques du Portugal et de leurs rapports avec la géologie du Quaternaire, les principaux gisements des deux rives de l'ancien estuaire du Tage*, Oficinas gráficas,'Casa Portuguesa'.

BRIZ GODINO, I., Ã• LVAREZ, M., BALBO, A., ZURRO, D. B., MADELLA, M., VILLAGRÁN, X. & FRENCH, C. 2011. Towards high-resolution shell midden archaeology: Experimental and ethnoarchaeology in Tierra del Fuego (Argentina). *Quaternary International,* 239**,** 125-134.

BULLOCK, P., FEDOROFF, N., JONGERIUS, A., STOOPS, G. & TURSINA, T. 1985. *Handbook for soil thin section description,* Wolverhampon, UK, Waine Research.

BURKE, A., MEIGNEN, L., BISSON, M., PIMENTEL, N., HENRIQUES, V., ANDRADE, C., FREITAS, M. D. C., KAGEYAMA, M., FLETCHER, W. & PARSLOW, C. 2011. The Palaeolithic occupation of southern Alentejo: the Sado River Drainage Survey. *Trabajos de Prehistoria,* 68**,** 25-49.

BUTZER, K. W. 1973. Spring sediments from the Acheulian site of Amanzi (Uitenhage District, South Africa). *Quaternaria,* 17**,** 299-319.

BUTZER, K. W. 1975. The ecological approach to archaeology: are we really trying? *American Antiquity,* 40**,** 106-111.

BUTZER, K. W. 1981. Cave sediments, upper pleistocene stratigraphy and mousterian facies in Cantabrian Spain. *Journal of Archaeological Science,* 8**,** 133-183.

BUTZER, K. W. 1982. *Archaeology as human ecology: method and theory for a contextual approach,* Cambridge University Press.

BUTZER, K. W. & BOWMAN, D. 1976. Algunos sedimentos arqueológicos asturienses de yacimientos de la España cantábrica. *In:* CLARK, G. A. (ed.) *El Asturiense Cantábrico.* Madrid: CSIC.

BUURMAN, P. & JONGMANS, A. G. 2005. Podzolisation and soil organic matter dynamics. *Geoderma*, 125**,** 71-83.

CABRAL, J. 1995. *Neotectónica em Portugal continental*, Instituto Geológico e Mineiro.

CANTI, M. G. 2003. Aspects of the chemical and microscopic characteristics of plant ashes found in archaeological soils. *CATENA*, 54**,** 339-361.

CARBALLO, J. 1926. *El esqueleto humano más antiguo de España*, Athor's edition.

CARDOSO, J. L. 2002. *Pré-História de Portugal*, Editorial Verbo.

CARVALHO, A. F. 2007. Novos dados sobre dois temas da Pré-História do Sul de Portugal: o Mirense e o processo de neolitização. *Promontoria, Revista do Departamento de História, Arqueologia e Património da Universidade do Algarve***,** 91-110.

CARVALHO, A. F. 2008. *A neolitização do Portugal Meridional: os exemplos do Maciço Calcário Estremenho e do Algarve Ocidental,* Faro, Universidade do Algarve, Departamento de História, Arqueologia e Património, Centro de Estudos de Património.

CARVALHO, A. F. 2009. O Mesolítico final em Portugal. *El mesolítico geométrico en la Península Ibérica. Monografías Arqueológicas 44.*

CARVALHO, A. F. & VALENTE, M. J. 2005. Novos contextos conquíferos pré-históricos na Costa Vicentina. *XELB: revista de arqueologia, arte, etnologia e história***,** 9-26.

CASADO, Y. D. & MORALES, M. R. G. La Prehistoria de las Marismas: excavaciones arqueológicas en los abrigos de la Peña del Perro, Santoña. Actuaciones arqueológicas en Cantabria 1984-1999, 2000. Consejería de Cultura, Turismo y Deporte, Gobierno de Cantabria, 93-96.

CAVA, A. 1978. El depósito arqueológico de la cueva de Marizulo (Guipúzcoa). *Munibe,* 4**,** 155-172.

CEARRETA, A., ALDAY, M., CONCEIÇÃO FREITAS, M., ANDRADE, C. & CRUCES, A. 2002. Modern foraminiferal record of alternating open and restricted environmental conditions in the Santo André lagoon, SW Portugal. *Hydrobiologia,* 475**,** 21-27.

CEARRETA, A., ALDAY, M., FREITAS, M. D. C. & ANDRADE, C. 2007. Postglacial foraminifera and paleoenvironments of the Melides lagoon (SW Portugal): towards a regional model of coastal evolution. *The Journal of Foraminiferal Research,* 37**,** 125-135.

CEARRETA, A., CACHÃO, M., CABRAL, M. C., BAO, R. & RAMALHO, M. D. J. 2003. Lateglacial and Holocene environmental changes in Portuguese coastal lagoons 2: microfossil multiproxy reconstruction of the Santo André coastal area. *The Holocene,* 13**,** 447-458.

CEARRETA, A. & GARCÍA FERNÁNDEZ, Z. 2015. El relleno sedimentario holoceno de la marisma de Txipio (Plentzia-Barrika, Vizcaya): registro de los cambios ambientales en el estuario del Butroe durante los últimos 8.500 años.

CEARRETA, A. & MONGE-GANUZAS, M. 2013. Evolución paleoambiental del estuario del Oka (Reserva de la Biosfera de Urdaibai, Vizcaya): respuesta al ascenso del nivel marino durante el Holoceno. *Geo-temas,* 14**,** 16.

CEARRETA, A. & MURRAY, J. 1996. Holocene paleoenvironmental and relative sea-level changes in the Santoña estuary, Spain. *Journal of Foraminiferal Research,* 26**,** 289-299.

CEARRETA, A. & MURRAY, J. W. 2000. AMS 14C dating of Holocene estuarine deposits: consequences of high-energy and reworked foraminifera. *The Holocene*, 10**,** 155-159.

CHAFETZ, H. S. & FOLK, R. L. 1984. Travertines: depositional morphology and the bacterially constructed constituents. *Journal of Sedimentary Research,* 54.

CLAASSEN, C. 1991. Normative thinking and shell-bearing sites. *Archaeological method and theory,* 3**,** 249-298.

CLAASSEN, C. P. 1996. A consideration of the social organization of the Shell Mound Archaic. *Archaeology of the mid-Holocene Southeast***,** 235-258.

CLARK, G. A. 1975. *El hombre y su ambiente a comienzos del Holoceno en la Región Cantábrica: los cazadores-recolectores asturienses,* Oviedo, Instituto de Estudios Asturianos.

CLARK, G. A. 1976. *El Asturiense Cantábrico,* Madrid, Instituto Español de Prehistoria.

CLARK, G. A. & CLARK, V. J. 1975. La cueva de Balmori (Asturias, España): nuevas aportaciones. *Trabajos de prehistoria,* 32**,** 35.

COBO, J. R. & SMITH, P. 2001. El yacimiento del Cubío Redondo (Matienzo, Ruesga) &58; Una estación mesolítica de montaña en Cantabria. *Munibe Antropologia-Arkeologia,* 53**,** 31-55.

COLONESE, A. C., TROELSTRA, S., ZIVERI, P., MARTINI, F., LO VETRO, D. & TOMMASINI, S. 2009. Mesolithic shellfish exploitation in SW Italy: seasonal evidence from the oxygen isotopic composition of Osilinus turbinatus shells. *Journal of Archaeological Science,* 36**,** 1935-1944.

COLONESE, A. C., VERDÚN-CASTELLÓ, E., ÁLVAREZ, M., BRIZ I GODINO, I., ZURRO, D. & SALVATELLI, L. 2012. Oxygen isotopic composition of limpet shells from the Beagle Channel: implications for seasonal studies in shell middens of Tierra del Fuego. *Journal of Archaeological Science,* 39**,** 1738-1748.

CHC 2018. Confederacion Hidrográfica del Cantábrico. *Marco físico*. [ONLINE] Available at: https://www.chcantabrico.es/marco-fisico. [Accessed 11 July 2018].

CORNWALL, I. W. 1958. Soils for the Archaeologist. Phoenix House.

COSTA, A. M., FREITAS, M. C., ARIAS, P., DINIZ, M., ARAÚJO, A. C. 2017. Sado River sediments as a major source of information to recostruct Mesolithic landscapes. . *1st Meeting of Histories of Nature and Environment: Dialogues and Perspectives, Lisbon, March 2017.*

COSTA, A. M., FREITAS, M. C., ARIAS, P., DINIZ, M., ARAÚJO, A. C., ANDRADE, C., RODRIGUES, A., DUARTE, J., CACHÃO, M., LEIRA, M. 2015. Lower Sado basin sediments: a source for information for the late Mesolithic behaviour. *Proceeding of Progress in Quaternary Archive Studies in the Iberian Peninsula, Seville, March 2015.*

COSTAS, S., FERREIRA, Ó., PLOMARITIS, T. A. & LEORRI, E. 2016. Coastal barrier stratigraphy for Holocene high-resolution sea-level reconstruction. *Scientific Reports,* 6**,** 38726.

COSTAS, S., REBÊLO, L., BRITO, P., BURBIDGE, C. I., PRUDÊNCIO, M. I. & FITZGERALD, D. 2015. The Joint History of Tróia Peninsula and Sado Ebb-Delta.

*In:* RANDAZZO, G., JACKSON, D. & COOPER, A. (eds.) *Sand and Gravel Spits.* Springer.

COURTY, M.-A. 2001. Microfacies Analysis Assisting Archaeological Stratigraphy. *In:* GOLDBERG, P., HOLLIDAY, V. T. & FERRING, C. R. (eds.) *Earth Sciences and Archaeology.* Boston, MA: Springer US.

COURTY, M.-A., CARBONELL, E., VALLVERDÚ POCH, J. & BANERJEE, R. 2012. Microstratigraphic and multi-analytical evidence for advanced Neanderthal pyrotechnology at Abric Romani (Capellades, Spain). *Quaternary International,* 247**,** 294-312.

COURTY, M.-A. & FEDOROFF, N. 2002. Micromorphologie des sols et sédiments archéologiques. *In:* MISKOVSKY, J.-C. (ed.) *Géologie de la Préhistoire: méthodes, techniques, applications.* Paris: Presses Universitaires de Perpignan.

COURTY, M.-A. & VALLVERDU, J. 2001. The microstratigraphic record of abrupt climate changes in cave sediments of the Western Mediterranean. *Geoarchaeology,* 16**,** 467-499.

COURTY, M., GOLDBERG, P. & MACPHAIL, R. 1989. *Soils and Micromorphology in Archaeology,* Cambridge, Cambridge University Press, Cambridge.

CROMBÉ, P. & ROBINSON, E. 2014. European Mesolithic: Geography and Culture. *In:* SMITH, C. (ed.) *Encyclopedia of Global Archaeology.* New York, NY: Springer New York.

CUBAS, M., ALTUNA, J., ALVAREZ-FERNÁNDEZ, E., ARMENDARIZ, A., FANO, M. A., LÓPEZ-DÓRIGA, I. L., MARIEZKURRENA, K., TAPIA, J., TEIRA, L. C. & ARIAS, P. 2016. Re-evaluating the Neolithic: the impact and the consolidation of farming practices in the Cantabrian Region (Northern Spain). *Journal of World Prehistory,* 29**,** 79-116.

CUENCA-SOLANA, D. 2014. The Use of Shells by Hunter-Fisher-Gatherers and Farmers From the Early Upper Palaeolithic to the Neolithic in the European Atlantic Façade: A Technological Perspective. *The Journal of Island and Coastal Archaeology***,** 1-24.

CUENCA SOLANA, D. 2013. *Utilización de instrumentos de concha para la realización de actividades productivas en las formaciones económico-sociales de cazadores-*

*recolectores-pescadores y primeras sociedades tribales de la fachada atlántica europea*, PUbliCan Ediciones - Universidad de Cantabria.

CUNHA, E., CARDOSO, F. & UMBELINO, C. Inferences about Mesolithic life style on the basis of anthropological data. The case of the Portuguese shell middens. *In:* LARSSON, L., KINDGREN, H., K. KNUTSSON, LOEFFER & AKERLUND, A., eds. Mesolithic on the Movie: Papers Presented at the Sixth International Conference on the Mesolithic in Europe, Oxbow Books, Oxford, 2003. 84-188.

CUNHA, E. & UMBELINO, C. 1995. Abordagem antropológica das comunidades mesolíticas dos Concheiros do Sado. *O Arqueólogo Português,* 4**,** 161-179.

CUNHA, E. & UMBELINO, C. 2001. Mesolithic people from Portugal: an approach to Sado osteological series. *Anthropologie,* 39**,** 125.

DE VICENTE, G., CLOETINGH, S., VAN WEES, J. D. & CUNHA, P. P. 2011. Tectonic classification of Cenozoic Iberian foreland basins. *Tectonophysics,* 502**,** 38-61.

DEÁK, J., GEBHARDT, A., LEWIS, H., USAI, M. R. & LEE, H. 2017. Soils Disturbed by Vegetation Clearance and Tillage. *In:* NICOSIA, C. & STOOPS, G. (eds.) *Archaeological Soil and Sediment Micromorphology.* John Wiley & Sons.

DEAN, R. M., VALENTE, M. J. & CARVALHO, A. F. 2012. The Mesolithic/Neolithic transition on the Costa Vicentina, Portugal. *Quaternary International,* 264**,** 100-108.

DEL RIO, H. A., BREUIL, H. & SIERRA, L. 1911. *Les Cavernes de la Région Cantabrique (Espagne),* Monaco, Imprimerie Vve A. Chene.

DETRY, C. 2007. Paleoecologia e Paleoeconomia do Baixo Tejo no Mesolítico Final: O contributo do estudo dos mamíferos dos concheiros de Muge. PhD thesis. Universidad de Salamanca/Universidade Autónoma de Lisboa.

DIAS, J. 2004. A história da evolução do litoral português nos últimos vinte milénios. *Actas do Colóquio: Evolução Geohistórica do Litoral Português e Fenómenos Correlativos. Geologia, História, Arqueologia e Climatologia. Lisboa: Universidade Aberta***,** 157-170.

DIAS, J. M. A., BOSKI, T., RODRIGUES, A. & MAGALHÃES, F. 2000. Coast line evolution in Portugal since the Last Glacial Maximum until present — a synthesis. *Marine Geology,* 170**,** 177-186.

DIAS, R., DETRY, C. & BICHO, N. 2016. Changes in the exploitation dynamics of small terrestrial vertebrates and fish during the Pleistocene–Holocene transition in the SW Iberian Peninsula: A review. *The Holocene,* 26**,** 964-984.

DIAS, R., DETRY, C. & PEREIRA, A. 2015. What's New? The Remains of Vertebrates from Cabeço da Amoreira - 2008-2012 Campaigns: Preliminary Data. *In:* BICHO, N., DETRY, C., PRICE, D. T. & CUNHA, E. (eds.) *Muge 150th: The 150th Anniversary of the Discovery of Mesolithic Shellmiddens.* . Cambridge Scholars Publishing.

DINIZ, M. T. & ARIAS, P. 2012. O povoamento humano do paleo-estuário do Sado (Portugal): problemáticas em torno da ocupação dos concheiros mesolíticos. *In:* ALMEIDA, A. C., BETTENCOURT, A. M. S., MOURA, D., MONTEIRO-RODRIGUES, S. & ALVES, M. I. C. (eds.) *Environmental changes and human interaction along the Western Atlantic edge / Mundanças ambientais e interação humana na fachada atlântica ocidental.* Coimbra: APEQ-CITCEM-CEGOT-CGUP-CCT.

DUPONT, C. 2011. Les invertébrés marins du "concheiro" de Toledo (Lourinhã, Portugal). *O concheiro de Toledo no contexto do Mesolítico Inicial do litoral da Estremadura. Trabalhos de Arqueologia,* 51**,** 185e227.

DUPONT, C. & ARAÚJO, A. C. 2010. Ressuscitar o concheiro mesolítico de Toledo (Lourinhã, Portugal): uma lixeira repleta de invertebrados marinhos. *Férvedes: Revista de investigación***,** 53-62.

DUPONT, C. & BICHO, N. 2015. Marine Invertebrates and Models of Economic Organization of the Coastal Zone during the Mesolithic: French and Portuguese Examples. *In:* BICHO, N., DETRY, C., PRICE, D. T. & CUNHA, E. (eds.) *Muge 150th: The 150th Anniversary of the Discovery of Mesolithic Shellmiddens.* . Cambridge Scholars Publishing.

DURAND, N., MONGER, H. C. & CANTI, M. G. 2010. 9 - Calcium Carbonate Features. *In:* STOOPS, G., MARCELINO, V. & MEES, F. (eds.) *Interpretation of Micromorphological Features of Soils and Regoliths.* Amsterdam: Elsevier.

ÉGÜEZ, N., MALLOL, C., MARTÍN-SOCAS, D. & CAMALICH, M. D. 2014. Radiometric dates and micromorphological evidence for synchronous domestic activity and sheep penning in a Neolithic cave: Cueva de El Toro (Málaga, Antequera, Spain). *Archaeological and Anthropological Sciences***,** 107-123.

ELORZA, M. 2012. Bird remains from the Post-Azilian levels of El Mirón Cave. *In:* STRAUS, L. G. & MORALES, M. R. G. (eds.) *El Mirón Cave, Cantabrian Spain: the site and its Holocene archaeological record.* Abuquerque: University of New Mexico Press.

ERLANDSON, J. M. 2001. The Archaeology of Aquatic Adaptations: Paradigms for a New Millennium. *Journal of Archaeological Research,* 9**,** 287-350.

ERLANDSON, J. M. 2013. Shell middens and other anthropogenic soils as global stratigraphic signatures of the Anthropocene. *Anthropocene,* 4**,** 24-32.

FAIRCHILD, I. J. & BAKER, A. 2012. *Speleothem science: from process to past environments*, John Wiley & Sons.

FANO, M. A. 1998. *El habitat mesolitico en el Cantabrico occidental. Transformaciones ambietales y medio físico durante el Holoceno antíguo.,* Oxford, British Archaeological Reports.

FANO, M. Á. 2004. Un nuevo tiempo: el Mesolítico en la región cantábrica. *Kobie (Serie Anejos),* 8**,** 337-402.

FANO, M. Á. 2018. The Mesolithic “Asturian” culture (North Iberia), one century on. *Quaternary International*.

FANO, M. Á., CUBAS, M. & WOOD, R. 2015. The first farmers in Cantabrian Spain: Contribution of numerical chronology to understand an historical process. *Quaternary International,* 364**,** 153-161.

FANO, M. A. & GONZÁLEZ MORALES, M. R. Nine decades of research on the «Asturian» of Cantabria. The Mesolithic of the Atlantic Facade: proceedings of the Santander Symposium, Tempe Anthropological Research Papers, 2004. 167-179.

FIGUEIREDO, O. 2012. Burial Practices in Muge Shell Middens (Portugal): State of the art. *In:* ALMEIDA, A. C., BETTENCOURT, A. M. S., MOURA, D., MONTEIRO-RODRIGUES, S. & ALVES, M. I. C. (eds.) *Environmental changes and human interaction along the Western Atlantic edge / Mundanças ambientais e interação* *humana na fachada atlântica ocidental.* Coimbra: APEQ-CITCEM-CEGOT-CGUP-CCT.

FISCHER, A., OLSEN, J., RICHARDS, M., HEINEMEIER, J., SVEINBJÖRNSDÓTTIR, Á. E. & BENNIKE, P. 2007. Coast–inland mobility and diet in the Danish Mesolithic and Neolithic: evidence from stable isotope values of humans and dogs. *Journal of Archaeological Science,* 34**,** 2125-2150.

FLOR, G. & FLOR-BLANCO, G. 2014. Raised Beaches in the Cantabrian Coast. *Landscapes and landforms of Spain.* Springer Netherlands.

FLÜGEL, E. 2004. *Microfacies of Carbonate Rocks,* Springer Berlin Heidelberg.

FONTANALS-COLL, M., SUBIRÀ, M. E., MARÍN-MORATALLA, N., RUIZ, J. & GIBAJA, J. F. 2014. From Sado Valley to Europe: Mesolithic dietary practices through different geographic distributions. *Journal of Archaeological Science,* 50**,** 539-550.

FORD, T. D. & PEDLEY, H. M. 1996. A review of tufa and travertine deposits of the world. *Earth-Science Reviews,* 41**,** 117-175.

FOUCHER, P., WATTEZ, J., GEBHARDT, A. & MUSCH, J. 2000. Les structures de combustion mésolithiques de la Pierre Saint-Louis (Geay, Charente-Maritime)/The mesolithic combustion structures from La Pierre-Saint-Louis (Geay, Charente-Maritime). *Paléo,* 12**,** 165-200.

FREITAS, M. C., ANDRADE, C. & CRUCES, A. 2002. The geological record of environmental changes in southwestern Portuguese coastal lagoons since the Lateglacial. *Quaternary International,* 93**,** 161-170.

FREITAS, M. D. C., ANDRADE, C., PIMENTEL, N., MARQUES DA SILVA, C., FATELA, F., COSTA, A. M., DINIZ, M. & ARIAS, P. 2013. Holocene evolution of the Sado estuary - preliminary data and implications on Mesolithic shell middens. *paper delivered at the 150th Anniversary of the Discovery of the Muge shell middens Conference, March, 2013, Salvaterra de Magos, Portugal*.

FRENCH, C. 2003. *Geoarchaeology in action: studies in soil micromorphology and landscape evolution,* London, Routledge.

GALOPIM DE CARVALHO, A. M., RIBEIRO, A. & CABRAL, J. 1983-85. Evolução Paleogeográfica da bacia Cenozóica do Tejo-Sado. *Boletim da SOciedade Geológica de Portugal,* XXIV**,** 209-212.

GAMBLE, L. H. 2017. Feasting, ritual practices, social memory, and persistent places: new interpretations of shell mounds in southern California. *American Antiquity,* 82**,** 427-451.

GANDIN, A. & CAPEZZUOLI, E. 2014. Travertine: distinctive depositional fabrics of carbonates from thermal spring systems. *Sedimentology,* 61**,** 264-290.

GARCÍA-ESCÁRZAGA, A., GUTIÉRREZ-ZUGASTI, I. & GONZÁLEZ-MORALES, M. 2015. Análisis arqueomalacológico de la unidad estratigráfica 108 del conchero mesolítico de El Mazo (Llanes, Asturias): conclusiones socio-económicas y metodológicas. *La Investigación Arqueomalacológica en la Península Ibérica: Nuevas Aportaciones***,** 77-89.

GARCÍA-MONDÉJAR, J., FERNÁNDEZ-MENDIOLA, P., AGIRREZABALA, L., ARANBURU, A., LÓPEZ-HORGUE, M., IRIARTE, E. & MARTINEZ DE RITUERTO, S. 2004. El Aptiense-Albiense de la Cuenca Vasco-Cantábrica. *Geología de España***,** 291-296.

GARCÍA-PUCHOL, O., MCCLURE, S. B., JUAN-CABANILLES, J., DIEZ-CASTILLO, A. A., BERNABEU-AUBÁN, J., MARTÍ-OLIVER, B., PARDO-GORDÓ, S., PASCUAL-BENITO, J. L., PÉREZ-RIPOLL, M. & BALAGUER, L. M. 2017. Cocina Cave Revisited: Bayesian radiocarbon chronology for the last hunter-gatherers and first farmers in Eastern Iberia. *Quaternary International*.

GARCÍA CODRON, J. 2004. El marco del poblamiento paleolítico: unidad y diversidad de los espacios cantábricos. *Las Sociedades del Paleolitico en la Region Cantabrica. Kobie,* 8**,** 11-28.

GARCÍA MONDEJAR, J., HINES, F. & PUJALTE, V. 1985. *Sedimentation and tectonics in the western Basque-Cantabrian area (Northern Spain) during Cretaceous and Tertiary times,* International Association of Sedimentologists, Institut d'Estudis Ilerdencs, Universitat Autònoma de Barcelona.

GARRALDA, M. D. 1982. El cráneo asturiense de Cuartamentero (Llanes, Oviedo). *Kobie,* 12**,** 7-29.

GOCHI, E. B. & PASTOR, J. L. A. 2014. La intervención arqueológica en el yacimiento de la cueva de Santa Catalina. *In:* GOCHI, E. B. & PASTOR, J. L. A. (eds.) *La Cueva de Santa Catalina (Lekeitio, Bizkaia): La intervención arqueológica. Restos vegetales, animales y humanos.* Bilbao: Diputación Foral de Bizkaia.

GOLDBERG, P. 1980. Micromorphology in archaeology and prehistory. *Paléorient***,** 159-164.

GOLDBERG, P. 2000. Micromorphology and site formation at Die Kelders Cave I, South Africa. *Journal of Human Evolution,* 38**,** 43-90.

GOLDBERG, P. & ALDEIAS, V. 2016. Why does (archaeological) micromorphology have such little traction in (geo)archaeology? *Archaeological and Anthropological Sciences***,** 1-10.

GOLDBERG, P. & BAR-YOSEF, O. 2002. Site formation processes in Kebara and Hayonim caves and their significance in Levantine prehistoric caves. *Neandertals and modern humans in Western Asia.* Springer.

GOLDBERG, P. & BERNA, F. 2010. Micromorphology and context. *Quaternary International,* 214**,** 56-62.

GOLDBERG, P. & BYRD, B. F. 1999. The interpretive potential of micromorphological analysis at prehistoric shell midden sites on Camp Pendleton. *Pacific Coast Archaeol Soc Q,* 35**,** 1-23.

GOLDBERG, P. & MACPHAIL, R. I. 2003. Short contribution: Strategies and techniques in collecting micromorphology samples. *Geoarchaeology: An International Journal,* 18**,** 571-578.

GOLDBERG, P. & MACPHAIL, R. I. 2006. *Practical and theoretical geoarchaeology,* Oxford, Blackwell.

GOLDBERG, P. & MACPHAIL, R. I. 2017. Microstratigraphy. *In:* GILBERT, A. S. (ed.) *Encyclopedia of Geoarchaeology.* Dordrecht: Springer Netherlands.

GOLDBERG, P., MILLER, C. E. & MENTZER, S. M. 2017. Recognizing Fire in the Paleolithic Archaeological Record. *Current Anthropology,* 0**,** 000-000.

GOLDBERG, P., MILLER, C. E., SCHIEGL, S., LIGOUIS, B., BERNA, F., CONARD, N. J. & WADLEY, L. 2009. Bedding, hearths, and site maintenance in the Middle Stone Age of Sibudu Cave, KwaZulu-Natal, South Africa. *Archaeological and Anthropological Sciences,* 1**,** 95-122.

GOLDBERG, P., NASH, D. T. & PETRAGLIA, M. D. 1993. *Formation processes in archaeological context*, Prehistory Press.

GOLDBERG, P., SCHIEGL, S., MELIGNE, K., DAYTON, C. & CONARD, N. 2003. Micromorphology and Site Formation at Hohle Fels Cave, Swabian Jura, Germany. *Eiszeitalter und Gegenwart,* 53**,** 1-25.

GOLDBERG, P., WEINER, S., BAR-YOSEF, O., XU, Q. & LIU, J. 2001. Site formation processes at Zhoukoudian, China. *Journal of Human Evolution,* 41**,** 483-530.

GOLUBIC, S., SEONG-JOO, L. & BROWNE, K. M. 2000. Cyanobacteria: Architects of Sedimentary Structures. *In:* RIDING, R. E. & AWRAMIK, S. M. (eds.) *Microbial Sediments.* Berlin, Heidelberg: Springer Berlin Heidelberg.

GONÇALVES, C. 2014. *Modelos preditivos de ocupação dp território no Mesolítico entre os vales do Tejo e do Sado. Doctoral dissertation*, Universidade do Algarve.

GONÇALVES, C., CASCALHEIRA, J. & BICHO, N. 2014. Shellmiddens as landmarks: Visibility studies on the Mesolithic of the Muge valley (Central Portugal). *Journal of Anthropological Archaeology,* 36**,** 130-139.

GONÇALVES, V. S., MARCHAND, G. & SOUSA, A. C. Mudança e permanência do Mesolítico final ao Neolítico (Reguengos de Monsaraz, Évora, Portugal). Actas del IV Congreso del Neolítico Peninsular, 2008. HERNANDEZ PEREZ, MS; SOLER DÍAZ, JA; LOPEZ PADILLA, J., 167-177.

GONÇALVES, V. S., SOUSA, A. C. & MARCHAND, G. 2013. *Na Margem do Grande Rio. Os últimos grupos de caçadores-recolectores e as primeiras sociedades camponensas no Guadiana Médio*, EDIA/DRCALEN.

GONZÁLEZ-ECHEGARAY, P. J., GARCÍA-GUINEA, M. A. & GEGINES, A. 1963. Cueva de la Chora. *Excavaciones Arqueológicas de Espana,* 26**,** 43-65.

GONZÁLEZ-MORALES, M., STRAUS, L. G., DÍEZ CASTILLO, A. & RUIZ COBO, J. 2004. Postglacial Coast & Inland: The Epipaleolithic-Mesolithic-Neolithic transitions in the Vasco-Cantabrian Region. *Munibe. Antropologia-Arkeologia*, 61-78.

GONZÁLEZ-SAINZ, C. & GONZÁLEZ-URQUIJO, J. E. 2004. El Magdaleniense reciente en la región cantábrica. *Las Sociedades del Paleolítico en la Región Cantábrica, Diputación Foral de Bizkaia, Anejo,* 8**,** 275-308.

GONZÁLEZ ECHEGARAY, J. 1980. *El Yacimiento de la Cueva de "El Pendo": excavaciones 1953-57,* Madrid, Instituto Español de Prehistoria.

GONZALEZ ECHEGARAY, J. & FREEMAN, L. 1971. Cueva Morín: excavaciones 1966-1968. *Santander: Diputación Provincial de Santander*.

GONZÁLEZ MORALES, M. R. 1982. *El Asturiense y otras culturas locales: la explotación de las areas litorales de la región cantábrica en los tiempos epipaleolíticos,* Santander, Dirección General de Bellas Artes, Archivos y Bibliotecas.

GONZÁLEZ MORALES, M. R. 1998. La prehistoria de Santona. *Monte Buciero*, 17-28.

GONZÁLEZ MORALES, M. R. La Prehistoria de las Marismas: excavaciones en la cueva de La Fragua, Santoña. Campañas de 1990, 1991, 1993, 1994 y 1996. Actuaciones arqueológicas en Cantabria 1984-1999, 2000. Consejería de Cultura, Turismo y Deporte, Gobierno de Cantabria, 177-180.

GONZALEZ MORALES, M. R. & MARQUEZ URIA, M. C. 1978. The Asturian Shell Midden of Cueva de Mazaculos II (La Franca, Asturias, Spain). *Current Anthropology,* 19**,** 614-615.

GOUDIE, A. S. 2017. Eolian Settings: Sand. *In:* GILBERT, A. S. (ed.) *Encyclopedia of Geoarchaeology.* Dordrecht: Springer Netherlands.

GUÉRET, C., GASSIN, B., JACQUIER, J. & MARCHAND, G. 2014. Traces of plant working in the Mesolithic shell midden of Beg-an-Dorchenn (Plomeur, France). *Mesolithic Miscellany,* 22**,** 3-15.

GUTIÉRREZ-ZUGASTI, F. I. 2009. *La explotación de moluscos y otros recursos litorales en la región cantábrica durante el Pleistoceno final y el Holoceno inicial,* Santander, PUbliCan Ediciones - Universidad de Cantabria.

GUTIÉRREZ-ZUGASTI, I., ANDERSEN, S. H., ARAÚJO, A. C., DUPONT, C., MILNER, N. & MONGE-SOARES, A. M. 2011. Shell midden research in Atlantic Europe: State of the art, research problems and perspectives for the future. *Quaternary International,* 239**,** 70-85.

GUTIÉRREZ-ZUGASTI, I., CUENCA-SOLANA, D., GONZÁLEZ-MORALES, M., GARCÍA-MORENO, A., ORTÍZ-MENÉNDEZ, J., RISSETO, J. & DE TORRES, T. 2013. Back to the Asturian: First result from the Mesolithic shell midden site of El Mazo (Asturian, Northern Spain) In: Daire, MY et al. Ancient Maritime Communities and the Relationship between People and Environment along the European Atlantic Coasts. Oxford: Publishers of British Archaeological Reports.

GUTIÉRREZ-ZUGASTI, I., GARCÍA-ESCÁRZAGA, A., MARTÍN-CHIVELET, J. & GONZÁLEZ-MORALES, M. R. 2015. Determination of sea surface temperatures using oxygen isotope ratios from Phorcus lineatus (Da Costa, 1778) in northern Spain: Implications for paleoclimate and archaeological studies. *The Holocene,* 25**,** 1002-1014.

GUTIÉRREZ-ZUGASTI, I. & GONZÁLEZ-MORALES, M. 2014. Intervención arqueológica en la cueva de El Mazo (Andrín, Llanes): campañas de 2009, 2010 y 2012. *Excavaciones arqueológicas en Asturias 2007–2012***,** 159-167.

GUTIÉRREZ-ZUGASTI, I., SUÁREZ-REVILLA, R., CLARKE, L. J., SCHÖNE, B. R., BAILEY, G. N. & GONZÁLEZ-MORALES, M. R. 2017. Shell oxygen isotope values and sclerochronology of the limpet Patella vulgata Linnaeus 1758 from northern Iberia: Implications for the reconstruction of past seawater temperatures. *Palaeogeography, Palaeoclimatology, Palaeoecology***,** 162-175.

GUTIÉRREZ-ZUGASTI, I., TONG, E., GARCÍA-ESCÁRZAGA, A., CUENCA-SOLANA, D., BAILEY, G. N. & GONZÁLEZ-MORALES, M. R. 2016. Collection and consumption of echinoderms and crustaceans at the Mesolithic shell midden site of El Mazo (northern Iberia): Opportunistic behaviour or social strategy? *Quaternary International,* 407**,** 118-130.

GUTIÉRREZ ZUGASTI, F. I., GONZÁLEZ MORALES, M. R., CUENCA SOLANA, D., FUERTES PRIETO, M. N., GARCÍA MORENO, A., ORTIZ MENÉNDEZ, J. E., RISSETTO, J. & DE TORRES PÉREZ-HIDALGO, T. 2014. La ocupación de la costa durante el Mesolítico en el Oriente de Asturias: primeros resultados de las excavaciones en la cueva de El Mazo (Andrín, LLanes). *Archaeofauna: International Journal of archaeozoology***,** 25-38.

GUTIÉRREZ ZUGASTI, F. I. & GOZÁLEZ MORLES, M. 2010. New data on Asturian shell midden sites: the cave of Mazaculos II (Asturias, Northern Spain). *Munibe,* 31**,** 110-118.

HAALAND, M. M., FRIESEM, D. E., MILLER, C. E. & HENSHILWOOD, C. S. Heat-induced alteration of glauconitic minerals in the Middle Stone Age levels of Blombos Cave, South Africa: Implications for evaluating site structure and burning events. *Journal of Archaeological Science*.

HAWS, J. A., BENEDETTI, M. M., FUNK, C. L., BICHO, N. F., DANIELS, J. M., HESP, P. A., MINCKLEY, T. A., FORMAN, S. L., JERAJ, M., GIBAJA, J. F. & HOCKETT, B. S. 2010. Coastal wetlands and the Neanderthal settlement of Portuguese Estremadura. *Geoarchaeology,* 25**,** 709-744.

HILL, C. L. 2017. Geoarchaeology, History. *In:* GILBERT, A. S. (ed.) *Encyclopedia of Geoarchaeology*. Dordrecht: Springer Netherlands.

HOYOS GÓMEZ, M. 1995. Paleoclimatología del Tardiglacial e la cornisa cantábrica basada en los resultados sedimentológicos de yacimientos arqueológicos kársticos. *In:* MOURE ROMANILLO, A. & GONZÁLEZ SAINZ, C. (eds.) *El Final del Paleolítico Cantábrico.* Santander: Universidad de Cantabria.

HOYOS GÓMEZ, M. & LAVILLE, H. 1982. Nuevas aportaciones sobre la estratigrafía y sedimentologia de los depósitos del Paleolítico Superior de la Cueva de El Pendo (Santander): sus implicaciones. *ZEPHYRVS,* 34**,** 285-293.

HOYOS, M. & HERRERO, N. 1989. El karst en la Cornisa Cantábrica. *El karst en España. Monografías de la Sociedad Española de Geomorfología***,** 109-120.

IRIARTE-CHIAPUSSO, M. J., ARRIZABALAGA, Á., ETXEBERRIA, F., HERRASTI, L. & ÁLVAREZ-FERNÁNDEZ, E. 2010. Shell midden people in northern Iberia. New data from the Mesolithic rock shelter of J3 (Basque Country, Spain). *ZEPHYRVS,* 65**,** 117-127.

JAMES, N. P. & JONES, B. 2015. *Origin of Carbonate Sedimentary Rocks*, John Wiley & Sons.

JIMÉNEZ-SÁNCHEZ, M., BISCHOFF, J. L., STOLL, H. & ARANBURU, A. 2006. A geochronological approach for cave evolution in the Cantabrian Coast (Pindal Cave, NW Spain). *ZEITSCHRIFT FUR GEOMORPHOLOGIE SUPPLEMENTBAND,* 147**,** 129.

JOCHIM, M. 2011. The Mesolithic. *European Prehistory.* Springer.

JONES, B. 2001. Microbial activity in caves—a geological perspective. *Geomicrobiology Journal,* 18**,** 345-357.

JONES, B. & RENAUT, R. W. 2010. Chapter 4 Calcareous Spring Deposits in Continental Settings. *In:* ALONSO-ZARZA, A. M. & TANNER, L. H. (eds.) *Developments in Sedimentology.* Elsevier.

JONGERIUS, A. 1983. The role of micromorphology in agricultural research. *In:* BULLOCK, P. & MURPHY, C. P. (eds.) *Soil micromorphology.* Berkhamsted: AB Academic Publishers.

JORDÁ, F. 1954. La cueva de Bricia (Asturias). *Boletín del Instituto de Estudios Asturianos,* 22**,** 169-197.

JORDÁ, F. 1958. *Avance al Estudio de la Cueva de la Lloseta (Ardines, Ribadesella, Asturias),* Oviedo, Diputación Provincial de Asturias.

JORDÁ, F. Revisión de la cronología del Asturiense. V Congreso Nacional de Arqueología, 1959 Zaragoza. Secretaría General de los Congresos Arqueológicos Nacionales, 63-66.

JORDÁ PARDO, J. F., ÁLVAREZ ALONSO, D. & IRIARTE CHIAPUSSO, M. J. 2014. Una aproximación geoarqueológica al hábitat humano Pleistoceno del occidente Cantábrico (Asturias, norte de España). *Entemu***,** 67-102.

KARKANAS, P. 2001. Site formation processes in Theopetra Cave: A record of climatic change during the Late Pleistocene and Early Holocene in Thessaly, Greece. *Geoarchaeology,* 16**,** 373-399.

KARKANAS, P. 2002. Micromorphological studies of Greek prehistoric sites: New insights in the interpretation of the archaeological record. *Geoarchaeology,* 17**,** 237-259.

KARKANAS, P. 2006. Late Neolithic household activities in marginal areas: the micromorphological evidence from the Kouveleiki caves, Peloponnese, Greece. *Journal of Archaeological Science,* 33**,** 1628-1641.

KARKANAS, P. 2010. Preservation of anthropogenic materials under different geochemical processes: A mineralogical approach. *Quaternary International,* 214**,** 63-69.

KARKANAS, P., BAR-YOSEF, O., GOLDBERG, P. & WEINER, S. 2000. Diagenesis in Prehistoric Caves: the Use of Minerals that Form In Situ to Assess the Completeness of the Archaeological Record. *Journal of Archaeological Science,* 27**,** 915-929.

KARKANAS, P., BROWN, K. S., FISHER, E. C., JACOBS, Z. & MAREAN, C. W. 2015. Interpreting human behavior from depositional rates and combustion features through the study of sedimentary microfacies at site Pinnacle Point 5-6, South Africa. *Journal of Human Evolution,* 85**,** 1-21.

KARKANAS, P. & GOLDBERG, P. 2010a. 23 - Phosphatic Features. *In:* STOOPS, G., MARCELINO, V. & MEES, F. (eds.) *Interpretation of Micromorphological Features of Soils and Regoliths.* Amsterdam: Elsevier.

KARKANAS, P. & GOLDBERG, P. 2010b. Site formation processes at Pinnacle Point Cave 13B (Mossel Bay, Western Cape Province, South Africa): resolving stratigraphic and depositional complexities with micromorphology. *Journal of Human Evolution,* 59**,** 256-273.

KARKANAS, P. & GOLDBERG, P. 2017. Soil Micromorphology. *In:* GILBERT, A. S. (ed.) *Encyclopedia of Geoarchaeology.* Dordrecht: Springer Netherlands.

KEHL, M., ÁLVAREZ-ALONSO, D., DE ANDRÉS-HERRERO, M., CARRAL GONZÁLEZ, P., GARCÍA SÁNCHEZ, E., JORDÁ PARDO, J., MENENDEZ, M., QUESADA, J. M., RETHEMEYER, J., ROJO, J., TAFELMAIER, Y. & WENIGER, G.-C. 2018. Towards a revised stratigraphy for the Middle to Upper Palaeolithic boundary at La Güelga (Narciandi, Asturias, Spain). Soil micromorphology and new radiocarbon data. *Boletín Geológico y Minero,* 129 (1/2)**,** 183-206.

KEHL, M., BUROW, C., CANTALEJO, P., DOMÍNGUEZ-BELLA, S., DURÁN, J. J., HENSELOWSKY, F., KLASEN, N., LINSTÄDTER, J., MEDIANERO, J., PASTOORS, A., RAMOS, J., REICHERTER, K., SCHMIDT, C. & WENIGER, G.-C. Site formation and chronology of the new Paleolithic site Sima de Las Palomas de Teba, southern Spain. *Quaternary Research*.

KEMP, R. A. 2013. Paleosols and wind-blown sediments | Soil Micromorphology. *In:* MOCK, S. A. E. J. (ed.) *Encyclopedia of Quaternary Science (Second Edition).* Amsterdam: Elsevier.

KEMP, R. A., ZÁRATE, M., TOMS, P., KING, M., SANABRIA, J. & ARGUELLO, G. 2006. Late Quaternary paleosols, stratigraphy and landscape evolution in the Northern Pampa, Argentina. *Quaternary Research,* 66**,** 119-132.

KOPPEL, B., SZABÓ, K., MOORE, M. W. & MORWOOD, M. J. 2015. Untangling time-averaging in shell middens: Defining temporal units using amino acid racemisation. *Journal of Archaeological Science: Reports*.

KOPPEL, B. D. 2017. *Disentangling shell middens: Exploring the complexities of deposit formation and transformation using amino acid racemisation.* Doctor of Philosophy thesis, University of Wollongong.

KUBIENA, W. L. 1938. *Micropedology*, Collegiate Press, Inc. Ames, Iowa.

KÜHN, P., AGUILAR, J. & MIEDEMA, R. 2010. 11 - Textural Pedofeatures and Related Horizons. *In:* STOOPS, G., MARCELINO, V. & MEES, F. (eds.) *Interpretation of Micromorphological Features of Soils and Regoliths.* Amsterdam: Elsevier.

KULLBERG, J. C., ROCHA, R. B., SOARES, A. F., REY, J., TERRINHA, P., CALLAPEZ, P. & MARTINS, L. 2013. A Bacia Lusitaniana: estratigrafia, paleogeografia e tectónica. *In:* DIAS, R., ARAÚJO, A., TERRINHA, P. & KULLBERG, J. C. (eds.) *Geologia de Portugal. Volume II - geologia Meso-cenozoica de Portugal.* Lisboa: Escolar Editora.

LAMOTTA, V. & SCHIFFER, M. 2005. Archaeological formation processes. *Archaeology: The Key Concepts***,** Routledge.

LARSSON, L. 1996. Late Atlantic settlement in southern Portugal. Results of an excavation of a Mesolithic shell midden by the River Sado. *Current Swedish Archaeology,* 4**,** 123-139.

LARSSON, L. 2010. Shells in the sand. Poças de São Bento–a Mesolithic shell midden by the River Sado, Southern Portugal. *In:* ARMBRUESTER, T. & HEGEWISCH, M. (eds.) *On pre- and earlier history of Iberia and Central Europe: studies in honour of Philine Kalb.* Bonn: Habelt.

LAVILLE, H. 1986. Stratigraphy, sedimentology and chronology of the La Riera Cave deposits. *In:* STRAUS, L. G. & CLARK, G. A. (eds.) *La Riera Cave. Stone Age hunter-gatherer adaptations in Northern Spain.* Tempe: Arizona State University

LENTACKER, A. 1986. Preliminary results of the fauna of Cabeço da Amoreira and Cabeço da Arruda (Muge, Portugal). *Trabalhos de Antropologia e Etnologia,* 26**,** 9-26.

LENTACKER, A. 1994. Fish remains from Portugal: preliminary analysis of the Mesolithic shell-midden sites of Cabeço da Amoreira and Cabeço da Arruda. *Annalen-Koninklijk Museum voor Midden-Afrika-Zoologische Wetenschappen*.

LEORRI, E. & CEARRETA, A. 2004. Holocene environmental development of the Bilbao estuary, northern Spain: sequence stratigraphy and foraminiferal interpretation. *Marine Micropaleontology,* 51**,** 75-94.

LEORRI, E., CEARRETA, A. & MILNE, G. 2012. Field observations and modelling of Holocene sea-level changes in the southern Bay of Biscay: implication for understanding current rates of relative sea-level change and vertical land motion along the Atlantic coast of SW Europe. *Quaternary Science Reviews,* 42**,** 59-73.

LEROUI-GOURHAN, A. The palynology of La Riera cave. *Anthrop. Papers*, 36 (1986), pp. 59-64.

LIGOUIS, B., KLEINEIDAM, S., KARAPANAGIOTI, H., KIEM, R., GRATHWOHL, P. & NIEMZ, C. 2005. Organic petrology: a new tool to study contaminants in soils and sediments. *Environmental Chemistry.* Springer.

LLOPIS LLADÓ, N. 1953a. Estudios hidrogeológicos y prehistóricos en Posada (Llanes). *Speleon,* IV**,** 266.

LLOPIS LLADÓ, N. 1953b. Sección de Exploraciones. Asturias. *Speleon,* IV**,** 105.

LÓPEZ-DÓRIGA, I. 2016. *The use of plants during the Mesolithic and the Neolithic in the Atlantic coast of the Iberian peninsula.*, PhD Thesis, Universidad de Cantabria.

LÓPEZ-DÓRIGA, I., DINIZ, M. & ARIAS, P. 2016. Macrobotanical remains and shell-midden formation processes, are they related? The case of Poças de São Bento (Portugal). *Archaeological and Anthropological Sciences*, 1-13.

LÓPEZ MERINO, L., MARTÍNEZ CORTIZAS, A. & LÓPEZ SÁEZ, J. A. 2010. Early agriculture and palaeoenvironmental history in the North of the Iberian Peninsula: a multi-proxy analysis of the Monte Areo mire (Asturias, Spain). *Journal of Archaeological Science,* 37, 1978-1988.

LUBELL, D., JACKES, M., SCHWARCZ, H., KNYF, M. & MEIKLEJOHN, C. 1994. The Mesolithic-Neolithic transition in Portugal: isotopic and dental evidence of diet. *Journal of Archaeological Science,* 21, 201-216.

LUBY, E. M. 2004. Shell mounds and mortuary behavior in the San Francisco Bay area. *North American Archaeologist,* 25, 1-33.

MACPHAIL, R. I. & CRUISE, J. 2001. The soil micromorphologist as team player. *Earth sciences and archaeology.* Springer.

MACPHAIL, R. I. & GOLDBERG, P. 2017. *Applied Soils and Micromorphology in Archaeology,* Cambridge, Cambridge University Press.

MACPHAIL, R. I., ROMANS, J. C. C. & ROBERTSON, L. 1987. The application of micromorphology to the understanding of Holocene soil development in the British Isles; with special reference to early cultivation. *Micromorphologie des sols*, 647-656.

MALLOL, C., CABANES, D. & BAENA, J. 2010. Microstratigraphy and diagenesis at the upper Pleistocene site of Esquilleu Cave (Cantabria, Spain). *Quaternary International,* 214, 70-81.

MALLOL, C. & GOLDBERG, P. 2017. Cave and Rock Shelter Sediments. *In:* NICOSIA, C. & STOOPS, G. (eds.) *Archaeological Soil and Sediment Micromorphology.* John Wiley & Sons.

MALLOL, C., HERNÁNDEZ, C. M., CABANES, D., MACHADO, J., SISTIAGA, A., PÉREZ, L. & GALVÁN, B. 2013a. Human actions performed on simple combustion structures: An experimental approach to the study of Middle Palaeolithic fire. *Quaternary International,* 315**,** 3-15.

MALLOL, C., HERNÁNDEZ, C. M., CABANES, D., SISTIAGA, A., MACHADO, J., RODRÍGUEZ, Á., PÉREZ, L. & GALVÁN, B. 2013b. The black layer of Middle Palaeolithic combustion structures. Interpretation and archaeostratigraphic implications. *Journal of Archaeological Science,* 40**,** 2515-2537.

MALLOL, C., MARLOWE, F. W., WOOD, B. M. & PORTER, C. C. 2007. Earth, wind, and fire: ethnoarchaeological signals of Hadza fires. *Journal of Archaeological Science,* 34**,** 2035-2052.

MALLOL, C. & MENTZER, S. M. 2017. Contacts under the lens: Perspectives on the role of microstratigraphy in archaeological research. *Archaeological and Anthropological Sciences,* 9**,** 1645-1669.

MALLOL, C., MENTZER, S. M. & MILLER, C. E. 2017. Combustion Features. *In:* NICOSIA, C. & STOOPS, G. (eds.) *Archaeological Soil and Sediment Micromorphology.* John Wiley & Sons.

MALLOL, C., MENTZER, S. M. & WRINN, P. J. 2009. A micromorphological and mineralogical study of site formation processes at the late Pleistocene site of Obi-Rakhmat, Uzbekistan. *Geoarchaeology,* 24**,** 548-575.

MANDEL, R. D. 2000. *Geoarchaeology in the Great Plains,* University of Oklahoma Press.

MANDEL, R. D., GOLDBERG, P. & HOLLIDAY, V. T. 2017. Site Formation Processes. *In:* GILBERT, A. S. (ed.) *Encyclopedia of Geoarchaeology.* Dordrecht: Springer Netherlands.

MARCHAND, G. 2001. Les traditions techniques du Mésolithique final dans le sud du Portugal: les industries lithiques des amas coquilliers de Várzea da Mó et de Cabeço do Rebolador (fouilles M. Heleno). *Revista Portuguesa de Arqueologia,* 4**,** 47-110.

MARCHAND, G. 2005. Interpretar as mudanças dos sistemas técnicos do Mesolítico final em Portugal. *O Arqueólogo Português,* 23**,** 171-195.

MAREAN, C. W. 2014. The origins and significance of coastal resource use in Africa and Western Eurasia. *Journal of Human Evolution,* 77**,** 17-40.

MARÍN-ARROYO, A. B. 2013. Human response to Holocene warming on the Cantabrian Coast (northern Spain): an unexpected outcome. *Quaternary Science Reviews,* 81**,** 1-11.

MARIN ARROYO, A. B. 2004. Análisis arqueozoológico, tafonómico y de distribución espacial de la fauna de mamíferos de la cueva de la Fragua (Santoña, Cantabria). *Munibe. Antropologia-arkeologia***,** 19-44.

MARÍN ARROYO, A. B. Evolución de la fauna de La Fragua del Pleistoceno al Holoceno. Actas del III Congreso del Neolítico en la Península Ibérica: Santander, 5 a 8 de octubre de 2003, 2005. Servicio de Publicaciones Universidad de Cantabria, 145-154.

MARÍN ARROYO, A. B. & GONZÁLEZ MORALES, M. R. 2007. La Fragua Cave, a seasonal hunting camp in the lower Asón Valley (Cantabria, Spain) at the Pleistocene-Holocene transition. *Anthropozoologica,* 41**,** 61-84.

MARQUARDT, W. H. 2010. Shell mounds in the southeast: middens, monuments, temple mounds, rings, or works? *American Antiquity,* 75**,** 551-570.

MARQUES GABRIEL, S. 2015. La ictiofauna del Holoceno Inicial y Medio de Portugal: Implicaciones tafonómicas, ecológicas y culturales. PdD theis. Universidad Autónoma de Madrid.

MARTÍNEZ GARCÍA, E. 1981. Memoria del Mapa Geologico de España - hoja 32 Llanes, IGME.

MARY, G. 1983. Evolución del margen costero de la Cordillera Cantábrica en Asturias desde el Mioceno. *Trabajos de Geología,* 13**,** 3-37.

MATEUS, J. & QUEIRÓZ, P. 1991. Holocene palaeoecology of the North-littoral of Alentejo. *International Paleoecological Excursion***,** 19-29.

MATEUS, J. E. Past climates. Evidences in Portugal. Extended Abstracts of the International Meeting on Climate Change and the Kyoto Protocol, 2001 University of Évora.

MATEUS, J. E. & QUEIROZ, P. F. 1993. Os estudos da vegetação quaternária em Portugal; contextos, balanço de resultados, perspectivas. *O Quaternàrio em Portugal, balanço e perspectivas***,** 105-131.

MATEUS, J. E. & QUEIRÓZ, P. F. 2000. Lakelets, lagoons and peat-mires in the coastal plane South of Lisbon–Palaeoecology of the Northern Littoral of Alentejo. Excursion guide of the 2nd workshop of the Southern European working group of the European Lake Drilling Programme (ELPD-ESF). *Rapid environmental change in the Mediterranean Region–The contribution of the high-resolution lacustrine records from the last*, 80**,** 33-37.

MEHTA, J. M. & CHAMBERLAIN, E. L. 2018. Mound Construction and Site Selection in the Lafourche Subdelta of the Mississippi River Delta, Louisiana, USA. *The Journal of Island and Coastal Archaeology***,** 1-26.

MENÉNDEZ, M., ÁLVAREZ-ALONSO, D., DE ANDRÉS-HERRERO, M., CARRAL, P., GARCÍA-SÁNCHEZ, E., JORDÁ PARDO, J. F., QUESADA, J. M. & ROJO, J. 2017. The Middle to Upper Paleolithic transition in La Güelga cave (Asturias, Northern Spain). *Quaternary International*.

MENTZER, S. M. 2014. Microarchaeological Approaches to the Identification and Interpretation of Combustion Features in Prehistoric Archaeological Sites. *Journal of Archaeological Method and Theory,* 21**,** 616-668.

MENTZER, S. M. & QUADE, J. 2013. Compositional and Isotopic Analytical Methods in Archaeological Micromorphology. *Geoarchaeology,* 28**,** 87-97.

MERZ-PREIß, M. 2000. Calcification in Cyanobacteria. *In:* RIDING, R. E. & AWRAMIK, S. M. (eds.) *Microbial Sediments.* Berlin, Heidelberg: Springer Berlin Heidelberg.

MILLER, C. E., CONARD, N. J., GOLDBERG, P. & BERNA, F. 2010. Dumping, sweeping and trampling: experimental micromorphological analysis of anthropogenically modified combustion features. *In:* THÉRY-PARISOT, I., CHABAL, L. & COSTAMAGNO S. (eds.) *The taphonomy of Burned Organic Residues and Combustion Features in Archaeological Contexts, Proceedings of the round table, May 27-29 2008. Palethnologie, 2 : 25-37.*

MILLER, C. E., GOLDBERG, P. & BERNA, F. 2013. Geoarchaeological investigations at Diepkloof Rock Shelter, Western Cape, South Africa. *Journal of Archaeological Science,* 40**,** 3432-3452.

MILNER, N., CRAIG, O. E. & BAILEY, G. N. 2007. *Shell Middens in Atlantic Europe*, Oxbow Books Limited.

MONTEIRO, P. D., BICHO, N. & ZAPATA, L. 2015. The Midden Is On Fire! Charcoal Analyses from Cabeço da Amoreira (Muge Shell Middens). *In:* BICHO, N., DETRY, C., PRICE, D. T. & CUNHA, E. (eds.) *Muge 150th: The 150th Anniversary of the Discovery of Mesolithic Shellmiddens.* . Cambridge Scholars Publishing.

MONTEIRO, P. D., ZAPATA, L. & BICHO, N. 2017. Fuel uses in Cabeço da Amoreira shellmidden: An insight from charcoal analyses. *Quaternary International,* 431, Part A**,** 27-38.

MORELLÓN, M., ARANBARRI, J., MORENO, A., GONZÁLEZ-SAMPÉRIZ, P. & VALERO-GARCÉS, B. L. 2018. Early Holocene humidity patterns in the Iberian Peninsula reconstructed from lake, pollen and speleothem records. *Quaternary Science Reviews,* 181**,** 1-18.

MORENO, A., VALERO-GARCÉS, B. L., JIMÉNEZ-SÁNCHEZ, M., DOMÍNGUEZ-CUESTA, M. J., MATA, M. P., NAVAS, A., GONZÁLEZ-SAMPÉRIZ, P., STOLL, H., FARIAS, P., MORELLÓN, M., CORELLA, J. P. & RICO, M. 2010. The last deglaciation in the Picos de Europa National Park (Cantabrian Mountains, northern Spain). *Journal of Quaternary Science,* 25**,** 1076-1091.

MUNOZ FERNÁNDEZ, E., MORLOTE EXPÓSITO, J. M., SANTAMARIA SANTAMRIA, S., CASTANOS, P., RUIZ ZAPATA, B., GIL GARCÍA, M. J. & UZQUIANO, P. 2013. Sondeo arqueológico en el Abrigo de Barcenilla (TM de Piélagos, Cantabria). *Kobie,* 32**,** 79-112.

MURELAGA, X., LÓPEZ QUINTANA, J., CASTAÑOS, P., GUENAGA LIZASU, A., BAILON, S. & ZUBELDIA, H. 2007. Vertebrados del yacimiento Holoceno de Kobeaga II (Ispaster, Bizkaia). *Geogaceta,* 41**,** 147-150.

NASH, D. T. & PETRAGLIA, M. D. 1987. *Natural formation processes and the archaeological record*, BAR.

NICOSIA, C. & STOOPS, G. 2017. *Archaeological Soil and Sediment Micromorphology*, John Wiley & Sons.

NOVAL, M. A. 2007. Excavación arqueológica en la cueva de El Toral III (Andrın, Llanes). *Excavaciones Arqueológicas en Asturias,* 2012**,** 381-384.

OBERMAIER, H. 1916. *El hombre Fósil*, Museo Nacional de Ciencias Naturales.

OLIVÉ DAVÓ, A., MARTÍN ALAFONT, J. M., RAMÍREZ DEL POZO, J. & PORTERO GARCÍA, J. M. 1982. *Memoria del Mapa Geologico de España - hoja 36 Castro Urdiales*, IGME.

OLIVEIRA, J. T., FERNANDES, P., PAIS, J., DIAS, R. P., JESUS, A., MATEUS, A., ANDRADE, A. S. D., LOURENÇO, C., MUNHÁ, J. & MATOS, J. X. 2013. *Notícia explicativa da folha 42-B: Azinheira de Barros*, Lisboa, LNEG-Unidade de Geologia e Cartografia Geológica.

PAIS, J., CUNHA, P. P., PEREIRA, D., LEGOINHA, P., DIAS, R., MOURA, D., DA SILVEIRA, A. B., KULLBERG, J. & GONZÁLEZ-DELGADO, J. 2012. The Paleogene and Neogene of Western Iberia (Portugal): A Cenozoic Record in the European Atlantic Domain. *The Paleogene and Neogene of Western Iberia (Portugal).* Springer.

PEDLEY, H. M. 1987. The Flandrian (Quaternary) Caerwys tufa, North Wales: an ancient barrage tufa deposit. *Proceedings of the Yorkshire Geological Society*, 46**,** 141-152.

PEDLEY, H. M. 1990. Classification and environmental models of cool freshwater tufas. *Sedimentary Geology,* 68**,** 143-154.

PEDLEY, M. 1992. Freshwater (phytoherm) reefs: the role of biofilms and their bearing on marine reef cementation. *Sedimentary Geology,* 79**,** 255-274.

PEDLEY, M. 2000. Ambient Temperature Freshwater Microbial Tufas. *In:* RIDING, R. E. & AWRAMIK, S. M. (eds.) *Microbial Sediments.* Berlin, Heidelberg: Springer Berlin Heidelberg.

PEÑA, V., BÁRBARA, I., GRALL, J., MAGGS, C. A. & HALL-SPENCER, J. M. 2014. The diversity of seaweeds on maerl in the NE Atlantic. *Marine Biodiversity,* 44**,** 533-551.

PENTECOST, A. 1991. Calcification processes in algae and cyanobacteria. *Calcareous algae and stromatolites.* Springer.

PENTECOST, A. 1995. The quaternary travertine deposits of Europe and Asia Minor. *Quaternary Science Reviews,* 14**,** 1005-1028.

PENTECOST, A. 2005. *Travertine,* Dordrecht, Springer.

PEREIRA, T., BICHO, N., CASCALHEIRA, J., GONÇALVES, C., MARREIROS, J. & PAIXÃO, E. 2015. Raw Material Procurement in Cabeço da Amoreira, Muge, Portugal. *In:* BICHO, N., DETRY, C., PRICE, D. T. & CUNHA, E. (eds.) *Muge 150th: The 150th Anniversary of the Discovery of Mesolithic Shellmiddens. .* Cambridge Scholars Publishing.

PERRY, C. & TAYLOR, K. 2009. *Environmental sedimentology,* John Wiley & Sons.

PEYROTEO STJERNA, R. 2016. *On Death in the Mesolithic: Or the Mortuary Practices of the Last Hunter-Gatherers of the South-Western Iberian Peninsula, 7th–6th Millennium BCE.* Department of Archaeology and Ancient History, Uppsala University.

PGRH 2012. *Planos de Gestão das Bacias Hidrográficas (Região Hidrográficas 6). Volume I - Relatório,* Lisboa: ARH do Alentejo I.P.

PIMENTEL, N. & AZEVÊDO, T. M. 1994. Etapas e controlo alpino da sedimentação na bacia do Sado (SW de Portugal). *Cadernos do Laboratorio Xeolóxico de Laxe: Revista de xeoloxía galega e do hercínico peninsular,* 19**,** 229-238.

PIMENTEL, N., NUKUSHINA, D., DINIZ, M. & ARIAS, P. 2015. Lithic materials in the Sado River’s shell middens: geological provenance and impact on site location. *In:* BICHO, N., CUNHA, E., DETRY, C. & PRICE, T. D. (eds.) *Muge 150th anniversary of the discovery of the Mesolithic shellmiddens.* Cambridge Scholars Publishing.

PIMENTEL, N. L. 1997. *O Terciário da Bacia do Sado, sedimentologia e análise tectono-sedimentar. Doctoral thesis.,* Universidade de Lisboa.

PINTO-LLONA, A. C., CLARK, G., KARKANAS, P., BLACKWELL, B., SKINNER, A. R., ANDREWS, P., REED, K., MILLER, A., MACÍAS-ROSADO, R. & VAKIPARTA, J. 2012. The Sopeña rockshelter, a new site in Asturias (Spain) bearing evidence on the Middle and Early Upper Palaeolithic in Northern Iberia. *Munibe,* 63**,** 45-79.

POLO-DÍAZ, A., ALONSO EGUÍLUZ, M., RUIZ, M., PÉREZ, S., MÚJIKA, J., ALBERT, R. M. & FERNÁNDEZ ERASO, J. 2016a. Management of residues and natural resources at San Cristóbal rock-shelter: Contribution to the characterisation of chalcolithic agropastoral groups in the Iberian Peninsula. *Quaternary International,* 414**,** 202-225.

POLO-DÍAZ, A., BENITO-CALVO, A., MARTÍNEZ-MORENO, J. & MORA TORCAL, R. 2016b. Formation processes and stratigraphic integrity of the Middle-to-Upper Palaeolithic sequence at Cova Gran de Santa Linya (Southeastern Prepyrenees of Lleida, Iberian Peninsula). *Quaternary International,* 417**,** 16-38.

POLO-DÍAZ, A. & ERASO, J. F. 2010. Same anthropogenic activity, different taphonomic processes: A comparison of deposits from Los Husos I & II (Upper Ebro Basin, Spain). *Quaternary International,* 214**,** 82-97.

PRENDERGAST, A. 2017. New research on the development of high-resolution palaeoenvironmental proxies from geochemical properties of biogenic carbonates. *Palaeogeography, Palaeoclimatology, Palaeoecology*.

PRICE, T. D. 1987. The mesolithic of Western Europe. *Journal of World Prehistory,* 1**,** 225-305.

PSUTY, N. P., EUGÉNIA, M. & MOREIRA, S. 2000. Holocene sedimentation and sea level rise in the Sado Estuary, Portugal. *Journal of Coastal Research***,** 125-138.

QUEIROZ, P. & MATEUS, J. 2004. Paleoecologia litoral entre Lisboa e Sines: do Tardiglaciário aos tempos de hoje. *Evolução geohistórica do litoral português e fenómenos correlativos. Geologia, História, Arqueologia e Climatologia. Universidade Aberta, Lisboa***,** 257-304.

QUINTANA, J. C. L. 1996. Definición y articulación del depósito estratigráfico de Pareko Landa (Sollube, Bizkaia) según la Estratigrafía Analítica. *Krei***,** 57-67.

QUINTANA, J. C. L. 1998/2000. El yacimiento prehistórico de la cueva de Kobeaga II (Ispaster, Bizkaia): cazadores-recolectores en el País Vasco atlántico durante el VIII y VII milenio bp. *Illunzar***,** 83-162.

QUINTANA, J. C. L. & LIZASU, A. G. 2006. Avance a la secuencia estratigráfica de la cueva de Santimamiñe (Kortezubi), tras la revisión de su depósito arqueológico en las campañas de 2004 a 2006. *Krei***,** 73-103.

RAPOSO, L. O sitio de Palheirões do Alegra e a" questao do Mirense". Arqueología en el entorno del Bajo Guadiana: actas del Encuentro Internacional de Arqueología del suroeste [(celebrado en) Huelva y Niebla, 25 a 27 de febrero de 1993], 1994. Universidad de Huelva, 55-70.

RAPP, G. 1975. The archaeological field staff: the geologist. *Journal of Field Archaeology,* 2**,** 229-237.

RAPP, G. R. & HILL, C. L. 1998. *Geoarchaeology: the earth-science approach to archaeological interpretation,* New Haven, Yale University Press.

REAL, F. 1984. Acerca do interesse da Geologia para a Arqueologia. *Informação Arqueológica*, 4.

REAL, F. 1985a. Estudo sedimentológico da Gruta da Feteira (Lourinhã). *In:* ZILHÃO, J. (ed.) *A Gruta da Feteira. Escavação de emergência de uma necrópole neolítica.* Lisboa: Instituto Português do Património Cultural.

REAL, F. 1985b. Reconstituição paleoclimática através dos sedimentos plistocénicos da Gruta do Caldeirão (Tomar). *Actas da I Reunião do Quaternário Ibérico***,** 127-139.

REAL, F. 1986. Geoarqueologia - uma disciplina a desenvolver. *Maleo*, 2**,** 13.

REAL, F. 1988. Geoarqueologia 2: os sedimentos na reconstituição do clima. *Arqueologia,* 18**,** 5-7.

RENFREW, C. 1976. Archaeology and the earth sciences. *In:* DAVIDSON, D. A. & SHACKLEY, M. L. (eds.) *Geoarchaeology: earth science and the past.* London: Duckworth.

RENTZEL, P., NICOSIA, C., GEBHARDT, A., BRÖNNIMANN, D., PÜMPIN, C. & ISMAIL-MEYER, K. 2017. Trampling, Poaching and the Effect of Traffic. *In:* NICOSIA, C. & STOOPS, G. (eds.) *Archaeological Soil and Sediment Micromorphology.* John Wiley & Sons.

RIDING, R. 1983. Cyanoliths (Cyanoids): Oncoids Formed by Calcified Cyanophytes. *In:* PERYT, T. M. (ed.) *Coated Grains.* Berlin, Heidelberg: Springer Berlin Heidelberg.

RIDING, R. 1991a. Calcified Cyanobacteria. *In:* RIDING, R. (ed.) *Calcareous Algae and Stromatolites.* Berlin, Heidelberg: Springer Berlin Heidelberg.

RIDING, R. 1991b. Classification of microbial carbonates. *Calcareous algae and stromatolites.* Springer.

RIDING, R. 2000. Microbial carbonates: the geological record of calcified bacterial–algal mats and biofilms. *Sedimentology,* 47**,** 179-214.

RIDING, R. E. & AWRAMIK, S. M. 2000. *Microbial sediments,* Springer Science & Business Media.

ROBSON, H. K., LITTLE, A., JONES, A. K. G., BLOCKLEY, S., CANDY, I., MATTHEWS, I., PALMER, A., SCHREVE, D., TONG, E. & POMSTRA, D. 2016. Scales of analysis: Evidence of fish and fish processing at Star Carr. *Journal of Archaeological Science: Reports*.

ROCHE, J. 1952. Les fouilles des amas coquilliers de Muge. *Boletim da Sociedade Geológica de Portugal,* 10**,** 145-152.

ROCHE, J. 1954. Résultats des derniéres campagnes de fouilles exécuteés a Moita de Sebastiäo (Muge). *Revista da Faculdade de Ciências, 2ª Série, C-Ciências Naturais,* IV**,** 179-186.

ROCHE, J. 1964/1965. Note sur la stratigraphie de l’amas coquillier mésolithique de Cabeço de Amoreira (Muge). *Comunicações dos Serviços Geológicos de Portugal,* 48.

ROCHE, J. 1966. Balance de un siglo de excavaciones en los cocheros mesolíticos de Muge. *Empúries: revista de món clàssic i antiguitat tardana,* 28**,** 13-48.

ROCHE, J. 1967. Seconde note sur la stratigraphie de l’amas coquillier mésolithique de Cabeço da Arruda (Muge). . *Comunicações dos Serviços Geológicos de Portugal,* 51**,** 243-252.

ROCHE, J. 1972. Les amas coquilliers (concheiros) mésolithiqiues de Muge (Portugal). *Funamenta. Die Anfänge des Neolithikums von Orient bis Nordeuropa.* Köln: Institut für Ur- und Frühgeschichte der Universitä zu Köln.

ROCHE, J. 1981. Algumas observações sobre a estratigrafia das jazidas de tipo "concheiro" e os problemas que levantam aos escavadores. *Arqueologia,* 1**,** 3-6.

ROCHE, J. 1989. Spatial organization in the Mesolithic sites of Muge, Portugal. *In:* BONSALL, C. (ed.) *The Mesolithic in Europe. Third International Symposium Jonh Donald.* Edinburgh.

ROCHE, J. 1990. Spatial organization in the Mesolithic sites of Muge, Portugal. *In:* BONSALL, C. (ed.) *The Mesolithic in Europe.* Edinburgh: John Donald Publishers.

ROCHE, J. & FERREIRA, O. D. V. 1957. Nota sobre a estratigrafia dos concheiros de Muge. *Comunicações dos Serviços Geológicos de Portugal,* 38**,** 261-268.

RODRIGUES, S. E. M. & RIBEIRO, J. P. C. 1991. Estação paleolítica do Cerro: Madalena, Vila Nova de Gaia. *Revista da Faculdade de Letras: História, 2. ª Série, Vol. VIII, 1991, p. 411-428.*

ROSELLÓ-IZQUIERDO, E., BERGANZA-GOCHI, E., NORES-QUESADA, C. & MORALES-MUÑIZ, A. 2016. Santa Catalina (Lequeitio, Basque Country): An ecological and cultural insight into the nature of prehistoric fishing in Cantabrian Spain. *Journal of Archaeological Science: Reports,* 6**,** 645-653.

ROSELLÓ IZQUIERDO, E. & GONZÁLEZ MORALES, A. 2014. Las ictiofaunas de Santa Catalina (Lequeitio, Vizcaya). *Kobie. Excavaciones Arqueológicas en Bizkaia,* 4**,** 161-262.

ROWLEY-CONWY, P. 2015. The Late Mesolithic of Southwest Portugal: A Zooarchaeological Approach to Resource Exploitation and Settlement Patterns. *In:* BICHO, N., DETRY, C., PRICE, D. T. & CUNHA, E. (eds.) *Muge 150th: The 150th Anniversary of the Discovery of Mesolithic Shellmiddens.* . Cambridge Scholars Publishing.

SANCHEZ MARCO, A. 2001. Aves del yacimiento mesolítico del Cubío Redondo (Cantabria). *Munibe Antropologia-Arkeologia,* 53.

SANTOS, M. F. D. 1967. Concheiro mesolítico do Barranco da Moura, Grândola. *O Arqueólogo Português***,** 113-114.

SANTOS, M. F. D. 1968. Concheiro mesolítico da Fonte da Mina, Grândola. *O Arqueólogo Português***,** 183.

SANTOS, M. F. D., SOARES, J. & SILVA, C. T. D. 1974. O concheiro epipaleolítico do Cabeço do Pez (Vale do Sado-Torrão). Primeira notícia. *III Congresso Nacional de Arqueologia (Porto 1973). Actas.* Porto: Juta Nacional de Educação.

SANZ DE SAUTUOLA, M. 1880. Breves apuntes sobre algunos objetos prehistoricos de la província de Santander. *Escritos y Documentos*, 69-104.

SCHIEGL, S., GOLDBERG, P., BAR-YOSEF, O. & WEINER, S. 1996. Ash Deposits in Hayonim and Kebara Caves, Israel: Macroscopic, Microscopic and Mineralogical Observations, and their Archaeological Implications. *Journal of Archaeological Science,* 23, 763-781.

SCHIEGL, S., GOLDBERG, P., PFRETZSCHNER, H.-U. & CONARD, N. J. 2003. Paleolithic burnt bone horizons from the Swabian Jura: Distinguishing between in situ fireplaces and dumping areas. *Geoarchaeology,* 18, 541-565.

SCHIFFER, M. B. 1987. Formation processes of the archaeological record. Albuquerque, University of New Mexico Press.

SCHOLLE, P. A. & ULMER-SCHOLLE, D. S. 2003. *A Color Guide to the Petrography of Carbonate Rocks: Grains, Textures, Porosity, Diagenesis,* Tulsa, AAPG.

SCHULTING, R. J. & RICHARDS, M. P. 2001. Dating women and becoming farmers: new palaeodietary and AMS dating evidence from the Breton Mesolithic cemeteries of Téviec and Hoëdic. *Journal of Anthropological Archaeology,* 20, 314-344.

SERPA PINTO, R. D. 1928. O asturiense em Portugal. *Trabalhos de Antropologia e Etnologia,* 4.

SHAHACK-GROSS, R. 2017. Archaeological formation theory and geoarchaeology: State-of-the-art in 2016. *Journal of Archaeological Science,* 79, 36-43.

SHAHACK-GROSS, R. & AYALON, A. 2012. Stable carbon and oxygen isotopic compositions of wood ash: an experimental study with archaeological implications. *Journal of Archaeological Science,* 40, 570-578.

SHAHACK-GROSS, R., BERNA, F., KARKANAS, P., LEMORINI, C., GOPHER, A. & BARKAI, R. 2014. Evidence for the repeated use of a central hearth at Middle Pleistocene (300Â ky ago) Qesem Cave, Israel. *Journal of Archaeological Science,* 44, 12-21.

SHAHACK-GROSS, R., BERNA, F., KARKANAS, P. & WEINER, S. 2004. Bat guano and preservation of archaeological remains in cave sites. *Journal of Archaeological Science,* 31**,** 1259-1272.

SHERWOOD, S. C. & KIDDER, T. R. 2011. The DaVincis of dirt: Geoarchaeological perspectives on Native American mound building in the Mississippi River basin. *Journal of Anthropological Archaeology,* 30**,** 69-87.

SHILLITO, L.-M., MATTHEWS, W., ALMOND, M. J. & BULL, I. D. 2011. The microstratigraphy of middens: capturing daily routine in rubbish at Neolithic Çatalhöyük, Turkey. *Antiquity,* 85**,** 1024-1038.

SILVA, C. T. D. & SOARES, J. 1997. Economias costeiras na Pré-História do Sudoeste Português: O concheiro de Montes de Baixo. *Setúbal Arqueológica,* 11-12**,** 69-108.

SOARES, A. M. 2003. A duna de Magoito revisitada. *Revista Portuguesa de Arqueologia,* 6**,** 83-100.

SOARES, J. 1996. Padrões de povoamento e subsistência no Mesolítico da Costa Sudoeste portuguesa.

SOARES, J. 2013. Caçadores-recolectores semi-sedentários do Mesolítico do paleoestuário do Sado (Portugal). *Setúbal Arqueológica-Pré-história das zonas húmidas-Paisagens de Sal,* 14**,** 13-56.

SOARES, J. 2017. Marine adaptations in the Late Mesolithic of the Portuguese southwest coast: use-wear analysis of the lithic industry of Vale Marim I. *Revista Portuguesa de Arqueologia,* 20**,** 31-44.

SOARES, J. & DA SILVA, C. T. 2018. Living in the southwest Portuguese coast during the Late Mesolithic: The case study of Vale Marim I. *Journal of Archaeological Science: Reports,* 18**,** 1011-1025.

SOARES, J. & SILVA, C. T. 1993. Na transição Plistocénico-Holocénico: marisqueio na Pedra do Patacho. *Almadan,* 2**,** 21-29.

SOARES, J. & SILVA, C. T. D. 2003. A transição para o Neolítico na costa sudoeste portuguesa. *Muita gente, poucas antas***,** 45-56.

SOARES, J. & SILVA, C. T. D. 2004. Alterações ambientais e povoamento na transição Mesolítico-Neolítico na Costa Sudoeste. *Evolução geohistórica do litoral português e fenómenos correlativos. Geologia, Historia, Arqueologia e Climatologia. University Aberta, Lisboa***,** 397-424.

SOUSA, A. C., GIBAJA BAO, J., MAZZUCO, N., MIRANDA, M., TERESO, J. P. V., OLIVEIRA, C. & GONÇALVES, V. S. 2018. Clay combustion structures in early Mesolithic at Cova da Baleia (Mafra, Portugal): Approaches to their functionality. *Journal of Archaeological Science: Reports,* 18**,** 984-999.

SOUSA, A. C., MIRANDA, M. & SOARES, A. M. M. 2016. O Concheiro de São Julião (Carvoeira, Mafra): as intervenções de 2007 e 2014. *Revista Portuguesa de Arqueologia,* 19**,** 11-26.

SOUSA, A. C. & SOARES, A. M. 2016. Continuity or discontinuity? Aquatic exploitation in the portuguese Estremadura during the Atlantic period: São Julião and Magoito shell middens as case studies. *Archéologie des Chasseurs-Cueilleurs Maritimes. De la fonction des habitats à l'organisation de l'espace littoral. Actes de la Séance de la Societé Préhistorique Française. Rennes 10-11 Avril 2014***,** 191-212.

STEIN, J. 1992. *Deciphering a shell midden,* San Diego, Academic Press.

STEIN, J. K. 2001. A review of site formation processes and their relevance to geoarchaeology. *Earth sciences and archaeology.* Springer.

STEIN, J. K. 2008. Geoarchaeology and Archaeostratigraphy View from a Northwest Coast Shell Midden. *In:* REITZ, E. J., SCUDDER, S. J. & SCARRY, C. M. (eds.) *Case Studies in Environmental Archaeology*. New York, NY: Springer New York.

STEIN, J. K. & FARRAND, W. R. 1985. *Archaeological sediments in context*, Center for the Study of the First.

STINER, M. C., BICHO, N. F., LINDLY, J. & FERRING, R. 2003. Mesolithic to Neolithic transitions: new results from shell-middens in the western Algarve, Portugal. *Antiquity,* 77**,** 75-86.

STOLZ, J. F. 2000. Structure of Microbial Mats and Biofilms. *In:* RIDING, R. E. & AWRAMIK, S. M. (eds.) *Microbial Sediments.* Berlin, Heidelberg: Springer Berlin Heidelberg.

STOOPS, G. 2003. *Guidelines for analysis and description of soil and regolith thin sections,* Madison, Wisconsin, Soil Science Society of America Inc.

STOOPS, G., MARCELINO, V. & MEES, F. 2010. 1 - Micromorphology as a Tool in Soil and Regolith Studies. *Interpretation of Micromorphological Features of Soils and Regoliths.* Amsterdam: Elsevier.

STRAUS, L. G. 1979. Mesolithic adaptations along the coast of northern Spain. *Quaternaria,* 21**,** 305-327.

STRAUS, L. G. 1991. The 'Mesolithic-Neolithic transition' in Portugal: a view from Vidigal. *Antiquity,* 65**,** 899-903.

STRAUS, L. G. 2008. The Mesolithic of Atlantic Iberia. *In:* BAYLEY, G. & SPIKINS, P. (eds.) *Mesolithic Europe.* Cambridge University Press.

STRAUS, L. G. 2015. The human occupation of southwestern Europe during the Last Glacial Maximum: Solutrean cultural adaptations in France and Iberia. *Journal of Anthropological Research,* 71**,** 465-492.

STRAUS, L. G., ALTUNA, J., CLARK, G. A., MORALES, M. G., LAVILLE, H., LEROI-GOURHAN, A., HOZ, M. M. D. L., ORTEA, J. A., BAHN, P. G., CLOTTES, J., DAVIDSON, I., FARRAND, W. R., GUINEA, M. A. G., GÓMEZ-TABANERA, J. M., ECHEGARAY, J. G., GOODYEAR, A. C. & RIGAUD, J. P. 1981. Paleoecology at La Riera (Asturias, Spain) [and Comments and Reply]. *Current Anthropology,* 22**,** 655-682.

STRAUS, L. G., CLARK, G. A. & ARIZONA STATE, U. 1986. *La Riera cave: Stone Age hunter-gatherer adaptations in Northern Spain,* Tempe, Arizona State Univesity.

STRAUS, L. G., GONZÁLEZ MORALES, M., FARRAND, W. R. & HUBBARD, W. J. 2001. Sedimentological and stratigraphic observations in El Mirón, a late Quaternary cave site in the Cantabrian Cordillera, Northern Spain. *Geoarchaeology,* 16**,** 603-630.

STRAUS, L. G., MORALES, M. R. G., MARTíNEZ, M. Á. F. & GARCíA-GELABERT, M. A. P. 2002. Last glacial human settlement in eastern Cantabria (Northern Spain). *Journal of Archaeological Science,* 29**,** 1403-1414.

SURGE, D., WANG, T., GUTIERREZ-ZUGASTI, I. & KELLEY, P. H. 2013. Isotope sclerochronology and season of annual growth line formation in limpet shells (Patella vulgata) from warm-and cold-temperate zones in the eastern North Atlantic. *Palaios,* 28**,** 386-393.

TEIXEIRA, S., GASPAR, P. & ROSA, M. Holocene sea-level index points on the Quarteira coast (Algarve, Portugal). Iberian Holocene Paleoenvironmental Evolution. Proceedings Coastal Hope Conference, 2005. 125-127.

TEXIER, J.-P. & MEIRELES, J. 2003. Relict mountain slope deposits of northern Portugal: facies, sedimentogenesis and environmental implications. *Journal of Quaternary Science,* 18**,** 133-150.

THOMPSON, V. D. & ANDRUS, C. F. T. 2011. Evaluating Mobility, Monumentality, and Feasting at the Sapelo Island Shell Ring Complex. *American Antiquity,* 76**,** 315-343.

THOMPSON, V. D., MARQUARDT, W. H., CHERKINSKY, A., THOMPSON, A. D. R., WALKER, K. J., NEWSOM, L. A. & SAVARESE, M. 2016. From shell midden to midden-mound: the geoarchaeology of Mound Key, an anthropogenic island in southwest Florida, USA. *PloS one,* 11**,** e0154611.

TOFFOLO, M. B. & BOARETTO, E. 2014. Nucleation of aragonite upon carbonation of calcium oxide and calcium hydroxide at ambient temperatures and pressures: a new indicator of fire-related human activities. *Journal of Archaeological Science,* 49**,** 237-248.

TRESGUERRES, J. 1976. Azilian burial from Los Azules (Asturias, Spain). *Current Anthropology,* 17**,** 769-770.

TRINDADE, J. 2011. Evolução geomorfológica do Baixo Alcabrichel e da Ribeira de Toledo. *In:* ARAÚJO, A. C. (ed.) *O concheiro de Toledo no contexto do Mesolítico Inicial do litoral da Estremadura.* Lisboa: Instituto de Gestão do Património Arquitectónico e Arqueológico, IGESPAR.

TURNER, E. C., JAMES, N. P. & NARBONNE, G. M. 2000. Taphonomic control on microstructure in Early Neoproterozoic reefal stromatolites and thrombolites. *Palaios,* 15**,** 87-111.

UMBELINO, C., GONÇALVES, C., FIGUEIREDO, O., PEREIRA, T., CASCALHEIRA, J., MARREIROS, J., ÉVORA, M., CUNHA, E. & BICHO, N. 2015. Life in the Muge Shell Middens: Inferences from the New Skeletons Recovered from Cabeço da

Amoreira. *In:* BICHO, N., DETRY, C., PRICE, D. T. & CUNHA, E. (eds.) *Muge 150th: The 150th Anniversary of the Discovery of Mesolithic Shellmiddens.* . Cambridge Scholars Publishing.

UMBELINO, C., PÉREZ-PÉREZ, A., CUNHA, E., HIPÓLITO, C., FREITAS, M. D. C. & CABRAL, J. P. 2007. Outros sabores do passado: um novo olhar sobre as comunidades humanas mesolíticas de Muge e do Sado através de análises químicas dos ossos. *Promontoria, Revista do Departamento de História, Arqueologia e Património da Universidade do Algarve***,** 45-90.

UZQUIANO, P. 1992. The late glacial/postglacial transition in the Cantabrian Cordillera (Asturias and Cantabria, Spain) based on charcoal analysis. *Palaios***,** 540-547.

UZQUIANO, P. 1995. L'évolution de la végétation à l'Holocène initial dans le nord de l'Espagne à partir de l'étude anthracologique de trois sites archéologiques [Early Holocene vegetation evolution in northern Spain from the study of charcoals in three archaeological localities.]. *Quaternaire,* 6**,** 77-83.

VALENTE, M. J., DEAN, R. M. & CARVALHO, A. F. 2014. Shell middens in Western Algarve (Southern Portugal) during the Mesolithic and Early Neolithic: functionality, subsistence and material culture. *In:* ROKSANDIC, M., MENDONÇA, S., EGGERS, S., BURCHELL, M. & KLÖKLER, D. (eds.) *Cultural Dynamics of Shell-Matrix Sites.* Gainesville: University Press of Florida.

VALERA, A. C. & SANTOS, H. 2010. O concheiro do Neolítico antigo do “Meu Jardim”(Nazaré): informação preliminar. *Apontamentos de Arqueologia e Património,* 6**,** 21-27.

VAN DER SCHRIEK, T., PASSMORE, D. G., MUGICA, F. F., STEVENSON, A. C., BOOMER, I. & ROLÃO, J. 2008. Holocene palaeoecology and floodplain evolution of the Muge tributary, Lower Tagus Basin, Portugal. *Quaternary International,* 189**,** 135-151.

VAN VLIET-LANOË, B. 1998. Frost and soils: implications for paleosols, paleoclimates and stratigraphy. *CATENA,* 34**,** 157-183.

VAN VLIET-LANOË, B. 2010. 6 - Frost Action. *In:* STOOPS, G., MARCELINO, V. & MEES, F. (eds.) *Interpretation of Micromorphological Features of Soils and Regoliths.* Amsterdam: Elsevier.

VEGA DEL SELLA, C. D. L. 1914. *La Cueva del Penicial (Asturias),* Marid, Comisión de Investigaciones Paleontológicas y Prehistóricas.

VEGA DEL SELLA, C. D. L. 1916. *Paleolitico de Cueto de la Mina (Asturias),* Madrid, Comisión de Investigaciones Paleontológicas y Prehistóricas.

VEGA DEL SELLA, C. D. L. 1921. *El Paleolitico de Cueva Morín y notas para a Climatologia Cuaternaria,* Madrid, Comisión de Investigaciones Paleontológicas y Prehistóricas.

VEGA DEL SELLA, C. D. L. 1923. *El Asturiense. Nueva industria preneolitica,* Madrid, Comisión de Investigaciones Paleontológicas y Prehistóricas

VEGA DEL SELLA, C. D. L. 1930. *Las cuevas de la Riera y Balmori: Asturias,* Madrid, Comisión de Investigaciones Paleontológicas y Preshistóricas.

VERA, J. A. 2004. *Geología de España,* Madrid, SGE-IGME.

VERRECCHIA, E. P. & VERRECCHIA, K. E. 1994. Needle-fiber calcite; a critical review and a proposed classification. *Journal of Sedimentary Research,* 64**,** 650-664.

VILLAGRAN, X. S. 2014a. Experimental Micromorphology on Burnt Shells of Anomalocardia brasiliana (Gmelin 1791) (Bivalvia, Veneridae) and Its Potential for Identification of Combustion Features on Shell-Matrix Sites. *Geoarchaeology,* 29**,** 389-396.

VILLAGRAN, X. S. 2014b. A redefinition of waste: Deconstructing shell and fish mound formation among coastal groups of southern Brazil. *Journal of Anthropological Archaeology,* 36**,** 211-227.

VILLAGRAN, X. S. 2018. The Shell Midden Conundrum: Comparative Micromorphology of Shell-Matrix Sites from South America. *Journal of Archaeological Method and Theory*.

VILLAGRAN, X. S., BALBO, A. L., MADELLA, M., VILA, A. & ESTEVEZ, J. 2011a. Experimental micromorphology in Tierra del Fuego (Argentina): building a reference collection for the study of shell middens in cold climates. *Journal of Archaeological Science,* 38**,** 588-604.

VILLAGRAN, X. S., BALBO, A. L., MADELLA, M., VILA, A. & ESTEVEZ, J. 2011b. Stratigraphic and spatial variability in shell middens: microfacies identification at the ethnohistoric site Tunel VII (Tierra del Fuego, Argentina). *Archaeological and Anthropological Sciences,* 3**,** 357-378.

VILLAGRAN, X. S. & GIANNINI, P. C. 2014. Shell mounds as environmental proxies on the southern coast of Brazil. *The Holocene,* 24**,** 1009-1016.

VILLAGRAN, X. S., GIANNINI, P. C. F. & DEBLASIS, P. 2009. Archaeofacies analysis: Using depositional attributes to identify anthropic processes of deposition in a monumental shell mound of Santa Catarina State, southern Brazil. *Geoarchaeology,* 24**,** 311-335.

VILLAGRAN, X. S. & POCH, R. M. 2014. A new form of needle-fiber calcite produced by physical weathering of shells. Geoderma, 213, 173-177.

VIS, G.-J., KASSE, C. & VANDENBERGHE, J. 2008. Late Pleistocene and Holocene palaeogeography of the Lower Tagus Valley (Portugal): effects of relative sea level, valley morphology and sediment supply. *Quaternary Science Reviews,* 27**,** 1682-1709.

WASELKOV, G. A. 1987. Shellfish Gathering and Shell Midden Archaeology. *Advances in Archaeological Method and Theory,* 10**,** 93-210.

WATERS, M. R. 1992. *Principles of geoarchaeology: A North American perspective,* University of Arizona Press.

WATTEZ, J. 1988. Contribution à la connaissance des foyers préhistoriques par l'étude des cendres. *Bulletin de la Société préhistorique française***,** 352-366.

WEHRMANN, A. 1998. Modern cool-water carbonates on a coastal platform of Northern Brittany, France: Carbonate production in macrophytic systems and sedimentary dynamics of bioclastic facies. *Senckenbergiana maritima,* 28**,** 151-166.

WEINER, S. 2010. *Microarchaeology: Beyond the visible archaeological record,* New York, Cambridge University Press.

WEINER, S., GOLDBERG, P. & BAR-YOSEF, O. 2002. Three-dimensional Distribution of Minerals in the Sediments of Hayonim Cave, Israel: Diagenetic Processes and Archaeological Implications. *Journal of Archaeological Science,* 29**,** 1289-1308.

WILSON, M. A. & RIGHI, D. 2010. 12 - Spodic Materials. *In:* STOOPS, G., MARCELINO, V. & MEES, F. (eds.) *Interpretation of Micromorphological Features of Soils and Regoliths.* Amsterdam: Elsevier.

WITKAMP, M. & FRANK, M. L. 1969. Loss of weight, cobalt-60, and cesium-137 from tree litter in three subsystems of a watershed. *Environmental Science & Technology,* 3**,** 1195-1198.

ZAMBUJO, G. & LOURENÇO, S. 2002. Duas novas datações absolutas para a Ponta da Vigia (Torres Vedras). *Revista Portuguesa de Arqueologia,* 6**,** 69-78.

ZAPATA, L. 1995. La excavación del depósito sepulcral calcolítico de la cueva Pico Ramos (Muskiz, Bizkaia). La industria ósea y los elementos de adorno. *Munibe Antropologia-Arkeologia,* 47**,** 35-90.

ZAPATA, L. 2000. La recolección de plantas silvestres en la subsistencia mesolítica y neolítica: Datos arqueobotánicos del País Vasco. *Complutum***,** 157-170.

ZAPATA, L., MILNER, N. & ROSELLÓ, E. 2007. Pico Ramos cave shell midden: Mesolithic-Neolithic transition by the Bay of Biscay. *In:* MILNER, N., CRAIG, O. E. & BAILEY, G. N. (eds.) *Shell middens in Atlantic Europe.* Oxford: Oxbow.

ZAPATA PEÑA, L., ESTEVEZ, J. J. I. & URQUIJO, J. G. 1997. El yacimiento de la cueva de Kobaederra (Oma, Kortezubi, Bizkaia). Resultados preliminares de las campañas de excavación 1995-97. *Munibe Antropologia-Arkeologia,* 49**,** 51-63.

ZBYSZEWSKI, G. 1943. *Les eléphants quaternaires du Portugal,* Direcção Geral de Minas e Serviços Geológicos.

ZBYSZEWSKI, G. 1977. Nova Contribuição para o conhecimento da jazida quaternária da Mealhada. *Memórias e Notícias. Museu LMG Univ. Coimbra,* 84**,** 1-37.

ZBYSZEWSKI, G., PENALVA, C., FERREIRA, O., LEITAO, M. & NORTH, C. 1982. A ‘‘Pebble Culture’’do nivel Calabriano de Seixosa (Portugal). *Aspectos tipologicos e geologicos. Memorias da Academia das Ciencias de Lisboa,* 24**,** 127-162.

ZERBONI, A. 2011. Micromorphology reveals in situ Mesolithic living floors and archaeological features in multiphase sites in central Sudan. *Geoarchaeology,* 26**,** 365-391.

ZILHÃO, J. 1992a. Estratégias de povoamento e subsistência no Paleolítico e no Mesolítico de Portugal. *In:* MOURE ROMANILLO, A. (ed.) *Elefantes, ciervos y ovicaprinos. Economía y aprovechamiento del medio en la Prehistoria de España y Portugal.* Universidad de Cantabria.

ZILHÃO, J. 1992b. *Gruta do Caldeirão o neolítico antigo*.

ZILHÃO, J. 1993. The spread of agro-pastoral economies across Mediterranean Europe: a view from the far west. *Journal of Mediterranean Archaeology,* 6**,** 5-63.

ZILHÃO, J. 2001. Radiocarbon evidence for maritime pioneer colonization at the origins of farming in west Mediterranean Europe. *Proceedings of the national Academy of Sciences,* 98**,** 14180-14185.

ZILHÃO, J. & CARVALHO, A. F. 1996. O Neolítico do Maciço Calcário Estremenho: crono-estratigrafia e povoamento. *Rubricatum: revista del Museu de Gavà***,** 659-671.

ZILHÃO, J., CARVALHO, E. & ARAÚJO, A. C. 1987a. A estaçao epipaleolitica da Ponta da Vigia (Torres Vedras) in Especial Eduardo Serrao. *Arqueologia (Porto)***,** 8-18.

ZILHÃO, J., REAL, F. & CARVALHO, E. 1987b. Estratigrafia e cronologia da estaçâo solutrense de Vale Almoinha (Cambelas, Torres Vedras). *O Arqueólogo Portugués, IV-5*.

ZVELEBIL, M. 1986. Postglacial Foraging in the Forests of Europe. *Scientific American,* 254**,** 104-115.

# RESUMEN

El presente trabajo pretende estudiar las adaptaciones costeras de los cazadores-recolectores del Holoceno a través de la reconstrucción del proceso de formación de concheros. Para ello se utilizará una metodología geoarqueológica, es decir, centrada en el analisis de sedimentos arqueológicos. Geográficamente se centra en dos de las areas costeras más destacadas en el contexto atlántico europeo en lo que concierne al fenómeno de acumulación de concheros mesolíticos: la región cantábrica (norte de España) y el valle del río Sado (suroeste de Portugal).

El enfoque geoarqueológico de esta tesis se basa en el principio de que los concheros son depositos esencialmente antrópicos, a diferencia de la mayor parte de contextos prehistoricos, cuya matriz sedimentaria resulta de factores naturales de sedimentación y alteración del registro y de los artefactos que contienen. Los concheros resultan de la acumulación y manipulación antrópica de sedimentos, por lo que se pueden considerar artefactos en si mismos y pueden ser estudiados como tales, al igual que otros contextos sedimentarios antrópicos como los hogares, y por ello son extremadamente interesante desde el punto de vista geoarqueológico.

Los concheros representan un reto para los arqueólogos por su compleja estratigrafía. En el campo, los niveles conchíferos pueden asumir la forma de un depósito massivo e homogéneo donde no se distinguen los diferente episodios de acreción antrópica de sedimentos conchíferos que acaban interpretandose como una misma unidad. Por otro lado, puede resultar en intercalaciones intrincadas de depositos lenticulares entrecruzados de dificil discernimimento y facilmente mezclados. En esta investigación se propone que el reto de excavar e interpretar concheros, el principal testigo arqueológico del Mesolítico en ambas regiones, pasa por buscar la percepción de los diferentes depositos antrópicos. En este sentido, se propone la micromorfología de sedimentos como metodología base de la investigación.

Las acciones humanas dejan huellas sedimentarias microscopicas, tanto a nivel de composición como de texturas, muchas veces solo apreciables a escala microscópica. El análisis micromorfológico permite observar tales huellas preservando intactos los componentes antrópicos y su relación con la matriz sedimentaria, es decir, el *contexto*, bajo el microscopio petrográfico. El estudio de estas huellas permite distinguir diferentes facies dentro de un mismo depósito arqueológico, aumentando en enorme medida las posibilidades de reconstrucción de los procesos de formación, a nivel de alta resolución.

Objectivos específicos de este enfoque son la distinción entre procesos naturales y antrópicos y la individualización de diferentes episodios de acreción de depositos antrópicos conchíferos y otros a estos asociados (p. ej. hogares), e inferir acciones concretas de las que deriva su formación. Estos aspectos son fundamentales para avanzar en cuestiones que són aún objeto de debate en la arqueología de los concheros prehistoricos, tales como la estacionalidad de las ocupaciones y su función – ¿eran estrictamente depósitos de detritos o superficies de habitat?

Con esta investigación se pretende profundizar el conocimiento del proceso histórico de la adaptación de los cazadores-recolectores a los cambios geográficos producidos en el Holoceno, lo que al final caracteriza el Mesolítico, y una comparación del proceso entre las dos regiones estudiadas, en el contexto de la creciente sedentarización y complejidad social de los grupos humanos del litoral atlantico ibérico.

## Antecedentes

La arqueologia de concheros viene siguiendo una misma tónica en las dos regiones a los largo de las ultimas décadas del siglo XX hasta hoy, con continuos avances en el estudio de los conjuntos líticos y faunísticos, pero tambien antropológico, dadas las posibilidades de realizar estudios genéticos y de paleodietas sobre los restos humanos conservados. Estos estudios demuestran que los concheros son excelentes fuentes de conocimiento, dada la densidad de material arqueológico que los caracteriza, que resultan directamente de la explotación de recursos acuáticos (entre otros), con lo cual son tanbién excelentes archivos de información paleoecológica. Sin embargo, todavía sigue sin explorarse detalladamente cómo se han formado los concheros, y como se ha procesado su manutencion y utilización, cuestiones sobre las que sabemos todavía muy poco.

La formación de concheros y hogares, al ser esencilmante inducida antrópicamente, genera componentes de naturaleza sedimentaria que conservan importantes datos relacionados con la actividad de los grupos humanos, y por lo tanto pueden ser considerados artefactos. El gran potencial informativo de estos contextos reside en el estudio de tales huellas a nivel microscópico. Existen casos puntuales de análisis geoarqueológicos en concheros de ambos ámbitos geográficos del proyecto, pero hasta hoy ninguno ha incluido micromorfología.

En la región cantábrica, los concheros donde se han llevado a cabo investigaciones sedimentológicas corresponden a las capas superficiales de secuencias estratigráficas pleistocenas, que eran el objetivo primordial de las investigaciones tempranas. Las características de los depósitos de conchero concrecionados de La Riera, El Cierro y Les Pedroses han impedido a Butzer y Bowman (1976) la realización de análisis de granulometría, contenido en materia orgánica y potasio y fósforo disponibles, que sistemáticamente empleaba en muestras más terrígenas de sedimentos arqueológicos. También en La Riera, Laville (1986) se vio limitado a la descripción macroscópica de esos niveles. Estos ejemplos manifiestan las significativas condicionantes que presentan los concheros asturienses cementados a la hora de realizar estudios geoarqueológicos tradicionales. Las interpretaciones de estos depósitos han reincidido sobre el factor paleoambiental, como señalando el inicio del Holoceno, asumiendo que la formación de estos niveles, tal y como de las capas de espeleotemaa que también se documentan sobre depósitos pleistocenos en las cuevas de la región, se potencia bajo condiciones templadas y húmedas. A este respecto no se ha planteado cuál es el origen del carbonato que cementa los depósitos asturienses, que puede ser biológico, de aguas meteóricas o freáticas, lo cual implica que se puede obtener información ambiental mucho más precisa. Estas limitaciones han impedido la realización de estudios sedimentológicos para la reconstrucción de los procesos de formación. Ante la imposibilidad de realizar excavación sistemática de los niveles más endurecidos por la cementación, la micromorfología ofrece la posibilidad de observar su organización interior y la organización de los componentes antrópicos y su relación con la matriz carbonatada, además de permitir determinar el origen de esta. Hasta el presente, no se han realizado en la región Cantábrica estudios micromorfológicos sobre niveles conchíferos ni holocenos. Además de los casos ya mencionados, solo en los yacimientos vascos de Kobega II (Areso y Uriz, 2000) y Pico Ramos (Areso y Uriz, 1995) se han realizados estudios sedimentológicos tradicionales de granulometría y calcimetría en los niveles conchíferos mesolíticos.

El caso portugués presenta características algo similares en cuanto a estado de conocimientos científico-técnicos; sin embargo, cuenta con un trabajo que se puede considerar el único precedente de la propuesta en esa investigación: el análisis micromorfológico del conchero de Cabeço da Amoreira, por Aldeias y Bicho (2016). Con este trabajo, en un yacimiento de Muge, análogo a los concheros del Sado del punto de vista cronológico y socioeconómico, se ha verificado que la micromorfología es adecuada para la identificación de determinadas acciones humanas a través del enfoque por microfacies propuesto en esta investigación (ver abajo) en sedimentos conchíferos. La clasificación de microfacies ha posibilitado la individualización de eventos de descarte directo de conchas, remoción en masa de detritos previamente depositados, preparación y renovación de superficies y pisoteo, además de distinguir periodos de sedimentación eólica intra-conchero, indicando momentos de no ocupación. Sobre todo, estos trabajos demuestran que el potencial de dar continuidad a este enfoque en los contextos conchíferos de aire libre asociados a los paleoestuarios holocenos del litoral portugués es enorme. En cuanto a estudios más tradicionales, similares a los realizados en la región cantábrica, podemos contar con la caracterización textural macroscópica del conchero de Cabeço do Pez (Arnaud, 2000) y los análisis texturales y químicos (contenido en carbonatos) del conchero de Toledo (Trindade, 2011). Aparte de Cabeço da Amoreira, ya de igual modo que en la región cantábrica, los estudios micromorfológicos previos en contextos coetáneos relacionables geográficamente, no incluyen depósitos conchíferos.

## Objetivos

Esta tesis se basa en el principio de que los concheros mesolíticos, como depósitos esencialmente antrópicos, resultantes de la manipulación y acumulación antrópica de sedimentos, conservan huellas sedimentarias microscópicas que pueden ser un interpretadas en su conjunto como indicadores de comportamiento. Esto convierte a los concheros en depósitos particularmente interesantes del punto de vista geoarqueológico, ya que constituyen una excepción en el registro arqueológico de los cazadores-recolectores en la península ibérica, que está dominado por contextos afectados y alterados postdeposicionalmente por sedimentación natural de diversos ordenes (fluvial, coluvial, eólico, etc.) que no tiene que ver con la ocupación humana. Por eso, considerando los concheros como depósitos como artefactos en sí mismos, son archivos de distintas acciones humanas, particularmente relevante por permitir el estudio de las adaptaciones al medio costero durante los cambios geográficos ocurridos en el Holoceno.

Estas dos razones – ser depósitos antrópicos y contener información esencial sobre adaptaciones costeras durante los cambios geográficos del inicio del Holoceno – son las dos que justifican el estudio de concheros desde el punto de vista geoarqueológico.

Así, el objetivo general de esta investigación es la reconstrucción de los procesos de formación, antrópicos y naturales. Precisamente en cocheros, esta tarea representa muchas veces un reto de difícil resolución por su compleja estratigrafía. En el campo, los niveles conchíferos pueden asumir la forma de un depósito masivo y homogéneo donde no se disntinguen los diferente episodios de acreción antrópica de sedimentos conchíferos que acaban interpretandose como una misma unidad. Por otro lado, puede resultar en intercalaciones intrincadas de depositos lenticulares entrecruzados de difícil discernimimento y fácilmente mezclados. Para ello se propone que la manera de lograr una reconstrucción a alta resolución es buscando la individualización de los varios eventos de acreción antrópica de sedimentos conchíferos y el estudio de las características diferenciadoras de cada uno de ellos. El uso de la micromorfología permite incluir en la interpretación de los yacimientos las características microscópicas de los sedimentos, lo cual potencia la individualización a nivel micro-contextual.

Reconstruir los procesos de formación en depósitos especialmente antrópicos como concheros, significa necesariamente conocer las acciones que los formaron y por lo tanto las dinámicas de ocupación, abandono, funcionalidades y también de alteraciones postdeposicionales que forman parte del registro arqueológico. El conocimiento de estos aspectos es pertinente porque se sabe muy poco sobre la producción, mantenimiento y alteración de los concheros.

Para llevar a cabo el objetivo planteado, se recurrirá de forma sistemática al estudio de los contextos seleccionados mediante análisis micromorfológico como técnica base. Este planteamiento busca reunir información a las siguientes materias específicas:

1) Microestratigrafía: tratar de individualizar los diferentes momentos sucesivos de acreción de depósitos antrópicos, proporcionando una lectura individual de cada momento de acumulación. Este enfoque se aplica tanto a concheros de estratigrafía lenticular como a concheros de estructura homogénea masiva, ya que ambos

representan problemas a la hora de excavar por la difícil individualización física de cada momento de acumulación en el campo.

2) Contexto: lo anterior ha hecho posible la definición de especificidades a nivel sedimentológico de cada contexto, de los componentes macroscópicos y microscópicos y de los artefactos que contienen, y su relación con la matriz sedimentaria y determinación de la naturaleza de la misma. Esto permitirá medir la influencia de procesos antrópicos, biológico y geológicos que actúan en la formación del registro arqueológico, lo cual es fundamental para la interpretación de los mismos y de los datos que nos aporta su estudio específico (incluyendo dataciones). En conjunto, se intentado investigar cómo estos depósitos se han alterado desde su formación hasta la actualidad.
3) Paleoecología: dado que los concheros están formados por moluscos y otros componentes de alto valor informativo paleoambiental, en acumulaciones esencialmente antrópicas, son sedimentos idóneos para investigar las adaptaciones del ser humano en los medios costeros en este momento de la Prehistoria.

El potencial de esta investigación sobre los aspectos microestratigraficos, contextuales, tafonómicos y paleoecológicos pretende también poner en valor el gran potencial de integración de la micromorfología con otras técnicas de investigación, algo que se considera fundamental, como por ejemplo arqueología espacial, para correlacionar intra-yacimiento las diferencias microscópicas apreciadas y definir zonas de diferentes usos, o técnicas de reconstrucción paleoambiental sobre materiales de los mismos depósitos, como la esclerocronología, que se pueden afinar mutuamente con esta aproximación al conocimiento del microcontexto de donde proviene las muestras.

## Metodología

En termino conceptuales, la propuesta se basa en una metodología geoarqueológica, es decir, en el estudio de sedimentos arqueológicos, en particular sus características microscópicas y contextuales. Para ello se basará principalmente en la aplicación de la técnica denominada micromorfología de suelos y sedimentos. El gran potencial informativo de contextos sedimentarios cuyo proceso de formación es antrópico como concheros y hogares reside en considerarlos artefactos sedimentarios. En este sentido, se considera esta tecnica particularmente adecuada, porque permite observar los componentes sedimentarios a escala microscópica, preservando intactas su organización y geometría, aumentando substancialmente la capacidad de comprender los procesos de formación e alteraciones postdeposicionais que afectaron a los depósitos, ya que muchos de estos aspectos solo son visibles a escala microscópica. El potencial de la técnica reside en la posibilidad de observar la integridad de las condiciones de deposición de los artefactos en su matriz envolvente, es decir, su contexto deposicional, permitiendo comprender la contribución de los tres factores en juego en la formación del registro arqueológico: el geológico, el biológico y el antrópico.

La primera tarea de la investigación fue el muestreo. Los casos de estudio seleccionados en la región cantábrica y en el valle del Sado forman una muestra representativa para varios tipos de depósitos conchíferos, pensando en las cuestiones planteadas en cada una de las regiones. En todos los yacimientos se ha utilizado la metodología de muestreo más extendidas, procediendo al aislamiento del bloque de sedimento en el perfil estratigráfico, abarcando el contexto/contacto estratigráfico o estructura que se pretende estudiar microscópicamente. El bloque se envuelve en bandas pre-enyesadas humedecidas para asegurar su íntegra extracción, cuya orientación se marca en el exterior, una vez debidamente acondicionado. Posteriormente, las muestras se consolidan mediante un proceso de impregnación con una mezcla de resina poliéster a la que se añade estireno en proporción de 7:3 y un catalizador para su correcta absorción por el material sedimentario y solidificación lo que permite un primer corte mecánico con sierra rotativa.

Sigue la fase de producción de las láminas delgadas, en la que, primero, los bloques son cortados de acuerdo con las dimensiones de la lámina delgada final y el lado que se pretende ver reflejado es pegado a un portaobjetos de cristal. Una vez pegado empieza el proceso de pulido de la muestra hasta el espesor de 30µm, el valor convencional en microscopía óptica para observación de materiales sedimentarios, hasta la obtención del producto final, la lámina delgada. Se ha procedido a la consolidación de los bloques en el Departamento de Ingenierías Química y Biomolecular de la E.T.S.I Industriales y de Telecomunicaciones y las instalaciones del Instituto Internacional de Investigaciones Prehistóricas de Cantabria (IIIPC) en Omoño (Ribamontán al Monte). El corte de las muestras se hizo en el Departamento de Ciencia e Ingeniería del Terreno y de los Materiales (DCITYM) de la E. T. S. I. de Caminos, Canales y Puertos. Para la obtención de láminas delgadas los bloques se enviaron a laboratorios especializados en este tipo de muestras.

El análisis de las láminas de los materiales en lámina delgada se basa en los principios de la petrografía y mineralogía ópticas para la identificación de los componentes inorgánicos, posible a través de la observación en equipos de microscopia petrográfica de polarización en luz polarizada plana y luz polarizada cruzada con aumentos entre 1,5x y 400x. Complementariamente, se ha recurrido a otras técnicas de observación como la microscopía de epifluorescencia, muy útil para la caracterización de componentes orgánicos y sobre todo carbonatos y fosfatos – dos de los componentes más importantes de los sedimentos arqueológicos, intrínsecamente relacionados con actividades humanas. Las descripciones se basan sobre todo en la identificación de los materiales y su organización. De la fracción mineral se describen los aspectos morfológicos y texturales perceptibles a dos dimensiones, que se complementa con observación de muestras de sedimento sueltos bajo una lupa binocular, así como su litología. La relación entre fracción gruesa y fina se determina mediante ratios y geometría de la distribución relativa entre ambas.

Estas descripciones son la base de la clasificación de las distintas unidades micro estratigráficas, en cuya interpretación se aplicó el principio de microfacies. El concepto de microfacies consiste en el reconocimiento de conjuntos de atributos en lámina delgada (abundancia y organización de componentes, textura, estructuras sedimentarias, etc.) cuando están consistentemente aisladas de depósitos adyacentes. Este enfoque permite asignar uno o varios depósitos no contiguos a un mismo proceso, agrupando los que son similares en una única mirofacies. Cuando dos de estas aparecen sistemáticamente juntas (p. ej. en una relación de superposición) se habla en asociación de microfacies, e implica dos procesos inherentes entre si, algo común en depósitos antrópicos como, por ejemplo, estructuras e combustión compuestas por una capa de ceniza que refleja la combustión completa del combustible, depositadas sobre una capa de carbones que, por su vez, corresponden la combustión parcial del material debido a la falta de oxígeno. Las asociaciones de microfacies son cruciales en la evaluación del grado de conservación de un determinado contexto y de la reconstitución de su historia deposicional ya que, al conservarse, indican que un determinado proceso antrópico esta conservado en posición primaria. La tarea de clasificación de microfacies se lleva a cabo a la vez que la observación microscópica y descripción sistemática de cada lámina delgada, para después interpretar los procesos involucrados y sus relaciones cronológicas.

## Resultados

### *La Fragua*

En esta pequeña cueva en un acantilado del Monte Buciero (Santoña, Cantabria), se conserva un depósito antrópico holoceno caracterizado por niveles milimétricos de cenizas y carbones, muy ricos en conchas, subyacente a un deposito mas homogéneo, de edad pleistocena. El estudio del deposito pleistoceno ha revelado dinámicas de sedimentación esencialmente naturales motivadas por erosion de suelos del exterior y transporte lento, homogeneizado por actividad biológica postdeposicional. La inclusión de materiales antrópicos y animales, aves en particular, en la matriz sedimentaria confirma que este es un palimpsesto formado por acreción lenta de material retrabajados provenientes desde el exterior de la boca de la cueva, posiblemente en la época situada mas delante de la posición actual.

Los depósitos holocenos han revelado una secuencia esencialmente antrópica, marcada por superposición de estructuras de combustión, muy ricas en moluscos. En lámina delgada se pueden distinguir los diferentes eventos de combustión (es decir, ocupaciones sucesivas) a alta resolución. Mediante el análisis de distribución de los productos de combustión ha sido posible reconocer los niveles correspondientes a productos de combustión y sustratos de combustión. Esto ha permitido diferenciar posibles niveles resultantes de combustión *in situ* de niveles de desecho de productos de combustión, resultantes de desmantelamiento de productos de combustión de actividades de cocina cercanas, por lo tanto, en posición secundaria.

Se ha observado que los sustratos de combustión están enriquecidos en materia orgánica fibrosa carbonizada, finamente mezclada con componentes sedimentarios microscópicos provenientes de medios intermareales, en particular, arenas estuarinas, lo cual sugiere la presencia de plantas acuáticas en la superficie donde se han hecho las hogeras. Las plantas acuáticas pudieron haber sido trasportadas para la cueva por múltiples razones, por ejemplo, fabricar redes de pesca u otros materiales. La realización de estudios específicos de arqueobotánica y traceología podría contribuir a contextualizar estos resultados.

### *El Mazo*

Localizado en Llanes (Asturias), este es un conchero con una larga y compleja estratigrafía en un amplio abrigo calizo. El muestreo micromorfológico se hizo de forma selectiva, abarcando los varios contactos estratigráficos discordantes del conchero y las estructuras de combustión visibles entre las capas conchíferas. El abrigo del Mazo también presenta depósitos conchíferos cementados adherido al techo rocoso, que han sido igualmente objeto de muestreo micromorfológico. Con el estudio microestratigráfico se ha podido individualizar los depósitos correspondientes a distintos eventos, para lo cual la discriminación de estructuras y composiciones sedimentarias a nivel micro-contextual han sido vitales. Con el concepto de microfacies ha sido posible inferir acciones humanas especificas en la formación del conchero.

Una implicación significativa del estudio es que los distintos depósitos están compuestos de materiales arqueológicos retrabajados por agentes naturales. Esto probablemente habrá causado mezcla de materiales arqueológicos de varias ocupaciones en otras partes del abrigo. Este aspecto debe ser tenido en cuenta a la hora de interpretar datos de materiales de estos niveles, para lo cual las microfacies ofrecen una forma de conseguir mayor resolución de la microestratigrafia presente en el nivel, con objeto de alcanzar mayor precisión en la datación y dinámicas de ocupación en el yacimiento. La evidencia de momentos succesivos de formación de algunos depósitos en pendiente que corresponden a retrabajamiento natural de material antrópico ofrecen datos que podrán contribuir a futuros debates en respecto a reorganización del poblamiento Mesolitico en el litoral asturiano.

El estudio del bloque cementado ha revelado dinámicas de formación propias que no parecen ofrecer una correspondencia clara con la del deposito estratificado. El proceso de cementación ha sido determinado por fluctuaciones de nivel freático y un evento de condiciones de mayor energía, revelado por distintos tipos de crecimiento de cristales relacionables con la actividad hídrica. Estos resultados revelan que el cemento tiene un gran potencial informativo, sobre todo si en el futuro su datación radiocarbónica permitiría inferir la edad del episodio de mayor energía y sus implicaciones en procesos de formación a mayor escala.

*El Alloru*

Situado también en Llanes, es un abrigo calizo donde existe un conchero totalmente concrecionado y endurecido por cementación carbonatada posterior. En el área excavada en 2013 delante de la entrada del abrigo se ha encontrado un nivel de cronología mesolítica con algunas conchas y otros restos de ocupación (industria lítica y fauna). El muestreo micromorfológico ha incluido tanto el conchero cementado como una columna vertical de muestras cubriendo la secuencia estratigráfica del sondeo exterior, lo cual permitió una correlación y caracterización de la ocupación entre ambos ambientes (dentro y fuera del abrigo). Tras el estudio micromorfologico, resulta difícil correlacionar ambos contextos.

El sondeo exterior ha revelado, a nivel microcontextual, una intensa ocupación durante el Mesolítico, que se refleja en superficies pisoteadas, ocasionalmente encharcadas. En el conchero cementado del interior del abrigo se han identificado productos de combustión en forma de agregados retrabajados, es decir, en posición secundaria. Sin embargo, su presencia apunta a la preexistencia de estructuras de combustión que han sido totalmente erosionadas. La actividad de un manantial en el fondo del abrigo parece haber pasado por oscilaciones energéticas, algunas bastante elevadas, juzgando por las microfacies carbonatadas del travertino de que esta compuesto el cemento. Tales eventos podrían haber sido responsables de la destrucción de los contextos habitacionales en el entorno del conchero.

Las microfaciess de toba calcárea identificadas como principal constituyente del cemento del conchero se caracteriza por diferencias verticales, lo que indica que se ha formado durante variaciones de las condiciones ambientales locales, en particular en cuanto a la posibilidad de exsurgencias que allí pudieron haber existido. Tales cambios de actividad hídrica a que responde la deposición de la toba, habrá tenido influencia directa en a acumulación del conchero y sobre todo en su modificación. Sin embargo, la influencia antrópica esa presente en la acreción selectiva de componentes como huesos, lapas o erizos de mar en determinados niveles. Este aspecto puede ayudar a explicar la inversión de fechas de $^{14}C$ obtenidas verticalmente en el conchero.

Finalmente, el análisis micromorfológico del conchero cementado del Alloru a revelado que la cementación de estos contextos es sindeposicional, lo cual los dota de gran potencial en investigaciones futuras, en termino de reconstrucción paleoambiental y cronologías de la ocupación humana de la costa de Asturias en el Mesolítico.

*Poças de São Bento*

Este es un conchero situado al aire libre, sobre una duna pleistocénica en una plataforma elevada sobre el valle del Sado (Alentejo, Portugal). La gran amplitud del yacimiento (c. 4000m$^2$) ha permitido un muestreo en diversas áreas de excavación que permite un detallado análisis intra-yacimiento. El conchero consiste en un único nivel conchífero de espesor variable y discontinuo lateralmente, macroscópicamente homogéneo en la mayor parte de su extensión conocida, cuyo muestreo sistemático, vertical, ha pretendido determinar si a nivel microscópico es posible discernir diferentes eventos de acreción de depósitos antrópicos. En zonas más circunscritas, el mismo nivel de conchero presenta estratificación interna, igualmente muestreadas. Una correlación regional es posible con datos micromorfológicos del conchero de Cabeço da Amoreira, en Muge.

Uno de lo resultados mas interesantes del análisis micromorfologico es la evidencia de que ha existido superposición intencional de depósitos conchíferos, y no solamente acreción lateral. El estudio ha permitido distinguir depósitos de desecho y superficies de ocupación en el Área 1 del yacimiento, dentro de lo que a escala macroscópica parece un nivel masivo homogéneo, que se extiende por la mayor parte del yacimiento. A escala microscópica, este nivel revela toda una dinámica interna que revela varios procesos de formación.

A escala mas amplia del valle del rio Sado, se ha señalado en lamina delgada la presencia de componentes tales como agregados de arcilla y foraminíferos en sedimentos antrópicamente retrabajados lo que posiblemente indique el transporte de componentes del margen estuarino hasta el yacimiento, debido a la recolección de moluscos en ese ambiente. La aparición de clastos calizos en los mismos depósitos, sin relación con la geología local, indican una posible área de explotación de moluscos donde estos se podrían incorporar al sedimento trasportado, que no se sitúa en la proximidad del yacimiento, sino unos 8 a 12 km rio abajo. Este aspecto tiene implicaciones en estudios sobre los desplazamientos logísticos de los cazadores-recolectores del Sado y sobre la extensión del pleo-estuario durante el Mesolítico.

En el depósito estratificado del Área 9, se han podido reconocer eventos de descarte directo individual de detritos y desecho intencional de sedimentos retrabajados. Estos resultados muestran falta de evidencia de periodos de abandono, lo cual se mantiene como cuestión en estudio. La realización de estudios isotópicos de estacionalidad podría contribuir a colmatar esta ausencia, con ayuda del la microestratigrafia revelada en lámina delgada, que permite distinguir los distintos eventos deposicionales.

Descrte directo, vertido y dispersión antrópica de sedimentos, pisoteo y áreas de desecho peferenciales son algunas de las actividades inferidas del registro microestratigráfico de Poças de São Bento en común con los análisis homólogos en Cabeço da Amoreira, en Muge. Estas semejanzas apuntan a un mismo patrón en las actividades antrópicas responsables por la formación de ambos yacimientos. Estas observaciones permiten abrir nuevas posibilidades de investigación en otros contextos coetáneos con respecto a dinámicas de comportamiento mas generales sobre el Mesolítico del centro y sur de Portugal.

## Discusión y conclusión

Gracias a la metodología seguida en esta tesis ha sido posible identificar huellas sedimentarias asociadas a aciones antrópicas especificas, a través de la micromorfología, en concheros, que son palimpsestos arqueológicos complejos. Esto permite la distinción entre eventos de acreción de sedimentos conchíferos mediante procesos naturales o antrópicos y aumenta las posibilidades y grado de resolución de reconstrucción de los procesos de formación.

El enfoque por microfacies llevado a cabo en los cuatro yacimientos ha permitido reconstruir las dinámicas de formación de los concheros a través de la observación del registro sedimentario microscópico de la matriz de los sedimentos conchíferos. La escala de observación microscópica aporta información relevante que ayuda en distinguir diferentes eventos de acción antrópica en el desarrollo de los concheros.

Los aspectos de microestratificacion, tan comunes en concheros como difíciles de individualizar y caracterizar, son posibles de estudiar en detalle en lámina delgada. La variabilidad observada en el tipo y microestructura de diferentes matrices sedimentarias orgánicas también es posible distinguir en lamina delgada y son importantes indicadores del grado de retrabajamiento relacionado con remobilizacion atropica de sedimentos derivados de ocupación. Del mismo modo, se asignan contextos y posibles evidencias de la explotación y procesamiento de recursos vegetales normalmente poco visibles en el registro arqueológico, como hongos o algas.

El estudio integrado de microfacies de concheros y estructuras de combustión ofrece información detallada acerca de la función de diferentes contextos. Hogueras hechas con la finalidad exclusiva de cocinar para descartar de inmediato las conchas de los moluscos al consumirlos no son susceptibles de conservarse intactas; sin embargo, indicios de esta actividad preservados *in situ* han sido reconocidos en microfacies especificas de Poças de São Bento. Por otra parte, hogueras intactas han sido reconocidas en los yacimientos cantábricos, conteniendo moluscos, entre otros componentes, que probablemente no han sido intencionadamente quemados, sino que ya estaban presentes en el sedimento como resultado de ctividades previas a la combustión.

El estudio micromorfologico de contextos microestrtigraficos ha permitido determinar qué efectos post-deposicionales se superponen a la sedimentación. Este aspecto es relevante en la interpretación de concheros en lo que respecta, por ejemplo, a la reconstrucción de los volúmenes y geometrías de los depósitos asociadas a periodos de efectiva ocupación humana versus periodos de retrabajamiento natural de los depósitos, y como ambos han contribuido para el registro que observamos hoy.

Se han hecho contribuciones en el campo especifico de la micromorfología respecto a aspectos petrográficos, en particular en el cmpo de carbonatos microbianos y algas calcáreas. En el contexto del Mesolítico Asturiense, el estudio de los concheros cementados de El Alloru y EL Mazo ha revelado esencialmente dos aspectos novedosos: 1) la cementación y acumulación de los depósitos puede haber sido sindeposicional y ocurrido predominantemente en condiciones subaereas, bajo la influencia de aguas saturadas, en lo que la posible actividad de manantiales puede haber estado involucrada; 2) los depósitos cementados podrán corresponder a acumulaicones de material arqueológico retrabajdo por procesos naturales, posiblemente motivados por variaciones en el régimen de circulación de agua y de las posibles exsurgencias kársticas, y no resultantes de la acción antrópica directamente relacionadas com la acumulación de concheros.

El estudio de estos cementos carbonatados ha proporcionado un conocimiento detallado sobre el tipo y las condiciones ambientales de los precipitados carbonatados involucrados en el proceso gracias a la identificación de microfacies de carbonatos.

En ultima instancia, estos resultados, junto con datos de trabajos a lo largo de los últimos años y proyectos en curso, contribuyen a una revisión de la interpretación de las dinámicas de poblamiento asturienses a nivel regional. Las condiciones de conservación generales (por cementación) de los concheros en la región puede estar ofuscando la posibilidad de que no todos responden l mismo proceso de formación. Además, probablemente la mayoría no corresponde a acumulaciones antrópica en posición primaria, sin que ello constituya prejuicio del potencial informativo de estos depósitos en relación con el propio Mesolítico, una vez que todo indica que la cementación es sin-deposicional. Quizás, las condiciones topográficas e hidrológicas locales han sido determinantes en la configuración diferencial del hábitat y organización espacial, caso a caso. Todos estos aspectos relativos a los concheros asturienses están abiertos a discusión y el Mesolítico Asturiense seguramente se beneficiaría de futuros estudios, a escala regional, que incorporen aportes significativos desde la karstologia específicamente diseñados para comprender la formación de los concheros.

Las inferencias conseguidas han sido posibles debido a su integración con varias escalas de análisis contextual. Mediante la combinación de datos micromorfológicos con análisis espacial ye geomorfológico es posible inferir aspectos precisos de organización espacial, comportamiento simbólico en respecto a practicas funerarias, monumentalidad predeterminada a través del amontonamiento de detritos conchíferos, y la influencia de las condiciones naturales en la formación de los yacimientos. Aspectos geoarqueológicos mas globales han revelado conexiones próximas a cuestiones paleoambientales, cuyo desarrollo futuro es vital en la investigación de estas sociedades en la Región Cantábrica y en el valle del Sado.

A través de la comparación de microfacies, con este trabajo queda demostrado el carácter global de la arqueología de concheros, permitido hacer interpretaciones relevantes en cuanto a la integridad y complejidad del registro basándose en descripciones micromorfológicas precisas en concheros, por lo tanto, es recomendable su aplicación a contextos similares.

Las implicaciones para interpretaciones a escala de yacimiento son criticas, particularmente en el soporte a proporcionar contexto a análisis multidisciplinarios tales como análisis de isotopos, dataciones o estudios de cultural material y restos bioarqueológicos. El conocimiento del grado de retrabajamiento y mezcla de materiales, y si es de origen antrópico o natural, son aspectos vitales para la correcta interpretación de cualquier muestra recogida de un contexto arqueológico, en particular aquellos susceptibles a movimientos e inestabilidades intensas como los concheros. Considerar el microcontexto a la hora de muestrear para análisis multidisciplinares debe ser el próximo paso en muchas de esas disciplinas investigando en concheros, y un reto para futuras excavaciones arqueológicas de este tipo de yacimientos, abriendo el camino a una integración más precisa y a mayor resolución de resultados. Esto es esencial para el conocimiento de la evolución de la relación y conexión del ser humano con los ambientes costeros.

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