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International Erasmus Mundus Master in
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Sedimentary structures of late Pleistocene layers (MIS 2 to 4) of Lezetxiki cave upper deposits (B to L layers), using scan thin sections.

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Abstract:

The study of the sedimentar y samples from Lezetxiki cave, located in the Basque country, Spain, using soil micromorphology approach served as the foundation for this master's thesis. This site is one of the most significant Basque country sites, known for its middle to upper paleolithic transition. Thus, the samples are being thoroughly studied to improve our comprehension of its lithostratigraphy and depositional settings as well as its post-depositional modifications. Many researchs (e.g., sedimentology, pollen studies, chronological study, anthropology...) have been conducted at Lezetxiki; however, a number of issues still need to be resolved.

The results of the investigation shows that Lezetxiki's deposits are composed of two facies types: primary loess modified by pedological processes (loess aggregates: granular fine silty loam, platy fine silty loam and granular fine silt) and loess like deposits (graded muddy silt, matrix supported muddy gravel and massive muddy silt), which, while exhibiting many sedimentological properties of aeolian loess (porosity, unstratification, homogeneity..), were not deposited by wind. The majority of those distinct facies are linked to the mass movement tranport processes and erosion. Lezetxiki post depositional features includes other deposit types, such as solifluction, which have also been demonstrated to be significant.

Keywords: Micromorphology; Lezetxiki cave; Stratigraphy; Facies, Modes of deposit, Loess, Loess like.

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1- Introduction:

Caves hold a significant amount of archaeological evidence from prehistoric periods and have played a significant role in shaping the concept of "home" for humans throughout time. They not only offered natural shelter and protection but also served as memorable and confined living spaces (Rolland, 2004). Across different cultures, caves have served various purposes and were particularly important in the early stages of human evolution (Straus, 1997). The stability and convenience of caves led to the accumulation of sediments and cultural artifacts. The extensive geological and archaeological records found within caves have provided valuable insights into prehistoric archaeology in many parts of the world.

In the realm of archaeological research, the quest to understand the intricate tapestry of human history often necessitates delving beyond the visible remains and into the microscopic fabric of the past, by peering into the microscopic world beneath our feet, we gain a deeper understanding of the forces that have shaped our collective past and continue to influence our present and future. Though, traditional archaeological methods often fall short in capturing the intricacies embedded within sediments and soils, which often focus on visible features and artifacts.

However, the emergence of micromorphology has revolutionized the field, representing a paradigm shift in archaeological inquiry, offering a lens through which we can peer into the microcosm of ancient landscapes, structures, and activities. Micromorphology delves into the unseen complexities of soil formation, stratigraphy, and depositional processes. By analyzing thin sections of sediment under a petrological microscope, archaeologists can discern a rich tapestry of microstructures, mineral compositions, and organic residues that provide invaluable clues about past human behaviors and environmental dynamics, enabling archaeologists to delve deeper into the microscopic fabric of archaeological sites, as each granule and each grain of soil has a story that is just waiting to be told. At its core, micromorphology represents a marriage of geology, soil science, and archaeology, providing a unique perspective on the dynamic interplay between humans and their surrounding environments, shedding light on issues ranging from ancient land use practices to the impacts of climate change on past societies.

As stated by Sageidet (2000), soil micromorphological analysis is today the most reliable method for identifying and understanding the processes involved in soil formation. Therefore, it is necessary to assume that the pedological features resulting from past pedogenic processes are similar to those produced by the same processes today. It is also necessary to assume that some soil features and processes are uniquely associated with specific environments (Birkeland, 1984).

Methodologically, micromorphology offers a unique set of challenges and opportunities for archaeological investigation, from the meticulous collection and preparation of soil samples to the detailed analysis of microscopic features, each step of the micromorphological process requires careful attention to detail and a keen understanding of geological principles. Through a combination of fieldwork, laboratory analysis, and interdisciplinary collaboration, researchers can unlock the hidden narratives encoded within the sedimentary matrix.

Through the lens of micromorphological analysis, this study aims to shed light on the depositional history and sedimentary structures that have shaped Lezetchiki cave's settlement in the Basque country (Spain). Throughout this thesis, we will explore the diverse applications of micromorphology in archaeological research to provide a window into the lived experiences of our ancestors. We will demonstrate the versatility of micromorphological analysis in generating new insights and refining existing interpretations of the past.

1-1 Aims and objectives:

The aim of this thesis is to understand the sedimentary settings and the evolution of Lezetchiki's cave settelment (Basque country, Spain) using buried soils (paleosols).

To achieve this aim, the following specific objectives were defined:

1. To correlate sedimentary structures, using macroscopic observations, archaeological context and micromorphological data with macroscopic observations, archaeological context and palaeo nvironmental data;

2. To identify the stratigraphic phases based on available site lithostratigraphic nomenclature and investigate potential patterns of stratigraphic discontinuity and continuity.

3. To document and interpret the microstratigraphic sequences, microfacies associations, and sedimentary current flows in order to argue loess and loess like deposits in Lezetxiki I cave.

These aims and objectives provide a structured framework for conducting this research and will help guide our investigation towards achieving meaningful outcomes.

CHAPTER ONE

1-Lezetxiki cave:

1-1 Geographic location:

The Lezetxiki site is located in the south-western part of the province of Guipzcoa, more precisely in the district of Garagarza, in the current municipality of Arrasate. The cave looms over the valley of the river Aramaio, one of the Deba's principal tributaries, in its upper course (Figure 1). The Udalaitz massif includes Mount Bostate. The Bostiturrixeta stream, which today flows 30 meters below the mouth of Lezetxiki, is responsible for the construction of this cave. It is located on a steep hillside at 380 meters above sea level and has a tunnel-like shape with a N-S orientation and a minimum of 50 meters of development (Juan Manuel Fernandez Lopez, 2015).

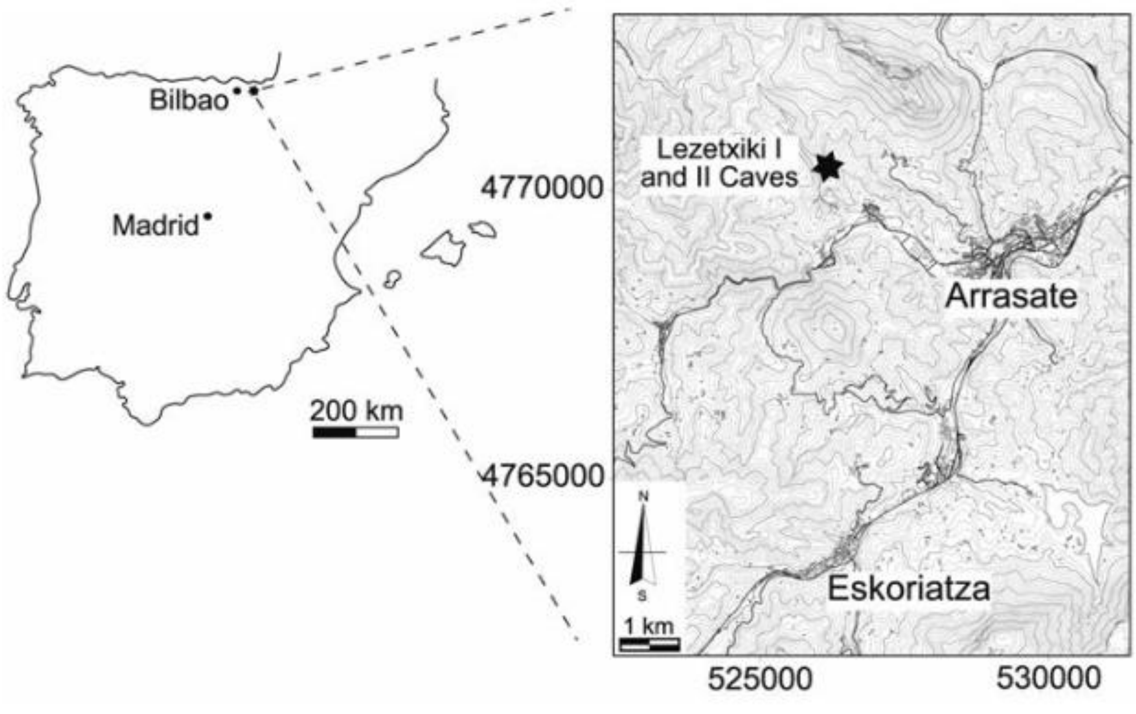

Figure. 1: Localisation of Lezetxiki cave (Castaños et al., 2011)

2-1 Discovery and excavations:

The cave of Lezetxiki was discovered in 1927 by Justo Jauregui-Arrabùauru, a seminarian and the son of Garagarza's teacher. In 1927, J.M. Barandiarán found flint and bone fragments, leading to the first excavation in 1928 (Barandiarán Ayerbe, 1960b). The excavation at Lezetxiki took place from 1956 to 1968 under

Barandiarán's supervision and is known as the "classical excavation." During this time, eight archaeological layers were discovered, which were further divided based on the presence of lithic industry remains. During this intervention, 100 m2 were along a stratigraphy of 10 meters. Inside this cave, a human humerus was found, believed to belong to a pre-Neandertal (Basabe 1966, 1970; Arrizabalaga and Iriarte, 2011).

During the classical excavation at Lezetxiki and the following years, various research projects were conducted and papers were published using the materials found there (Chaline, 1970; Kornprobst and Rat, 1967). However, the dating methods used by C14 were not satisfactory (Mariezkurrena, 1990), and no further fieldwork was carried out until 1996. In the three decades that followed, there have been significant developments in the understanding of the quaternary period. Numerous analyses have been conducted on materials (Altuna & Lazuen-Fernández, 2012; Álvarez-Alonso & Arrizabalaga, 2012; Arrizabalaga, 1995; Baldeón, 1987, 1993) and samples (Sánchez-Goñi, 1991) from the classical excavation, but the results have been inconsistent and contradictory. As a result, a new excavation project was planned to focus on a small surface (6 m2) of the deposit. This project was coordinated by the present authors (Arrizabalaga, 2006a, 2006b; Arrizabalaga *et al.*, 2005; Falguères *et al.*, 2006). Because of the cave's complex form, the excavation was expanded to cover an area of 20 m2 during the 2012 field season. And then, from 1996 to 2015, the excavation was under the supervision of Arrizabalaga, leading to the discovery of various remains. In 1999, the excavation of Lezetxiki II began in order to determine the sedimentary context of a human humerus fossil (Arrizabalaga, 2006b). The excavation area is a 1x4-meter trench, and the upper layers of the stratigraphy have been dated to over 74,000 years old (Falgueres *et al.*, 2006). During the first series of seasons, an extensive sequence of Late Pleistocene levels was excavated, and three human fossil remains were recovered: two Neandertal teeth from Level IV and a humerus from Level VIII (Arrizabalaga et al., 2005). In order to provide a clearer context for the human fossils and other finds from this site, excavations were resumed with an updated methodology (Arrizabalaga, 2006). In 2006, the equivalent of level VI was excavated, which was previously the base of the sequence in the "*classical excavation*" at the south profile, where is placed the actual excavation. Below this point, levels identified as L, M, N, and O were discovered, which are believed to correspond to level VII in the traditional sequence. During the 2007 excavation, a collapse level (Level M) was found, indicating a change in the occupation patterns at Lezetxiki. The preservation of this sedimentary level is exceptional (Arrizabalaga *et al.*, 2009). This new work has been carried out on the southern side of the classic deposit at Lezetxiki I and also in a neighboring cave (known as Lezetxiki II) which is connected physically with Lezetxiki I, precisely in the place where the human humerus was found. The site was closed after reaching the bedrock in 2016.

3-1 Chronology:

The geochronology of the Lezetxiki complex is a challenging aspect of its reinterpretation. During recent excavation campaigns, many new samples of charcoal and bone for radiocarbon dating were collected but have yielded unsatisfactory results. C. Falguéres has joined the Lezetxiki team to obtain new dating using different procedures (U/Th or ESR) on materials from both the main site and a secondary location called Lezetxiki II (Falguères et al., 2005). The challenge is finding suitable materials for dating, such as well-crystallized molars and speleothems. A dating of over 100,000 BP has already been obtained for one of the speleothems from Lezetxiki II. The presence of Ursus spelaeus specimens under the dated stalagmitic flow suggests that this level may correspond to the last interglacial period. In contrast, the lower levels of the main cave in Lezetxiki contain a good collection of Ursus deningeri, which is considered older in the genus's evolutionary history (Arrizabalaga, 2003). The main source of information (Falguères et al., 2005_2006) for interpreting the age of the fill in Lezetxiki II is a Th/U date of 74,000 BP obtained from a speleothem located about 150 cm above a macaque jaw (precisely on the borderline between the quadrants, M15 and N15). Two additional dates were calculated using the amino acid racemization of Ursus teeth from the same layer, resulting in a range of 70,000 BP to 86,800 BP and a mean value of 78,400 BP (Torres et al., 2002).

4-1 Geology and geomorphology:

Lezetxiki is a part of an ancient karstic abandoned by the waters. It is located on the southwest side of the Kobate ravine and sits at an altitude of approximately 375 meters. The highest points in the surrounding area are less than 100 meters above Lezetxiki. These points include Karraskagain (469m), Olasu (431m), and Hillock (411m). However, Lezetxiki is now separated from the Kobate basin by the Garagarza stream, and the neighboring reliefs rise to 1092 meters in the Udalaitz limestone massif (Kornprobst and Rat, 1967).

The geological study of the fill is based on samples collected during the summer 1967 excavation campaign. These samples were taken from the section located at the boundary of bands 9 and 11 (J. M. Barandiaran's grid). In summary, the materials used to fill Lezetxiki cave can come from various types of limestone found in the surrounding area and various varieties of Urgonian or para-Urgonian calcrete in which the cave is dug out and which form part of the surrounding relief, as well as sandy or clayey residues from the alteration of these limestones. Additionally, minerals formed near the surface of the soil, such as iron concretions, biological materials such as bones, teeth, and phosphate, as well as human artifacts, are also present and studied by archaeologists and paleontologists (Kornprobst and Rat, 1967).

The fill's color remains homogeneous, appearing yellowish-brown when dry and dark yellowish-brown when wet. It is composed of black limestone with a white patina that matches the limestone found in the cavity. The limestone pieces are typically larger than 1 mm and can sometimes exceed a meter in length. They are often like platelets with angular edges, which are more or less worn; they can also be less typical and rounder in shape; sandstone elements with varying compositions, ranging from real quartzites to clay-cemented sandstones with aleurites grain size (10 microns to 100 microns); muscovite is abundant in some minerals; these elements are always rolled, and their dimensions range between 100 microns and 5 cm; Isolated quartz grains, typically transparent and unweathered, are also present and are derived from the disintegration of the previous elements; they are usually between 100 and 10 microns in size. Additionally, there are accessory elements such as iron-rich limonite concretions, pyrite grains, and limestone concretions. The number of these elements is too small for statistical analysis. Animal remains, such as teeth and bones, are also found at certain levels. The entire structure is covered in a yellow-brown limestone cement and creates "S" concretions that developed after the elements were deposited (Kornprobst and Rat, 1967).

The observations reveal three facts. Firstly, the sandstone materials and concretions are of allochthonous origin; the analysis of these materials provides insights into variations in the origin and deposition processes. Secondly, the limestone concretions known as "S" were formed within the cave after it was filled, requiring a certain level of humidity and a mild temperature. Lastly, the limestone elements could be either formed within the cave due to freezing and fracturing of the cave walls, indicating a cold period during deposition, or brought from outside during a wet period when water was circulating (Kornprobst and Rat, 1967).

CHAPTER ONE

5-1 Sedimentology and climate:

In 1967, Kornprobst and Rat conducted a sedimentological analysis of the Lezetxiki deposit using samples collected from the 9/11 bands (Fig. 2). Their findings were published in Munibe. The study examined the various phases observed in the sequence, although some of these subphases were defined based on a single or two samples. It is important to mention that only samples from the first six archaeological levels could be collected, similar to the sequence established by Palynology (Kornprobst and Rat, 1967).

The filling of the Lezetxiki cave is made up of different types of rocks from the Lower Cretaceous period, specifically Urgonian limestones. Through sedimentological analysis, it has been discovered that the cave experienced cold phases with frost, followed by milder and wetter periods when water was present. These climatic oscillations occurred during the Würm period (Kornprobst and Rat, 1967).

The series starts with a phase that includes beds F and G in level VI. Bed H, which is parallel to the bottom part of sublevel Vb, represents a period of high thermal heat and low humidity. On the other hand, bed I, located between levels Vb and Va, shows a visible improvement in temperature, which coincides with a large decrease in humidity. However, the upper part of level Va and the entire level IV develop in a cold and humid environment. As opposed to a more temperate and less humid environment that occurs within the whole of level III (Kornprobst and Rat, 1967).

Additionally, this sedimentological study suggests that the sequence of beds at the site can be divided into different phases. The lower levels show a crisis in temperature and humidity, while the upper levels are characterized by colder and more humid conditions. There is a significant gap in the sedimentological record between the Early Aurignacian and Gravetian levels, which may explain the lack of habitation at the site during that time. The sequence ends with level I, which consists of different beds indicating varying temperature and humidity conditions. The N bed indicates a temperate and dry period, whereas the other beds indicate a cold and humid time. Beds O, P, Q, and M are attributed to Würm IV, L to Würm III, and J to at least Würm II. It was not stated whether the dry cold found in bed H corresponds to Würm II or I (Kornprobst and Rat, 1967).

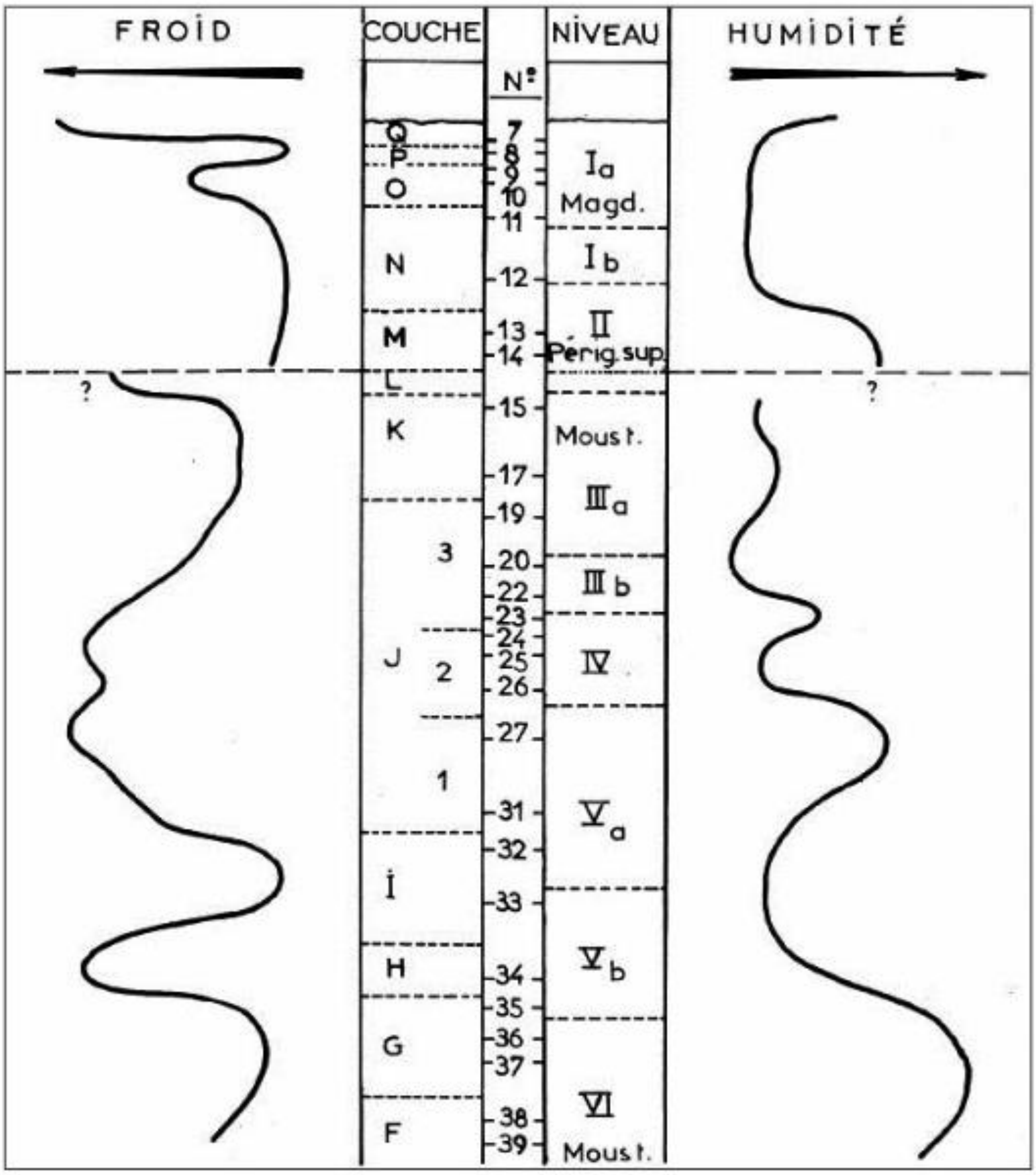

Figure. 2: Sedimentological summary diagram (according to Kornprobst and Rat, 1967).

6-1 Stratigraphy:

Barandiarán uses Roman numerals to represent the levels, while Arrizabalaga uses letters (Fig. 3 and 4). The cave has different levels, with each level corresponding to a specific time period. The Bronze Age surface layer is on top, followed by the Magdalenian level Ia, which contains lithic fragments, carvings, and bone tools. Level B is sterile, while the Upper Perigordian is Level II. Level D is the Solutrense. Level IIIa, also known as the Archaic Aurignacian, has the highest concentration of archaeological relics and may have some contamination or overlapping of different occupations. This level is equivalent to level E and was shared by both humans and bears (Juan Manuel Fernandez Lopez, 2015).

Mousterian is classified into different levels, ranging from IIIb to VI, related to F-L stages. Each level has its own unique characteristics and artifacts. At level IIIb, there are dental pieces with taurodontism and polished shell fragments. Level IVa has survived lithic objects and carvings with varying features. Level IVb is characterized by sterility. Level IVc has different lithic fragments and is associated with lamellar industries in the context of levallois points, and two shell fragments are believed to have been used as pendants. Level Va indicates sterility, while level Vb is known as the sixth level of Mousterian. At level VI, there is a diverse collection of lithic and bone tools, including retouched tools and flakes. This level suggests a period of moderate and humid climate with the growth of large hardwood forests, likely during the Eem interglacial (Riss-Würm) (Juan Manuel Fernandez Lopez, 2015).

Level VII has very few lithic remains, in which bear and carnivore remains are more present than ungulates. A Neanderthal or Heidelbergensis humerus was found in Level VIII, but no lithic industry was recovered. Levels VII and VIII correspond to levels M-R. Level R, the deepest level, probably corresponds to MIS 7. Another level (IX) has been discovered (Juan Manuel Fernandez Lopez, 2015).

Current Letzetxiki levels	Old Letzetxiki levels	MIS Correlation	Archaeological assamblage
A-B	I	1	Magdelanian – Bronze age
C-D	II	2	Aurignacian - Solutrean
E	IIIa	3 (30-34 ka)	Aurignacian
F	IIIb	3 (47 ka)	Middle palaeolithic
G-H-I	IV	3	Aurignacian Middle palaeolithic
J-K-L	V-VI	4	Middle palaeolithic
M-N		5	

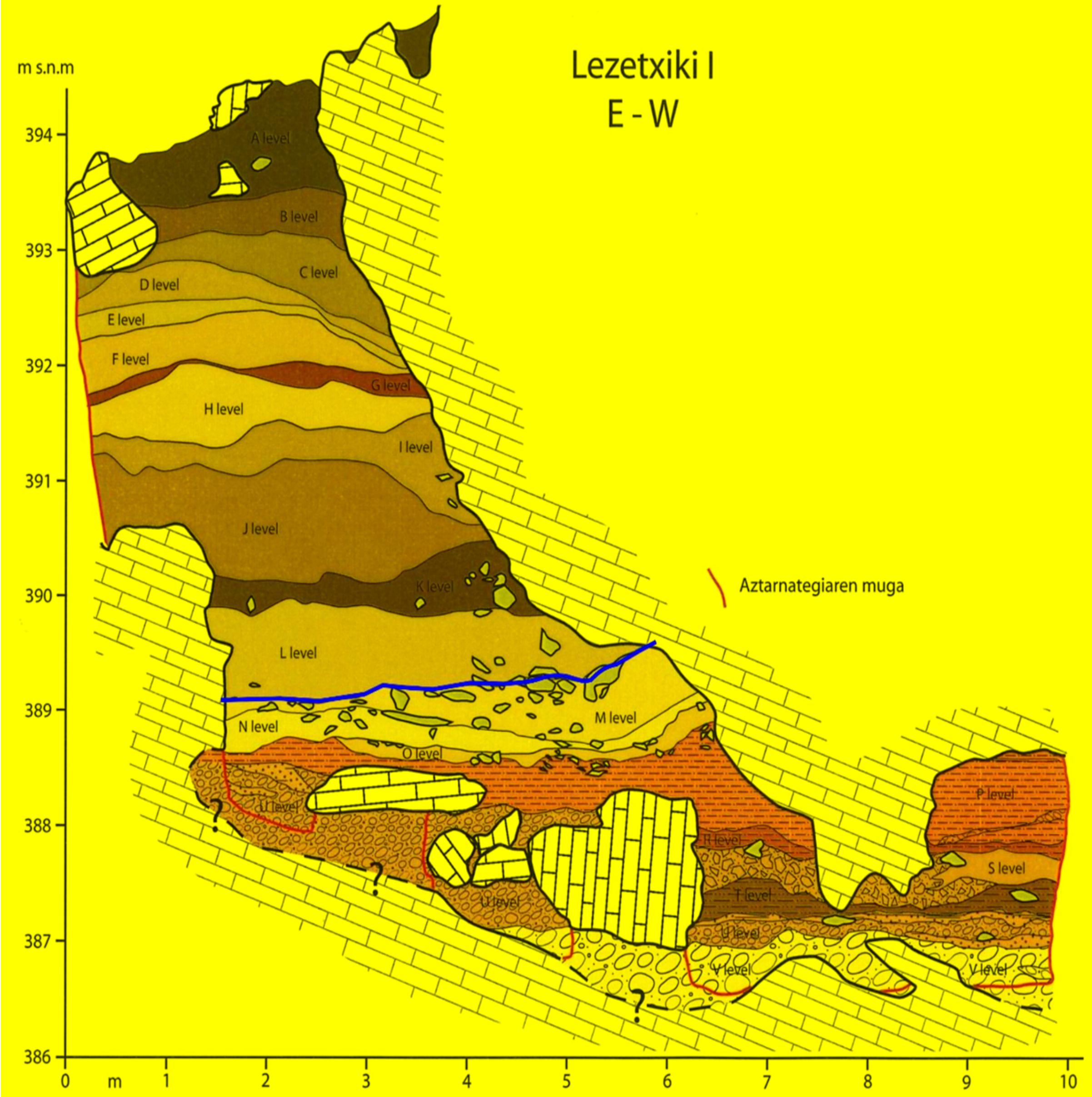

Figure. 3 : Plan showing the section view of the sampled units.

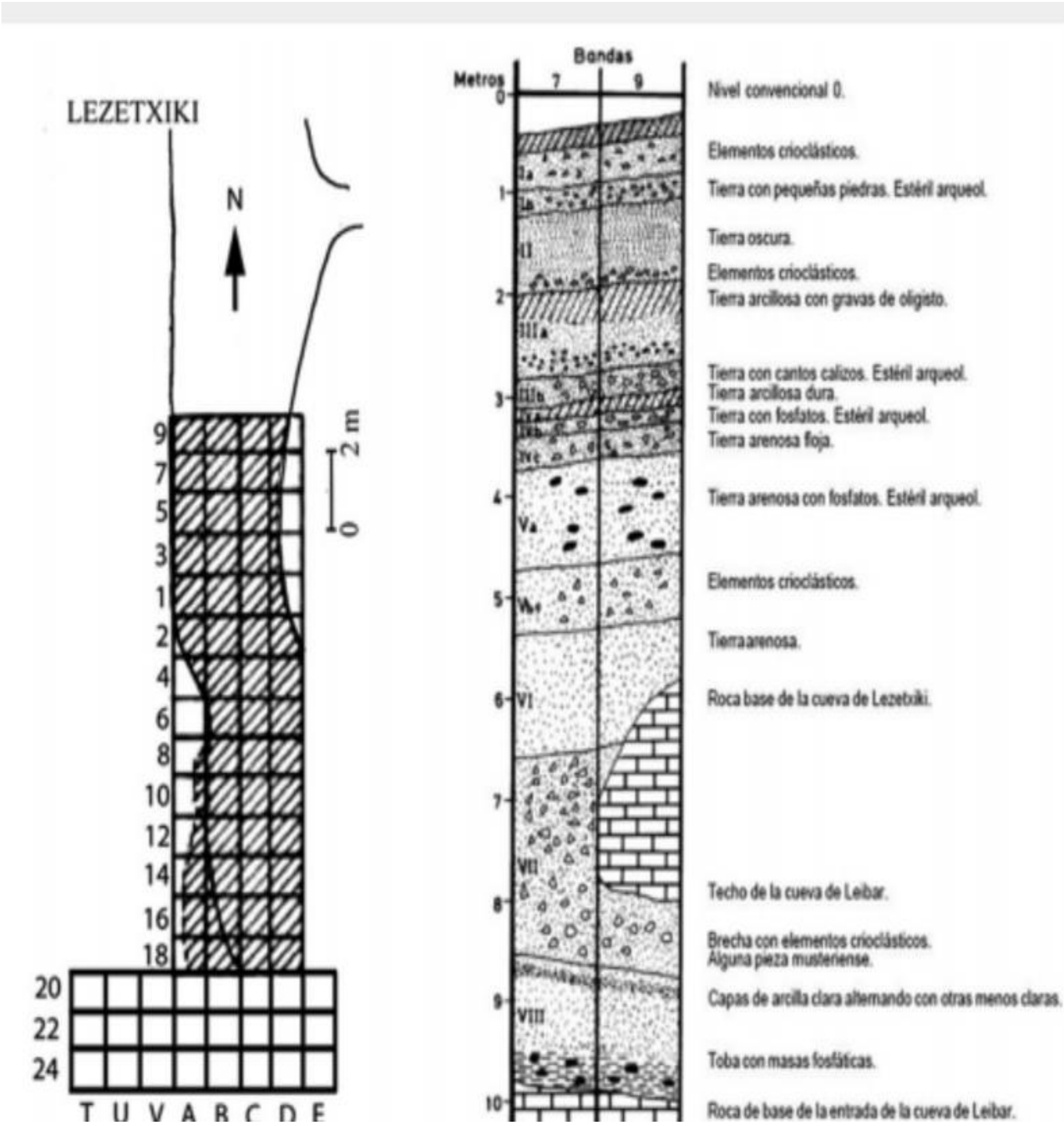

Figure. 4: Plan of the site (left). The Barandiarán excavation corresponds to the shaded sector. Lezetxiki II, with the unshaded squares (Álvarez-Alonso and Arrizabalaga, 2012, modified from Altuna, 1972). Stratigraphic profile (right) made on the northern cliff (Altuna, 1972).

7-1 Discoveries and cultural belongings:

1-7-1 Human:

The cave was successively occupied by humans of the types H. heidelbergensis (levels VIII and VII), Neanderthal (levels VI to IIIb), and AMH (levels IIIa to I), and all of them left human fossils (Homo Heidelbergensis in level VII, Homo Neanderthalensis in both IVa and IIIb levels, Homo sapiens in level I

(Arrizabalaga 2005/2006; Arrizabalaga and Iriarte 2006; Álvarez-Fernández 2006; Taborin 1993).

A human right humerus (possibly Heidelbergensis) has a very advanced degree of mineralization. It was found by Mr. José Miguel Barandiarán in 1964 in the cave of Lezetxiki (Mondragón, Guipúzcoa), under all the Mousterian layers, at the base of the deposit in level VIII. The radiological analysis suggests an individual of about 30 to 35 years of age, of rather female sex, although it is noted the insecurity of sexual diagnosis in a piece of these conditions. And the global study of a set of characteristics manifests an appreciable number of traits of the Neandertal. Additionally, within level III, there were two dental specimens (Basabe 1970) (Fig. 5) found that were bigger than those of current Homo sapiens and had a rare, marked taurodontism, which is not commonly seen in sapiens (Basabe, 1966 and 1970; Arrizibalaga, 2009).

Figure. 5: Homo Neandertal teeth from the Lezetxiki transitional layers (Arrizibalaga, 2009).

2-7-1 Bone industry:

The levels representing the transition from the Middle to the Upper Palaeolithic at Lezetxiki (IIIa, IVa, and IVc) provide a very archaic bone industry that, however, appears to be particularly old (Arrizabalaga 2005/2006; Arrizabalaga & Iriarte 2006; Álvarez-Fernández 2006; Taborin 1993). The bone industry at this site was first analyzed and summarized in 1967 by Barandiaran (Barandiaran, I., 1967). A second synthesis was published in 1983 by Mujika (Mujika, 1983), which included material from Lezetxiki. Mujika noted that there were a small number of tools found in the deposit, which he attributed to different criteria and the uneven preservation of the remains. He also observed that the site was not continuously used. Most of the bone industry remains were found in level VI, while only a fragment of a harpoon and a spear were found in level I. The remains in levels II, III, and IV were considered to be tools made by natural factors (MUJIKA, 1991). A possible bone point (Fig. 5) was discovered in Lezextiki, at the base of level V, and was tentatively dated to 50,000 BP; in the same context, a full punch was discovered; it's fractured and looks like a bone point (Arrizibalaga, 2009).

Figure. 5: Bone point from Lezetxiki *(*Arrizibalaga, *2009).*

3-7-1 Lithic industry:

The levels representing the transition from the Middle to the Upper Palaeolithic at Lezetxiki (IIIa, IVa, and IVc) appear to provide mixed technical traditions: lithic knapping schemes belonging to the Mousterian and the Aurignacian found together, and a very archaic bone industry that, however, appears to be particularly old (Arrizabalaga 2005/2006; Arrizabalaga & Iriarte 2006; Álvarez-

Fernández 2006; Taborin 1993). The excavator and different specialistshave studied the lithic industry at the site, but they have different views on the chronology of Levels III and IV. Some specialists think they belong to the Musterian period, while others believe they are Upper Palaeolithic levels. The excavator at the site has published multiple papers that include an inventory and drawings of the significant lithic artifacts found at the site. These artifacts are considered to be the most remarkable ones discovered. At Lezetxiki, there are various blade (figure, 6) or bladelet forms found in the basal sequence. However, these coexist with centripetal chaines opératoires (Arrizabalaga, 2006). This has led authors to confusion when determining whether the units at Levels III and IV belong to the Mousterian or the Aurignacian (Arrizabalaga, 2009).

Figure. 6: Retouched blade from the transitional levels of Lezetxiki (Arrizibalaga, 2009).

4-7-1 Malacological remains:

In the Lezetxiki cave, ornamental marine malacological remains have been found in levels III and IVc. While these levels have been associated with both the Mousterian and the early Upper Palaeolithic periods, the discovery of Neanderthal teeth near the shells suggests that these objects belonged to the Neanderthals. Due to the difficult preservation conditions in the cave, it is hard to determine if the shells were manipulated by humans, but it is likely given their presentation. In addition, a part of the right valve of a Spondylus sp. (Fig. 7) was found 417 cm below the base level of the cave. It is important to note that the presence of human remains at these levels does not indicate burial contexts. The Neanderthal and Homo Heidelbergensis remains found are likely to be ordinary tooth losses rather than intentional burials (Basabe, 1970; Arrizabalaga, 2005 and 2006; Arrizabalaga et al., 2005).

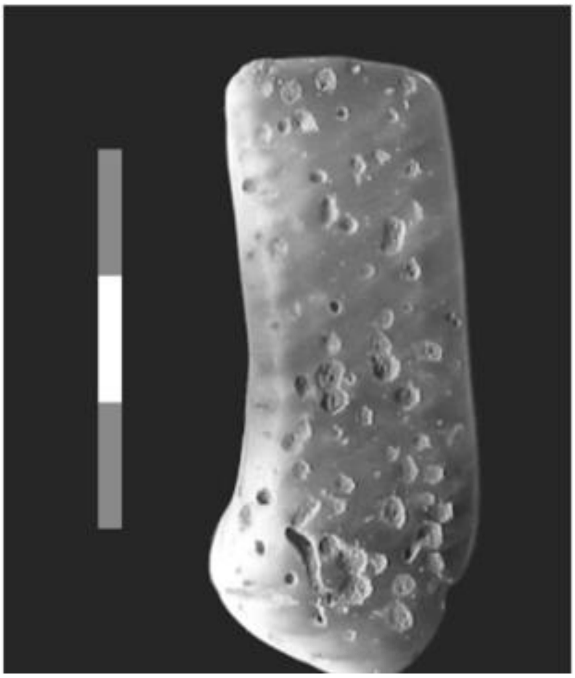

Figure. 7: Fragment of the valve of Spondylus from Lezetxiki cave (Alvaro Arrizabalaga et al, 2011)

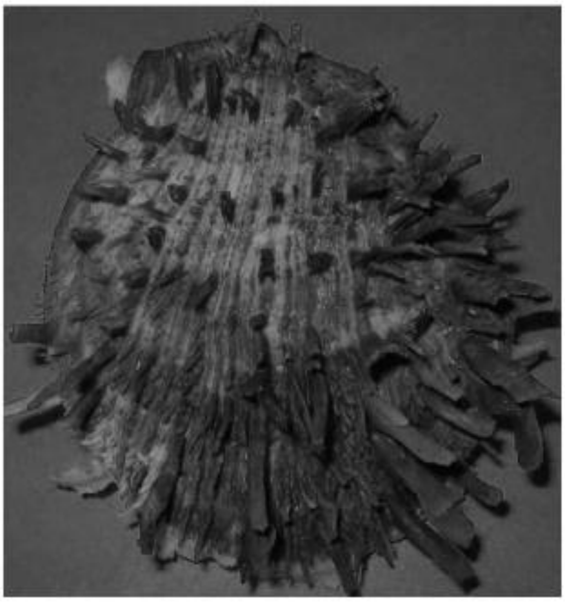

Figure. 8: Spondylus gaederopus (Alvaro Arrizabalaga et al, 2011)

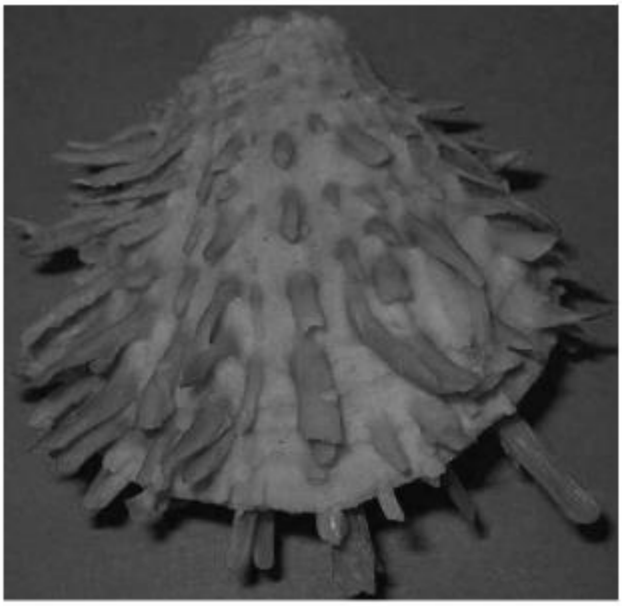

Figure. 9: Spondylus gussonii (Alvaro Arrizabalaga et al, 2011)

5-7-1 Palynology:

In 1985, M.F. Sanchez took over the study and collected 77 samples, dividing them into 38 sterile and 39 valid samples. The analysis of the samples revealed different pollen zones from bottom to top; the following pollen zones were described: a, b, c1, c2, sterile, c3, d, sterile, and e. The author established the following political correlation: zone a/VI; zone b/Vb; zones c1 and c2/Va; sterile zone; zone c3/IVb-IVa; zone d/IIIb; sterile zone/IIIa y II; zone e/level I (Sanchez, 1991).

In Zone A, certain plants that prefer a specific climate are gradually decreasing (such as Quercus, Castanea, Corylus, and Juglans), while plants that thrive in dry and sunny conditions, as well as grasses, are increasing. In Zone B, the favored plants are almost absent, except for occasional sightings of Alnus and some Pinus pollen. There is also a significant increase in non-arboreal pollen in Zone B compared to the presence of grasses and Asteraceae plants. The area is separated into three subzones, each with a significant lack of natural pollen. The majority of pollen is human-made. Castanea can be found in samples 7, 9, 13, and 18. Artemisia is occasionally seen in natural pollen, indicating the presence of a steppe. Subzone C1, which was discovered in samples 7 and 8, contains a moderate proportion of human-made pollen, including Pinus, Castanea, Quercus caducifolio, and Q. sempervirens. Spores increased to around 20% (SANCHEZ, 1987 and 1991).

Subzone C2, seen in samples 9–17, has more pollen from human activity, topping 50%. Tree diversity is larger in C2 than in C1, with Pinus, Quercus, Castanea, and Juglans growing alongside Fraxinus, Ulmus, Populus, Taxus, Phillyrea, Daphne, and Salix. Almost always present are Tilia, Betula, Quercus t. ilex-coccifera, Alnus, and Corylus. While subzone C3 contains a lower percentage of thermophilic taxa (Quercus, Castanea, Tilia, Juglans, Alnus, and Corylus), Pinus is still dominant. Zone D has an important decrease in tree pollen, particularly from Pinus and Betula. Instead, there is a dominance of herbaceous species like Asteraceae, Plantago, Poaceae, and Artemisia in this zone. However, the areas of level IIIa and II, which are interesting, have been found to be sterile (Sanchez, 1987 and 1991).

The final section, area E, in Lezetxiki corresponds to level I of the stratigraphic development. In this area, there is a significant amount of NAP (non-arboreal pollen), with Asteraceae being the most prevalent, followed by Poaceae, Cyperaceae, Chenopodiaceae, and Caryophyllaceae. Except for Pinus, Alnus, and Betula, tree pollen is no longer present in this zone, although Picea is occasionally found (Sanchez, 1987 and 1991).

6-7-1 Fauna and microfauna:

The lower levels of Lezetxiki contain a significant amount of Ursus spelaeus remains (Fig. 10), making it the dominant taxon in these layers (Arrizabalaga *et al.*, 2009). J. Altuna (1965, 1966) studied the Marmotte (Marmota marmota) within the context of a somewhat temperate fauna, along with Arvicola terrestris; Cuniculus Oryctolagus; Arctos arctos; Lupus canis; Vulpes vulpes; cf. foina Meles Meles Martes; Putorius putorius; Crocus crocus; The feline pardus; Sylvestris felis; The Lynx sp.; Horse Equus caballus; Sus scrofa; Rhinoceros sp.; Elaphus Cervus; Capreolus capreolus; Pyrenaica Capra; and Rupicapra rupicapra. Recently, the site of Lezetxiki II has yielded one left mandibular corpus, attributable to Macaca sylvanus (Cantanos et al., 2011)

According to J. Altuna (1965), the microfauna includes various species such as Microtus arvalis, Microtus ratticeps, Microtus malei, Pitymys sp., Arvicola sp., Pliomys lenki, Apodemus sp., Sorex sp., and Batracien.

This microfauna is primarily made up of rodents. The appearance of a type of Pliomys lenki among them is rather surprising. Pliomys lenki is a primitive Arvicolidae that first appeared in Europe at the start of the Middle Pleistocene and was thought to have disappeared during the Mindel-Riss interglacial era. The occurrence of a Lenki group form in the early Würm of northern Spain shows that it survived as a relic in this nation until a very recent era (Jean Chaline, 1970). Microtus ratticeps' presence in Spain in the upper strata indicates that severe cooling occurred throughout the Magdalenian epoch during the recent Würm period. The microfauna on other layers suggests a more temperate environment (Jean Chaline, 1970).

Figure. 10: A cave bear skeleton in layer M of Lezetxiki (Arrizibalaga, 2009)

CHAPTER TWO

2-State of art:

1-2 Middle to Upper Paleolithic transition in the Basque Country:

In this chapter, we'd like to provide a small insight into the Middle to Upper Paleolithic transition in the Basque Country, which is located in both Spain and France, between the Pyrenees and the Bay of Biscay. As a result, it is a zone through which prehistoric populations frequently passed as they journeyed between the Iberian Peninsula and Europe, and it has a number of significant sites. On the other hand, we will resume a little bit the current "state of the art" of micromorphology in general and micromorphology applied to archaeology, as well as a short insight into the origin and evolution of modern life science and some of the new approaches applied to its study.

In the Basque Country, José Miguel de Barandiarán-Ayerbe was the most dominant figure of Paleolithic research for almost the entire 20th century (Barandiarán-Maestu 1967, 1988b; Barandiarán-Irizar 1976; Arrizabalaga 2005c, in press b). His proximity to the famous masters of the Vienna Cultural Historical School, as well as his training in Ethnology at the University of Leipzig with Wundt, sparked his interest in the History of Religions and Archaeology. His career as a teacher was cut short by the Spanish Civil War, and he went into exile in the French Basque Country, from which he returned with solid training and professional contacts with archaeologists such as Laplace, Bouchud, Méroc, and Bordes. His excavations in Lezetxiki, Urtiaga, and Ekain upon his return from exile were a field school that would multiply in the last three decades of the century. When Barandiarán retired in the early 1970s, his students, including Apellániz, Barandiarán-Maestu, and Altuna, took on and conducted fresh studies in Vizcaya, Guipzcoa, and Navarre (Barandiarán-Maestu 1988b).

Only ten years later, a considerable generational renewal occurred, with new specialists developing some of the new research methodologies. The increase in the number of researchers coincided with a renewed interest in the Middle-Upper Paleolithic transition following the discovery of Saint-Césaire in France and, later, the first dates for the transitional levels in the caves of El Castillo, L'Arbreda, and Abric Romani. The new generations unearthed previously unknown sites (Antoliñako Koba, Labeko Koba, Arrillor, and Aitzbitarte III) as well as re-excavated previously researched sites from a new perspective (Axlor, Lezetxiki, El Polvorn, and Bolinkoba). This convergence resulted in a critical mass of new data, allowing for easier contextualization of Basque sites within a broader regional framework. Rather than the application of new methodology or epistemological ideas, the realization of a critical mass of sites, researchers, and data can best explain information advancement. However, they do exist, both through features such as specialism in studies such as use-wear analysis and taphonomy and through the application of models that place the Basque Paleolithic in a greater geographical area than had previously been employed.

Before 1975, ten sites dating between the Mousterian and Gravettian periods had been excavated (Barandiarán-Maestu 1980; Barandiarán-Maestu and Vallespí 1984).

However, in the following thirty years, many of these sites were being re-excavated, and an additional twelve sites were being studied (Beguiristain, 2000; Sáenz de Buruaga, 2000; Arrizabalaga, 2005b; Arrizabalaga, 2008).

The Lezetxiki site, one of the classic sites in the Basque and Cantabrian Pleistocene records, has several archaeological values, among which we highlight the existence of different human fossil remains within a protracted Pleistocene sequence. The geochronology of Lezetxiki has been a pending subject due to many conditions, which have already been thoroughly discussed. Furthermore, if we examine the occurrence of a sedimentary sequence dated to Lezetxiki II that is imbricated with the main sequence of Lezetxiki, at least at level VIII, we might assess the probability of certain faunal elements from Lezetxiki II overlapping. The stalagmitic crust dated at Lezetxiki II (74 ka) appears to be higher in elevation than the sample from Lezetxiki level VII (Falgueres, 2005).

Over the last few years, it has become routine practice to apply a standard technique of environmental investigation to Pleistocene deposits. Palynological investigations (Sánchez-Goi 1991; Iriarte and Arrizabalaga 1999; Iriarte et al. 2005; Ruiz-Zapata and Gil-Garca 2005), sedimentology, and the study of micromammals, among other things, have supplemented the more typical archaeozoological study of large animal remains. Similarly, other types of research, such as micromorphology and anthracology, are being used more infrequently at a number of locations. This common protocol has been extended to all significant transition locations in recent decades. A large number of sites from this period had been excavated in the first decades of the twentieth century; much of this type of information was lost. However, some of the most intriguing new material has come from the re-excavation of sites like Axlor or Lezetxiki, where the first rounds of research were lacking in these approaches. The expansion of this shared protocol has further consequences. Similarly, from a geoarchaeological and less conventionally environmental standpoint, the spectrum of sedimentology and micromorphology applications is expanding. The application of these disciplines to archaeological sites is changing our understanding of the sedimentary origins of Basque Pleistocene deposits, which was previously underestimated throughout the Iberian Peninsula and has taken on unexpected relevance.

2-2 Loess research:

In recent years, there has been a growing interest in Quaternary sciences; in terrestrial areas, deposits of loess and intercalations of loess and buried soils, known as loess-paleosol sequences, are valuable sources of information for understanding how the land has responded to climate changes and reconstructing past environments during the Pleistocene period. Loess is a widespread type of sedimentary deposit from the Pleistocene era found in the northern hemisphere. It represents an important record of glacial periods in Europe (Haase et al., 2007; Markovi´c et al., 2015; Bertran et al., 2016), Loess variations account for about 10% of the Earth's land surface (Pye, 1987).

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Loess Paleosol sequences, which consist of alternating layers of loess and buried soil, provide valuable information about paleoclimates (Gallet et al., 1996; Obreht et al., 2017; Torre et al., 2020), paleoenvironments (e.g., Hatte et al., 2013; Liu and Liu, 2017; Schaetzl et al., 2018), and paleolandscapes (e.g., Hughes et al., 2010; Lehmkuhl et al., 2016).

For a long time, researchers have concentrated on stratigraphical correlation, palaeopedology, periglacial processes, and dating within the European loess belt (e.g., Bronger, 1976; Kukla, 1977; Sommé et al., 1980; Haesaerts, 1985; Lautridou, 1985; Rousseau, 1987; Zöller et al., 1988; Zöller et al., 1994; Zöller et al., 2004; Antoine et al., 1999; Antoine et al., 2003b; Frechen, 1999; Frechen et al. 2003). These studies have resulted in a consistent, high-resolution stratigraphical framework for the Upper Pleistocene in Western and Central Europe (Antoine et al., 2001; Antoine et al., 2003a; Antoine et al., 2003b; Haesaerts et al., 2003; Gerasimenko, 2006). Based on this context, new research has been completed that focuses on the variability and influence of rapid climatic events and variability on European loess environments during the Last Glacial (e.g., Hatté et al., 1998; Rousseau et al., 1998; Rousseau et al., 2001; Rousseau et al., 2002; Vandenberghe et al., 1998; Antoine et al., 2001; Antoine et al., 2003a; Moine et al., 2005; Moine et al., 2008).

A study by Ding et al. (2018a) identified 1824 as the starting point for loess research, as that was when the term "loess" was first introduced. The term "loess" was first used in 1824 by the famous mineralogist Professor Leonhard in Section 89 of the 3rd volume of his book "Charakteristik der Felsarten" to describe the red and yellow sediment found in Heidelberg using about 700 German words (Lyell, 1833). Over time, our understanding of the chemical and physical properties of loess has improved. In recent years, there has been growing interest in the history of loess research. Zöller and Semmel (2001) emphasized the contributions of German geologists to the field of loess research. Smalley et al. (2013) initiated "The Loess Biobibliographical Project" to provide a comprehensive view of the history of Loess research, focusing on key individuals. Jovanovič et al. (2014) summarized the contributions of 11 highly regarded geologists: K. Leonhard (1779–1862), H. G. Bronn (1800–1862), A. Boué (1794–1881), J. Steininger (1794–1874), F. Voltz, P. Merian (1795–1883), M. Rozet, S. Hibbert (1782–1846), J. Nöeggerath (1788–1877), H. von Meyer (1801–1869), and L. Horner (1785–1864). While Smalley and Marković (2016) praised the work of C. Lyell (1797–1875), F. von Richthofen (1833–1905), V. A. Obruchev (1863–1956), and L. B. Berg (1876–1950) in the field,. Marković et al. (2016) provided a critical historical review of loess studies in the Danube region, categorizing them into five stages. Smalley and Kels (2017) highlighted Horner as the first person to focus on loess as a material.

Before the term "loess" was accepted by the geological community, people in Heidelberg, Germany, referred to this sediment as "Löβ" or "Löss," while residents of Alsace, France, called it "Lehm." (Lyell, 1833). Other terms, such as Loesch, Schneckenhusel Boden, Mergel, and Briz, were also used (Leonhard, 1824). Steininger

(1821) named it "Britz" and provided a definition, but it was not widely accepted in scientific literature.

Professor Leonhard was an influential figure in the early study of Loess. He began teaching about loess sediment in 1823 at the University of Heidelberg, and his lectures attracted renowned geologist Lyell (Lyell, 1881), the most famous geologist in the 19th century. In 1825, Leonhard collected loess specimens from the Rhine valley and displayed them in a mineral museum in Heidelberg, selling a large number of geognostic collections to academic institutions and museums via his company, “Heidelberger Mineralien Comptoir.” These collections included Loess samples from Haarlass near Heidelberg (Jovanovič et al., 2014).

In addition to Leonhard, another important scholar in the early study of Loess research is H. G. Bronn (1800–1862). He was a professor of natural history at the University of Heidelberg and provided a detailed geographic description of loess in the Heidelberg region (Jovanovič et al., 2014).

Horner and Lyell were the first to bring knowledge about loess from the Rhine Valley to Britain during the initial phase of loess research. In 1830, Horner became the first warden of London University but faced opposition from Professor Pattison over salary and personnel issues (Martin, 1969). In September 1831, Horner and his family moved from London to Bonn, Germany. There, he joined a geological excursion and was introduced to the scientific community studying loess in the Rhine valley (Lyell, 1890). Horner became fascinated with loess and conducted investigations in Bonn, creating the first geological map of the region and observing how loess disaggregates when in contact with water. Horner was the first scholar to bring loess research from the Rhine valley to the attention of the geological community in Britain. In 1833, he gave a presentation at the Geological Society of London, which is considered the first public discussion of loess in Britain (Smalley and Kels, 2017). Horner (1836) described the characteristics of loess and emphasized its geological significance. The paper he presented was published in "Transactions of the Geological Society of London" three years later.

In 1830, Lyell published the first volume of "Principles of Geology," in which he pointed out that the Earth's surface features were the result of gradual, natural processes and that studying the present could help understand the past. He also introduced the concept of uniformitarian or successive change, which transformed geology into a legitimate scientific field (Wilson, 1972). The author discusses the contributions of Lyell to the field of geology in the 19th century. Lyell's works, "Principles of Geology " and "Elements of Geology," went through multiple versions and consistently added new knowledge. Both books included historical sketches of the development of geology and argued that the forces currently shaping the Earth are the same as those in the past. Lyell's focus on loess, a type of sediment, differed between the two books, with "Principles of Geology " examining its initial distribution events and "Elements of Geology" discussing the fossils found in it. Throughout the updates, Lyell gradually shifted his hypothesis of how loess formed from a catastrophic to uniformitarian.

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Lyell met Professor Voltz in Stuttgart in August 1833 while inspecting Dr. Hahl's mineral collection (Lyell, 1881). Voltz (1828) wrote on the region's geology but did not appear to have had a significant impact on Loess's early history. He looks to be a minor figure in the Loess legion, along with Lozet, Von Meyer, and Merian. Horner praised his work for making key statements about Loess (Voltz, 1828).

Some authors associate H.G. Bronn with Von Leonhard, who was not only based in Heidelberg but also active in the long-term publication of mineralogical journals. In his study of the region around Heidelberg, Horner attributed to him the greatest early account of Loess: "Der Loess ist eine erst neuerlich aufgestellte und, wie es scheint, dem Rheinthale eigenthum liche Gegirtsart von sehr allegeimer, aber unzusammenhängender Verbreitung." (Brunn, 1830).

Rudolf Grahmann was based at the University of Leipzig. His mapping of Europe's loess is now widely regarded as a significant contribution to the advancement of loess research. The fact that numerous standard publications have used these European maps and continue to do so demonstrates their significance and longevity. The Grahmann maps are found in Scheidig (1934), Charlesworth (1957), Woldstedt (1961), and Flint (1957). The creation of the new map of Europe was a major project, and the people involved deserve recognition. They are a distinguished group of European Loess scholars (Fink et al., 1977; Smalley, 1980).

In 1961, the INQUA Sub-Commission on the Loess Stratigraphy of Europe was created by Julius Fink of the University of Vienna. In 1969, it was elevated to full Commission status, and its scope was expanded to include the entire world, with the emphasis on stratigraphy giving way to a concern for all aspects of life.

The idea that the loess carries a precise record of climate change during the whole Pleistocene, and possibly even the later portion of the Pliocene, is very remarkable. It is quite rightly connected with the name George Kukla. Fink and Lozek were involved, as were other Austrian and Czechoslovakian investigators, but Kukla has taken the notion further with remarkable consistency. Kukla (1970) was the first to link the loess record to that produced from deep-sea cores, provided details on the creation of precise stratigraphic investigations (Kukla, 1975), and analyzed Pleistocene land and sea correlations for Europe (Kukla, 1977). There have been many attempts to define loess (derived from the German 16ss or Idsch = loose), and no single definition, including that proposed by the INQUA Loess Commission (Fink, 1976; Lill and Smalley, 1978), has gained universal acceptance. Loess is defined simply as a windblown silt deposit consisting chiefly of quartz, feldspar, mica, clay minerals, and carbonate grains. Heavy minerals, opal phytoliths, salts, and volcanic ash shards are also sometimes important constituents. Loess is typically homogeneous, non-stratified, and highly porous. Most commonly, it is buff in color but may be gray, yellow, red, or brown. The grain size distribution of typical loess shows a pronounced mode 1 in the range of 20–40 gm (5.70–4.65 phi) and is positively skewed. Loess containing more than 20 percent sand-size grains (>63 jum) is defined here as sandy loess; if the sediment contains more than 20 percent clay (<2 jum), it can be described as clayey loess.

Boue advocated for large-scale inundations of the continent and interpreted the observed evidence accordingly. He was unequivocally in favor of loess being an aqueous sediment. He was active in the early stages of Loess. In 1823, he was in the Rhine Valley and discovered human bones in the loess, which he reported on many years later (Boue, 1852). Von Leonhard had a significant influence on him (as a system maker), as evidenced by many works (Boue, 1835–1836).

While there are doubts about determining the transportation direction during loess formation, more studies are now using magnetic fabric analysis to identify past wind directions of loess in Europe. The first studies on magnetic fabric in the European Loess Belt were conducted in Tönchesberg loess in Germany (Reinders and Hambach, 1995) and the Lower Danube Basin in Bulgaria (Jordanova et al., 1996). The German study aimed to identify the Blake magnetic excursion. The Bulgarian study focused on sampling techniques and warned about improper sampling practices that could distort the fabric. Matasova et al., 2001–2004, conducted research on loess deposits in Siberia, aiming to investigate the formation and origin of the loess deposits by characterizing the MF. The study conducted by Hus in 2003 connected different locations in Belgium, Ukraine, and Siberia through the analysis of loess fabric. The study focused on various aspects, including the impact of bioturbation and neoformed magnetic components in paleosols, as well as the role of phyllosilicates in loess with low magnetic susceptibility (Hus, 2003).

Nawrocki et al. (2006) studied loess from Poland and western Ukraine and focused on the marks of imbrication in the fabric, which were supported by the alignment of magnetic grains indicating the direction of ancient winds. They found that the dip of the magnetic grains and fabric could be used to determine imbrication and the paleowind direction during the Late Pleistocene. A series of studies have been conducted on loess in the Middle Danube Basin. The first study by Bradák in 2009 used magnetic fabric orientation to determine paleowind direction in the Middle Pleistocene era. Subsequent studies focused on the formation and transformation of loess fabric in the Cérna Valley in Hungary. In their research, Song et al. (2018) conducted magnetic fabric investigations as part of their study on the paleomagnetic results from the Titel-Stari Slankamen loess section in Serbia. Similarly, Obersteinová (2016) and Hrouda et al. (2018) were the first to examine magnetic fabric in loess successions from different regions in the Czech Republic. Obersteinová (2016) focused on analyzing the fabric to understand the various surface processes that influenced the development of the studied loess profiles. On the other hand, Hrouda et al. (2018) introduced and applied new methods, including frequency-dependent magnetic susceptibility and anisotropy of out-of-phase magnetic susceptibility measurements in their study on loess. More recent studies have examined different types of loess by using statistical analysis to analyze the magnetic fabric characteristics (Bradák and Kovács, 2014) and the influence of depositional and post-depositional processes on loess fabric development (Bradák et al., 2018a; Bradák et al., 2018b; Bradák et al., 2019a). On the other hand, in some studies of loess profiles in Ukraine, Nawrocki et al. (2018–2019) combined magnetic fabric analysis with absolute age dating to determine the paleowind direction (Nawrocki et al., 2018; Nawrocki et al., 2019). These studies help to summarize valuable insights into the nature of magnetic fabric and the importance and limitations of studying the magnetic fabric of loess, as well as present new findings that could provide new perspectives in future research.az

Advances in quaternary dating methods have led to increased applications in loess and loess-like sediments. The past decade has seen significant advancements in existing research methodologies and the emergence of new ones. A variety of approaches are employed to estimate the timing of loess deposition and the direct ages of artifacts. The most frequent methods are luminescence dating, which establishes the age of the accumulation of quartz and feldspar minerals following a bleaching event, usually the last sunlight exposure during eolian transport before deposition (e.g., Zeeden *et al*., 2009; Scheidt *et al*., 2021); radiocarbon dating (e.g., Moine *et al*., 2021; Bosq *et al*., 2020; Scheidt *et al*., 2021); and magnetic stratigraphy (e.g., Zeeden *et al*., 2009; Scheidt *et al*., 2021; Scheidt *et al*., 2021; Blaauw *et al*., 2018; Maher, 1998; Ahmed and Maher, 2018; Bösken *et al*., 2017; Lomax *et al*., 2019; Stevens *et al*., 2020; Stone and Fenn, 2020; D'Amico *et al*., 2021). Depending on the available grain size, single-grain or single-aliquot procedures are commonly used (Reimann et al., 2012).

Inorganic geochemistry is used to analyze the dust source area, as well as the degree of weathering and soil formation. Although there are more suitable approaches for provenance investigations, such as zircon chronology (e.g., Újvári et al., 2012; Ducea et al., 2018), bulk geochemical analysis can distinguish various sediment sources and transit pathways (Pötter et al., 2021b). Several indices based on mineral alteration can be used to determine the degree of weathering (Buggle et al., 2011; Obreht et al., 2019). Color measurements from loess or soil samples are also employed to determine paleoenvironmental change (Sprafke et al., 2020). Spectrophotometric measurements can be taken on sediment samples in the laboratory (Eckmeier et al., 2010; Gocke et al., 2014; Krauß et al., 2016), or digital photos can be evaluated non-destructively (Zeeden et al., 2017). The redness index is an additional parameter used in the Loess study (Barron and Torrent, 1986).

Loess proxy data has been correlated with ice cores, allowing for links to Greenland interstadials and past European soil development within loess sequences (Rousseau et al., 2017) and across the entire Eurasian content, with remarkable similarities (e.g., Haesaerts and Mestdagh, 2000; Bronger, 2003; Marković et al., 2015, 2018a; Laag et al., 2021). They are frequently correlated with other regional records that describe landscape change and occupation history throughout time and space (Romanis et al., 2021; Nerudová et al., 2021).

Despite the fact that analytic units are still unstable (Reynolds, 2020), loess records have been utilized on a larger scale to inform diachronic changes in paleodemography and typotechnological trends that originated primarily in the lithic record (Morgan et al., 2011; Schmidt and Zimmermann, 2019). More recently, Schulte and Lehmkuhl (2018) provided a method for estimating the degree of chemical weathering in loess-paleosol sequences. Grain-size analysis is used in geoarcheological investigations as well as in pure sediment studies (Chu et al., 2018; Marković et al., 2021b; Malinsky-Buller et al., 2021). This proxy method is widely employed in geoarcheological research, mainly to provide a paleoenvironmental context for human occupation (Degryse and Alexander Bentley, 2017; Bösken et al., 2019; Chu et al., 2019).

More recent works have focused on the formation processes of Paleolithic sites embedded in European loess, from north-western to south-eastern Europe, starting with a detailed investigation of Middle Pleistocene loess-paleosol deposits in northern France (Antoine *et al*., 2021), followed by a study about the impact of katabatic winds on the Neanderthal environment (Lefort *et al*., 2021), and several studies concentrating on Upper Paleolithic sites (Moine *et al*., 2021; Molnar *et al*., 2021; Sümegi *et al*., 2021; Valde-Nowak and Łanczont, 2021). Finally, studies dealing with methodological investigations and paleoenvironmental focus in several loess-paleosol sequences and one lacustrine record in central and south-eastern Europe (Krauss *et al*., 2021; Ludwig *et al*., 2021; Marković *et al*., 2021a; Zeeden *et al*., 2021).

Maps depicting the distribution of Quaternary aeolian deposits are useful for understanding paleoenvironments in spatial and contextual terms, as well as determining source and sink interactions at larger geomorphological scales. Maps are also valuable in paleoecology for reconstructing past relief limits on human distribution and society complexity. The earliest loess maps at the European scale were created by Grahmann (1932) and Fink et al. (1977). Later, Haase et al. (2007) produced a digital European Loess Map.

Bertran et al. (2016) created a map of European Pleistocene aeolian deposits using topsoil textural data from the Land Use and Cover Area Frame Statistical Survey database (LUCAS, Orgiazzi et al., 2018; Tóth et al., 2013). Finally, Li et al. (2020) showed global distribution maps of significant loess areas' provenance and transport paths, as well as discussions about their genesis. Although there are various instances of Loess maps, most mapping methodologies run into issues with scale and geodata availability.

Three regional-scale maps were created while gathering and processing continent-wide geodata for an updated, seamless map of aeolian deposits in Europe. The loess map of Hungary and western Romania was created using geological and pedological data (Lindner et al., 2017). The ensuing map of the entire Carpathian Basin incorporates geodata from 10 different countries (Lehmkuhl et al., 2018a).

Several cross-border issues arose as a result of differing terminologies and definitions of loess and related sediments, which are caused by the complex genesis of loess sediments and a fundamental lack of representative genetic formation models (Lehmkuhl et al., 2018a; Smalley et al., 2011; Sprafke and Obreht, 2016). Such issues are not limited to national borders but can even occur within a single country, as illustrated by the map of loess and other Quaternary deposits in Germany (Lehmkuhl et al., 2018b). Due to Germany's federal system, artificial gaps between states could only be avoided by merging loess and loess derivatives in a single mapping unit (Lehmkuhl et al., 2018b).

Loess deposits are not as widespread on the Iberian Peninsula as elsewhere on the planet, but they have gained recognition in recent decades (Lehmkuhl et al., 2021). Reports on Iberian loess and loess-like deposits include González-Martín et al. (2000) in the South-East of the Spanish Plateau, Günster et al. (2001) in Southern Spain (Andalucia), and detailed studies by García and Gonzalez (2006) and García-Giménez et al. (2012) in the Tajo River Valley.

Loess is a significant terrestrial archive for European Paleolithic archeology, dating back to 2.5–1.8 Ma (Pastre et al., 1996). These records are often semi-continuous and cover the same time period as current models of Pleistocene hominin occupancy. However, loess is frequently used as a generic term for sediments created by multi-genetic processes characterized by a diverse set of unstandardized vocabulary (Sprafke and Obreht, 2016). Unsurprisingly, the concept of loess and its formation processes are still debated (Smalley and Obreht, 2018).

Loess deposits are more locally widespread throughout Europe than other prime Pleistocene sedimentary records, such as karstic traps and fluvial terrace deposits, and frequently have higher temporal depth and resolution (Haase et al., 2007; Bertran et al., 2016; Lindner et al., 2017; Lehmkuhl et al., 2021). Where chronological patterns are unclear, they can be refined, allowing for broader, landscape-wide interpretations of the archaeological record (Zeeden et al., 2018). Indeed, the spatial scope of loess and its effects on human trace preservation have previously been noted. Increased sedimentation increases opportunities for artifact capture and preservation, resulting in a higher possibility for sites to join the Paleolithic record (Roebroeks and Speleers, 2002; Hijma *et al*., 2012; Antoine *et al*., 2015).

CHAPTER THREE

3-Materials and methods:

1-3 Sample collection:

The samples used for this study were already prepared at the Institut de Paleoecología Humana I Evolució Social (IPHES) in Tarragona, Spain. The sampling was done at different and relevant stratigraphic units from two (2) profile sections of the site (C and D) (Fig. 11). 44 samples in all were taken from the site's previously excavated areas (Table, 1).

2-3 Steps pf micromorphological analysis:

A normal micromorphological study consists of the following successive steps: sampling, preparation of thin sections, analysis and description of the thin sections, and finally the interpretation and summarizing of the results (Stoops, 2003).

1-2-3 Sampling:

sampling techniques are critical to any micromorphological study. The purpose of sampling is to obtain information relating to solving a particular problem or to extrapolate information gained to understand other similar materials or soils; thus, errors made in sampling can influence subsequent interpretations (Stoops, 2003).

Soil samples selected for micromorphological study should be representative of the area. A complete soil profile description should be prepared before sampling so the location of the sample can be documented. Generally, the sample should be taken at the midpoint of a horizon and not across horizon boundaries, unless a horizon boundary is an item of investigation. Samples of the A1 horizon should include the uppermost part of the top horizon, unless the overlying material is sampled separately (Stoops, 2003).

Soil samples for micromorphological study should be collected so that they are undisturbed while being transported to the laboratory (Murphy, 1986). Knowing the orientation of the thin section may be an important aid to interpretation, therefore, the vertical orientation of the samples should be clearly marked (Murphy, 1986).

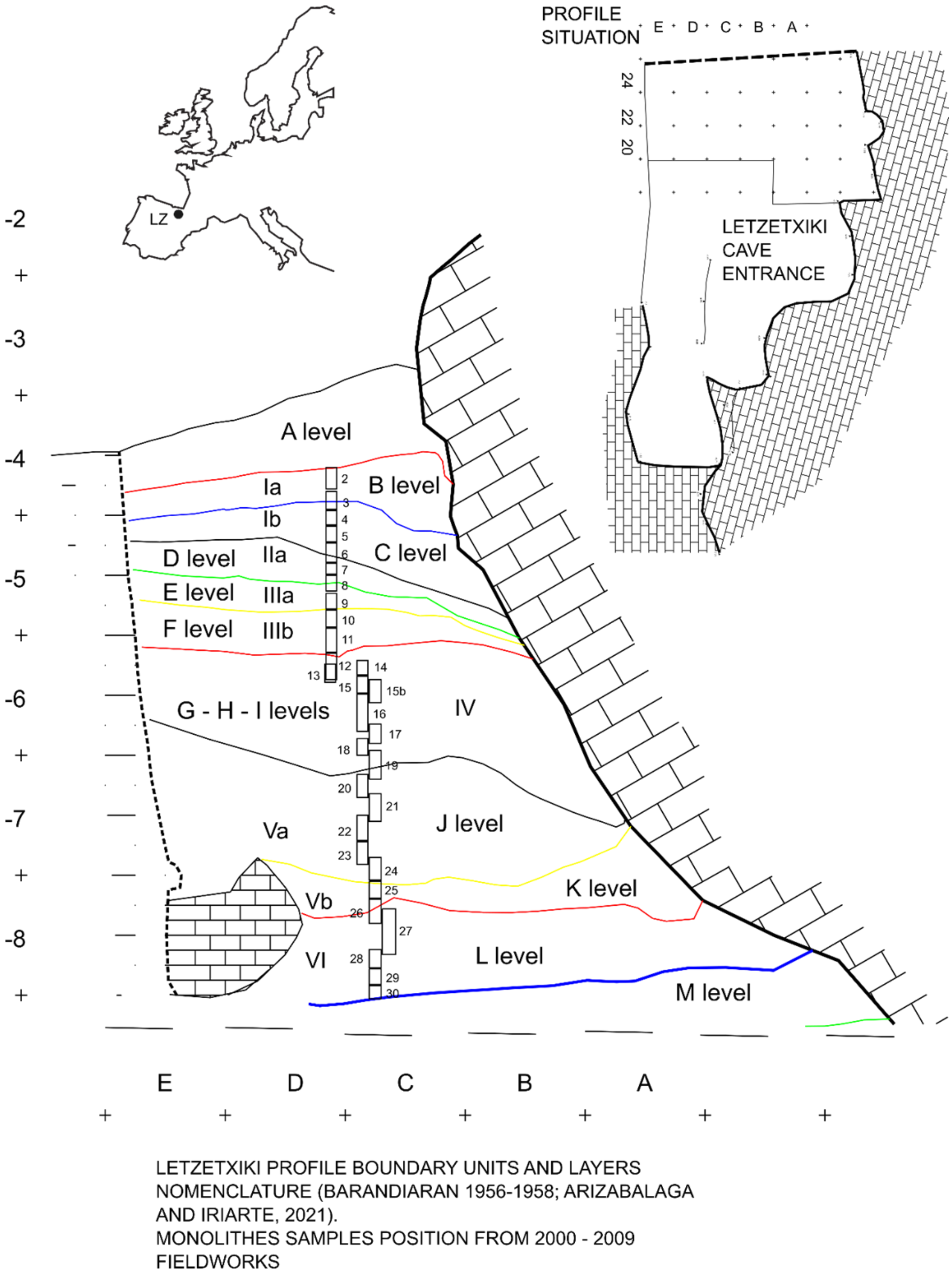

Figure. 11: Plan showing the position of the sampling (sections C/D) and stratigraphic units (Barandiaran, 1956-1958; and Arribazabalaga .- Iriartre 2021).

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2-2-3 Thin section description and interpretation:
The thin sections were classified according to their block labels and their positions within the blocks (table, 1), and were analyzed by referring to the standards put forward by Courty et al. (1990), Stoops et al., (2010), Macphail and Goldberg (2017), and Nicosia and Stoops (2017). Subsequently, the samples were identified and described based on the principles and concepts from soil micromorphology and sediment petrography (Bullock, 1985; Stoops, 2003; Macphail and Goldberg, 2017).

Thin section name	Thin section number	Section	Length
LZ 00 - 1	1	D (Southern section)	14 cm
LZ 00 - 2	2	D (Southern section)	13 cm
LZ 00 - 2 - Bis	2 Bis	D (Southern section)	14 cm
LZ 00 - 3	3	D (Southern section)	10 cm
LZ 00 - 4	4	D (Southern section)	14 cm
LZ 00 - 5	5	D (Southern section)	14 cm
LZ 00 - 6	6 Baix	D (Southern section)	10 cm
LZ 00 - 6 - Dalt	6 Dalt	D (Southern section)	9 cm
LZ 00 - 7	7	D (Southern section)	17 cm
LZ 00 - 8	8	D (Southern section)	10 cm
LZ 00 - 9	9	D (Southern section)	8 cm
LZ 00 - 9 - Bis	9 Bis	D (Southern section)	5 cm
LZ 00 - 10	10	D (Southern section)	18 cm
LZ 00 - 11- Baix	11 Baix	D (Southern section)	10 cm
LZ 00 - 11 - Dalt	11 Dalt	D (Southern section)	13 cm
LZ 00 - 12	12	C (Southern section)	15 cm

LZ 00 - 13	13	D (Southern section)	16 cm
LZ 09 - 14	14	C (Southern section)	8 cm
LZ 09 - 15	15	C (Southern section)	13 cm
LZ 09 - 15 - Bis	15 Bis	C (Southern section)	13 cm
LZ 09 - 17	17	C (Southern section)	11 cm
LZ 09 - 18 - Baix	18 Baix	C (Southern section)	12 cm
LZ 09 - 18 - Dalt	18 Dalt	C (Southern section)	10 cm
LZ 09 - 19 - Base	19 Base	C (Southern section)	11 cm
LZ 09 - 19 - Dalt	19 Dalt	C (Southern section)	13 cm
LZ 09 - 20 - Baix	20 Baix	C (Southern section)	13 cm
LZ 09 - 20 - Dalt	20 Dalt	C (Southern section)	11 cm
LZ 09 - 21	21	C (Southern section)	13 cm
LZ 09 - 22 - Baix	22 Baix	C (Southern section)	9 cm
LZ 09 - 22 - Dalt	22 Dalt	C (Southern section)	10 cm
LZ 09 - 23: Baix	23 Baix	C (Southern section)	10 cm
LZ 09 - 23 - Dalt	23 Dalt	C (Southern section)	10 cm
LZ 09 - 24 - Baix	24 Baix	C (Southern section)	13 cm
LZ 09 - 24 - Dalt	24 Dalt	C (Southern section)	14 cm
LZ 09 - 25	25	C (Southern section)	12 cm
LZ 09 - 26: - Baix	26 Baix	C (Southern section)	13 cm
LZ 09 - 26 - Dalt	26 Dalt	C (Southern section)	14 cm
LZ 09 - 27, Baix	27 Baix	C (Southern section)	12 cm
LZ 09 - 27 - Mig	27 Mig	C (Southern section)	14 cm
LZ 09 - 27 - Dalt	27 Dalt	C (Southern section)	13 cm
LZ 09 - 28, Baix	28 Baix	C (Southern section)	8 cm
LZ 09 - 28 - Dalt	28 Dalt	C (Southern section)	9 cm
LZ 09 - 29	29	C (Southern section)	12 cm
LZ 09 - 30 - Baix	30	C (Southern section)	11 cm
LZ 09 - 30 - Dalt	30	C (Southern section)	13 cm

Table. 1: thin sections, labels, position and length.

3-3 Microstratigraphy:

The goal established during the stratigraphic thin section arrangements was focused on determining micro(litho)stratigraphic units Furthermore, this analysis was also effective in improving the field's stratigraphy and bringing out a new stratigraphic framework.

4-3 Digitalization of the microstratigraphy:

With the use of the digital table (Fig. 12) and the AutoCAD 2024 program, we were able to report or digitize the details completed in the stratigraphic sequence; this task allowed us to number the terrain data, and then we used Inkscape software for further modifications.

5-3 Sedimentary petrography and soil micromorphology reference frames:

The thin sections were orgamized according to their block labels and their positions within the impregnated blocks (table, 1). Thin section were observed referring to the descriptive standards put forward by Courty et al. (1990), Stoops et al., (2010), Macphail and Goldberg (2017), and Nicosia and Stoops (2017). Subsequently, the samples were identified and described based on the principles and concepts from soil micromorphology and sedimentary petrography (Bullock, 1985; Stoops, 2003; Macphail and Goldberg, 2017).

1-5-3 Sedimentary structures and and micromorphological features:

Description based on microscopic examination of sediment thin sections should clearly describe the entire thin section using scan pictures and, if necessary, refocus on smaller areas for specific descriptions of certain microstructures or unusual aspects. Only then can potential interpretations be evaluated using multiple working hypotheses. The interpretation of sedimentary structures and micromorphological features has frequently been based on comparisons between thin section observations, macromorphological features, and laboratory data (Stoops et al., 2018; Vernon, 2018). We use Mucher (1986) and Karkanas, (2019) to help us describe and interprete the loess-like deposits found in Lezetchiki sediments samples (table, 2).

Mucher (1986)	Karkanas (2019)
- A silt of aeolian origin, consisting predominantly of silt-sized quartz particles - Mostly calcareous - Massive, homogeneous - Highly porous - Yellowish brown in colour, could be yellow or buff coloured - Usually contains less than 20% of clay and less than 15% of sand	- Very well sorted - Quartz grains are predominantly subangular - A massive microstructure punctuated with voids - Feldspars and carbonates (if present) tend to be subrounded to round - Has an isotropic, non-oriented fabric - Clay minerals are aggregated

Table. 2: loess description according to (Mucher, 1986) and (Karkanas, 2019).

For the description and interpretation of the depositional and post-depositional processes that took place in Lezetchiki we relied on the same authors (tables 3 and 4). We could interpret one of these as such if we find three or more descriptive characteristics specific to it in our samples.

High energy Flow: (Karkanas, 2019)	**Hyperconcentrated Flow:** (Karkanas, 2019)	**Afterflow (overland without splash or sheetwash):** Mucher, 1986; Karkanas, 2019	**Rainwash:** (Mucher, 1986)
- Laminated, clast Supported - Single grain structure without matrix -Fine-grained units - Normally graded -Microscopic cross lamination	- Micro Lamination - Rounded rip-up Clasts - Small laminar Ondulations - Inverse grading - No internal sorting	- Moderately to very well sorted - Very well layered -Vesicles with escaping air as a result of turbulent shallow Flow _ Loosely packed	- Poorly layered -Poorly sorted individual laminae - Tightly packed - Some micro-laminations could be present sometimes

Table. 3: high energy flow, hyperconcentrated flow, afterflow and rainwash description according to (Mucher, 1986) and (Karkanas, 2019).

Shallow stream Flow: (Karkanas, 2019)	**Debris Flow:** (Karkanas, 2019)	**Mudflows:** (Karkanas, 2019)
- Grading microscopic cross Lamination: - Clear sand laminae - Lamination and rhythmic alternation of sand and silt	- Uniform distribution of all sizes, from clay to boulders Coarse particles floating in a silty clay matrix numerous vesicles - Normal and inverse crude grading	- Lack of internal sorting - A fine-grained matrix that is relatively homogeneous; - Lack of internal stratification - Lack of lamination and Grading

	- Extremely poorly sorted	

Table. 4: shallow stream, debris flow and mudflow description according to (Mucher, 1986) and (Karkanas, 2019).

The first step was general, as it took considerable time to recognize the descriptive nature of the thin sections. The very thoughtful and definitional part of the step relies on the matrix that, in turn, is considered to play a significant role in description and interpretation (Stoops, 1998). The second step therefore, concerned with the new configuration that involved structures and microstructures, the best represented micostructures are channels and vesicles. At this, one feature may affect another, and this feature may either coat a void, a grain or an aggregate. Pedological transformations occur when changes take place within the soil and the resultant changes are identified as pedological features (Fedoroff et al., 1992).

The approach to describing thin sections depends on the purpose of the study; it involves a detailed examination and characterization of the features present in a sample under a microscope. Here are some steps we can follow for an effective description in our study:

There is a crucial first step: the material to be described should be studied in detail in terms of its range of fundamental elements, structure, and pedofeatures, before the description is initiated. Moreover, it is advisable to quickly examine narrow pieces of nearby material, such as the horizons above and below, at this same time. This gives a general overview of the subject matter before getting into the mechanics of description (Stoops, 2003). The thin sections of Lezetchiki were described and interpreted using specialized manuals in micromorphology (Bullock, 1985; Stoops, 2003; Macphail and Goldberg, 2017; Karkanas, 2019).

6-3 Microscopic mesoscopic techniques:

Analyzing soils through thin section analysis involves studying their microscopic characteristics to gain insights into the sediment architecture and the processes involved in sediment formation: which involves depositional, deformation and/or emplacement processes (Menzies, 2000). This analysis complements field observations and stratigraphic profiles, providing insights into post-depositional processes and bioturbation. In conclusion, visualization of thin sections with a microscope is like traveling through time.

This study involved using a petrographic microscope (ZEISS AXIO scope) (figure. 12), it has five objectives. The eyepiece (ocular) on 10x and the revolver of the microscope were with the magnifications (2X: 1000µm, 4X: 500µm, 10X: 250µm, 20X: 100µm, and 40X: 50µm), to conduct micromorphological investigations on the thin sections and to examine sediment samples at different magnifications using alternatively PPL and XPL. We then measured the size of objects using an optical micrometer while the abundance of objects was obtained based on the number counted at different magnifications, and the microstructure was captured through a camera.

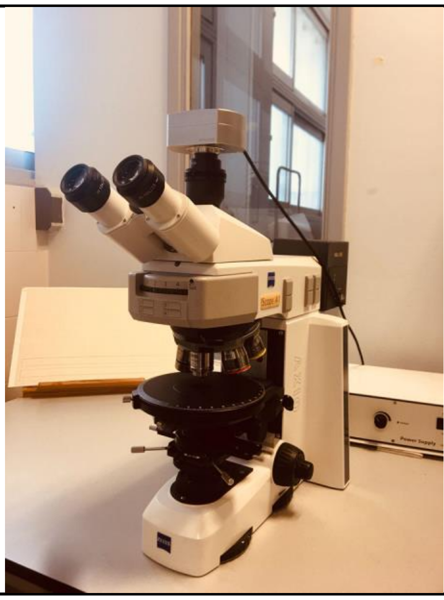

Figure. 12: ZEISS Axio Scope

Subsequently, the EPSON V500 PHOTO (Figure.13) scanner was used to scan, digitize and capture images of microstructure and sedimentary structures; it provided a global view of the thin sections; it offers up to 6400 x 9600 dpi scan resolutions enabling a high-quality scans and capturing sedimentary structure figures.

Figure. 13: EPSON V500 PHOTO

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The Munsell soil color chart was used for the color description of each sample. Then, Gimp 2. 10. 14 software (GNU Image Manipulation Program) was also used for photo editing and adjustment of the scans at a resolution of 600 DPI, it also permits certain kind of modification like brightness, contrast, and color balance of the scanned pictures without actually having to make the changes permanently on the scanned images.

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4- Results:

Our results contribute to the understanding of Letzetxiki lithostratigraphy, that is a cave entrance locality made from fine grained and poorly stratified sedimentary succession. Letzetxiki's sediment textures consists in fine silts and clays of yellow – brown colour which could be due to the presence of iron oxides, organic matter, or other mineral compositions that are typical in certain soil types.
In our case, we have primary loess modified by pedological processes and loess like deposits (Edwards, 1979), which, while exhibiting many sedimentological properties of aeolian loess (porosity, unstratification, homogeneity..), were not deposited by wind. Thus, it is important to distinguish between reworked loess, which consists of material eroded from primary loess and redeposited by slope processes and running water (Yaalon & Dan, 1974; Sneh, 1983), and wind-deposited primary loess.
Concerning the similarities across the samples, we can observe: poor sorting, indicating a turbulent depositional environment where particles of various sizes were mixed together, vesicles (small, rounded pores) that are a common feature across the samples, indicating processes like biological activity, or organic decomposition, clay coatings, nodules and various types of infillings (e.g., dusty, excremental) pointing to illuviation processes and void filling by finer material. In addition, several samples (e.g., "muddy silt" and "massive muddy silt") exhibit a close porphyric distribution, where coarse particles are surrounded by a fine matrix, indicating similar particle arrangements. In contrast, the muddy silt units includes rounded rip-up mudclasts and intercalations, which are not observed in the other samples. The muddy gravel units exhibits excremental infillings and a microstructure affected by the coarse grading, setting it apart from the silty samples. The massive muddy silt is notable for its orthogonal planes, simple packing, and inclusion of sedimentary crust fragments, features that are absent in the other samples.

1-4 Granular fine silty loam:

Description:

Here, there are very few fine sub-angular and rounded coarse sand grains in a fine silty loam texture, which is moderately to well sorted. In the samples, yellow and brown are the two most prevalent colours. With regard to microstructure and pedofeatures, microscopic observations point out: granular aggregates, channel and fisural porosity, clay illuviation, link cappings. Dense and complete infillings on root passages made from granular aggregates of excremental origin (Figure, 14).

Granular fine silt is observed in the units (1, 4, 5, 6, 7, 10, 11, 12, 14, 15, 17, 18, 19 dalt, 20 baix and 22).

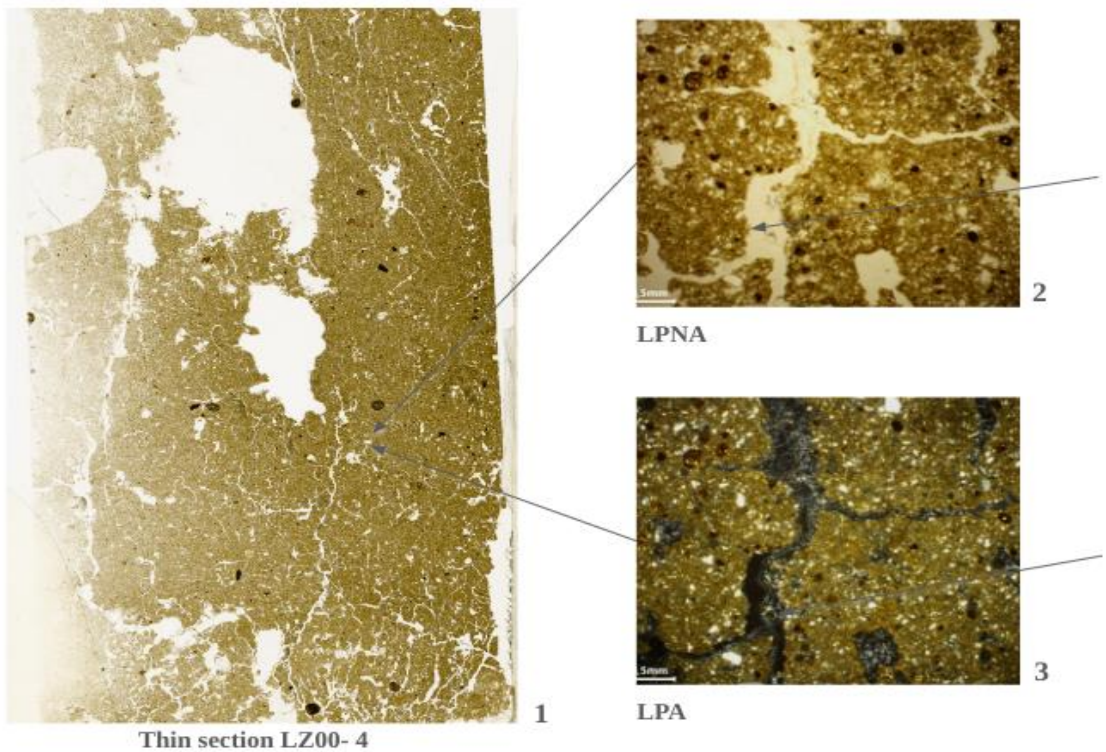

Figure. 14: Thin section LZ- 00- 4 (14 cm), southern section (D).

1- general view of the thin section.
2- channel microstructure in non analysed polarized light.
3- idem, in analysed polarized light.

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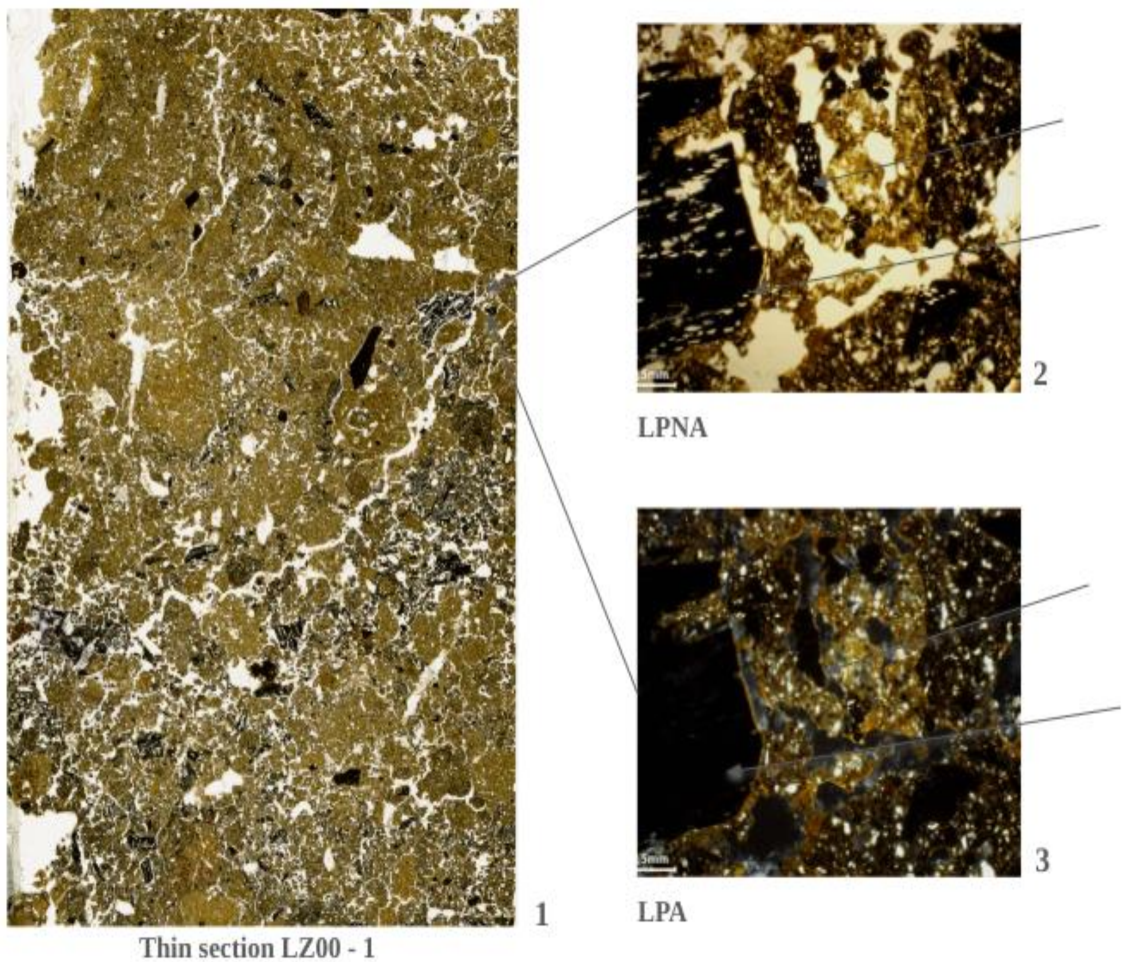

Figure. 15: Thin section LZ- 00- 1 (14cm), southern section (D).

1- general view of the thin section.
2- charcoal fragments in non analysed polarized light.
3- idem, in analysed polarized light.

Thin section 1 contains partial massive microstructure with coarse fabric in linear basic distribution. In addition, loss and complete infillings made from charcoal rich sediments and granular aggregates of excremental origin complete the heterogeneous fabric material of this thin section 1.

Interpretation :
Granular aggregates of excremental origin, channels and fisural porosity suggests bioturbation by earthworms and roots. Biological modification of

sediments characterize surface horizons in sedimentary deposits. This section 1 contains coarse fabric in a lineal basic distribution, and it could be a living floor, as the organic cultural content of a living floor sediment frequently impart a darker color to the layer, depending on the nature of the activities at the site and the location. The only likely universal microscopic trait of 'living floors' is the presence of a thin layer defined by compaction and trampling (Karkanas, 2019), which is represented in this unit throught the compacted aggregates.

2-4 Platy fine silty loam:

Description:
Fine silty loam are well sorted and yellow/brown. Platy microstructure have subvertical basic orientation based on similar orientation of fisural porosity. There are planes pores with ortogonal basic orientation. Concerning the pedofeatures, we can observe some clay coatings, faecal pellets structures and papules, dense and complete infillings composed of brown silty loam share a similar composition of fabric with rounded mudclasts in the matrix (Figure, 16). Observed in the thin sections: 2, 3, upper part of 19 baix, 24 baix, and the upper part of 25)

Interpretation:
Platy microstructure in frost-affected soils can be attributed directly to freeze-thaw cycles (Karkanas, 2019). Subvertical basic orientation of platy microagregates indicates colluvial short movements (frost creep) and fabric heterogeneity likely enhanced by bioturbation (root action and earthworms) (Mucher 1986).

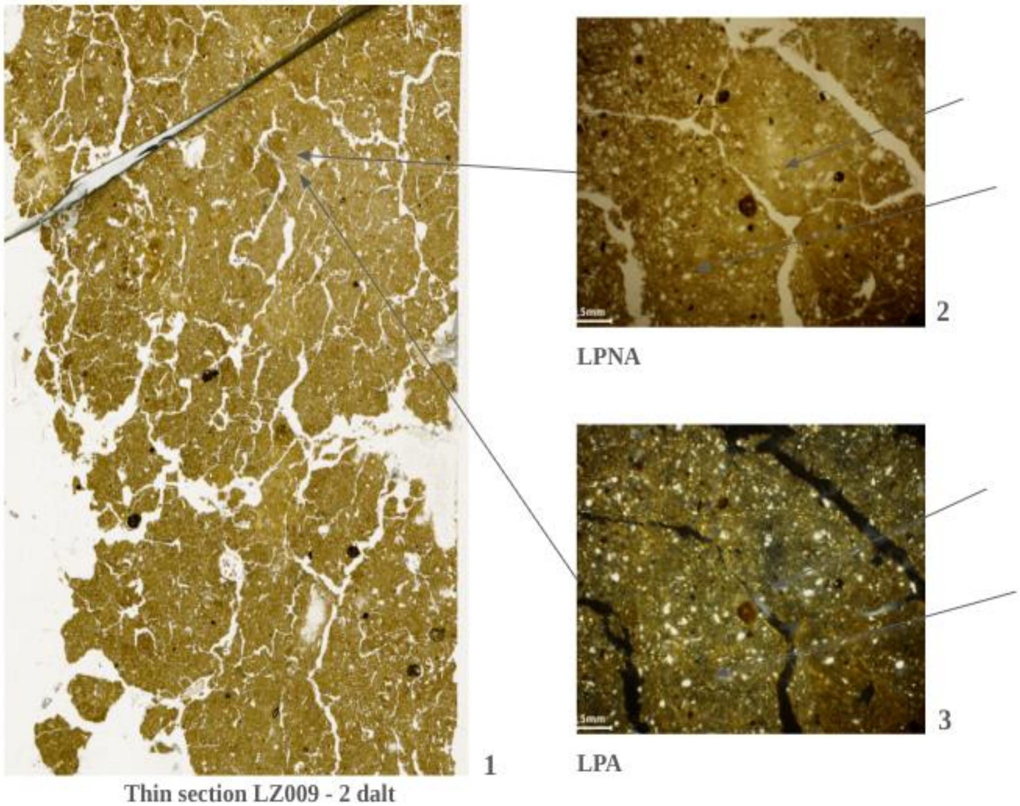

Figure. 16: Thin section LZ- 09- 2 dalt (13cm), southern section (D).

1- general view of the thin section.
2- angular microstructure in non analyzed polarized light.
3- idem, in analyzed polarized light.

3-4 Granular fine silt:

Description:
Granular fine silt is observed in the lower part of the monolithe sample 19 lower part), the fine silt is well sorted, and brown in color, having chitonic-gefuric related distribution (c/f: 8/2). Concerning the pedofeatures, we can observe link cappings, intercalations, simple rotational structures, channels, vesicles and infillings (Figure, 17).

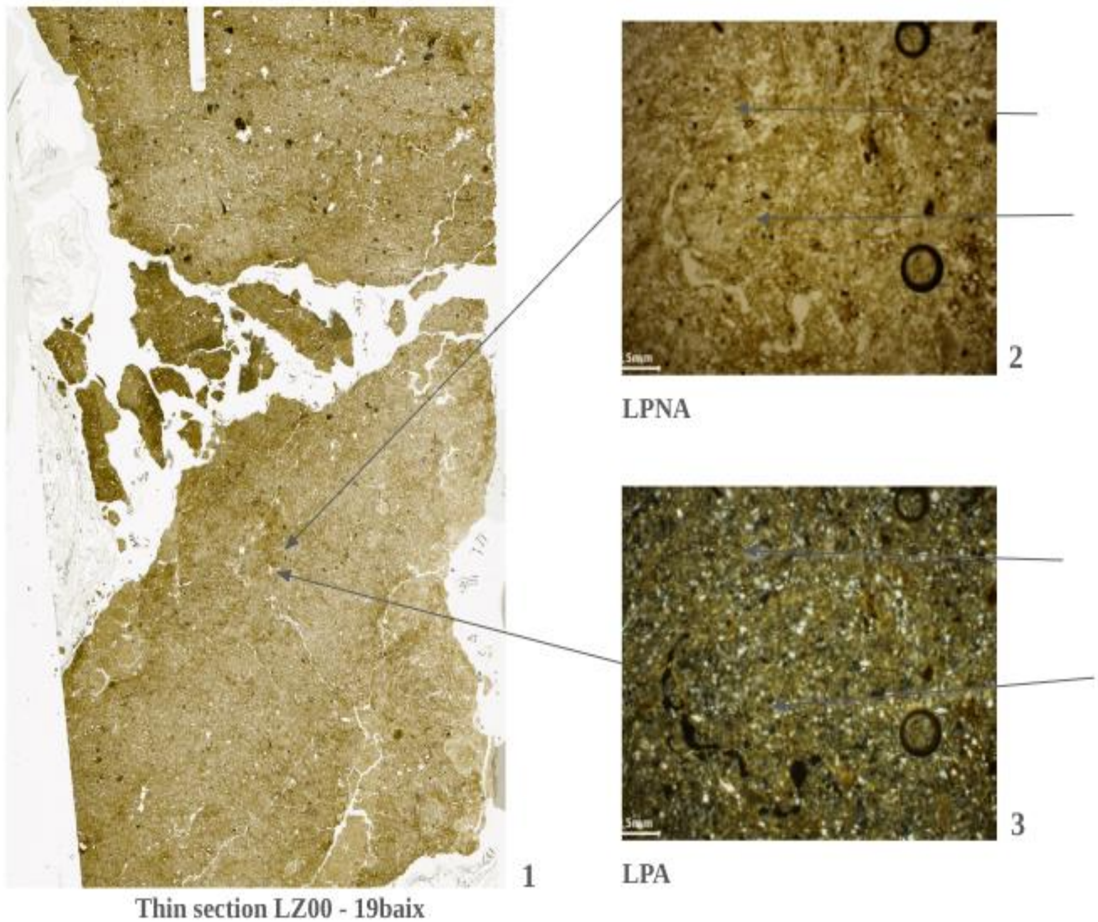

Figure. 17: Thin section LZ- 00- 19 baix (11cm), southern section (C).

1- general view of the thin section
2- granular microstructure in non analyzed polarized light.
3- idem, in analysed polarized light.

Interpretation :

According to Van-Vliet-Lanoë (2010) and Bertran and Texier (1998), the description of granular aggregate fabric in gelifluxion sedimentary deposits focuses on transport movement following cycles of freezing and thawing on slopes. According to Van Vliet-Lanöe (1985, 2010), link cappings adhere to banded fabrics in thin section scan observations at low magnification. Furthermore, the dusty intercalations imply that the groundmass's gefuric-chotonic related distribution is formed via cryosuction.

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4-4 Graded muddy silt:

Description:

Poorly sorted muddy silt that is grey and brown in colour (Figure, 18 and 19). Coarse sands are rounded (including mudclast) and shows thick lamination and grading. Fine fraction is grey and isotrope. Link cappings, rotational structures, nodules, infillings, and rounded rip up mud clasts are among the pedofeatures found here. Microstructure is vesicular and c/f related distribution is close porphyric. Graded fine silty loam are recorded in the thin sections (8, 9, 28, and upper part of 30).

Interpretation:

High sediment load based on textural composition of vesicular muddy silt is a result of excessive rainfall and a rapid snowmelt (Karkanas, 2019). According to Smith (1986), these deposits are caused by a short flood that forms poorly sorted and graded deposits.

The isotrope and the grey color of the fine fraction indicates a poorly drained iron depletion, or local hidromophy, in relation to thawing and vesicular microstructure's formation (raindrop splash) (Mucher 1986).

In accordance with grading, a close porphyric linked distribution suggests a short transport distance and poor laminaton. According to Mucher (1989), "overland flow," "sheet flow," or "afterflow" includes: extremely good lamination, loss packing (simple packing voids) (Karkanas, 2019). Mud aggregates and vesicles point out sedimentary crust fragmentation in relation to rain splash (Mucher, 1986). Link cappings suggest likely frost effects related to snow melt.

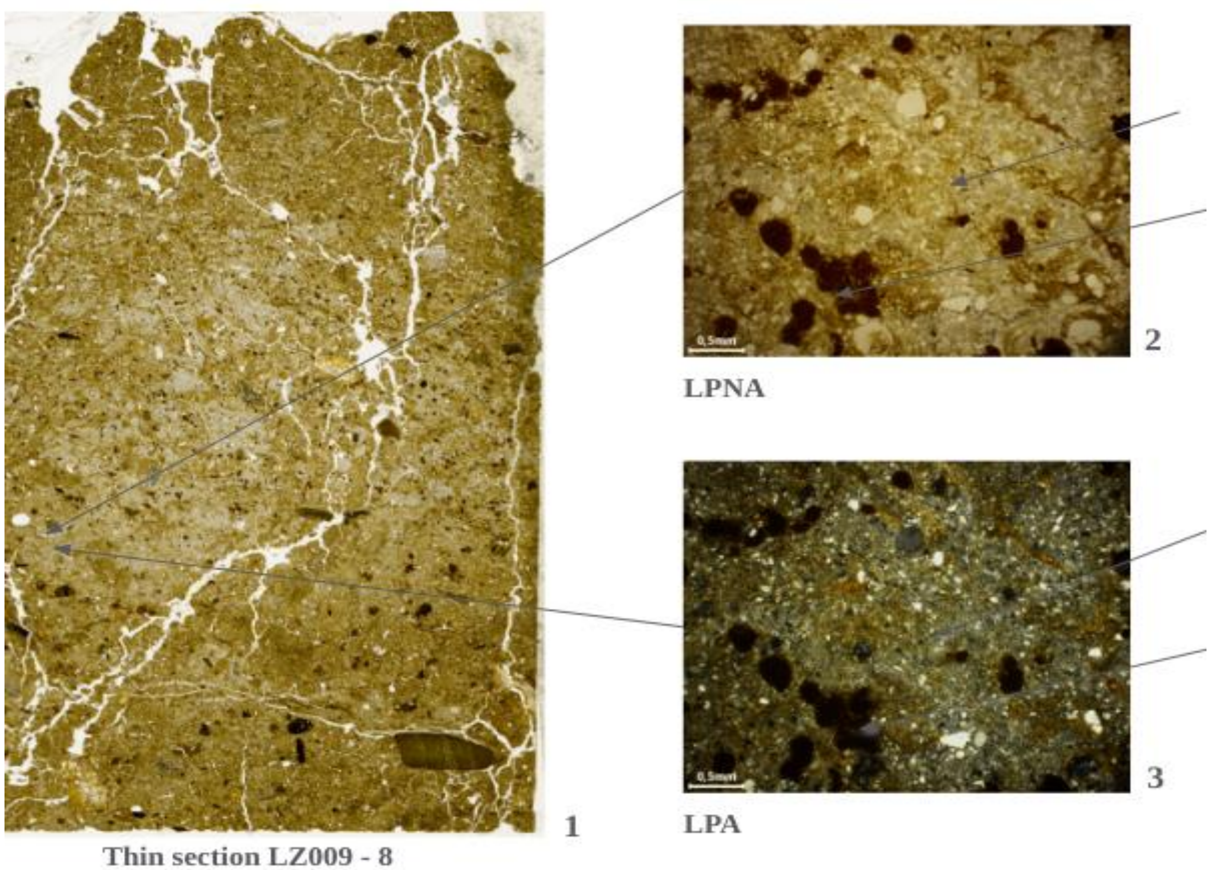

Figure. 18: Thin section LZ- 09- 8 (10cm), southern section (D).

1- general view of the thin section.
2- iron nodules and oxide reduction in non analyzed polarized light.
3- idem, in analyzed polarized light.

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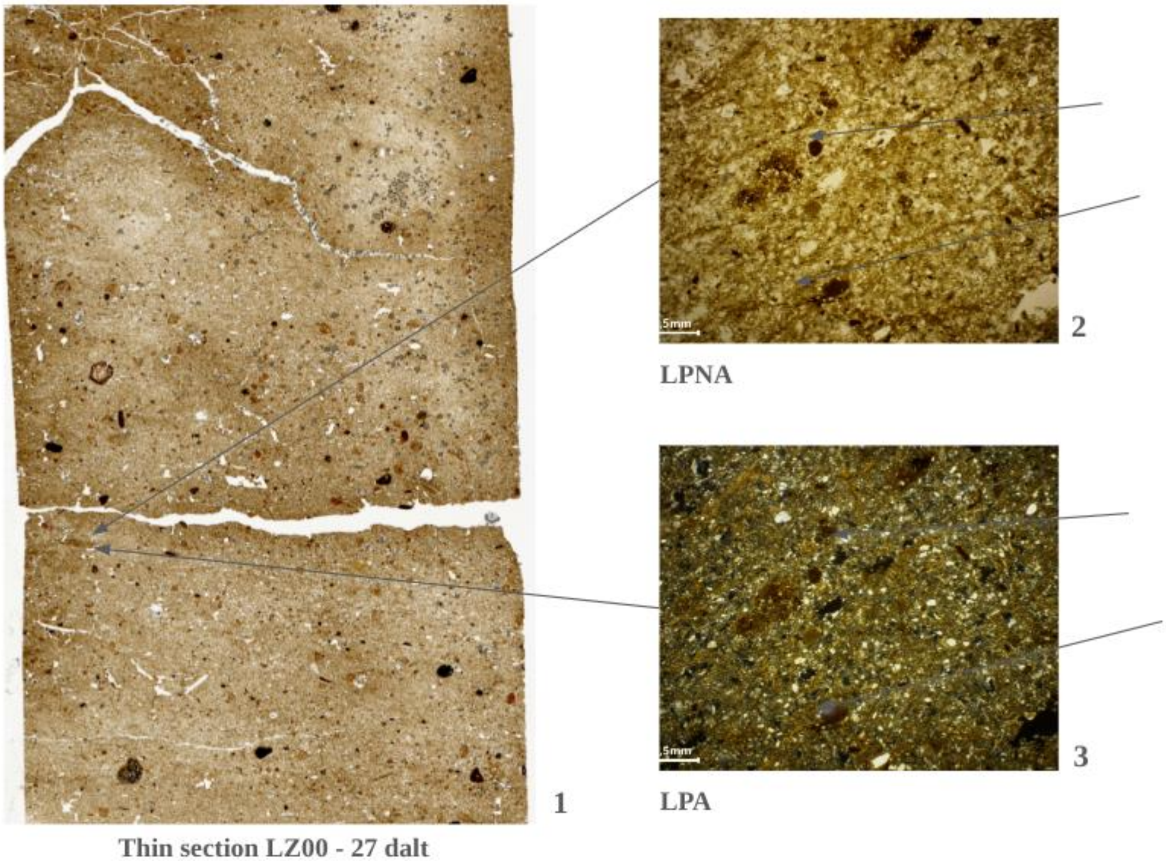

Figure. 19: Thin section LZ- 00- 27 dalt (13cm), southern section (C).

1- general view of the thin section.
2- fine link cappings in non analysed polarized light.
3- idem, in analysed polarized light.

5-4 Matrix supported muddy gravel:

Description:

Poorly sorted muddy gravels showing normal to inverse crude (coarse-tail) grading, it is observed in thin section (11 baix). Vesicles, nodules, clay coatings and excremental infillings are among the pedofeatures and the microstructure found here (Figure, 20).

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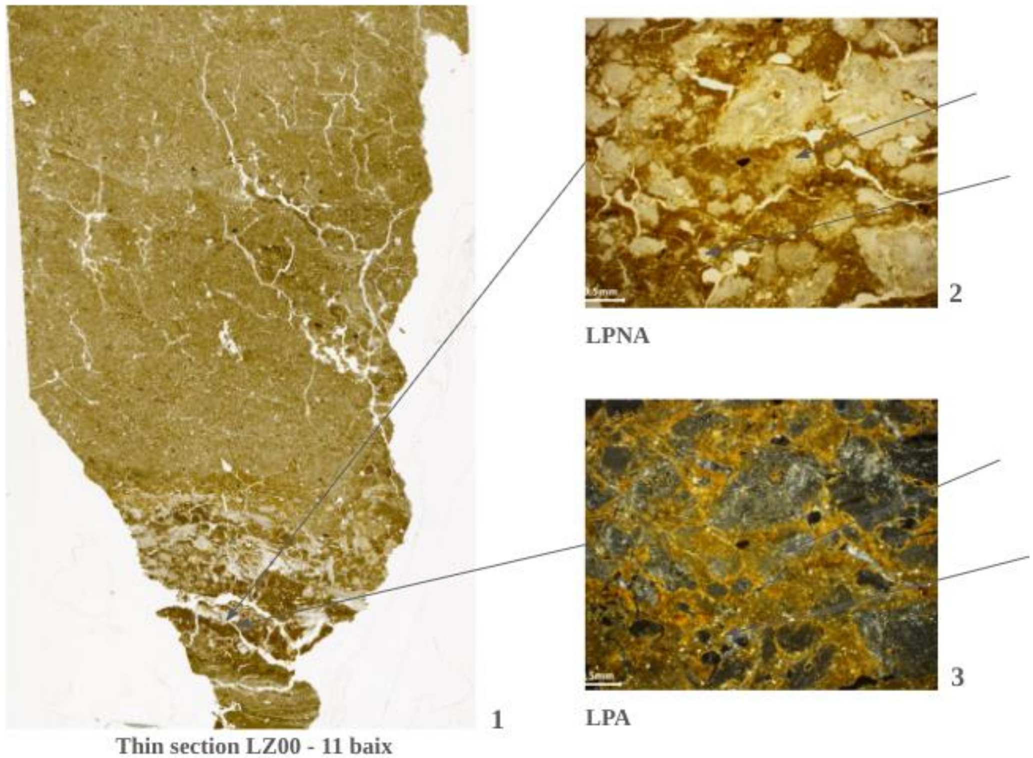

Figure. 20: Thin section LZ- 00- 11 baix (10cm), southern section (D).

1- general view of the thin section.
2-coarse material floating in a silty clay matrix in non analyzed polarized light.
3- idem, in analyzed polarized light.

Interpretation:
Heavy rainstorms or melting snow can provide the water required for debris flow formation (Selby, 1993). According to Karkanas and Goldberg (2010a), grading and vesicular microstructure indicate debris flow deposits. In addition cave sediments are frequently remobilized by rainwater, resulting in debris flows (Karkanas and Goldberg, 2010a).

6-4 Sandy mud lamination:

Description:
Mud and sandy silt lamination has deformed the convex laminations, the single grain and massive microstructure and plane and vesicular porosity.

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Among the pedofeatures found here are: link cappings, segregations and load cast sedimentary figures (Figure. 21). Observed in the microstratigraphic units (14, 22, 23 , 26, 27 mig, 27 baix, lower part of 28 baix and 29).

Interpretation:
Oveland/sheet flow deposits are well laminated (Mucher 1986). Deformation of massive mud microstructures indicates modifications based on plane porosity and vesicles related to snow melt occurring by different water content in the sedimentary deposits (load cast).

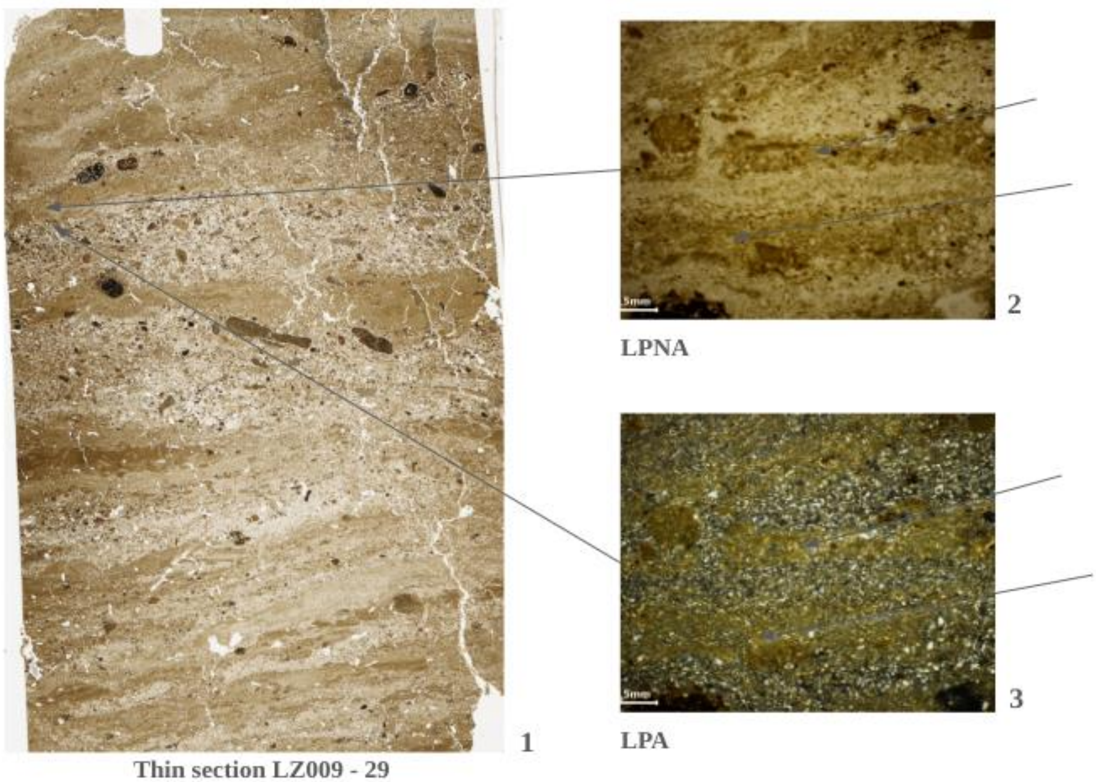

Figure. 21: Thin section LZ09-29 (12 cm), southern section (C).

1- general view of the thin section.
2- Sorted fine (deformed) lamination in non analysed polarized light.
3- idem, in analysed polarized light.

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7-4 Sandy silt lamination:

Description:
Sandy silt sorted textures showing microscopic cross laminations and monic to chitonic basic distribution. Rhythmic lamination consists of silt and sand with very few fine sub-angular to rounded gravels with lineal (one grain) basic distribution. All of the samples share the same colour: yellowish brown. In reference to the pedofeatures and microstructures, fissures, compound packing voids and vesicles, fragmented microscopic lamination (Figure, 22), link cappings, intercalations and clay coatings (Figure, 22). Observed in the thin section units (upper part of 28 baix and lower and upper part of 30 dalt).

Interpretation
Sorting in sandy sil lamination is moderately sorted in order to transport and to deposit particles of similar sizes reflecting an episodic stream deposit succession (Karkanas, 2019). Link capping indicates cryosuction according to (Mucher, 1989).

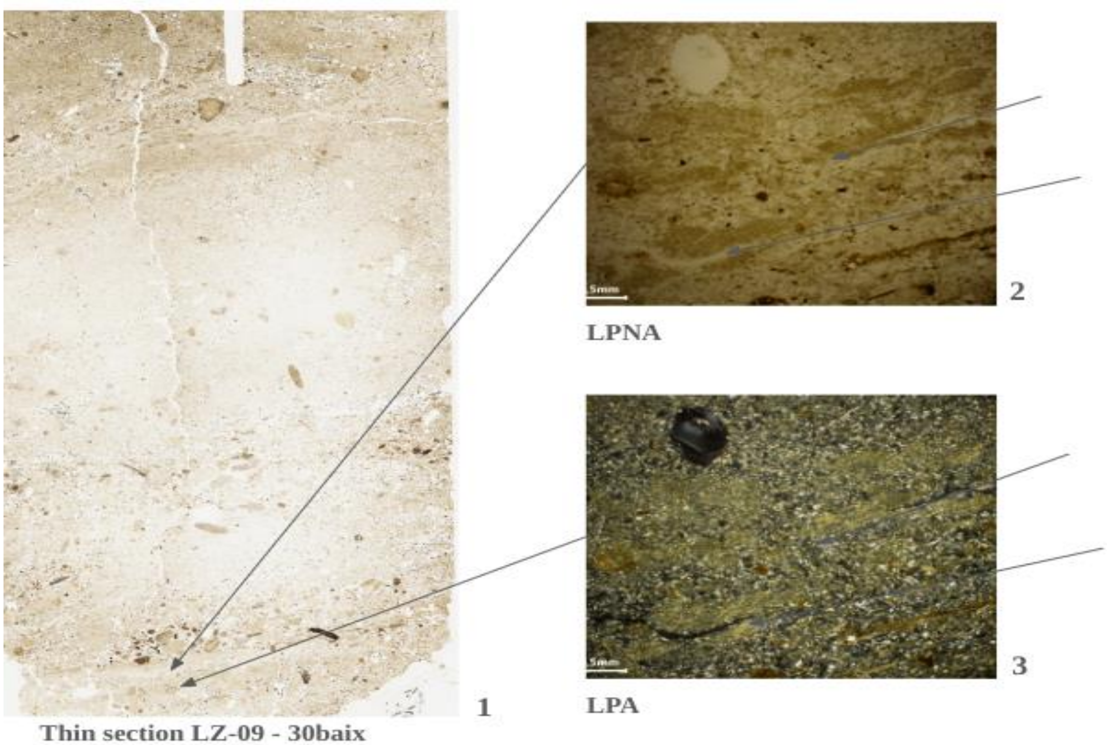

Figure. 22: Thin section LZ- 09-30 baix (11cm), southern section (C).

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1- general view of the thin section.
2- broken microscopic lamination in non analysed polarized light.
3- idem, in analysed polarized light.

8-4 silt:

Description:

A poorly sorted massive silt that is brown in colour. Concerning the pedofeatures and microstructure (Figure, 23) there are simple packing, vesicles, voids and orthogonal planes, clay coatings and dusty infillings. Massive silt contains single grain microstructure and close porphyric coarse/fine related distribution. In addition, fragments of sedimentary crust made from silty mud are integrated in the groundmass. Observed in thin section units: (lower part of 21, lower part of 25, 26 baix and upper part of 26 dalt).

Interpretation:

Loess affected by raindrop splash description shows no stratification and no sorting (Mucher 1986). Simple packing voids characterize primary eolian deposition. Furthermore, fragments of silty mud sedimentary crusts and orthogonal planes indicates pedoturbation (roots) and colluvial movements homogenizing primary eolian deposits during burial. Dusty infillings point out to eluvial horizon formation process (Courty et al 1989).

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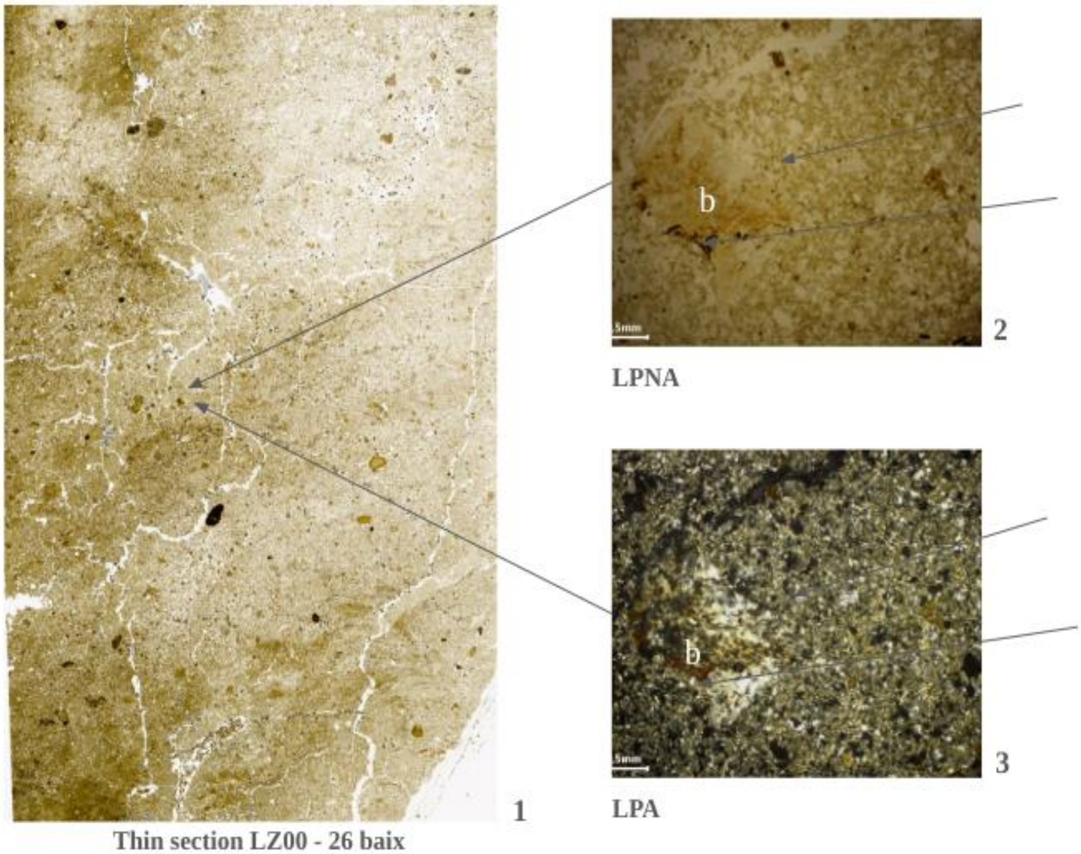

Figure. 23: Thin section LZ- 00- 26 baix(13cm), southern section (C).

1- general view of the thin section.
2- highly porous loess, b: bone fragment with post-depositional pigmentation, in non analysed polarized light.
3- idem, in analysed polarized light.

4-4 Microstratigraphy:

The units of the stratification were correlated and phased according to the features observed in the thin sections analysis (Figures 24 and 25). This resulted in the creation of new periodization of stratigraphic sequences and stratigraphic phasing. The stratigraphic phases are Ia/B (Magdalenian- Bronze age), Ib/C (Steril), IIa/D (Aurignacian- Solutrean), IIIa/E (Aurignacian), IIIb, IIIb/F (Middle paleolithic), and Iva/G (Aurignacian- Middle paleolithic), IV/H-I (Aurignacian- Middle paleolithic), V/J (Middle paleolithic), V/K (Middle paleolithic), and V/L respectively, while the periods are B, C, D, E, F, and G (Figure, 25). The period B is composed of the units (1, 2 and upper part of the unit 3), the period C is composed of the units (lower part of unit 3, 4, 5 and 6), the period D is composed of the unit (7), the period E is composed of the unit (8), the period F is composed of the units (9 and 10), the period G is composed of the unit (12), the periods H/I are composed of the units (13 to 20d), the period J is composed of the units (20b to 24b), the period K is composed of the units (25 and 26d), the period L is composed of the units (27d to 30b).

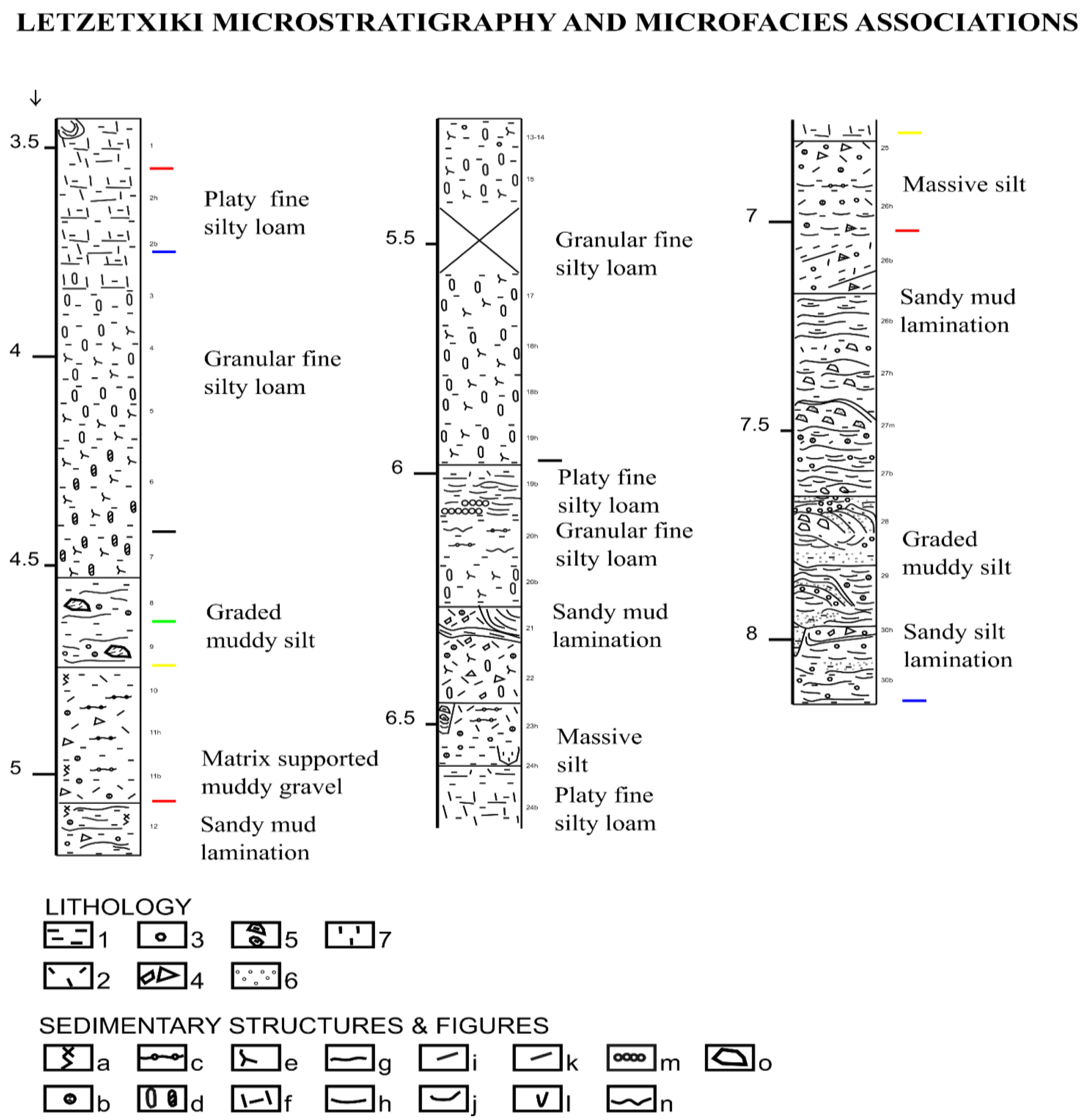

Figure. 24: Lezetxiki microstratigraphy and microfacies associations.

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1- sorted mud; 2- unsorted mud; 3- rounded gravels; 4- angular and subangular gravels; 5; ;6- sand grains; 7- silt; a- fissure structure; b- iron nodules; c- vesicles; d- channels (with or without infillings); e- roots; f- undeveloped angular microstructure; g- horizontal lamination; h- cross lamination; i and k- micro lamination; j- micro cross-lamination; l- infillings; m- granular structure; n- intercalations; o- oxide reduction structure.

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LETZETXIKI MICROSTRATIGRAPHY AND TYPES OF CURRENT FLOWS

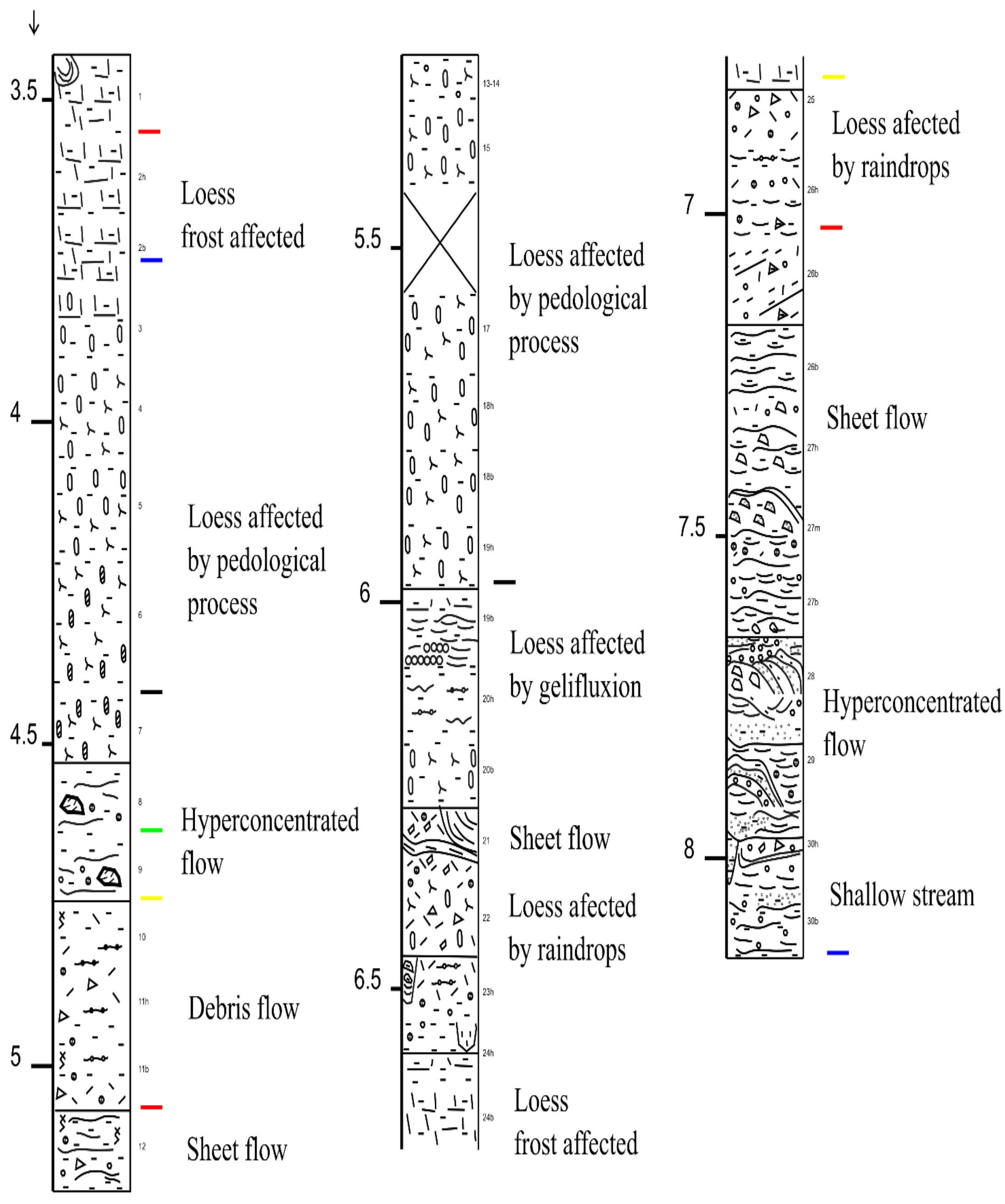

Figure. 25: Lezetxiki microstratigraphy and types of current flows.

CHAPTER FIVE

5- DISCUSSION:

In cave entrance environments, aeolian inputs, particularly sand-sized material are expected to be significant, especially in coastal caves and during glacial periods. These aeolian deposits are often found along major rivers, which can carry substantial amounts of sand and silt-sized particles (Smalley, 1972). Vegetation also plays a crucial role in dust deposition, with loess accumulating preferentially near rivers. Additionally, in caves located in regions that are now temperate, microfacies associated with solifluction deposits and cold-climate processes, such as frost creep and gelifluction, are commonly observed (Courty et al., 1989).

The micromorphological investigation at Leztechiki cave reveals a variety of depositional and post-depositional processes that altered the original loess structure, indicating that the cave experienced multiple sedimentary events.

Recent research suggests that the geochemical composition of loess varies significantly by region and is more dependent on local sources than previously thought (Muhs & Bettis, 2003; Muhs & Budahn, 2006; Rousseau et al., 2014). Factors such as grain-size sorting caused by river movement, the recycling of older aeolian sediments, and syn-sedimentary weathering may contribute to these observed variations (Buggle et al., 2008; Gallet et al., 1998). Therefore, loess deposition can be influenced by the concentration of silt, clay, and fine sand-sized particles in the air, the characteristics of dust-bearing winds, and the presence or absence of precipitation during accumulation (Bruins & Yaalon, 1979; Cegla, 1972; Goossens, 1988; Mucher, 1986; Fye, 1984). Additionally, topographic relief, vegetation, surface roughness, permeability, moisture content, and the suction force of the sedimentation surface affect the deposition and consolidation of loess (Cegla, 1972; Goossens, 1988; Mucher, 1986; Pye, 1984; Vreeken, 1975).

While primary loess is often described as a homogeneous deposit lacking bedding or stratification (Mucher, 1986; Fye, 1984), redeposited loess frequently shows macro- and micro-lamination. Micromorphological studies and laboratory experiments indicate that processes like rainwash (a combination of splash and flow), overland flow without splash, or meltwater flow can lead to the formation of these laminations (Mucher & De Ploey, 1977; Mucher, 1986; Mucher et al., 1981). Typically loess deposits are characterized by a non-laminated structure, which is indicative of aeolian sedimentation. However, it's possible that aeolian loess deposits were originally laminated under certain conditions, although no experiments have confirmed this hypothesis yet (Mucher, 1981). Thus, it is important to distinguish between reworked loess, which consists of material eroded from primary loess and redeposited by slope processes and running water (Yaalon & Dan, 1974; Sneh, 1983), and wind-deposited primary loess. Primary loess that has undergone significant modifications due to weathering, soil formation, and diagenesis is referred to as weathered loess (Pye, 1984).

There are notable similarities between the Lezetchiki loess and loess-like deposits described by Edwards (1979), which, while exhibiting many sedimentological properties of aeolian loess, were not deposited by wind. These include colluvial slope-wash deposits, lacustrine silts, and overbank alluvial silts (Edwards, 1979). Moreover, most Quaternary loess was deposited during Pleistocene glacial periods; however, the primary role of glaciation was often to concentrate silts through fluvioglacial action, enhance cold weathering processes, and facilitate the reworking of Tertiary weathering profiles (Pye, 1984).

Frost action, commonly observed in soils with fine silt to clayey textures, is linked to the findings from Phase Ia (MIS 2)and the upper part of Phase Ib (MIS 2), particularly the underdeveloped granular microstructure (Crampton, 1977). This process typically occurs in the upper soil layers, where it is more susceptible to freeze-thaw cycles and multidirectional frost. Other pedofeatures associated with frost-affected soils, such as link cappings (Van Vliet-Lanoë, 1988), clay coatings, and infillings (FitzPatrick, 1956; Kubiena, 1970), are attributed to surface liquefaction and/or rapid percolation of runoff after snowmelt (Kuhn et al., 2010). The impact of frost action varies depending on soil characteristics and temperature regimes (Karkanas, 2009).

The microstructure analysis of the medium and lower parts of Phase Ib (MIS 2), and the upper part of Phase IIa/D (MIS 2) and IV/ H- I (MIS 3), indicates significant bioturbation, likely caused by fauna and root activity. Endogeic earthworms, known for creating regular channel systems in upper soil layers (Kooistra, 1982b; Joschko et al., 1993), may have contributed to this bioturbation. These channels and associated chambers could have been formed for various purposes, such as retreat, reproduction, or storage by soil organisms (Kooistra, 1982b). Additionally, channels with infillings related to meltwater percolation were observed (Van Vliet-Lanoe & Langohr, 1981). Erosional and depositional processes, in conjunction with synsedimentary loess deposition, are associated with silt infillings in the lower loess deposits (Rognon et al., 1987).

In the lower part of Phase IIa/D to IIIa/E (MIS 2-3), IIIb/F (MIS 3) and Iva/G (MIS 3), loess was redeposited by debris flows and mudflows and sheetflow, which were influenced by frost action. Furthermore, debris flows, characterized by a chaotic mix of particle sizes due to high sediment load and turbulence, differ from mudflows, which exhibit a matrix-supported structure indicative of high water content and viscous flow (Selby, 1993). Thin section analysis revealed voids, particularly rounded vesicle pores, indicative of liquefaction in muddy flows (Bertran & Texier, 1999). Vesicles, the most common void type, form under varying conditions of crust formation and are often found in frost-affected soils (Luk et al., 1990). The formation of vesicles may be attributed to air expulsion during freezing, as suggested by multiple studies (FitzPatrick, 1956; Bunting, 1977; Harris & Ellis, 1980; Van Vliet-Lanoë et al., 1984; Van Vliet-Lanoë, 1985, 1988a).

During Phases IIIb, V/J (MIS 4), V/K (MIS 4), V/L (MIS 4), evidence of a second mass movement flow, which redeposited loess with horizontal laminations, was found. Redoximorphic features such as clay coatings and nodules indicate processes related to clay repositioning and water saturation (Veneman et al., 1976; Bouma et al., 1990). The presence of clay coating fragments or papules in this phase may result from bioturbation or cryoturbation, both of which can disrupt infillings and coatings (Van Vliet-Lanoë, 1985; Van Vliet-Lanoë, 2010). Finally, oxide reduction, the process where Fe oxides are removed from particles under anaerobic conditions, was also observed in this phase. This process requires specific conditions, including water saturation, sufficient organic matter and bacteria, and temperatures above biological zero to support microbial activity (Vepraskas, 2004; Vepraskas & Faulkner, 2000).

CHAPTER FIVE

LETZETXIKI LITHOSTRATIGRAPHIC UNITS AND MIS CORRELATION

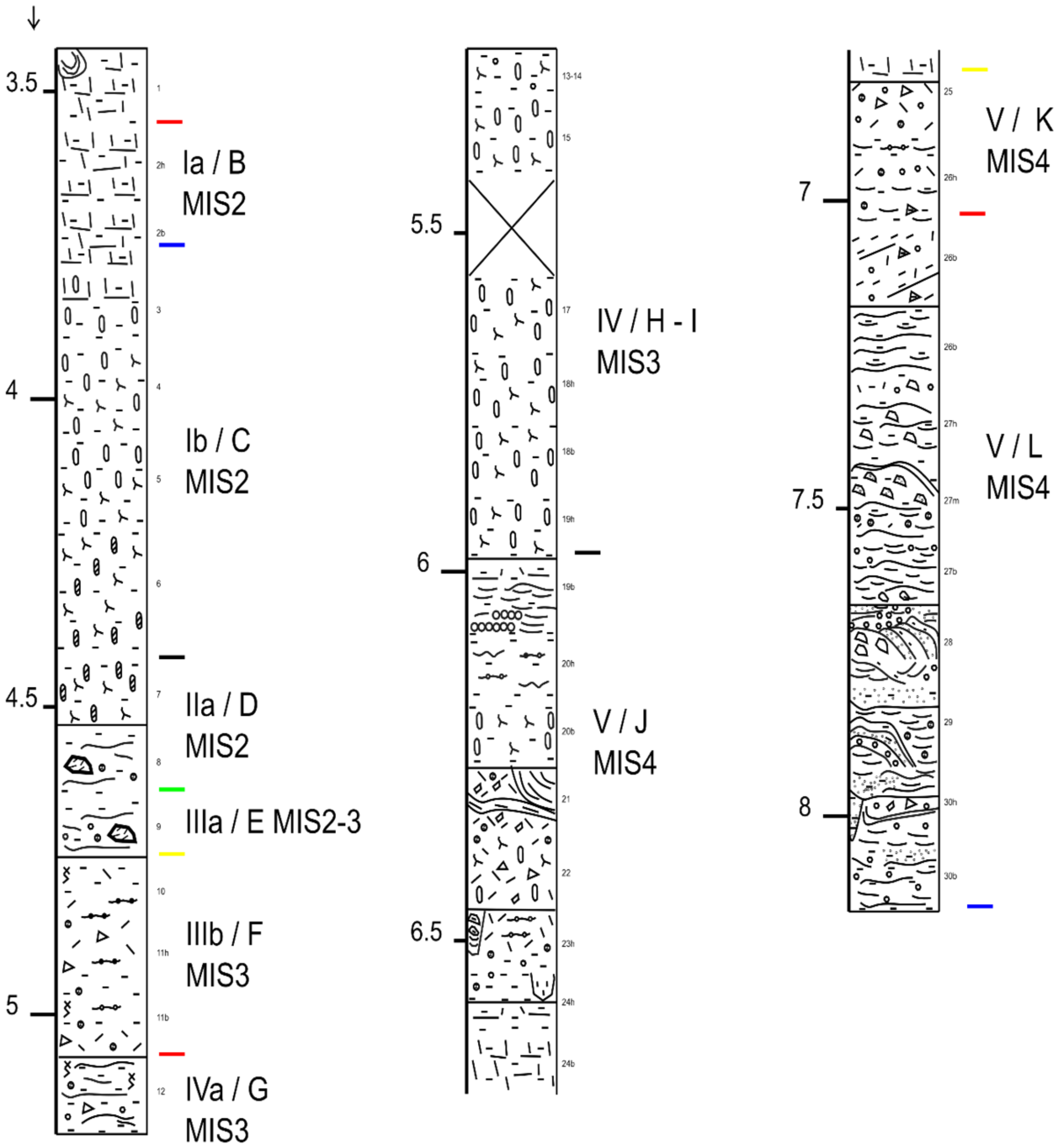

Figure. 26: Lezetxiki lithostratigraphic units and MIS correlation.

6- Conclusion:

This soil micromorphological study has proven to be useful in the study of undisturbed soils in identifying components of a deposit and the activities that occurred on an archaeological site. Although, it is more likely than not, that no single methodological approach could be sufficient in unravelling the complex arrangement of anthropogenic and natural elements at a site, micromorphological analysis provided complimentary information to that obtained on the field and from the previous research works at Lezetxiki.

The micromorphological analysis of sedimentary deposits from Lezetxiki cave has provided significant insights into the complex depositional and post-depositional processes that have shaped this site. By examining thin sections of the cave's sediments, this study has identified two primary facies types: primary loess modified by pedological processes and loess-like deposits, each associated with different transport and depositional mechanisms. These findings underscore the complexity of the cave's stratigraphy, revealing that while some of the deposits exhibit characteristics typical of aeolian loess, their origins are more closely linked to mass movement processes, erosion, and solifluction.

The study has also highlighted the importance of post-depositional modifications, including bioturbation, frost action, sheet flows, hyperconcentrated and debris flows. These processes, particularly the impact of frost in various phases, have led to the formation of specific pedofeatures such as vesicles, clay coatings, and nodules, contributing to the intricate microstratigraphy observed in the cave entrace sediments.

Furthermore, the research emphasizes the necessity of integrating micromorphological data with macroscopic observations and other archaeological evidence to achieve a more comprehensive understanding of the site. The identification of distinct microstructures and mineralogical compositions within the deposits has not only enhanced our knowledge of Lezetxiki's depositional history but also provided a clearer picture of the environmental conditions and human activities that influenced the cave's development.

In conclusion, this study demonstrates the invaluable role of micromorphology in archaeological research, particularly in complex cave environments like Lezetxiki. The findings contribute to a more nuanced understanding of the site's lithostratigraphy and highlight the dynamic interplay between natural processes and human activities over time. This research not only resolves some of the outstanding issues regarding the cave's sedimentary history but also lays the groundwork for future investigations that could further unravel the complexities of the region's paleoclimatic and paleoenvironmental history.

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