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QUATERNARY AND PREHISTORY

Fuel sources and paleovegetation in a Late Middle Paleolithic Iberian context: Anthracological analysis of Layer XI from El Salt (Alcoy, Alicante)

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Los dos años que conformaron este máster, que con el presente trabajo concluye, fueron dos años cargados de enseñanzas vitales. Durante ellos he vivido experiencias hasta antes impensables, conocido a gente inolvidable y me he formado profesionalmente en un contexto inmejorable para ello. Pero esta experiencia va más allá de lo académico, es una etapa de crecimiento como pocas lo habían sido hasta ahora, de enfrentar y afrontar incomodidades y de haber redefinido mis límites. No han sido fáciles, eso ya era bien sabido desde antes de empezar, pero tampoco cambiaría nada de lo que he hecho durante este tiempo, ni de lo mucho que me ha cambiado como persona.

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Se sabe que el vacío que nos queda
es el hermoso todo que tuvimos:
como un bosque inmolado.

La tarde, Juan Gil-Albert

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Abstract / Resumen

ENG

The Middle Paleolithic site of El Sal (Alcoy, Alicante), has been object to intensive investigations with the objective of achieving the highest resolution possible for archaeological palimpsest dissection. Out of the multiple proxies studied, anthracology, the study of wood charcoal, has been one of them. The great conservation state altogether with the systematic excavation methodology and the processing of the materials has allowed for a thorough study, as the one here presented.

The results of the initial study of the archaeological Unit XI will be presented in this work. Starting from the anthracological method, through the combination of the classic taxonomic identification methodology altogether with the taphonomic and spatial study of the assemblage, the main objective is the characterization of the wood resources management by the Neanderthal groups that occupied the site. The landscape is not a mere spatial frame where Neanderthals developed their activities, but a conditioning agent for those actions. The joint execution of the diverse approximations to the material allows to obtain a broader and comlex picture of the human decisions reflected on the wood charcoal fragments. The results make headway of the scientific significante of Unit XI, as well as the potential of the new anthracological methodologies.

CAST

El yacimiento del Paleolítico Medio de El Salt (Alcoy, Alicante) ha sido objeto de intensivas investigaciones con el fin de lograr la mayor resolución posible en la disección de palimpsestos arqueológicos. De los múltiples proxies aplicados, la antracología, el estudio de los carbones de madera, ha sido uno de ellos. El buen estado de conservación junto a una metodología de excavación y procesado del material sistemático posibilita un estudio minucioso como el que aquí se presenta.

En este trabajo se expondrán los resultados del estudio inicial de la Unidad arqueológica XI. Partiendo del método antracológico, mediante la combinación de su metodología clásica de identificación taxonómica, junto al estudio tafonómico y espacial del conjunto, el objetivo principal es la caracterización de la gestión de los recursos leñosos por los grupos Neandertales que ocuparon este espacio. El paisaje es no solo el marco espacial en que desarrollaron sus actividades, sino un agente condicionante de las mismas. La aplicación conjunta de las distintas aproximaciones al material permite obtener una imagen más amplia y compleja de las decisiones humanas reflejadas en los restos de carbón. Los resultados avanzan la relevancia científica de la Unidad XI a la vez que el potencial de las nuevas metodologías antracológicas.

1. INTRODUCTION

1.1. Problematic

When thinking about Neanderthal economy and how these groups managed their resources the vegetal world tends to remain relegated, shadowed by the more prominent archeological remains: stone tools and animal carcasses remains. Human diet is, in broad terms, always perceived and talked about from the meat consumption, establishing it as a key element of debate within the *Homo* evolution. And even the habitat structuration and spatial arrangement of these begun to be investigated on these terms, following the lithic and faunal remains display through the surface. Yet, something more perishable and fragile was considered the central element of the settlements: fires and hearths. The study of these elements can be done through multiple proxies, being the perishable materials within them one of the possibilities, like that of wood charcoal.

Wood as a primary resource must be managed, selected, gathered and transported for its use. All these can be seen as cultural-driven logistical choices and actions, further away from the more ecological facet. However, these actions remain invisible on the archeological record, at first. The questions regarding the decisions taken over these supplies may never be answered, but new methodological developments within the anthracological field allow the attempt. Within this, the Iberian Peninsula is a place of great interest and value for its application, due to the multiplicity of Middle Paleolithic sites and the high resolution that some of them preserve (i.e., Galván *et al.,* 2014; Mallol *et al.,* 2013a *;* Vallverdú *et al*., 2005; Vaquero & Pastó, 2001). Yet, the 'palimpsest problem' is a trend within them, in need of a strategic excavation and record method developed. Out of the sites comprised in this geographical extension, the Mediterranean coastland is where most of them are gathered. The site of El Salt (Alcoy, Alicante) is between them, and the chosen one for the present work.

The studies undertaken in El Salt up to the date focus on the palimpsest dissection, as well to shed some light into the debate of the Neanderthals and its disappearance (Galván *et al*., 2014). Its geographical position in the south-eastern Iberian Peninsula makes it of great interest to assess the dates for the last Neanderthals in the territory. Out of the several hypotheses, the one that this data seems to correlate more to is the one linking the Neanderthal disappearance with a series of recurrent climatic variations that altered the fauna and flora from large part of occidental Europe (Mayor Benadero, 2017).

The site of El Salt is a paradigmatic case of accumulative palimpsest (Bailey, 2007), with a severe overlap between the occupations (Marrero *et al.*, 2011). The diverse methodologies and proxies taken to study the site over the years suggest that the possible most readily observable material manifestation of a Middle Paleolithic single occupation episode is a single combustion structure and the surrounding archeological remains (i.e., Machado *et al.*, 2013; Vaquero & Pastó, 2001; Vaquero *et al.*, 2001; Vallverdú *et al.*, 2005). There is complementary data supporting the inference of hearths and their associated materials as the closest accumulations to a single occupation episode. There were different ways in how this information was gathered: analogy with household-type accumulations from the ethnographic record (Binford, 1980, 1982; Fisher & Strickland, 1991; Picornell-Gelabert, 2009) and high temporal resolution data from archeosedimentary records excavated in caves and rockshelters (Machado *et al*., 2015), like the one from El Salt.

An archeological palimpsest is defined as a deposit formed by the conjunction of sedimentary and anthropic dynamics which result in the interstratification of material deposited over different episodes in time within the same space (Machado *et al*., 2011). This recurring superposition and transformation of added elements from natural and anthropic actors develops into complex stratigraphic realities comprising the remains from an indeterminate number of successive occupations (Bailey, 1983; Binford, 1981; Lucas, 2008, 2012, 2021; Vaquero, 2012), the so called 'palimpsest problem'. To define their spatial and chronological succession it is needed an intended investigation plan. This must take and work with the physical proximity of materials and structures recorded during the excavation process (Machado et al., 2011). The dissection of the complex realities that palimpsests are is understood as an ongoing process (Sossa-Ríos *et al.,* 2024), allowing for continuous renewed and experimental approaches.

1.2.Objectives

With the present study our main objective is to delve into the management of wood resources by Neanderthals in the Unit XI of El Salt (Alcoy, Alicante). To achieve so, there is special interest in the taphonomical aspect as a mechanism that may provide some insights into the preferential selection or not of one or some species and even about wood condition and its soundness. The research questions are mainly focused on the interactions between humans and the environment, and how the anthropic decisions over the firewood resources may or not be seen in the record. With this regard, the differences in the study of wood charcoals retrieved from the scattered assemblage or combustion structures may be of great value to assess time scale, for which the implementation of some analyzes on the spatial distribution of the materials will be convenient. There is the plan on shadowing some light on the paleoenvironmental setting of assemblage, with the limitations that anthracological material has after its marked anthropic filter, but with the recognition of the local scope of its ecological reach. The main inconvenient, as with any Middle Paleolithic archeological assemblage is its palimpsest nature, to which is expected to contribute to the interdisciplinary discussion regarding its dissection for this Unit XI.

The main objectives of this work are:

1. To characterize the charcoal assemblage of Unit XI of El Salt site, with an intended economical perspective.
2. To define and understand the taphonomical processes affecting the assemblage, delving into the natural factors and human decisions that led to them.
3. To propose some paleoenvironmental context.
4. Lay out the contributions from the anthracological record to the main problematic and aim that is palimpsest dissection.

2. STATE OF THE ART

2.1. The Middle Paleolithic: biogeographic and chronological context

The time frame of this study is within the Upper Pleistocene (ca. 126-11.8 ka B.P.) (Rasmussen *et al.*, 2006, 2014), during which several Marine Isotopic Stages (MIS) occurred. The first of them was the MIS 5 – or Last Interglacial (Woillard, 1978) – subdivided in several substages, characterized by the minimum ice volume presence at high latitudes between ca. 126-75 ka B.P. For the glacial period of MIS 4 (ca. 75-69 ka B.P.), the lower insolation on the northern latitudes produced greater extension of the polar icecaps and the descent of the sea level (Rasmussen *et al*., 2006; Sánchez-Goñi & d'Errico, 2005). However, MIS 3 (ca. 60-25ka B.P.) is the isotopic stage were the events recorded by the assemblage presented in this work took place. This is also defined by great climate variability, characterized by the alternation of temperate cycles, also called Dansgaard-Oeschger events (Dansgaard *et al*., 1993) during which the forests developed, and cold phases or Heinrich events (Heinrich, 1988) of semi-arid areas expansion (Fletcher & Sánchez-Goñi, 2008; Marquina *et al.*, 2017). It was also during the MIS 3 when the Greenland records show the highest sea level rising rate (between 60-55 ka B.P.) (Rasmussen *et al.*, 2014; Siddall *et al.*, 2003). This variation has a valuable impact on the arrangement of vegetation and its altitudinal distribution.

For the time Neanderthal groups inhabited the European continent, the woody landscapes of eastern and western regions were somewhat different. In the eastern regions the milder environmental conditions prompted trees and shrubs such as *Quercus* spp. and *Prunus* spp. from different arboreal communities, being wood the main fuel (Allué *et al.*, 2018; Baruch *et al.*, 1992; Ntinou & Kyparissi-Apostolika, 2016). Meanwhile, in western territories, along central Europe and the Mediterranean coast predominated extensive conifer forest mostly distributed in mountain ranges. The widespread and abundance of montane pine (*Pinus nigra, Pinus sylvestris, Pinus uncinata*) led to its recurrent exploitation as fuel (Allué *et al.*, 2017, 2018; Arsuaga *et al.*, 2012; Badal & Carrión, 2001; Badal *et al.*, 2012a; Théry-Parisot, 2001; Théry-Parisot & Texier, 2006; Uzquiano & Cabrera, 1999; Uzquiano *et al.*, 2008; Vidal-Matutano, 2018; Vidal-Matutano *et al.,* 2017). The archeological data gathered point towards a selective firewood gathering strategy of Neanderthals attending not only to the presence and abundance of wood, but high correlation between the factors seems to exist when referring to the *Pinus* spp. (Allué *et al.*, 2022).

In the Iberian Peninsula, the identified and published flora at Middle Paleolithic sites classifies into five groups:

- Cryophilous pines. Mostly identified as *Pinus nigra-sylvestris* (comprehending also *Pinus uncinata* and *Pinus nigra* ssp. *salzmannii*, the latest growing above 500 m.a.s.l.). Nowadays can be found above 1000-1200 m.a.s.l., occupying the supra-mediterranean and/or oromediterranean mountains (Rivas Martínez, 1987).
- Warm pines. Identified as *Pinus pinea, Pinus halepensis* or *Pinus pinea-pinaster*. These pine species has warmer bioclimatic requirements and are commonly archeologically documented south of the 40ºN Parallel (Badal *et al.*, 2012b).
- *Juniperus* forest and heliophilous taxa. Even though the *Juniperus* genus cannot be differentiated up to the species level based on the anatomical observation, all of them are species showing great resistance to extreme aridity conditions, which is the reason behind the inclusion of other heliophillous taxa such as woody Fabaceae, *Ephedra* or *Artemisia* in this group.
- Mixed forest is composed by sclerophyllous and deciduous taxa: Rosaceae species, *Pistacia*, Lamiaceae, *Rhamnus* or Cistaceae. For the northern Iberian sites Eurosiberian taxa exclusive to these latitudes like *Corylus avellana* or *Castanea sativa* are also included.
- Ripisylve. Comprised by taxa typical of the bottom of the valleys or humid areas such as *Fraxinus, Salix, Populus* and *Ulmus* (Vidal-Matutano, 2018).

2.2. The presence and study of fire in Prehistory

Fire is an element with broad implications in human live and evolution, comprising fields as the biological, social, economic, technical or symbolical, proclaiming it with a unique status in the history of research in Prehistory (Perlès, 1977; Binford, 1998; Wadley & Jacobs, 2006; Vitezović, 2013). Fire as a tool provided humans with several advantages due to its transformative capacities of numerous materials and food. This allowed humans to expand into regions with colder climates or to enrich their diets by enlarging the range of edible food (Oakley, 1970; Leopold & Ardrey, 1972; Stahl *et al.*, 1984; Wrangham *et al.*, 1999; Aiello, 2017). The increase in the hours devoted to work and social activities through the production of artificial illumination is not free of debate (see Medina-Alcaide *et al.,* 2021). During the final stages of the Lower Paleolithic (ca. 400-500 ka B.P.) the use of fire is frequently recorded (Gowlett, 1999; Rolland, 2004). It will be with the beginning of the Middle Paleolithic (or the second half of the Middle Pleistocene, ca. 250-350 ka B.P) when the evidence for its use becomes unequivocal, even though date is still under discussion (Albert & Cabanes, 2007; Gamble, 1999; James, 1989; Roebroeks & Villa, 2011; Roebroeks *et al*., 2021; Shimelmitz *et al*., 2014).

The role of fire increased over time, reaching a point where current studies of Middle Paleolithic Neanderthal settlement patterns use the combustion structures as one of their main proxies given their frequent occurrence. The stacking of these combustion structures, interpreted as hearths, were recorded at many sites (Mallol *et al.*, 2013a; Vaquero & Pastó, 2001; Vallverdú *et al*., 2010, 2012), turning it into the main aspect of Neanderthal space division conceptualization (Dorta, 2009; Dorta *et al.*, 2010; Gómez *et al.*, 2010; Machado, 2010; Marrero *et al.*, 2011; Sistiaga *et al.*, 2011; Vidal-Matutano, 2017). There are many evidences of combustion structures on the Levant and Europe within this timeframe operating as the axial elements due to them being sources of warmth and heat (i.e., Yellen, 1977; Galanidou, 1997; Vaquero and Pastó, 2001; Vallverdú *et al.*, 2005), testifying to complex habitat structuration (Albert *et al.*, 1999, 2000, 2003; Madella *et al.*, 2002; Rosen, 2003; Cabanes *et al.,* 2007, 2010; Albert and Cabanes, 2007; Mallol *et al.,* 2010; Aldeias *et al.*, 2012; Fernández Peris *et al.*, 2012; Goldberg *et al.,* 2012; Vallverdú *et al.,* 2012, and references therein). And, not only do they provide rich information related to contemporary activities undertaken by the group, but also their stratigraphic position directly links them with the occupation surface, becoming key elements for the dissection of archeological palimpsests (Bailey, 2007; Henry, 2012; Herrejón-Lagunilla *et al.,* 2024; Martínez-Moreno *et al.*, 2004). These ideas were inspired by ethnoarcheological work, namely Binford's (1998) note on the presence of a 'central hearth', which becomes the central element for different activities.

Through time, diverse proxies and disciplines undertook the study of the combustion structures, the fuels used and the combustion process. Approaches from archaeobotany, both from phytolith (Albert *et al.*, 2000, 2003, 2012; Albert and Cabanes, 2008; Cabanes *et al.*, 2010; Burguet-Coca 2020), and anthracology (Allué, 2002; Carión-Marco, 2005; Badal *et al.,* 2008; Théry-Parisot *et al.*, 1996, 2010; Théry-Parisot, 1998, 2001, 2002; Théry-Parisot & Meignen, 2000; Uzquiano *et al*, 2008; Vidal-Matutano, 2017), or other disciplines like zooarcaheology (Asmussen, 2009; Costamagno *et al.,* 1999, 2005, 2010;

Yravedra *et al.*, 2005) and microstratigraphic studies (Berna and Goldberg, 2008; Goldberg *et al.*, 2009, 2012; Miller *et al.*, 2010) are between the most notorious and proliferous studies (Allué *et al.*, 2022). The preservation state of these combustion structures is a critical feature to approach the use and control of fire by Neanderthals. There are several aspects that determine their preservation such as climatic conditions, sedimentation rates, diagenesis, type of fuel used, and post-depositional disturbances –caused by anthropogenic or other biogenic agents – (Weiner and Goldberg, 1990; Meignen *et al.*, 2001; Rodríguez & Cabanes, 2015; Sistiaga *et al.*, 2011).

2.3. Middle Paleolithic combustion structures: General features

Most Middle Paleolithic combustion structures are simple, flat and open, constructed on unprepared surfaces (one of the first descriptions in James, 1989), being pit-hearths infrequent. These stone-lined/constructed hearths became more common during Upper Paleolithic, with this change being interpreted by Chazan (2017) as a reflex of the perspective shift on fire, from a natural phenomenon to a cultural item (Allué *et al*., 2022). When fires are of anthropological origin, the archeological remains are mostly composed of the direct products from the fuel combustion, commonly wood (Albert & Cabanes, 2007). Alternative fuels have been identified (i.e., bone, animal dung, coal, pine cones, grasses or other plant materials), interpreting their use as a response to specific purposes or steps within the combustion process: ignition, maintenance or particular functional purposes of that hearth (Albert *et al.,* 2000; Allué *et al.,* 2017a; Carrión *et al*., 2008; Courty *et al.,* 2012; Madella *et al.,* 2002; Théry *et al.,* 1996; Théry-Parisot, 2001; Théry-Parisot & Meignen, 2000). The presence and abundance of small bone fragments has been a topic of research related to hearths and their possible use as fuel, as well as various possibilities why they were being used use (i.e., cleaning living floors and avoid predators) (Braadbaart *et al.*, 2020; Costamagno *et al.*, 2009; Gabucio *et al.*, 2014; Théry-Parisot, 2002a; Yravedra & Uzquiano, 2013).

The typical sedimentary sequence of these hearths consists of two or three layers with sharp contacts. Their structure has most of the times suffered from erosion, weathering, diagenesis or a combination of these postdepositional processes. The topmost white layer, mostly compounded by ashes, tends to be missing, only remaining some reminiscences. It is followed by the black layer, ‘carbonaceous layer’ or ‘charcoal layer’, the archeologically most notorious evidence. It is presumed as an anthropogenic marker since it was generally assumed as partially combusted fuel (Leroi-Gourhan, 1973). Current data from micromorphological evidence of archeological and experimental fires whose black layers composition comes from the mix of combustion residues and topsoil particles (Mallol *et al.*, 2013a)–or even ethnoarcheological fires missing this layer (Mallol *et al.*, 2007)–, do not support such claim. The more recent works have pointed out towards the possibility that the archeological black layers represent indeed the charred organic matter from the living floor of the Neanderthal occupation. What concludes is that the archeological material and sediment within the top white/grey (ash) layer is the actual representation of the combustion event, leaving what is under as altered traces of anthropogenic or zoogenic previous events (Courty *et al.*, 1989; Mallol *et al.*, 2013a).

2.4. Wood and firewood: some notes on Neanderthal gathering practices

Wood as biotic material is one of the several components within the archeological record, both from natural and anthropic origin. Its examination provides insightful data on past people's behaviours and cultural patterns for the modification of wooded landscapes and forest resilience to this agent. Besides humans, it can also be used as a paleoenvironmental proxy (Newsom, 2022), however, without forgetting that its presence is almost always due to anthropic actions, which already imposes a bias to the assemblage. The difficulty inherent to the archeological record for studying this almost invisible facet through the archeological remains led to a heavy reliance on ethnography.

The predictive model proposed by Binford (1980) for hunter gatherers fuel gathering strategies, combining archeological evidence with ethnographic analogies, was synthetized by Asouti & Austin (2005): the collection was done locally from the already available firewood materials (Allué & García-Antón, 2006; Allué *et al.*, 2017a; Shackleton & Prins, 1992; Smart & Hoffman, 1988). There are several variables affecting human selection of firewood: availability and abundance, deadwood production, type and length of settlement, energy input required and the socioeconomic organization of the group. The assemblages may represent two different collecting strategies with an equilibrium between the investment and the efficiency relating to the abundance and the distribution of the resources through the environment (Solé *et al.*, 2013).

The introduction of pyrotechnology into Neanderthal lifestyle requires changes and adaptations of daily activities. As well, it conditions the settlement choices. As a consequence of this technological adoption, wood gathering practices became part of Neanderthals' daily life, a daily requirement. The need for a high frequency in this activity is after fire was involved in different events like cooking, heating or as a light source (Vaquero, 2022). For the duties of firewood gathering they resorted to different but proximate plant communities, different ecologies and even diverse areas within an altitudinal gradient (from valleys to hillsides) in accordance with the site location. This required supply of firewood is indeed a technical act, because despite the environmental constraints that are in between the production of fire, human groups –in a more or less conscious way– still get to choose from technological and functional alternatives (Lemonnier, 1993). This continuous variability is seen as another constant adaptation of the always in motion hunter-gatherer groups (Álvarez-Fernández *et al*., 2020).

The phonological state of the wood used as fuel might have implications and hints about their settlement patterns and technical knowledge. In the case of collecting and storing dried fuel, one must know about fuel properties and foreseen some degree of planning, maybe relating to longer occupation or cyclical circuits. Their preferences would be oriented towards species with high dead-wood rate production but also looking for specific sizes and quality (Allué *et al.,* 2022). The use of fresh wood has been frequently seen as an intentional decision to prepare a fire with particular combustion properties and application (Albert & Cabanes, 2007; Henry & Théry-Parisot, 2014; Vidal-Matutano *et al*., 2017). Also, rotten wood as fuel was defined in the same terms, proposed as the desired firewood in smoky hearths. This kind of hearths were recorded in the ethnoarcheological record for several different options, depending on environmental variations and cultural choices (i.e., meat preservation, hides treatment or as repellent of mosquitoes and flies) (Vidal-Matutano *et al*., 2017). To have more insight into the possibilities of Neanderthal firewood gathering strategies we may look into what the ethnographic record states. There are several authors putting forward that the abundance of deadwood in the surroundings may be the most influential factor in the collection strategies, since there are barely no requirements to collect and transport it with easiness (Ford, 1979; Heizer, 1963; Scheel-Ybert, 2001). Various groups over boreal Siberia and northern America, environments dominated by conifers, resort to the reduced combustion properties of rotten wood for smoking production (Henry & Théry-Parisot, 2014). Whatever the type of fire lighted, the objective is the optimization and efficiency in fuel wood use, which would be burning all the available/usable fuel mass (Kabukcu & Chabal, 2021).

The studied proximity of the gathering areas suggests the common practice of collecting from the ground or from the lower branches of trees (Allué *et al.,* 2017a; Vidal-Matutano *et al.*, 2017). This would favour pine forests with their natural high production rates of wood or fallen trunks, intensified by processes such as storms, heavy snow or flooding (Henry & Théry-Parisot, 2014; Théry-Parisot, 2002b). It will be seen with more detail, but the results from several sites point towards that wood gathering practices were looking for specific calibre branches, as recorded in Abric Romaní, Spain (Solé *et al.*, 2013), and Grotta di Fumane, Italy (Peresani *et al.*, 2011). This selection allowed for a better control of the hearth-type (braziers, flame fire, lighting) and the temperatures, enabling different purposes and uses (Courty *et al.*, 2012; Solé *et al.*, 2013).

Another aspect observed among hunter-gatherers is that what we conceive as 'preferred firewood' has not the same value for them; we tend to think about individual species heating efficiency and easiness of ignition, meanwhile for these groups the term corresponds with the function of multi-purpose hearths (Théry, 2002). It can happen that this notion exists within the group (like for the Benga, agropastoralists), but they may consider the naturally dried wood produced during daily/annual agricultural practices being enough for them, without the need to fell down trees (Picornell-Gelabert, 2020). If firewood selection was done with the main focus placed on the diameter and rate of humidity (Chabal, 1994) as the Montpellier school proposed, and not so much by looking into species properties, the wood diameter may be a more suitable variable for characterizing the technical system of wood acquisition (Dufraisse, 2012). And this is what ethnoarcheological studies are finding, that the diameter is the main factor when choosing daily firewood, not the species, even when there is common knowledge of the qualities of each species (Picornell-Gelabert, 2020).

This shift in how the archeological charcoal analysis is assumed and, potentially, the gathering practices it may reflect, could diminish the importance of the Principle of Least Effort (PLE) (Shakleton & Prins, 1992). This frequently adopted supposition recalls that there exists a deterministic relationship between the species collected for firewood and their environmental recurrence, supported by the ethnobotanical perspectives (Dufraisse, 2012). This hypothesis stutters when the focus is over the wood's quality. When the selection of firewood focuses more on its immediate availability the recognition of the alterations and the phonological state of the wood may be of greater interest than the species themselves. It would be expected to find greater amounts of dead wood, and a limited floristic list. The combination of traditional anthracology with the taphonomical studies is proposed as a method to discriminate whether the PLE may be occurring or not (Henry & Théry-Parisot, 2014).

Nevertheless, and without diminishing the method and intentions to test the PLE, it has to be remarked the comparatively lesser attention that other factors have received (i.e., subsistence goals, land uses, access to fuel source catchments, habitation practices, fire technologies, culinary cultures and their seasonality). This bias happens even after ethnographic records, ethnohistorical and archeological evidence suggest the inter-connected impacts from landscape and resource management strategies (Asouti, 2025). This bias on the investigation corpus leads to reduced perspectives and proposals.

3. ARCHEOLOGICAL CONTEXT

3.1. Site description and History of the investigation: El Salt (Alcoy, Alicante)

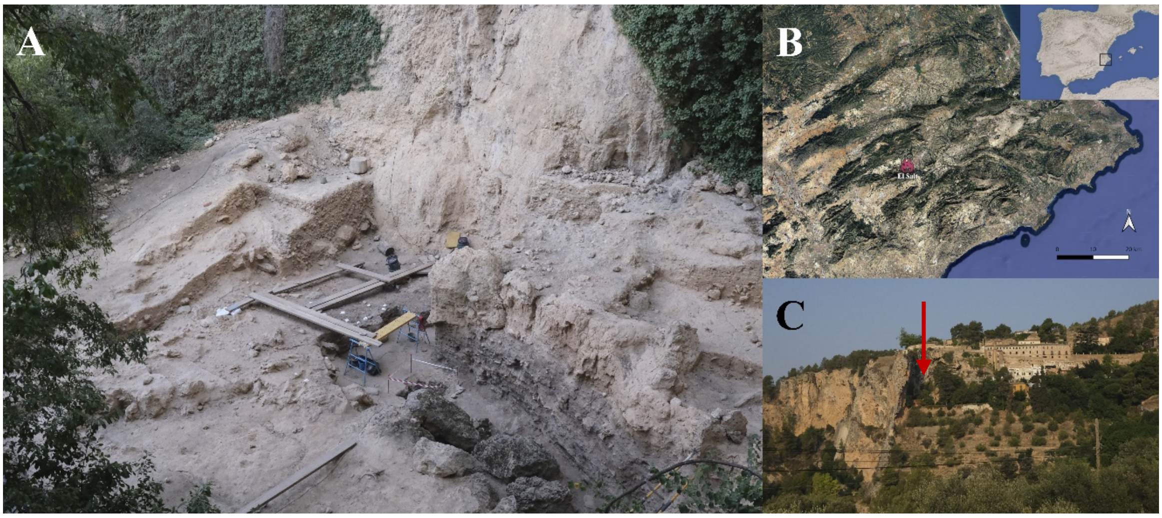


Figure 1Contextualization of the site. Photograph of the excavation area (a), map with the location of the site (b) and a photograph of El Salt, signaled by an ar row, within its landscape.

The site of El Salt (Figure 1) is located within the northeast sector of the alicantine Pre-betic geological range. This geological structure is characterized by a faulted and folded relief, resulting in a rugged topography with pronounced hills, deep valleys and natural corridors that connect the Mediterranean coastland with the inland peninsula (Dorta *et al.*, 2010; Estévez *et al.* 2004). Established in the southeast foothills of the Serra Mariola, within the Barxell river valley, at 700 m.a.s.l., this Middle Paleolithic human settlement is strategically found amid diversified biotopes, granting immediate accessibility to diverse essential resources. The site lies at the foot of a near 40 m high limestone cliff draped by travertine. The known base of the stratified sedimentary sequence, Unit XIII, was dated by Th/U to 80.157±4000 B.P. (J. Bischoff, Geological Survey, California). The preservation of the archaeological record is very good, with evidence of in situ hearth-related assemblages (Galván, 2000; Galván, *et al*,. 2006).

Its hydrographic connection with the Beneixama corridor, the natural passageway between the Meseta and the Mediterranean coast (Aura *et al.*, 1993) makes the site of El Salt subject of interest for studies of mobility and spatial organization patterns of Neanderthal hunter-gatherers, which became of great interest since the last decades of the XXth century. For the region, the main cluster of Mousterian sites is found within the *Hoya de Alcoy,* formed by the headwaters and upper course of the Serpis River. There are four essential sites: El Salt (Alcoy), Abric del Pastor (Alcoy), Cova Beneito (Muro) and the

Figure 2Map displaying all the Neanderthal sites of the region: El Salt (Alcoy), Abric del Pastor (Alcoy), Cova Beneito (Muro), Cova d'Estroig (Cocentaina) and Cova Negra (Xátiva).

Coves d'Estroig (Cocentaina) (Dorta *et al.,* 2010). But the presence of Neanderthal occupations in the central Mediterranean region is also evident in other MIS 3 sites such as Cova Negra (levels E/F) or Cova Beneito (level D1) (Fumanal, 1995) (Figure 2).

The prevailing view – based on zooarchaeological data from Cova Negra and Cova Beneito – is one of a high-mobility pattern characterized by the existence of small groups scattered in the landscape, occupying caves and rock shelters during short periods, alternating their presence with that of carnivores and with long periods of site abandonment (Marrero *et al.*, 2011). Those valleys harbour a variety of biotopes and resources needed for human survival: abundant water sources, and a diversity of plants and hunting game, including fish (Galván *et al.,* 2006).

The site of El Salt was first studied after J. Faus Cardona, natural from the locality, discovered the first lithic evidence of retouched Mousterian in 1959 (Faus *et al.*, 1987). He notified V. Pascual, the Museu Arqueologic d'Alcoi curator, who latter also notified L. Pericot from Universidad de Barcelona. It was decided to dig the site, which was done during two short campaigns in 1960 (directed by V. Pascual) and 1961 (Directed by R. Martí, from Universidad de Barcelona). It will be later on within the frame of a pluridisciplinar research program in 1986, authorized and financed by the Dirección General de Patrimoni Artistic (Consellería de Cutura), Generalitat Valenciana, and coordinated from the Universidad de La Laguna when the site began being intensely researched (Galván, 1992; Galván *et al.*, 2006).

Chronologically, based on TL and OSL dates, the site occupations can be framed between the onset of MIS 3 and ca. 45ka B. P. (Galván *et al.*, 2014), a period of variable climatic conditions with abrupt climatic changes in the Iberian Peninsula by (Kehl *et al.*, 2014). Pollen and charcoal sequences in the region show coniferous woodlands next to dry steppe formations, accompanied by an important Mediterranean component – evergreen

Quercus, *Olea*, *Pistacia* and *Myrtus* – during MIS 3 (González-Sampériz *et al.,* 2010). Neanderthal occupations of El Salt took place throughout MIS 3, between 60.7±8.9 ka B.P in Unit XII and 44.7±3.2 ka B.P. in Unit V (Galván *et al.*, 2014). The base of Unit V records the last Neanderthal presence at the site and includes dental remains assigned to the maxilla of a single Neanderthal individual, possibly a juvenile or young adult of unknown sex (Galván *et al.*, 2014a; Garralda*. et al.*, 2014).

Current excavation at El Salt cover 38m^2 surface, which has been divided into two main zones (inner and outer zones) based on their macroscopic sedimentary features and archeological content. Their difference comes from the abundance of organic matter and antgropogenic combustion remains in the sediment in the inner zone. The outer zone is made up of homogeneous deposits of calcitic sandy clayey silt with common tufa fragments (Leierer *et al.*, 2019; Mallol *et al.*, 2013; Sossa-Ríos *et al.*, 2024). The stratigraphic sequence of El Salt was first analyzed by Pilar Fumanal (1994), leading to the lithostratigraphic division of the deposit into 13 units (XIII-I). According to their macroscopic textural appearance and archeological content the units can be grouped into five different stratigraphicsegments (Galván *et al.,* 2014a).

The basal stratified segment, a 1.5m thick sequence of horizontally bedded fine silty sands in Units XII and IX (segment D; TL 52.3±4.6ka; Galván *et al.*, 2014) contains a high concentration of archaeological remains and in situ combustion features. The combustion structures show variable dimensions (0.2-1m of diameter) (Sistiaga *et al.*, 2011; Mallol *et al.,* 2012, 2013; Leierer *et al.,* 2019). Regarding taphonomic processes, Units XII and XI show low-energy surface runoff without density sorting (Fumanal, 1994) nor significant physical or diagenetic alteration, as demonstrated by the fresh state of flint artefact edges, angularity of charcoal fragments and well preserved, angular and subangular bone fragments (burned and unburned) (Gómez *et al.,* 2010). In the overlying strata, from Unit VIII to the middle of Unit V, evidence of human input is spatially reduced and gradually diminishing upwards through the sequence (Galván *et al.*, 2014b).

3.2. Unit XI and Unit X: the core of the Neanderthal occupations

Unit XI is the subject of this anthracological study. As previously mentioned, the lower units at El Salt (XII-X) have yielded evidence of regular Neanderthal occupations involving fire making throughout MIS 3, prior to HE 5 (50-47 ka) (Galván et al., 2014). Layer

XI is 10-30 cm thick, composed of brown to dark brown phosphatic silty-sandy clay, with weathered limestone gravel, and shows a diffuse or locally erosional contact with overlying Layer Xb (Fumanal, 1994, Leierer et al., 2020).

Unit XI is a dense archaeological palimpsest. The sedimentary matrix is generically classified into different facies according to color and texture as observed in the field: “Lm” (limos marrones), “La” (limos anaranjados) or “Lg” (limos grises). The latter stands out for its ashy color and texture and rich archaeological content. These facies are spatially and stratigraphically constrained (rows 5-8 and rows 1-4 near the cliff wall). They are present only in the inner excavation zone and are usually 1-2 cm in thickness. The outer area (rows 8 to 11) is homogeneous, richer in calcite, with a more orange coloration, paler, with common tufa clasts. It has been classified as facies succession B1-5 (tentatively correlated with inner facies Lm1-5). This study is focused on the top part of Unit XI, which includes three stratified inner Lm/Lg/La and outer B facies: Lm1-3 and B1-3.

Each of the mentioned facies is laterally associated with numerous overlapping combustion structures (33 combustion structures in total). Unit XI resembles the previous Unit X, where 60 hearths were found near the travertine wall, associated with abundant faunal remains, flint flakes and anthropogenically modified cobbles. For the fauna of Unit X, among the large mammals, Spanish ibex (*Capra pyrenaica*), red deer (*Cervus elaphus*) and wild horse (*Equus ferus/hydruntinus*) are the most abundant and most anthropogenically altered with cut-marks, percussion-marks or thermal alterations. Less abundant, but following the same patterns, there are also other taxa such as aurochs (*Bos primigenius*), wild boar (*Sus scrofa*) and Mediterranean tortoise (*Testudo hermanni*). Small mammals such as lagomorphs (*Oryctolagus cuniculus*) were also present (Fagoaga *et al.*, 2018; Rodríguez & Cabanes, 2015). There are other taxa present without anthropogenic manipulation: Rhinocernotidae, *Panthera pardus, Cuon* sp., and *Lynx* sp. (Sanchís *et al.,* 2015; Pérez *et al.,* 2017). The lithic artifacts were made from flint acquired within a 25km distance-radius, being Serrata flint the most used type. The prevalence of scrapers among the retouched tools remarkable (Galván *et al.,* 2014b). Use wear studies on a selection of flint artifacts have shown evidence for butchery, hide and wood work (Rodríguez *et al.,* 2002).

3.3. Current ecology and vegetation

The site of El Salt is within the l'Acloià region, in the east of the Iberian Peninsula. The climate in Alcoy is determined by the geography and relief, with precipitations being high in comparison with their surroundings, with average annual values of 500-800mm depending on the altitude (López Gómez & Rosselló Verger, 1978). Regarding temperatures, Alcoy shows the values for an inferior mesomediterranean: mean temperature is 14.5ºC, with 2.8ºC as the mean minimum temperature for the coldest month and 12.2ºC as the mean maximum for the same period of time (Rivas-Martínez, 1987). Annually, it is defined by a pronounced summer drought typical of the Mediterranean climate (Vidal-Matutano, 2016).

What refers to vegetation nowadays, the vegetal formation around the site is highly anthropic, with a predominance of cultivated fields of olive and almond trees. There is an abundance of Jerusalem pine (*Pinus halepensis*) above the gorse bushland (*Ulex parviflorus*), rosemary (*Salvia rosmarinus*), scorpion broom (*Genista scorpius*). It is also frequent to find kermes oak (*Quercus coccifera*) and some specimens of turpentine tree (*Pistacia terebinthus*) and Mediterranean buckthorn (*Rhamnus alaternus*). There are two natural settlements in the surrounding area, Font Rotja and Serra Mariola, of great ecological interest and value (for more information about these surrounding vegetation areas see Vidal-Matutano, 2016).

4. MATERIALS AND METHODS

4.1. Anthracological context

4.1.1. Brief historical introduction to the discipline

The initial anthracological method developed had a paleoenvironmental purpose, defining the composition, diversity, representativeness and the capacity of charcoal to describe the environmental context in which human societies evolved and developed their activities (Badal-García, 1992; Chabal, 1997; Kabukcu & Chabal, 2021). The debate around the reliability of the method as a tool for paleoenvironmental reconstruction began in the 1940s in Britain, after the publication of Salisbury & Jane (1940). The pivot of the discussion, started with the reply from Godwin & Tansley (1941) who rejected their position. Its argument was around the accuracy in past vegetation proportions when being observed only through the frequency of individual trees and shrubs from archeological wood charcoal species (Asouti & Austin, 2005; Picornell-Gelabert, 2009). In these studies, only charcoal associated to combustion structures were retrieved and analyzed. The idea behind was that since they were by-products of daily domestic fuel collection and consumption, they must be the best portray of the surrounding environment (Badal-García, 1992; Chabal, 1992; Kabukcu & Chabal, 2021).

By the end of the 1960s the introduction and recurrent use of reflection microscope entailed a revolution, cutting on costs and time, as well as allowing for the analyses of a high number of fragments (Badal-García, 1992). And so, the distinct subfield of archaeobotany – or paleoethnobotany – emerged as one within archaeology around the 1960s-1970s (Newsom, 2022). This event took its epicentre in France, where theoretical and methodological works defining this palaeoecological aspect were developed, leading to the so-called Montpellier School (Vernet, 1967, 1973, 1997; Chabal, 1997; Chabal *et al.*, 1999). These early research suggested that gathering was done randomly in the surroundings (Bazile-Robert, 1979; Vernet, 1967). As the time passed by and new works were developed, anthracologists realised that anthropic assemblages do not equal past vegetation functioning (Picornell-Gelabert, 2009), and the concept of the *chaîne opératoire* was incorporated to fire studies, with interest from the production, the use and the disposal of the remains (i.e., Collina-Girard, 1998; Olive & Taborin, 1987; Perlès, 1977).

Afterwards, anthracology has focused on the anthropological perspective, with issues related to the use of fire by reducing the scope to the identification of wood as fuel and its properties. These new studies were developed on the assumption that the management of the phonological and seasonal state of wood, altogether with the notion of heat transfer were the best information providers of the fireplace's operations (Allué *et al.*, 2022; Thiéry-Parisot, 2002; Thiéry-Parisot *et al.,* 2025; Vidal-Matutano *et al.*, 2014, 2020). With that in mind, the subsistence economy theories and site catchment analyzes have been their methodological bases (Uzquiano, 1992, 1997, 2008; Uzquiano *et al.,* 2008, 2012; Yravedra & Uzquiano, 2013).

Out of the scope of this method, the interpretative issues mostly relate to understanding the preservation conditions and the state of the wood consumed to elucidate the use of fuel by Neanderthal groups (Allué, 2002; Allué *et al.*, 2007, 2009, 2017a; Théry-Parisot, 2001; Théry-Parisot *et al.*, 2010; Vidal-Matutano *et al.*, 2015; Vidal-Matutano, 2017, 2018). To comprehend the representativeness of the archeological assemblages, a topic not forgotten, a lot of works on charcoal fragmentation had been completed, with special interest on the potential bias due to species-dependent behavior, a possible correlation between fragmentation rates and species (Arranz-Otaegui, 2017; Chrzavzez *et al.*, 2014; Deforce *et al.*, 2013; Dussol *et al.*, 2017; Fréjaville *et al.*, 2013; Hudspith *et al.*, 2018; Kabukcu & Chabal, 2021; Mas *et al.*, 2020; Théry-Parisot *et al.*, 2010).

Besides the above mentioned, the focus has also been over subsistence economy and/or site catchment analysis. The issue of selection patterns is still subject to ongoing debate (Delhon, 2021), and for most of the analysis it is assumed as random patterns in wood gathering (Allué *et al.*, 2017a, 2017b; Knight, 2024, 2025; Théry-Parisot & Meignen, 2000; Uzquiano *et al.*, 2012; Vidal-Matutano *et al.*, 2015). This discussion goes beyond further into the original debate of the wood charcoal assemblage representativeness and it potential for reconstruction (paleoenvironmental or human actions). It has been emphasized (Kabukcu & Chabal, 2021) that an assemblage's taxonomic composition cannot be used as a criterion to evaluate past wood uses because in the ethnographic studies the firewood selection for particular functions tends to vary as many communities are described. One key example is that the species selection is rarely based on objective parameters. In any way, numerous evidence exist which indicate the Neanderthals' capacity to foreseen future actions and their consequences, being selective with their fuel choices among other resources (Knight, 2024).

4.1.2. The material of analyzes: wood charcoal

What is commonly referred as wood is, in fact, the complex tissue system known as secondary xylem, the durable material found at the center of a tree, enclosed inside the vascular cambium, the secondary phloem –inner bark– and the cortex – outer bark. The carbonized wood –also referred as *charcoal*– is a black amorphous form of carbon made by slow pyrolysis of wood, in the general absence of oxygen, causing loss of moisture content and burning off volatile compounds (Newsom, 2022). This substance is not uniform and exists in a variety of states based on the wood type and the circumstances of carbonization: from quite soft and friable to relatively hard and resistant to fracturing. This wood charcoal can be found in archeological records clustered, as possible firewood remnants from hearths or other wood-burning contexts, depicting fragmentary cultural evidence (Newsom, 2022).

Within the scope of studying human fires in occupation contexts, the study of wood charcoal is crucial since wood, and woody taxa consequently, was the main fuel used (Allué *et al.*, 2017a, 2018; Théry-Parisot, 2001; Théry-Parisot *et al.*, 2010; Vidal-Matutano *et al.*, 2015). For this is that analysing the anthracological remains is crucial for the interpretation of fuel uses. There are many publications (Allué *et al.*, 2017a; Mallol & Henry, 2017; Théry-Parisot, 2001; Théry-Parisot *et al.*, 2010), manuals (Newsom, 2022) and guides (IAWA List of Microscopic Features for Hardwood Identification) that delve into cell structure and the analysis methods developed with archeological purposes.

4.2. The reference collection

One of the ways to verify the taxonomical identification – besides atlas of wood anatomy and identification keys – is through reference collection samples, which allows the direct observation of the vegetal remain in three dimensions (Rousou & Kouka, 2024). Taking into consideration the relevance and impact that local ecological conditions have on the flora and how it influences morphological variations, it was of great interest to create one for the site of El Salt, compound with samples of the surrounding region. The recollection place and process are of vital importance because of this morphological variability. So, the best method for the creation of a reference collection is with correctly identified specimens and saving some of the samples in green for the herbarium, for possible future considerations (verification or ulterior taxonomical reviews). The resulting collection must be easy to manipulate during laboratory work and the samples must have enough anatomical diagnostic traits. It is essential to contemplate the shrinkage produced by the carbonization process and take fragments large enough, trying to avoid young and thin branches (Rousou & Kouka, 2024).

In order to assess the correct identification of the species and to have the possibility to find as many species as possible from the floristic list, we contacted the Fundación Victoria Laporta (Alcoy, Alicante), a local foundation dedicated to the preservation of the local flora. The Fundación Victoria Laporta accepted helping us and collaborate in this scientific quest. The main benefit of this partnership was the security on taxonomical identifications and the knowledge that the ranges have about the development of these species into the ecosystem. Within their installations there were most of the species we were looking for, some of them do not grow in the area anymore outside the reservoirs due to anthropic pressure or because of the changes in the ecosystem. To create the floristic list, we followed the works of Vidal-Matutano (2016, 2017, 2018) and the taxonomical identifications made for the Middle Paleolithic levels. In the resulting listing our main problem was to find the *Pinus nigra-sylvestris* since nowadays it almost only grows over the 1200 m a.s.l. mark in the area. Moreover, this species constitutes most of the archeological record and its absence entails a big gap in our collection, which must be completed soon.

Reference collection creation process	
1. Preparation	Bibliographic review to create the floristic list.
	Search of the place to recollect the samples
2. Recollection of the samples	Meeting with the rangers and gathering of the samples
3. Processing of the materials in the laboratory: preparation of the samples and carbonization	Cutting of the samples to the desired length
	Measuring, weighting and storing each sample individually
	Burning of the samples in the furnace
	Retaking the measurements and weights
4. Samples preparation for storing	Inclusion of the samples on the existing reference collection
	Thin slices of green wood of each anatomical section
	ESEM photographs of each anatomical section

Table 1 Phases of the reference collection creation process. In grey the unfinished step.

The process to create our reference collection can be divided into four phases (Table 1). The first one was *Preparation*: the bibliography was reviewed to compose the floristic list and the place to recollect the samples was decided and checked. The second phase was the *Recollection of the samples* at the Fundación Victoria Laporta. This task was undertaken the 26th of July 2024 with the guidance of the rangers. The rangers collected and identified the samples. They were also the ones to confirm which species did not grow anymore in the region and that it would be very difficult for us to find them due to shifts in the ecosystem. All the samples were temporarily coded by number in the field, and once we were back at the field laboratory, we named them with the correct-full codes on each. The codding was created *ex profeso*, and it is not according to the reference collection of any of the institutions profiting from it (the Institut Català de Paleoecologia i Evolució Social or the Universidad de La Laguna). It is composed of two numerical parts: the first one refers to the species itself (6, *Quercus ilex*), and the number that follows the dot concerns the specificity of the sample (6.2, *Quercus ilex* dry and with lichen; 6.3. *Quercus ilex* bark). With this is how the register was completed, as seen in the Table 2.

The third phase corresponds with the *Processing of the materials in the laboratory: preparation of the samples and carbonization*. This operation was subdivided into four subphases: cutting the samples into 4 same-length pieces, measuring and storing each sample individually (with reference) for the pyrolysis, burnt with the help of a Nabertherm GmbH L 15/11/B510 laboratory furnace during 90' at 400ºC (preceded by 30' to reach the temperature), and the final steps of re-taking all the measurements and prepare each sample for its final storage. During the carbonization process and in order to secure the anoxic conditions each sample was wrapped in aluminum foil. The last phase is up to be completed, which consists of the incorporation of these samples into the already existing reference collection, the extraction of thin sections from the green branches and taking the photographs of the three sections under the Scanning Electron Microscope. The samples, due to lack of time, were not let drying in a heater prior to the pyrolysis; instead, they were laid out of the bags over a table for over a week and let to dry up to the atmospheric humidity.

This last phase that remains unconcluded – mainly due to lack of time – comprehends preparing for observation the non-carbonized material. This is one step that we do not want to miss and fulfil since the carbonized and non-carbonized materials allow the observation of different elements or alterations. Some authors (Newsom, 2022) have warned against the exclusive use of carbonized reference material after they only tend to feature one or a few specimens of each taxon, not representing the range of ecological and functional variation associated. Also, because the process of carbonization causes several distortions, with extensive literature documenting and quantifying problems with the distortions caused in the cell structure (i.e., McGines *et al.*, 1971; Prior & Alvin, 1986; Prior &

Gasson, 1993; Gerards *et al.*, 2007; Dias Leme *et al.*, 2010; Gonçalves *et al.*, 2012; Gasson *et al.,* 2017). For us, even if we agree with these propositions, we believe that it is necessary to have a broad knowledge on wood anatomy and on how the tissues react to different alterations and elements in order to understand and correctly identify the changes. Moreover, it must be said that in the end and through the taxonomical and taphonomical identification process this reference collection was scantly used because almost none of the taxa were in the assemblage, and the most common one could not be retrieved from the area. Anyway, it remains an interesting source of comparisons for future works on the site of El Salt or the mountainous regions of the Mediterranean façade.

Nº.	**SPECIES**	**FAMILY**	**COMMON NAME (SPANISH)**	**OBSERVATIONS**
1.1.	*Pistacia terebinthus*	Anacardiaceae	Lentisco	
2.1.	*Pinus pinaster*	Pinaceae	Pino resinero	
2.3.				Bark
3.1.	*Juniperus phoenicea*	Cupressaceae	Sabina negral	
4.1.	*Juniperus oxycedrus*	Cupressaceae	Enebro	
5.1.	*Quercus coccifera*	Fagaceae	Coscoja	
6.1.	*Quercus ilex*	Fagaceae	Encina; carrasca	Some leaves
6.3.				Dry + liquen
6.5.				Bark
7.1.	*Pinus halepensis*	Pinaceae	Pino carrasco	
8.1.	*Ulex spp.*	Fabaceae	Género de los tojos	
9.1.	*Prunus armeniaca; dulcis*	Rosaceae	Albaricoque; almendron	
10.1.	*Ficus carica*	Moraceae	Higuera	Seasoned
11.1.	*Salix atrocinerea*	Salicaceae	Bardaguera; sarga negra	
12.1.	*Populus tremula*	Salicaceae	Álamo temblón	
13.1.	*Populus alba*	Salicaceae	Chopo; álamo negro	
17.1.	*Ulmus minor*	Ulmaceae	Olmo	
17.2.				With leaves
18.1.	*Olaea europaea*	Oleaceae	Acebuche	
19.1.	*Quercus faginea*	Fagaceae	Quejigo	
20.1.	*Ulmus laevis*	Ulmaceae	Olmo blanco	
21.1.	*Taxus baccata*	Taxaceae	Tejo	With leaves

Table 2 The resulting reference collection species list, with the provisional coding. The missing numbers were given to non-woody material.

4.3. Methodology

4.3.1. Method for material retrieval: flotation

The retrieval of the wood charcoal fragments from the sediments begins with the sampling method decided on: hand-picking the fragments while excavating, manual dry/wet-sieving or flotation. The method chosen will affect the diversity and reliability of the assemblage (Allué *et al.*, 2002; Chrzazvez *et al.*, 2014; Vidal-Matutano, 2017; Vidal-Matutano *et al.*, 2015), so it is important to establish a well-defined methodological approach to obtain an accurate image of local vegetation (Chabal *et al.,* 1999; Badal, 1992; Vernet, 1997). Nowadays, flotation techniques are one of the most common methods to retrieve carbonized plant macroremains in archeological contexts (Pearsall, 2000; White & Shelton, 2014) since they allow the systematic processing of large amounts of sediment in relatively short time, with fairly inexpensive materials (Arranz-Otaegui, 2017). The principle behind the method is that the density from the botanical remains is inferior to that of water, so when the sediment is submerged in water the carbonized elements rise to the surface.

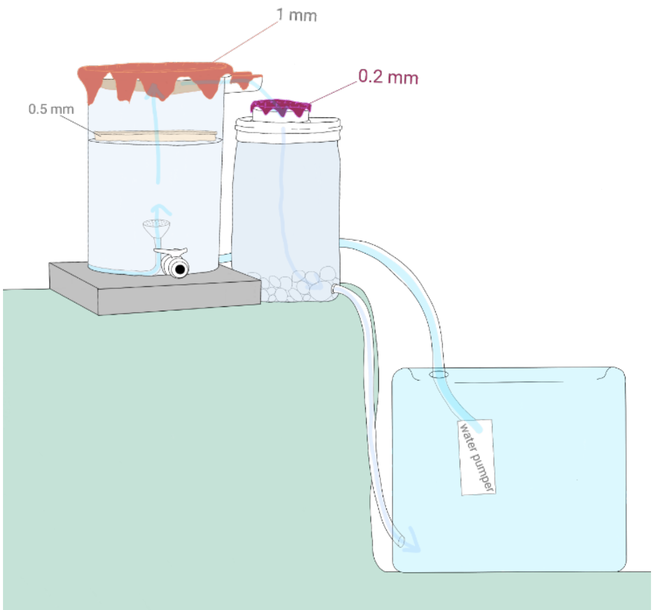


Figure 3 Schema of the flotation system with a siraf-type machine. The sieves measurements are within.

For this work the flotation was done with a siraf-type machine (Figure 3), which recycles the water in a close circuit with the aid of a pump. It was cleaned weekly. Built from a large container of 220 l, a showerhead is attached at the bottom pointing towards the upper part, which will be the water and air pumping source. At the top, a column of sieves retrieves the sediment that later will be processed for micro mammal remains. The floating particles are channeled through a half-cut pipe out to another mesh-screen, which is left to dry in a shaded area. The recovered material later will be selected and analyzed.

Regarding the possible over-fractioning of the material there are two main causes. First, all the sediment goes into the flotation machine. Second, for the more difficult excavation areas like those full of combustion structures the sediment is retrieved using vacuum cleaners. When using a water method for recovery, it has been stated that through flotation the materials re-fragment less than when compared with manual water-sieving (Chabal, 1989). Despite the benefits of water-sieving, some authors have warned about the potential under-representation of some species or remains after they had partially or completely disintegrated during the water recovery process (Wagner, 1988), and even the possible over-representation of alterations like vitrification (Arranz-Otaegui, 2017).

Even if mechanical flotation is advised as one of the best methods for wood charcoal and carpology recovery, some authors have highlighted that not all plant macroremains tolerate the water sieving process, they are too friable and split open or even completely disintegrating when getting in contact with water (Wagner, 1988). The samples that suffer this the most are coming from arid or semi-arid areas, as well as the ones that were in very bad condition due to preservation or to the wood phenological state before burning. This has been seen in archeological assemblages and checked with experimental works like that of Arranz-Otaegui (2017), where there was a reduction in frequency of decay alterations (i.e., presence of cell weakness, boreholes, hyphae, cell morphology deformation) after the flotation process. The state of the fragments makes them more susceptible to damage due to water processing, which can lead to the underrepresentation of these alterations in assemblages recovered with flotation. Another representation bias was recorded through those experiments, and it relates to the over-representation of vitrified fragments since the alteration itself made them more resistant to water.

4.3.2. Sampling strategy, taxonomical richness and invested effort

Once the floated fraction was retrieved, it was brought into the laboratory, correctly labelled into individual small bags, and with the same information on their label as it was written down in the sediment bags: site, archeological level, facies, square, subsquare, date, and litres/weight in kg. Once there, we screened the samples with two sieves of 4mm and 2mm and the aid of the binocular loupe and tweezers, hand picking all the specimens and counting them, to have an overall idea of the bulk of material to be analyzed (Figure 4). Originally, the

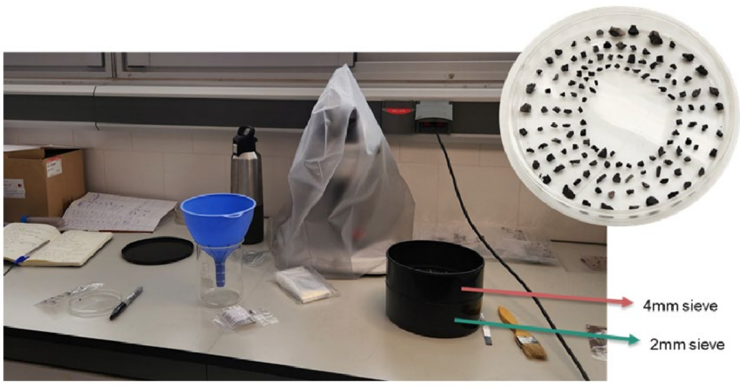


Figure 4 Photograph of the laboratory selection process, with the binocular loupe and the sieving meshes, and a detail photograph of the fragments recovered and counted from one sample.

4mm sieve was determined as the minimum sample-size (on its longest axis, which was not always the cross section), but due to some samples fracturing after being retrieved and also the recovery of the 4-2mm fraction when there was too little or no charcoal in the upper classes, the minimum size ended up being 2mm.

For this study only the specimens from the coarser subsamples were taken into consideration (until the 2mm). We decided on this for different reasons, all of them related to each other. The two main ones go side by side, which are my little experience on analysing big assemblages like this and the increased difficulties on the identification process once you go into the fraction of under the 2mm. Also, there are authors defending that there is no need to go to the smaller size fractions to find the 'rare' taxa (Kabukcu & Chabal, 2021).

It was decided to analyze all the fragments above the 2mm mark. With the purpose to test if this was worth it with relation of time and effort put, for what the floristic saturation curve stabilization is essential (Figure 8). This graphic representation is derived from the work of several authors who observed that through the identification process, the taxonomic recovery follows an exponential curve: through the first charcoal specimens analyzed the taxa variability increases quickly, and as more specimens are analyzed less new taxa appear and it reaches a plateau, where only the rare taxa remain (Chabal *et al.,*1999; Kabukcu, 2018; Smart & Hoffman, 1988). Overall, for Paleolithic assemblages in European contexts taxa diversity is limited following the type of vegetation available and the exploitation strategies for short-term occupations (Allué *et al.*, 2018).

A lot has been written about the minimum number count needed to obtain an accurate representation of the assemblage (Asouti, 2003; Johannessen & Hastorf, 1990; Miller, 1985; O'Donnell, 2011; Thompson, 1994, 1999; Veal, 2009). For Paleolithic sites where charcoal remains can be scarce, their saturation curves tend to show that by the 100 sample count the curve can be stabilized (Uzquiano, 1997). What is usually followed in the west Mediterranean sites are the works of L. Chabal during the 80's and 90's (Chabal, 1982, 1988, 1992, 1997; Chabal *et al.*, 1999). She argued that the lower limit must be raised up to 250 samples per level, but the optimal fragment count would be about 400-500 per phase/layer. When for the whole layer/unit the identified specimens are under 80, the interpretation should be done with extreme caution (Kabukcu & Chabal, 2021).

Coming forward, we believe that some changes within the remains retrieval methodology would be of great interest. The mechanical water flotation is the best way to retrieve as much wood charcoal as we can, and the same goes for the use of vacuum cleaners. The problem with these methods is the potential over-fragmentation of the remains, and the over or underrepresentation of certain alterations (and potentially species) as we will explain. Also, this is not ideal when our main interest is to study the economical uses and implications of firewood, for which knowing that several fragments come from the same individual branch is of great interest. For these reasons, starting from the field campaign of 2025 as many fragments above 1cm will be coordinated as possible, not only for studying the alterations within the same fragment even if it breaks once recovered, but also to compare with what we have done in this work and look for any substantial changes, or even test spatial distribution problems.

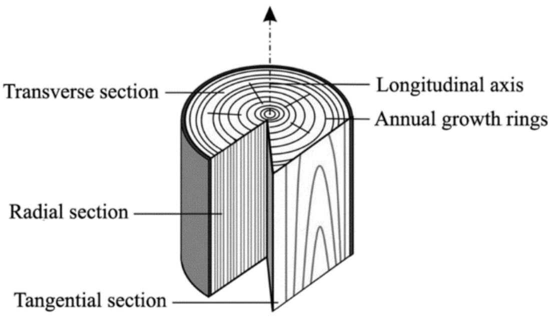


Figure 5 The three wood anatomical sections (from Geus et al., 2020).

The analyses came out of the observation of the three anatomical sections (Schweingruber, 1990) (Figure 5) through an optical microscope (Olympus BX41) using reflected light, bright and dark fields and the magnifications of x40, x100, x200 and x500. To hold the samples during microscope work, we put them in a tiny container filled with amaranth seeds, which make the work easier since they are small and fair in color, allowing for great support to the charcoal. All the process was done in the facilities available at the Institut Català de Paleoecologia Humana i Evolución Social (IPHES-CERCA). Later, when all the identifications were done, the images were obtained at the Servei de Recursos Científics i Tècnics de la Universidad Rovira i Virgili using an Environmental Scanning Electron Microscope (ESEM – Quanta 600 FEI Company). Images of the three anatomical sections of each species and alterations were taken from selected samples.

In order to prepare each sample for visual inspection, most of the individual specimens were hand-snapped before observation to expose clean, clear surfaces of each of the three anatomical planes. But not all of them were fractured, due to their small size and/or their friable and soft condition, a decision that was taken to enhance the possibility of analysing the smallest ones. The three anatomical sections are: cross section (or transversal), tangential and radial section (Figure 5). Analysis always starts from the cross section, which is perpendicular to the fibre direction, and discriminates between gymnosperms and angiosperms, which have different anatomical composition and terminology (see a resume of the essential diagnostic traits in Salavert, 2024). This is the referential one for various kinds of analyzes like dendroanthracology, Alteration Levels (Henry & Théry-Parisot, 2014) or postdepositional taphonomy. The longitudinal sections are the tangential and radial, which are perpendicular to the cross section and regarding the plant functioning, they connect the tissues internally. The information from these sections adds diagnostic information from its anatomical structure and taphonomically, the presence of fungi is often registered here.

Since most of this assemblage is composed by gymnosperms, we would take special interest describing its anatomy and particular features. Softwood, or gymnosperm wood has relatively homogeneous structure, which consists of mostly traqueids with uniseriate xylem rays. The traqueids serve the purposes of mechanical support and water conduction (Schwarze, 2007), both relevant from the taphonomical point of view. It is also of interest to briefly explain the internal layers of the wood cell-wall: to the thin primary wall is attached a secondary one, much thicker and compound by three layers (S1, S2 and S3). The bonding of adjacent cells occurs through the middle lamella, which consists of lignin, calcium and pectic substances (Schwarze, 2007). Regarding its chemical composition, generally gymnosperm wood presents higher content of lignin, consisting almost exclusively of guaiacyl monomers (Schwarze, 2007). The S2 has a particular high concentration of this guaiacyl units, making them particularly resistant to fungi causing various decay types (Blanchette *et al.,* 1988; Faix *et al.*, 1985; Nilsson *et al.*, 1989).

The identification of the specimens was carried out applying standard anthracological techniques (Chabal *et al.*, 1999), and with the terminology of Tutin *et al.*, (1964), except for the *Salvia rosmarinus* (formerly known as *Rosmarinus officinalis*) (Drew *et al.*, 2017). For the recognition of the sections and the traits in them it was used specialized atlas on wood anatomy (Schweingruber, 1990) as well as the direct comparison with the reference collection. Detailed in the previous section, a specific reference collection was created with the aim of this and future studies of the site, but not all the species retrieved and analyzed are represented on it. For those, we resorted to the reference collection existing at the archaeobotany lab at IPHES-CERCA, where there were already existing samples.

Every charcoal identified corresponds to one taxon, indiscriminately from the level of identification reached. The anthracoanalysis gathers the different categories defined: genus, family, species (sp.) or type. When it is not clear between two species or family, we opted for a category that comprises both, like Lamiaceae (cf. *Salvia rosmarinus*). Alike this case, when we could not reach the end of the identification process due to severe alteration of some anatomical traits, we placed '*cf.*'. When the identification was impossible, the fragments were designated as '*Unidentified*', and when only the genus Gymnosperm or Angiosperm was reached, it was named as '*Gymnosperm/Angiosperm unidentified*'. There is one particular taxon named *Group 1 (Angiosperm undetermined),* under which we grouped the specimens with the same anatomical traits, insufficient to reach an identification but diagnostic enough to group them.

The case with the *Pinus* fragments is slightly different, and they were grouped into the taxa *Pinus nigra-sylvestris* following the previous works of Vidal-Matutano (2017). On an anatomical basis *Pinus sylvestris, Pinus nigra* spp. *salzmannii* and *Pinus uncinata* cannot be differentiated (Schweingruber, 1990), and all of them are cryophilous pines. There had been attempts to discriminate them through different elements: the position of the resin channels (Bazile-Robert, 1979; Heinz *et al.,* 1988), the thickness of the growth rings (Heinz, 1990), the morphology of the cross-fields (Badal, 1984; Ros, 1985; Figueiral, 1987), the morphology of the pits (Chabal, 1991) (see also Roig *et al.,* 1997, for specific metric issues on *Pinus nigra*). The *Pinus* sp. category was used when *P. nigra-sylvestris* type features were not observed, such as windows-like punctuations. In most of the cases this was due to the size of the charcoal piece or because their structure was altered. Anyway, the most probable case is that these pines pertain to the same taxa rather than other pine species.

Further, the statistical analyses were done using the free software Past4.15. The graphics were mostly done with the same software. For the specific accumulative anthracological figures (Figure 26 and 28) the free software Tilia 3.0.3. was used. When needed and to obtain higher resolution, the free software InkScape was the tool applied.

4.4. Taphonomical analyses

The term *taphonomy* was first used by Efremov (1940) and it refers to all the processes occurring from the moment of death of an organism up until its fossilization. The definition for archaeology is wide since it does not only include the natural processes modifying the thanatocenose, but also all the cultural decisions and actions which impact on the materials (vegetal, animal or human) and their natural environment up to their fossilization (Théry-Parisot *et al.*, 2010). The taphonomical studies of wood charcoal remains are done observing the micro- and macroanatomical features of the ligneous cellular structure. The affecting factors are various, intrinsic and extrinsic to wood growth, and may take place during the initial growing conditions, due to human selection, transformation/use and discard, the postdepositional processes and even due to archeological sampling strategies (Vidal-Matutano *et al.*, 2020).

Even though the interest on taphonomical processes and cell-structure alteration comes from the early systematic charcoal analysis (Vernet, 1992; Thiébault, 2002; Badal, 2004; Fiorentino & Magri, 2008), over the last two decades anthracology has given more attention to this aspect (Badal *et al.,* 2012b; Damblon, 2013; Dotte-Sarout *et al.*, 2015; Ludemann & Nelle, 2017; Théry-Parisot *et al.*, 2010; Kabucku, 2018; Vidal-Matutano *et al*., 2020). Out of these works and new methodological proposals for the study of microanatomical features on charcoal, it can be differentiated two main streams depending on their aim: to identify firewood management through a systemic interpretative methodology, or to identify features related to woodland management and paleoecological reconstruction (references in Vidal-Matutano *et al.*, 2020). The charcoal cell structure alterations have been the main focus on these studies to identify the different markers (Allué, 2002a, 2002b; Henry & Théry-Parisot, 2014; Théry-Parisot, 2001, 2002; Théry-Parisot *et al.*, 2010).

The alterations and the preservation state of the fragments were some of the several factors impacting on the accuracy of the botanical identification, conditioning the ranks up to where it was possible to identify species, genus, groups or types. Frequent alterations such as the cell collapse, may have several causal conditions: the state of the wood, the combustion processes or even the tree growth (Schweingruber, 1978; Théry-Parisot, 1998). The characterisation and typification of these alterations is with the aim to identify commonly states of the wood: decayed, green or healthy (Marguerie & Hunot, 2007; Théry-Parisot & Henry, 2012; Henry & Théry-Parisot, 2014). When an assemblage is dominated by wood charcoal remains of healthy appearance, without alterations, it has been related to the exploitation of green wood or to the groups' capacity to dry the wood in optimal conditions (Arranz-Otaegui, 2017). In experimental works it has been corroborated that standing dead wood directly collected in the forest displayed greater alteration patterns (Henry & Théry-Parisot, 2014).

The modifications on the wood anatomical structure may happen due to intrinsic or extrinsic stress elements during all the live stages of trees and shrubs, from natural factors or human activities (Dufraisse, 2006; Limier *et al.*, 2018; Schweingruber, 2007; Terral, 2000). Their identification sheds light on woodland management's practices and environmental impact on woody plants. These processes can be grouped into two categories: biological ones affecting the anatomical structure of the woody parts, conditioning the selection (i.e., Allué *et al.*, 2009a; Carrión & Badal, 2004; Dufraisse & García-Martínez, 2011; Théry-Parisot, 1998, 2001; Théry-Parisot & Henry, 2012), or mechanical forces that increase fragmentation and charcoal dispersion (Chrzavzez, 2013; Chrzavzez *et al.*, 2014; Lancelotti, 2010; Piqué, 1999b; Théry-Parisot, 1998; Théry-Parisot *et al.*, 2010; Vidal-Matutano *et al.*, 2017).

One main key to understanding the taphonomical processes suffered by this assemblage is to discriminate its origins: biological, from combustion processes (mostly linked with human selection) or postdepositional. Biological alterations refer to the presence and attack of fungi or insects and to the modifications appearing due to ecological and climatic stress during its growth (Schweingruber *et al.*, 2006; Théry-Parisot *et al.*, 2010). Even so, it must be highlighted the problems of equifinality of how some of these alterations are displayed on the wood charcoal fragments (i.e., cell collapse). The combustion process is the main alteration event that we have when studying wood charcoal assemblages, but the alterations produced during it are not well known or defined, or they can resemble other mechanical or biological ones (i.e., cell collapse). The mechanisms conditioning are the ones of carbonization, transforming and altering the internal cellular structure and morphology of wood.

Regarding the postdepositional processes, which are for the most part of mechanical origin, they can affect fragmentation, charcoal dispersion and the cell-structure modification, as the aftermath of water presence, roots, freeze/thaw or even sedimentary pressure (Chrzazvez *et al.,* 2014; Rodríguez-Ariza, 1993). One frequently observed in limestone/travertine contexts is mineralization and carbonate depositions, which tend to create a coating over the charcoal. It is mainly caused by the introduction of water into the cells, altering its structure by depositing diverse minerals (Allué *et al.*, 2009). In any case, and as it was discussed earlier, we must not forget that fragmentation can be also caused by the selected recovery method and the possible biases that it implements (Arranz-Otaegui, 2017; Chrzazvez *et al.*, 2014).

Since there is a clear dominance of *Pinus nigra-sylvestris* (87.9%) in the assemblage, it was decided to base the taphonomy study on its observations, since the characterization of the cell-structure modifications allows for a better classification of the alterations. Anyway, when considered of interest, other taxa may be reviewed. The following alterations were reviewed in the El Salt assemblage whose definition is based on specific methodologies.

4.4.1. Alteration Levels (A.L)

Out of the taphonomical issues, the identification of decayed wood has been considered in several Middle Paleolithic sites, such as Abri Pataud, La Combette and Abri Castanet in France (Théry-Parisot, 2001; Théry-Parisot & Texier, 2006), Abric Romaní (Allué *et al.*, 2017a; Fernández-Iriarte, 2024), El Salt and Abric del Pastor (Vidal-Matutano *et al.*, 2015) in Spain, and Grotta di Fumane in Italy (Basile *et al.*, 2014; Peresani *et al.*, 2011). There had been attempts to carry on comparative analysis (Allué & Mas, 2020), but not without difficulties. Knowing the recurrence of these phenomena and that in previous levels decayed wood were suggested as being specially selected for smoking fires (Vidal-Matutano *et al.*, 2017), it was of our interest to analyze it in our assemblage and later on compare with the previous studied levels.

Alteration index values

Ai	Batch signal
< 0.15	Low values, healthy wood
0.2 – 0.34	Medium values, dead wood with mild alterations
> 0.5	High values, rotten wood

Table 3 Alteration index (Ai) values and the interpretation of the macroscopical state of the wood for each group (from Henry & Théry-Parisot, 2014)

For the study of the materials coming from El Salt the applied methodology is based on the one developed by Henry & Théry-Parisot (2014) of the 'Alteration Levels' (A.L.) to assess the state of the wood. Since the cross section is the one where the fungal decay is most recognisable, this is the section chosen for the purpose of this methodology. It is important to note that the state of one single charcoal fragment cannot depict the overall state of the branch or the wood assemblage where it comes from. Four stages were defined by the authors: A.L. 0, with no fungal signals. A.L. 1, low, concerning the incipient stages of fungal colonization. The A.L. 2 (medium) and 3 (high) refer to the more advanced structural cellular alterations (modifications of shape, deformations and cellular voids), establishing the difference between them on the spatial extension or the gravity on cellular deformation.

After studying the assemblage, with the results the Alteration index (*Ai*) is obtained: the addition of all the altered charcoals is multiplied by their respective alteration level, divided by a theoretical maximal A.L. of 3 on each fragment, and multiplied by the total number of fragments studied (Henry & Théry-Parisot, 2014):

$$Ai=((nA1*1 + nA2*2 + nA3*3)/nTOT*3)$$

Our main interest in applying this method is not only assessing the overall state of the wood assemblage, but to look for possible differences in the results between the combustion structures and the scattered assemblage, and even if they exist between facies. Also, as the authors of the work proposed, this is a wood proxy that through the correlation of microscopical to the macroscopical state of the wood allows to assess firewood gathering strategies: the higher the *Ai* appears, the greater the probability of advanced decayed wood within the vicinity, with the focus located on fallen dead wood (Henry & Théry-Parisot, 2014).

4.4.2. Dendrotypology: growth ring curvature

Despite the several problems and difficult applications that the dendrological methodology supposes for Paleolithic contexts, some interest was still on this approximation. As it was described in previous chapters, the charcoal sizes were so small that it would not have been possible to obtain a good and reliable measurement or a possible pit-distance. The proposal for a minimum of 4mm x 4mm in the cross section (Dufraisse *et al.*, 2018) is above the measurements of almost all this fragments. Moreover, in most of the cases there were no more than one or two remaining growth rings in the cross section. Furthermore, the bad condition of the materials made particularly difficult the identification of the angiosperms, blurred the distinguishing line between early-late wood and even the growth rings morphology.

Taking into account all these determinant factors, and since a dendrotypology study takes long time and it was not contemplated from the beginning, the following technique was decided on. The description and definition of the curvature was done into three categories: *straight, soft curve* or *pronounced curve.* This was only applied to the fragments identified as conifers, where it was easier to distinguish the growth rings and their curvature.

The aim behind the recollection of this data is to sum on the list of observations to characterize firewood collection strategies. Also, a high number of growth rings in *Pinus* sp. small sized cross sections is of interest since there had been proposals relating it with specific species or stress-related alterations.

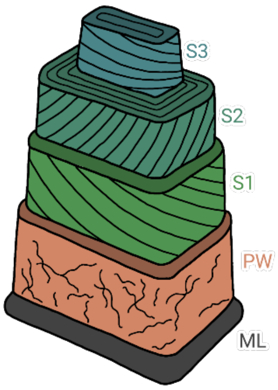
4.4.3. Reaction wood

While analyzing the assemblage, the presence and frequency of reaction wood in *Pinus nigra-sylvestris* specimens lead to its record for further analysis. What this term refers is to the formation of helical thickening-pattern inside and all through the traqueids (Figure ???) (Schweingruber, 1988) to provide further mechanical support when the deflection angle is greater than just a few degrees; to bring itself back to an upright position. Defined as a 'gravitropic mechanism' (Newsom, 2022), it is usually interpreted as 'posture control' (Beeckman, 2016) and associates with branches and leaning or crooked stems.

Even though it is not new within the archeological studies (Allué & Mas, 2020; Théry-Parisot *et al.*, 2010), frequently it appears under the name of *Tension wood*, which properly speaking associates to hardwoods, being the term *Compression wood* the one applied for softwoods. The differences between them concern the part where it forms: for angiosperms, the tension wood forms in the upper surfaces of the leaning members due to tensile stress (Evert, 2006), meanwhile, compression wood forms in the lower surfaces due to compression stress (Newsom, 2022). Anyway, in this work we will be using the broader term of *Reaction wood*. Another anomaly in the wood structure is that the faster growth of the lower part of the rings may end up with the branch having an elliptical outline (Bräuning *et al.*, 2016; Haygreen & Bowyer, 1996). For the opposed side of the ring, they tend to be much narrower, and this region is termed *opposite wood* (Haygreen & Bowyer, 1996).

The ecological and economic interest on measuring this phenomenon lays on its association with branches and leaning stems, which would verify their presence as firewood, and may be referring to sloppy terrain, heavy winds or prolonged periods of snow. The most recognizable pattern for the naked eye in tension wood is in the cross section, because of the marked eccentric growth rings and the off-center pith region (Newsom, 2022). In the Paleolithic assemblages, this element is hardly recognizable; at most, it could be inferred that a higher number of 'straight' growth-ring rays may be representing the later side of the branches. But, down to the anatomical scale, there are other changes and signs besides the already described helical thickening of the traqueids, which is developed into the S2

Figure 6 Conventional cell-wall model which distinguishes five cell-wall layers. These are the middle lamella (ML), the primary wall (PW), and the three-layer secondary wall (S): outer (S1), middle (S2) and inner secondary wall layer (S3). Edited from Schwarze (2007)



layer (Newsom, 2022) (Figure 6). This traqueids tend to be shorter and their outline is rounded, differently from the typical angular form (Barnett & Jeronimidis, 2003; Bräuning *et al.*, 2016). This circular shape leads to the appearance of intercellular spaces between individual traqueids, which can be noticeable. The S2 cell walls have been abnormally thickened, with increased lignin content and the spiral grooves, which are very visible in the tangential and radial sections, but also may be recognizable in the cross section when it is prominent. The S3 wall layer is usually missing (Newsom, 2022).

In order to record this alteration, three categories were created regarding the strength of the phenomena: 0 or 'no alteration', 1 for 'present' and 2 for 'pronounced'. The categories were defined in an attempt to retrieve more information about the ubiquity of the phenomena and to find out if it is statistically representative. To analyze them and try to define some tendency, the results were plotted with point-and-line graphs for comparison.

4.4.4. Thermoalteration or alterations related to the combustion process

The alterations related to combustion and carbonization may cause shrinkage, fragmentation and deformation of the wood's cell structure. They are mostly related to the previous phonological state of the wood (Knight, 2025; Rossen & Olson, 1985; Prior & Gasson, 1993; Slocum *et al.*, 1978; Loreau, 1994; Théry-Parisot & Henry, 2014) and can provide information on the assemblage soundness. The interest of this information relies on human recollection strategies and the potential bias this creates in the burnt firewood, as well as in the burning practices.

<u>Vitrification</u>

The phenomena designated within the anthracological record as vitrification is one widely referred and studied, with numerous authors experimenting and aiming to define its origin (Allué *et al.*, 2009; Courty *et al.*, 2012, 2020; Marguerie & Hunot, 2007; McParland *et al.*, 2010; Théry-Parisot, 2001; Vidal-Matutano *et al.*, 2020). Together with radial cracks, its causal factors are still unknown but are directly derived from the combustion (Braadbaart & Poole, 2008; McParland *et al.*, 2007, 2010; Prior & Alvin, 1983;

Schweingruber, 1990; Tardy, 1998; Théry-Parisot, 1998, 2001; Thinon, 1992). The diagnostic criterion is the fusion of the cells, turning the surface homogeneous and with glossy appearance and consistency (Allué *et al.*, 2009; Marguerie & Hunot, 2007; Scheel-Ybert, 1998; Théry-Parisot, 2001), where any anatomical element disappears.

Out of several propositions for its origin, there are two possible hypothesis which illustrate the lack of agreement. On one hand, Carrión (2005) suggested the lack of oxygen and low gas liberation during the combustion as the cause, which would release and accumulate certain substances on the wood cell structure surface, altering its morphology. On the other hand, we have authors like Scheel-Ybert (1998) or Py & Ancel, (2006) who argue that the presence of resins, or burning green wood, might be the cause. Most of the proposals revolve around the burning temperature and length of the combustion, some of them suggest temperatures above 800ºC, meanwhile others propose lower temperatures, between 310-530ºC (McParland *et al.*, 2010). Overall, it seems less ubiquitous in conifers than in angiosperms (Allué *et al.*, 2009) and some species tend to show more vitrified fragments than others (i.e., *Pistacia* ssp.; Allué, pers. com.), regarding all the archeological contexts studied, the ones of combustions in close environments (i.e., kilns, furnaces or peats) commonly offer the most vitrified fragments (Fabre, 1996; Scheel-Ybert, 1998).

In this study, an attempt to assess the representativeness of the phenomena was made by creating four categories: 0 or 'none', 1 or 'some/very shinny overall surface', 2 or 'localized glossy parts/thickening of the parenchyma walls and rounding of the quadrangular shapes' and 3 or 'overall glossy appearance, unidentifiable or at most to the softwood/hardwood level'. It was decided on this after observing the recurrence of the alteration but with different intensity levels. In order to compare facies or combustion structures/scattered assemblage the percentage values were plotted in point-and-line graphs to confront them.

Radial cracks

Another frequently recorded alteration in anthracological taphonomy studies are radial cracks identified in the cross section. Their presence has been generally attributed to water evaporation within the early stages of the combustion process (Caruso Fermé. *Et al.*, 2018). Following Zicherman (1981), they are produced after the thermic stress on the radius during the first states of the combustion process, by shrinking due to water evaporation (between 200-270ºC. For this reason, their appearance is often considered as an indicator of high moisture content in the wood before it was burned, and so, associated with the use of green wood (Scheel-Ybert, 1998). On the anatomical level, as with other combustion alterations, it produces the general deformation of the structure.

For this work its presence (1) or absence (0) was measured to have another proxy indicator of the phonological state of the wood before combustion, but it is not one that was given a prominent position.

4.4.5. Biological alterations: fungi, bacteria and insects

The presence of the different biological alterations like fungal hyphae or boreholes from xylophages represents decayed wood (Asouti & Austin, 2005; Badal, 2004; Carrión-Marco, 2005; Moskal-del Hoyo *et al.*, 2010; Théry-Parisot, 2001). Depending on the type of biological agent attacking the extension of the damage may be restricted and clearly defined, as for insects, or they can be spread through a bigger area, as with fungi (Gorczynski & Molki, 1969; Henry & Théry-Parisot, 2014; Pyle & Brown, 1999; Schweingruber, 1988, 2007; Vidal-Matutano *et al.*, 2019). Regarding these last ones, they may be seen locally or expanded through the wood cell structure, utterly modifying the traqueids, assessing the level of decay (Allué & Mas, 2020). The fungi usually attacking wood are hyphae: white mycelium of filaments that penetrate dead and living wood (Allué *et al.*, 2009), altering the carbohydrates structure (cellulose and hemicellulose) and/or lignin by mineralisation (Blanchette, 2000). When hyphae develop once the tree has died, it affects the parts without bark, and it usually happens when the temperatures are high, and the environment humidity is between 70 and 90% (Allué, 2009).

Even if it is difficult to differentiate the categories when studying wood charcoal, the tendency is for brown-rot to colonize gymnosperm wood, meanwhile white-rot attacks angiosperm wood. In some studies, conifers showing a sinuous aspect on the growth-rings, the deformation of the cell morphology and even the collapse of the cells when the deformation is extreme, had been associated with brown-rot (Blanchette, 2000; Moskal-del Hoyo *et al.*, 2010). The correlation between brown-rot and conifers matches the small number of species attacked and the predominantly northern distribution on these fungi, while the white-rots have a more tropical distribution (Schwarze, 2007; Watling, 1982). It is relevant to highlight that experimental studies have shown that fungi-degraded wood-charcoal are more susceptible to post-depositional mechanic damage (Théry-Parisot, 2001; Théry-Parisot *et al*., 2010).

4.5. Spatial analysis

Spatial analysis as a discipline was developed starting on the 1970s, which includes the novelty of developing analysis intra-site in archaeology, with the focus on the archeological spaces (Clarke, 1977). During its first moments the purpose was finding spatial patterns through bi-dimensional scatter points maps (Whallon, 1973). The quantitative analysis was brought in later with the *nearest neighbor* (Whallon 1974). In statistical and quantitative terms, the increase in the application of Geostatistics to archeological studies resulted in the application of Kernel densities (Weiss *et al*., 2004), based on the autocorrelation of continuous variables (Maximiano-Castillejo, 2012). It is essential to always remember that the application and results obtained from these studies on Paleolithic contexts are interpretative (Mas, 2018). There are software's that allow to integrate and analyze information associated with a specific geographic space and establishing relationships between different variables, as for Qgis (Graser, 2013). This software is one of the various Geographic Information Systems (SIG): informatics systems developed for the analysis and representation of geographically referenced information, aiding on the resolution of complex problems within a defined space (Church *et al*., 2000).

Within the anthracological discipline these studies intra-site did not become widespread, with the first work published in the nineties (Thiébault, 199~~5~~). More recent and extensive work on the matter and for the Iberian Peninsula was undertaken by Vidal-Matutano in this same site of El Salt (Vidal-Matutano, 2016; Vidal-Matutano *et al*., 2017). She focused the analysis on taxa clusters, with an interpretation of the results after the densities and concentrations. Another research on intra-site spatial analysis was by Mas (Mas, 2018; Mas & Allué, 2021), in this case for the Magdalenian site Molí del Salt (Tarragona, Cataluña). More recent work was undertaken by Fernández-Iriarte on his master thesis (Fernández-Iriarte, 2024), focusing on the Neanderthal site of Abric Romaní (Barcelona, Cataluña), a context and analysis pretty like the ones being presented here.

For the spatial intra-site analyzes of the anthracological assemblage the software Qgis (v. Prizren 3.34.11) was used. The archeological Unit is the unit taken for the analysis. The first step was to delimit the workspace and its coordinates, creating the archeological area where the data is coming from. Relative coordinates were given to the planimetry, but the combustion structures have their own referenced coordinates. This step was followed by the grid-square creation, with columns named after letters (C-Y) and rows by numbers (1-10). (Figure 7). To each square and subsquare the associated data was assigned (count number, taxa and further information from each fragment) extracted from the flotation process. Due to the nature of the recollection method, there are no specific coordinates for each fragment. To work with the materials, they were plotted randomly within their assigned subsquare.

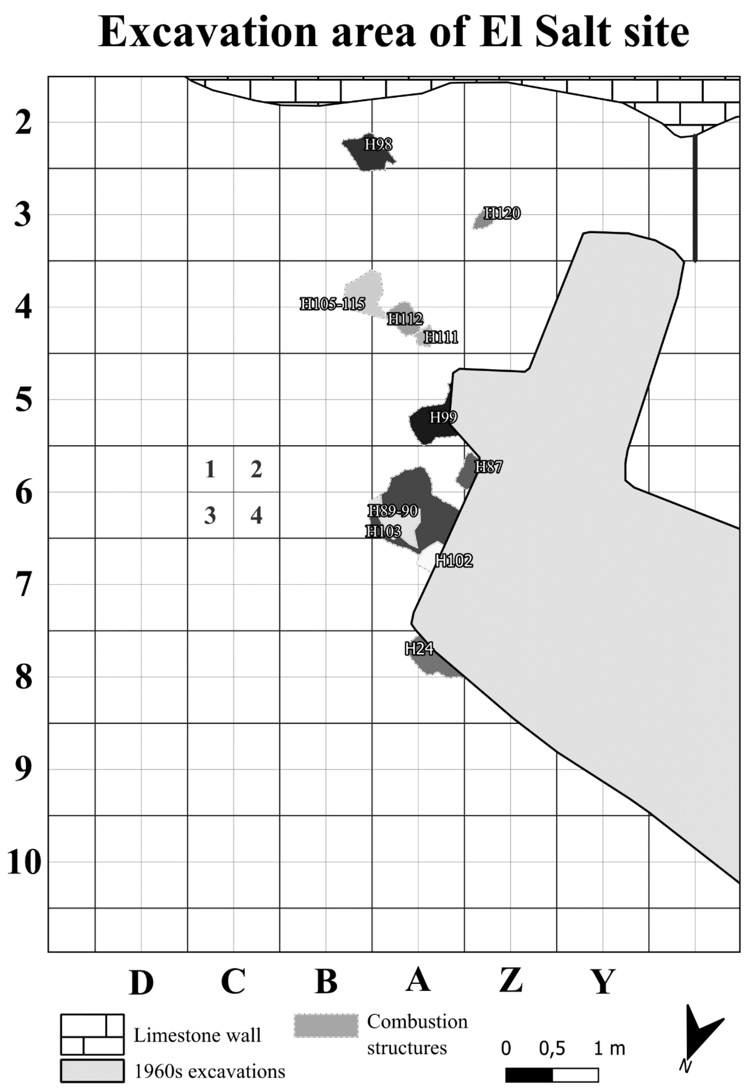


Figure 7 Excavation area of El Salt site comprised in this study, with the indications of how the subsquares are organized within each square. The combustion structures are also displayed.

Once the information was interconnected the complementary elements (the limestone wall, previous excavations alterations) were drawn into a vector layer. The same process was followed with the combustion structures, drawing the polygons on top of the point cloud from the delimiting points taken on site. With everything settled, the first analysis undertaken was the density distribution (Figure 15). It was done by counting the number of repeated entries on each square, linking one entry to one fragment. This was applied to squares (Figure 15a) and subsquares (Figure 15b) due to the different resolutions offered.

To actually see the representation of each fragment the point cloud was the source to resort to. With this information, where the given point of each fragment must be remembered that was randomly assigned by the software, analysis on the types of clustering and their conditionings (presence of combustion structures, different behavior by taxa) was done. For the first part, the analysis on the specific distribution taxa by taxa (Figures 17 to 23) was undertaken. With these same elements the fragments over 1cm were discriminated and represented in one map (Figure 23a) Since this under 1cm measurements uptake most of the assemblage studied (ca.96%), it was considered of interest to pay special attention and apply other analysis to those identified fragments above the centimetre threshold. Equally was done with the fragments identified as vitrified (Figure 23b)

Besides, other two representations of the data were desirable. In direct connection with the first density distribution map, it was considered of interest the representation of a pie chart into each square for a quicker visualization of the dispersal by square of the species and their proportions. It was decided to leave out all the *No charcoal* and *Unidentified* classes, but to plot all the identified arboreal taxa because the main aim was to check the dispersion of those 'rare' taxa. The possibility of only representing the two or three most frequent taxa was pushed aside because the second, *Acer* sp., is only 2.53%, and it would not be representative. Also, because the results from the single species distributions showed spatial particularities for some of them, one being *Acer* sp. Like that, the main visual representation desired with this graphical element was the floristic richness dispersal and accumulation.

The last of the analysis was through the creation of a heat map, which indeed is the representation of Kernel densities distribution (Figure 16). This was done starting from the point cloud. The distribution follows the number of entries of each square and subsquare, being plotted from the central point instead of taking each randomly plotted fragment as the centre. Preference of one method over the other was decided to try avoiding the bias created by the artificial random plotting.

4.6. The anthracological assemblage

The wood charcoal assemblage in this study reviewed from combustion structures is coming from the hearths: H87, H89-90, H98, H99, H102, H103, H105-115, H111, H112, H120, H124, H126. The great majority of the combustion structures here studied follow the techno-functional schema of flat hearths laid over the living floor, the most frequent ones at El Salt and Eurasian Middle Paleolithic contexts. The particularity arises in the *Area C* (B4 and A4), where the successive hearths show particular morphology and traits.

- H112 (UE XI) has been defined as a possible 'pit hearth', with the identification of this alleged pit after the concave morphology of the BL. On top of it there was a thick deposit of ashes well preserved. The BL has an erosive lower contact, cutting through a series of simple-flat hearths, which is what led to the adscription of its origin as anthropic. Altogether with this structure there are two small circular holes filled with brown sediment like that of UE Xb.
- H96 (UE Xb-roof XI) has been described as a possible hearth delimited by limestone pebbles and travertine slabs. This simple, flat and circular combustion structure is on top of the *Area C* set and only the BL remains, with few patches of ashes. Out of the possible stones surrounding it, one is drove and shows partial thermoalteration signs. In other one of them it was found the mark of a black residue, possible from a liquid deposition.

The remaining combustion structures follow the model of simple flat hearths. Their structure and information are resumed in the following Table 4.

Combustion structures Unit XI

Hearth number	Layers	Area	Grid squares
H87	WL + BL	F	A6; Z6
H89-90	WL + BL	G	A6
H98	WL + BL	A	B2
H99	WL + BL	E	A5
H102	BL	G	A7
H103	BL	G	A7
H105-115	BL	C	B4
H111	WL + BL	C	A4
H120	BL	B	Z3
H124	BL	-	A8
H126	BL	-	A6

Table 3 Information of the combustion structures comprised in this study. When introduced on the matrix, the accumulation area is also signaled. In orange are the ones chosen for further analysis.

Out of all of the combustion structures, for this work we will be focusing on H120 and H105-115 (colored in salmon in Table 4), since they are the only ones with more than 50 fragments retrieved and the interpretations reached are more reliable than for any of the others, where none has more than 10 identified fragments between both the WL and BL.

Besides these concentrations and primary assemblages, there is also all the wood charcoal coming from the scattered assemblage. The facies from which these fragments were recovered are: La13, La14, La15, La16, B1-3, Lm1-3, Lm2 and Lm3. All of them have been defined on Chapter 3.2. and correspond to the contextual sediment from the aforementioned combustion structures of Unit XI.

5. RESULTS

5.1. Anthracological results

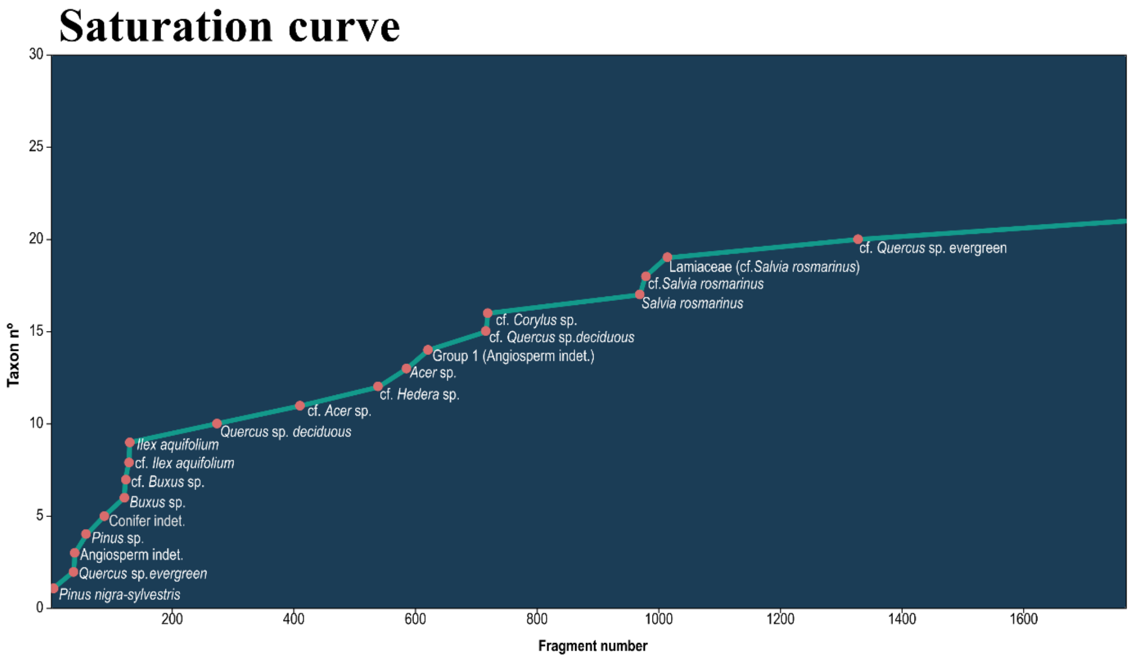


Figure 8 Floristic saturation curve. Accumulation of the taxa from Unit XI.

There are a total of 1769 wood charcoal fragments. Out of them, 85.02% were concluded to be wood charcoal, reaching the taxonomical level of identification during analysis. The remaining percentage, 7.24% falls under the category of '*Unidentified*', and what is left, that 7.69% could not even be discriminated as wood charcoal, resembling in appearance that of trabecular burnt bone.

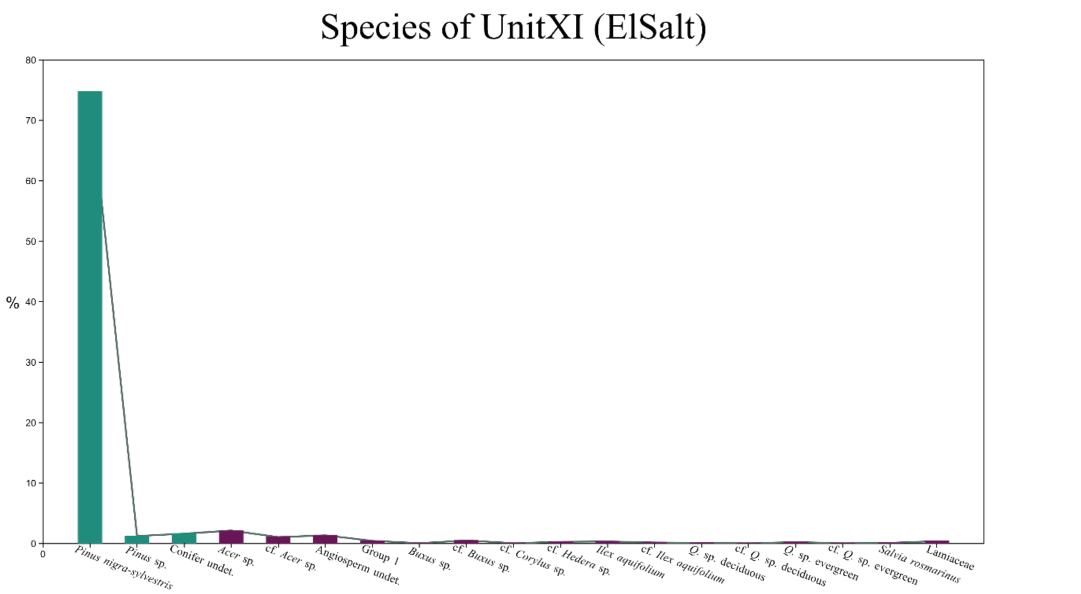


Figure 9 Bars graph with all the species identified in Unit XI in relative units. The percentage total is after all the fragments analyzed (see Table 5 for the absolute values).

Taxons	n	%
Pinus nigra-sylvestris	1322	74.73
Acer sp.	38	2.15
Buxus sp.	1	0.06
cf. *Corylus* sp.	1	0.06
cf. *Hedera* sp.	5	0.28
Ilex aquifolium	6	0.17
Quercus sp. deciduous	2	0.11
Quercus sp. evergreen	4	0.23
Salvia rosmarinus	2	0.11
Total taxons	**9**	
Pinus sp.	22	1.24
cf. *Acer* sp.	19	1.07
Group 1 (angiosperm undet.)	8	0.45
cf. *Buxus* sp.	9	0.51
cf. *Ilex aquifolium*	3	0.17
cf. *Quercus* sp. deciduous	1	0.06
cf. *Quercus* sp. evergreen	1	0.06
Lamiaceae (cf. Salvia rosmarinus)	7	0.40
Total determinable	**1504**	
Undetermined	128	7.24
Conifer undet.	29	1.64
Angiosperm undet.	24	1.36
No charcoal	136	7.69
Total fragments	**1769**	**100**

Table 4 Results of the anthracological analysis of Unit XI from El Salt, expressed in absolute frequencies (n) and relatives (%).

Taking into consideration all the species recovered and counted on the assemblage, gymnosperms (or softwood) account for 91.29% of the total, being the remaining 8.71% the angiosperms (or hardwood).

It has been stated in the literature that the specimens analyzed must be over 2mm in the cross section to ensure enough surface for reliable observation of anatomical details in their spatial position, for greater accuracy of taxonomic assignment (Asouti & Austin, 2005). The cross section sometimes did not exceed 1mm, causing difficulties on the identification process due to the lack of some keys. This happened mostly with *Pinus* sp. charcoals, which followed the same fracture pattern and tended towards the same morphology: very light-weighed, thin cross and radial sections and elongated tangential section. The thinning of the cross and radial sections hindered the identification process and the possibility to reach the species level since some of the most relevant keys are found within those sections.

5.2. Floristic list

The identifications were based on Schweingruber (1990), which is the manual for the eurosiberian species. Further ecological and the nowadays distribution maps of the species in the Iberian Peninsula are taken from Arbolapp (CSIC/FECYT) and Flora Ibérica, where most of the illustrations are coming. In the cases where more than one species could possibly be, but through their anatomy those are indistinguishable, it is explained. The nomenclature decided on is also clarified.

5.2.1. Pinus nigra-sylvestris

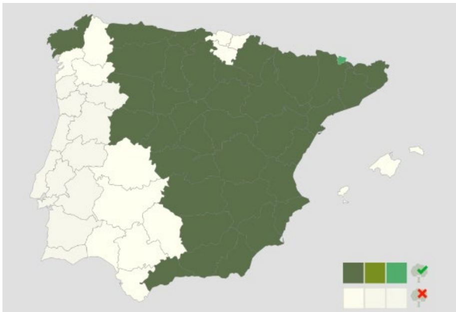
GYMNOSPERMAE

Class	Pinopsida
Family	Pinaceae
Genre	*Pinus*
Species	*Pinus nigra spp. Salzmanii, Pinus sylvestris, Pinus uncinata*

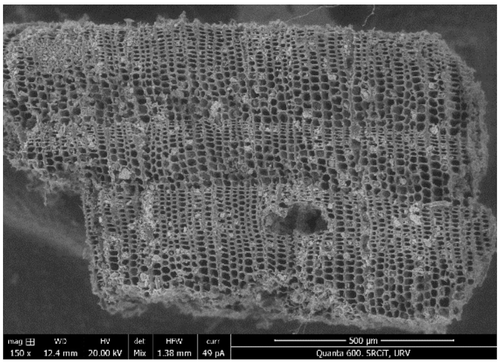
Total count: 1344

Percentage: 89.36%

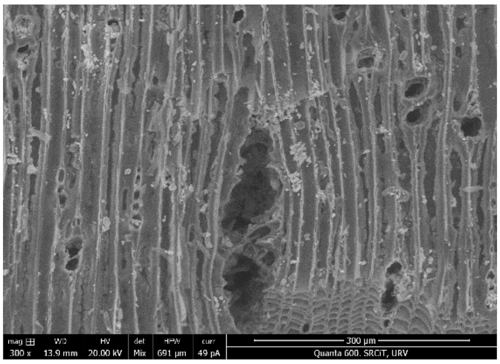
(a)



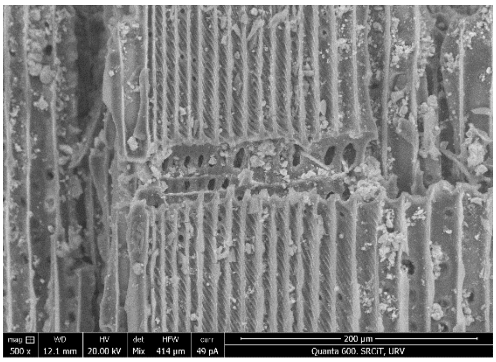
(b)



(c)



(d)



Composition 1 (a) nowadays distribution of P. nigra; (b) cross section; (c) tangential section; (d) radial section

- **Cross section**: homoxilous wood, with ubiquitous axial and radial resin channels, mostly located in the LW. Abrupt transition between early wood and late wood, with well-defined growth-rings.
- **Longitudinal tangential section**: heterogeneous radius, uni- and multiseriated, but in the case of transversal resin channels they are bi-seriated. Ray height goes between 1 and 12 cells, being the most frequent the 5-11 cell range (Postigo-Mijarra *et al.*, 2017).
- **Longitudinal radial section**: it is not possible to distinguish the cryophilous pines from Iberia (*Pinus nigra* sp. *salzmanii, Pinus sylvestris, Pinus uncinata*) based on their anatomical structure (Caracaillet & Vernet, 2001; Schweingruber, 1990). All of them show window-like punctuations in the cross-fields and dentated walls in the horizontal traqueids.

Following the previous studies of the site and in the area, it was decided to keep naming the taxa as *Pinus nigra-sylvestris*. Only when, due to the small size of the fragment or to high alteration levels it was not possible to properly distinguish these diagnostic traits, the term *Pinus* sp. was regarded as the best.

The *Pinus* type *sylvestris* is all over from the northeast and northwest of the Iberian Peninsula up to the north of Siberia, reaching altitudes of 2600 m.a.s.l. In the Iberian Peninsula it tends to be distributed on the mountains, between 600-1800 m.a.s.l., but it can exceed those altitudes (like in the Vall d'Aràn, Lleida) (Galán *et al.*, 1998). This species tends to make up for the main forestry mass, even though it also grows well with other species such as *Pinus uncinata, Pinus nigra, Abies alba Mill., Fagus sylvatica L., Quercus pyrenaica Wild.* And *Quercus petraea*. It has great resistance to low temperatures, frosts and snows. It cannot bear with excessive heat and requires partial shadow areas. It grows in siliceous and clayey soils, usually poor in nutrients and with little moisture (San-Miguel-Ayanz *et al.*, 2016).

On the other hand, *Pinus nigra spp. salzmanii* grows on a greater range of edaphic contexts: from limestone soils, dolomitic serpentines and chalky soils (San-Miguel-Ayanz *et al.*, 2016). From 500 to 1000 m.a.s.l., it is a submediterranean and continental species, which is in the mountains of the Mediterranean mountain region.

Pinus uncinata is the species out of the three growing at higher altitudes (starting at 1400 m.a.s.l.), resistant to cold environments and the best adapted to all type of rocky soils, low on nutrients and lacking nitrogen (San-Miguel-Ayanz *et al.*, 2016).

5.2.2. Acer sp.

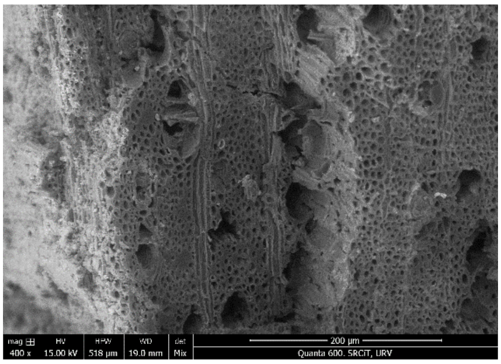
ANGIOSPERMAE

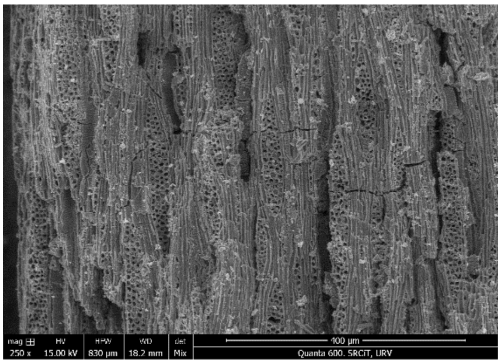
Class	Magnoliopsida
Family	Aceraceae
Genre	*Acer*
Species	*Acer campestre L., Acer monspessulanum L., Acer opalus Mill, Acer platanoides L., Acer pseudoplatanoides, Acer pseudoplatanus*

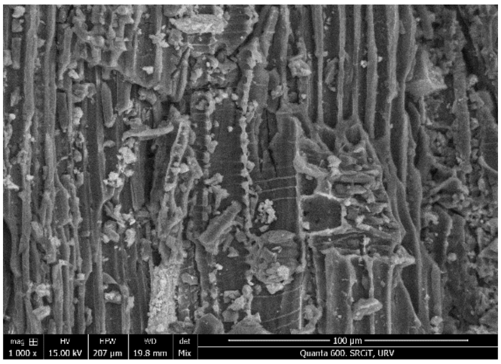
Total count: 57

Percentage: 3.79%

(a)


(b)


(c)


(d)


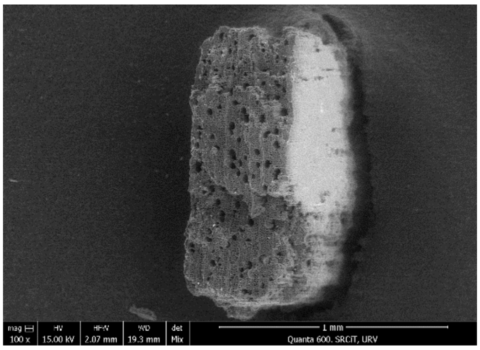
Composition 2 (a) current distribution of Acer campestre; (b) cross section; (c) tangential section; (d) radial section

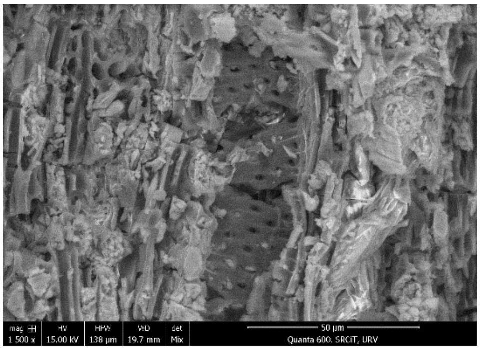
- **Cross section**: diffuse wood, with porous distributed isolated or grouped in radial rows of 2 to 6. Their morphology is rounded or with a polygonal tendency. The limits of the growth rings are clear, and the parenquima is diffuse.
- **Longitudinal tangential section**: multiseriated rays, even if some uni- or bi-seriate rays can be seen. For some authors the count on the cell's width and the shape of the cells on the extremes is the more reliable criteria to distinguish between species (see Alcolea, 2017). Other authors like Heinz (1990) or Allué (2002) classified the genre on three types depending on the ray length.
- **Longitudinal radial section**: homogeneous rays. Thin spiral thickening and simple perforation in all the vases. The fibers are libriform in morphology and there is the presence of small pits, circular or elliptical in the radius extremes.

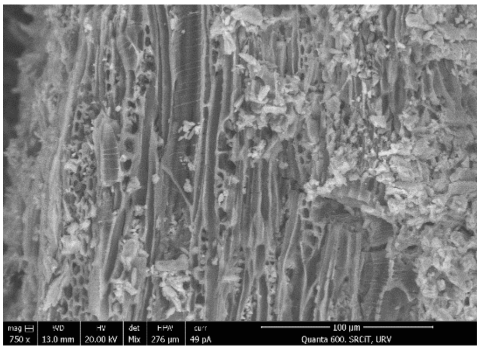
The genre *Acer* sums up deciduous mesophilous trees and bushes, which can reach a height between 8-15m but never grow as dense communities. They are associated to cool, humid and shaded space, to riverine forests and forests of fringe communities, as well as ravine bottoms in lower altitudes, especially for mountain valleys (Pascual, 1994).

Nowadays, *Acer campestre* and *Acer platanoides* are part of the eurosiberian vegetation group, which grows at high altitudes in deciduous mixt forest like beech forests, hazelnut forests, oak groves, chestnut groves and pinus forests (Pascual, 1994). Meanwhile, *A. monspessulanum* and *A. opalus* are from submediterranean contexts, growing next to deciduous mixt forest over limestone soils and sunny ravines, cooler and more humid areas.

5.2.3. *Group 1 (cf. Acer* sp.)

(i)


(ii)


(iii)


Composition 3 Detail images of Group1: (i) cross section; (ii) and (iii) details from the radial section

Total count: 8

Percentage: 0.53%

During the study of Unit XI a series of wood charcoal fragments with resembling anatomical features were found, grouped and defined. Due to the bad preservation state and the lack of some of the key elements it was not possible to subscribe them to any existing taxa. Those features are:

- **Cross section**: diffuse-porous wood
- **Longitudinal tangential section**: uni- and biseriate rays
- **Longitudinal radial section:** spiral thickening. Perforation plate simple.

These identified anatomical features resemble a lot those of the genus *Acer* sp. here described, since some of the key elements cannot be recognized, it was decided to give them the name of *Group 1*, which has all these traits. This naming will be followed through the entire work.

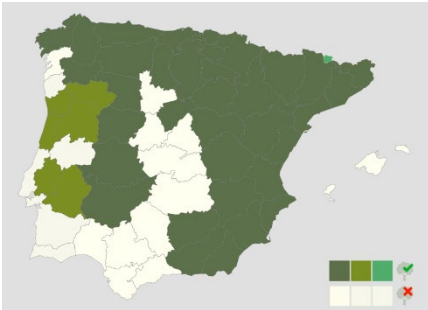
5.2.4. *Buxus sempervirens*

ANGIOSPERMAE

Class	Magnoliopsida
Family	Buxaceae
Genre	*Buxus*
Species	*Buxus sempervirens L., Buxus balearica Lam.*

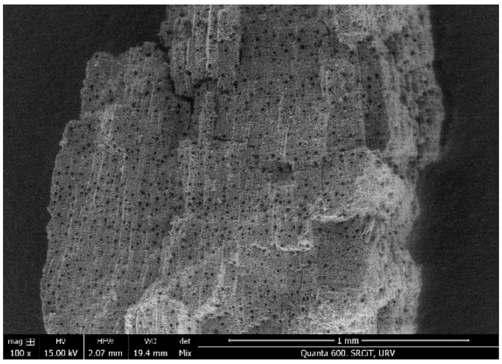
Total count: 10

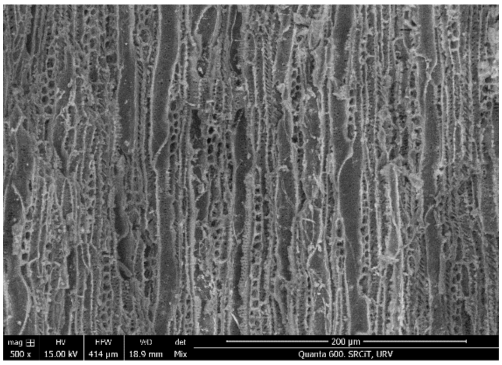
Percentage: 0.67%

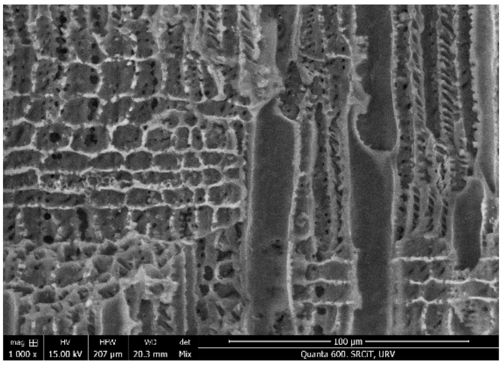
(a)


- **Cross section**: homogeneous wood, with diffuse narrow pores, distributed regularly and isolated. Growth ring boundaries are often distinct.
- **Longitudinal transversal section**: bi-seriate rays, rarely uni- or 3 seriate, heterogeneous
- **Longitudinal radial section**: vessels with scalariform perforation plates with 5 to 10 bars. Short heterogeneous rays, with one to 3 rows of thick-walled square and upright cells.

The genre is formed by bushy trees which grow over limestone soils, in dry areas in supramediterranean contexts. They tend to form the understory of oak groves or when this landscape is in degradation state. For the thermo and mesomediterranean contexts it looks for greater humidity levels (Allué, 2002).

(b)


(c)


(d)


Composition 4 (a) current distribution of Buxus sempervirens; (b) cross section; (c) tangential section; (d) radial section

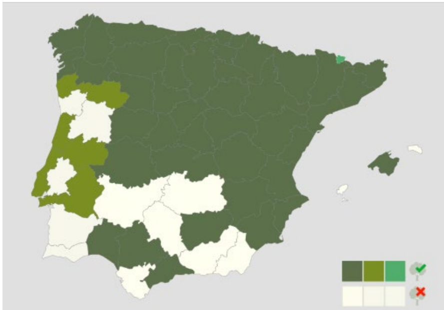
5.2.5. *cf. Corylus avellana*

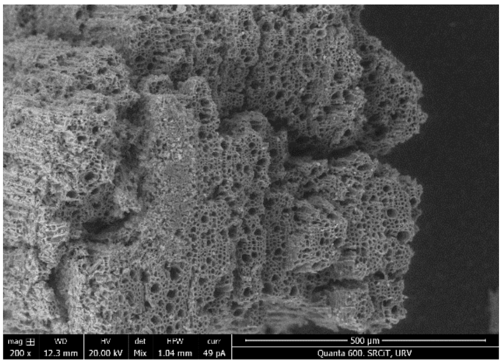
ANGIOSPERMAE

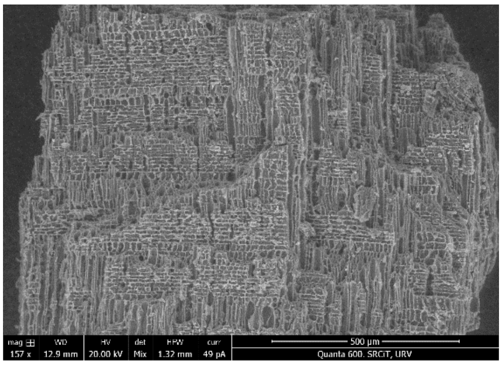
Class	Magnoliopsida
Family	Betulaceae
Genre	*Corylus*
Species	*Corylus avellana*

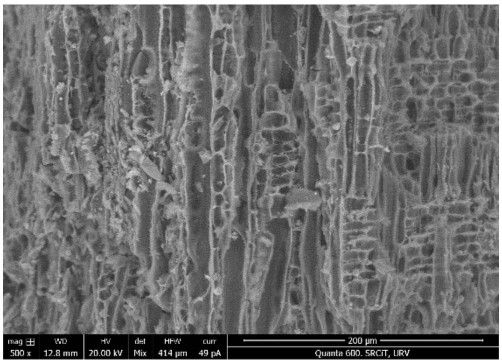
Total count: 1

Percentage: 0.07%

(a)


(b)


(c)


(d)


Composition 5 (a) current distribution of Corylus avellana; (b) cross section; (c) and (d) details of the radial section

- **Cross section**: diffuse-porous. Pores in rather wide, radial clusters and groups.
- **Longitudinal tangential section**: rays uniseriate.
- **Longitudinal radial section**: rays generally heterogeneous. Small ray-vessel pits. Scalariform perforations. Fine spiral thickening.

Corylus avellana is a bushy deciduous tree. It is a colonizer specie, which grows in thalwegs, ravines and valleys. It can grow alone, around other forests or even as a companion for other species (preferentially deciduous forests) provided enough humidity. It can grow on any kind of soil if it is not very sandy and poor. The altitudinal range varies from sea level up to 1900 m.a.s.l. The main utility of this species is culinary, derived from its fruits. This wood has great properties as fuel and provides charcoal of good quality.

The bad preservation and the impossibility to clearly discriminate some of the traits were the reasons behind its adscription as cf. *Corylus avellana.* The fragment here presented would be the first and only registered for now in the site of El Salt, marking a new species in the site assemblage.

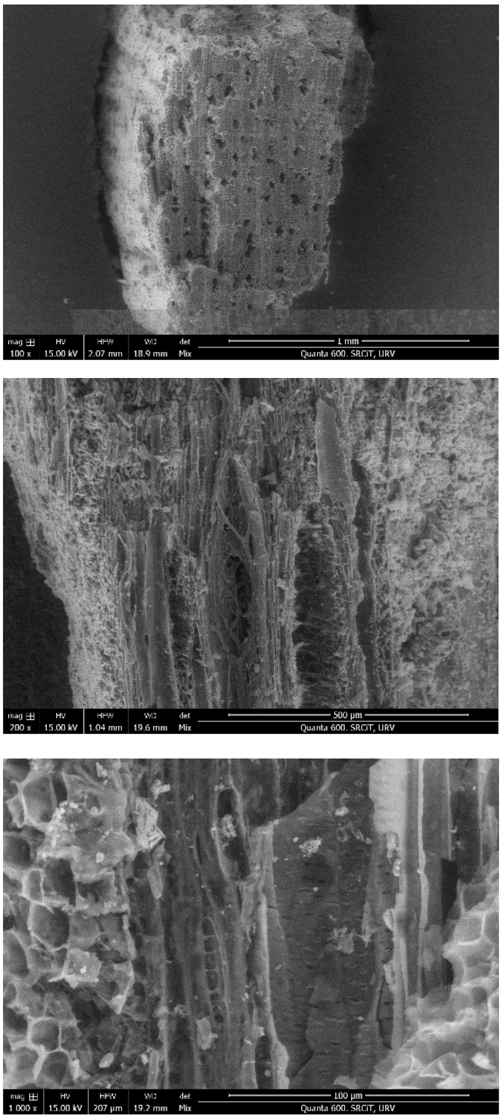
5.2.6. *cf. Hedera sp.*

ANGIOSPERMAE

Class	Magnoliopsida
Family	Araliaceae
Genre	*Hedera*
Species	*Hedera helix* ssp. *helix L.*

Total count: 5

Percentage: 0.33%



(a) (b) (c)

Composition 6 (a) cross section; (b) and (c) details

- **Cross section**: semi-ring porous to diffuse-porous. Pores grouped in cluster with predominantly tangential orientation.
- **Longitudinal tangential section**: rays 4 to 8 seriate. Arranged in wide rays, where large round intercellular spaces are frequent.
- **Longitudinal radial section**: simple perforation plates. Homogeneous to heterogeneous rays, often with 3 rows of square or upright marginal cells. Large vessel-ray pits. Libriform fibers occasionally septet.

This evergreen climbing plant has a broad geographical distribution. It usually appears in shadowed areas of humid forests, climbing trees or rocks. In previous levels its presence was interpreted as an unintentional secondary contribution from dead branches (Vidal-Matutano, 2016).

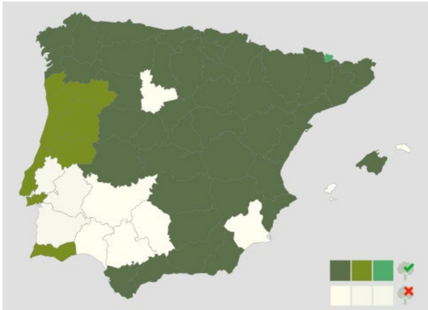
5.2.7. Ilex aquifolium

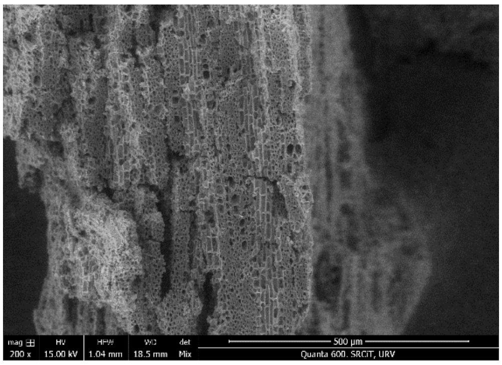
ANGIOSPERMAE

Class	Magnoliopsida
Family	Aquifoliaceae
Genus	*Ilex*
Species	*Ilex aquifolium*

Total count: 9

Percentage: 0.60%

(a)


(b)


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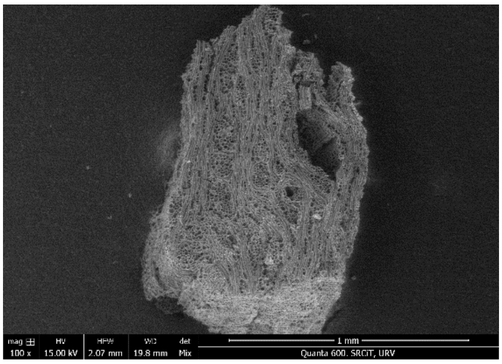
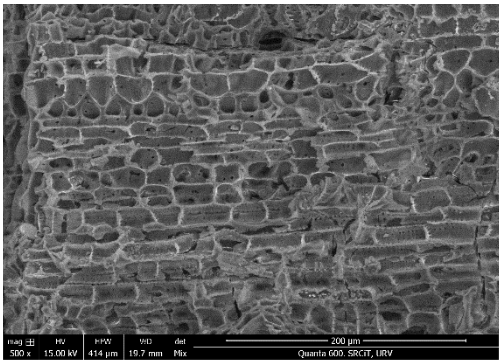


(d)


Composition 7 (a) current distribution of Ilex aquifolium; (b) cross section; (c) tangential section; (d) radial section

- **Cross section**: diffuse porous, small and distributed in radial rows.
- **Longitudinal tangential section**: uniseriate rays with axial cells oval, and multiseriated (4 to 8 rounded cells wide).
- **Longitudinal radial section**: scalariform perforations with 12 to 20 bars. Spiral thickening in the vases and the fibrotracheids. Heterogeneous rays with numerous rows of upright marginal cells.

Bushy tree growing in supramediterranean conditions. It tends to prefer acid and humid soils. It can be found in oak groves, beech forests or common-pine forest, and less frequently into oak forests, gall oaks and Austrian pine groves. One particularity about this wood is that it is very resistant to rooting (Blanco *et al.,* 1998).

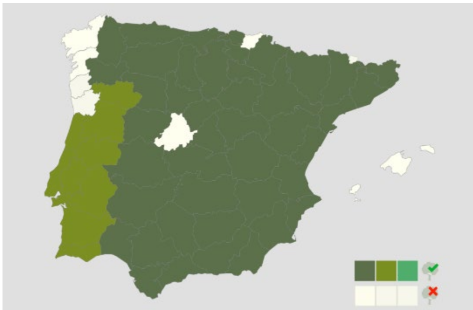
5.2.8. *Quercus sp. deciduous*

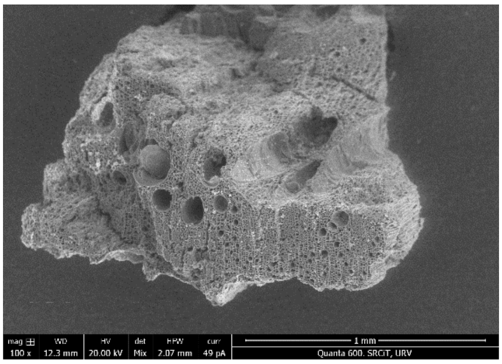
ANGIOSPERMAE

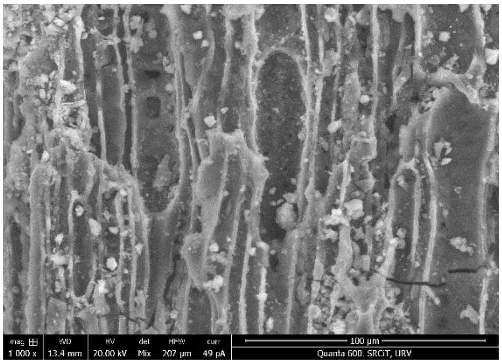
Class	Magnoliopsida
Family	Fagaceae
Genus	*Quercus*
Species	*Quercus faginea, Quercus pyrenaica, Quercus petraea, Quercus canariensis, Quercus pubescens*

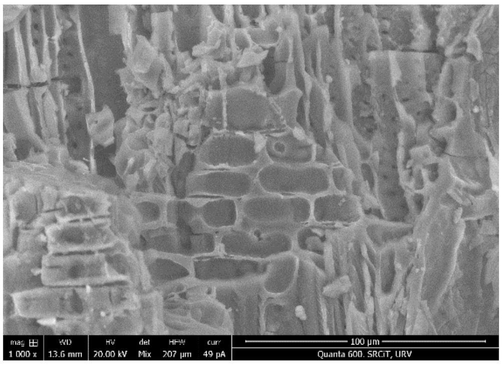
Total count: 3

Percentage: 0.20%

(a)


(b)


(c)


(d)


Composition 8 (a) current distribution of Q. faginea; (b) cross section; (c) tangential section; (d) radial section

- **Cross section**: diffuse-porous. Pores in radial files and groups, associated with scanty paratracheal parenchyma. Early wood with one or several rows of more or less compact pores. Late wood with solitary pores with radial orientation in dendritic groups. The diameter of the latter differs by species.
- **Longitudinal tangential section**: rays uni- to 3 seriate and there is also the presence of multiseriate rays. Simple perforation plates.
- **Longitudinal radial section**: homogeneous uniseriate with upright square cells. Multiseriate rays heterogeneous. Simple perforation plates. Presence of libriform fibers.

The *Quercus* genus is usually divided between the evergreen and deciduous species. Ecologically, the deciduous species are more efficient in reabsorbing the nutrients, particularly nitrogen and phosphorous (Cavender-Bares *et al.*, 2004). The deciduous species are distributed through different vegetation areas.

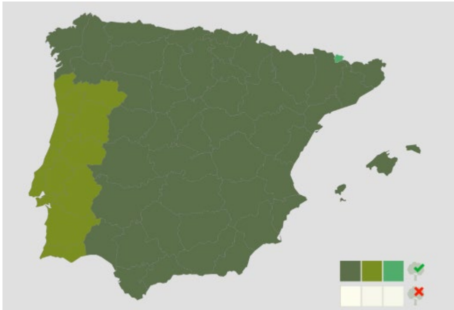
5.2.9. *Quercus* sp. evergreen

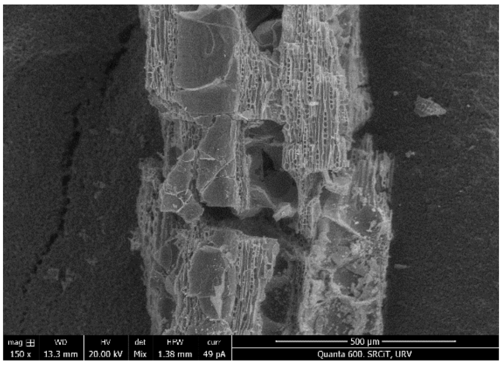
ANGIOSPERMAE

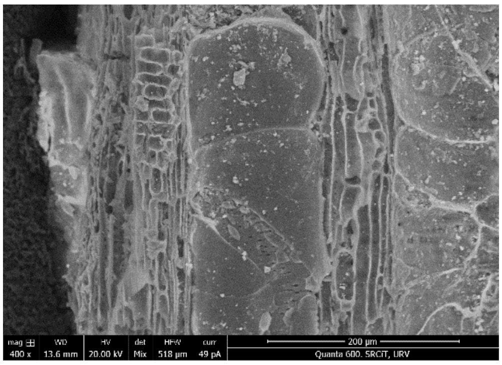
Class	Magnoliopsida
Family	Fagaceae
Genre	*Quercus*
Species	*Quercus coccifera L., Quercus ilex L.*

Total count: 5

Percentage: 0.34%

(a)


(b)


(c)


Composition 9 (a) current distribution Q. ilex; (b) and (c) details

- **Cross section**: diffuse-porous wood, isolated and of greater size the ones at the early wood. The smaller pores are organized in a flame-like manner. This pattern is intermittently halted by the presence of multiseriated rays.
- **Longitudinal tangential section**: counting the radius cell number can be differentiated between uni- (up to 10 cellules height) and multiseriated (up to 30 cells wide). The multiseriate rays can be up to 1mm wide and 5mm high.
- **Longitudinal radial section**: homogeneous radius. Simple vase perforation and cross section radius-vase pits are small to medium, elliptical in shape.

The *Quercus* genre is usually divided between the evergreen and deciduous species. The evergreen *Quercus* are the species *Quercus coccifera* and *Quercus ilex*, which cannot be differentiated from their anatomical features (Schweingruber, 1990), so they were grouped under the *Quercus* sp. evergreen class.

Quercus ilex is a frequent woody taxon within the circunmediterranean vegetation, developing up to 1400 m.a.s.l. It reaches a maximum growth between 5 and 15m height

(Pascual, 1994). Its concentrations are the holm-oak groves, of humid or subhumid conditions, with great density within the coastline and in dry sunny places in the lowlands and foothills (Más, 2018). According to the other species to the assemblage, this is the more probable species regarding its ecological needs.

Quercus coccifera on the other hand is a ramified bush that can stand the conditions of continental Mediterranean climate, of extreme temperatures and scarce precipitations. It rarely grows above 6 m in height. It develops in holm-oak groves, burnt oak groves and open bushlands, from the 400 up to 900 m.a.s.l. It grows in dry and sunny slopes, highly resistant to dry and semi-arid climates (Baquedano & Castillo, 2007).

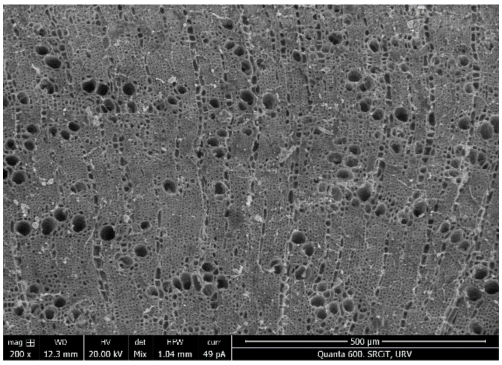
5.2.10. Salvia rosmarinus (former Rosmarinus officinalis)

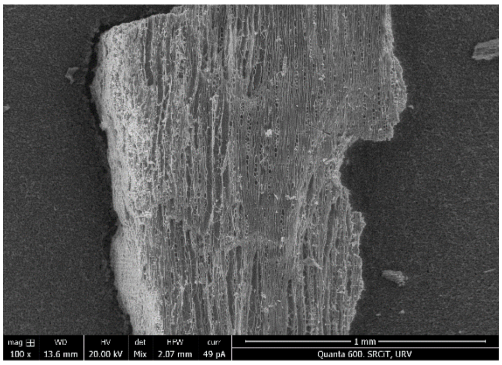
ANGIOSPERMAE

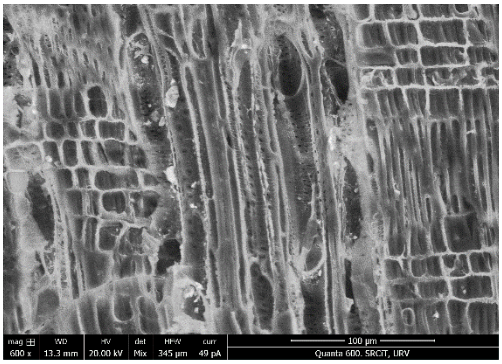
Class	Magnoliopsida
Family	Lamiaceae
Genre	*Salvia*
Species	*Salvia rosmarinus*

Total count: 9

Percentage: 0.60%

(a)


(b)


(c)


Composition 10 (a) cross section; (b) tangential section; (c) radial section

- **Cross section**: diffuse to semi-ring porous. Pores mostly in irregular groups or solitary together with parenchyma cells in dendritic to diagonal groups.
- **Longitudinal tangential section**: rays uni- to 3 seriate, up to 30 cells high. Large and variable cell shape.
- **Longitudinal radial section**: simple perforation plates. Fine spiral thickening distinct in vessels and vascular tracheids.

Salvia rosmarinus (former *Rosmarinus officinalis)* is a typical bushy Mediterranean species. It has been widely utilized for popular medicinal purposes. Within the Lamiaceae family, this would be the first species identified in the site of El Salt from the family. However, some Lamiaceae fragments were identified in Abric del Pastor on Unit IV (c and d4).

5.3. Taphonomical results

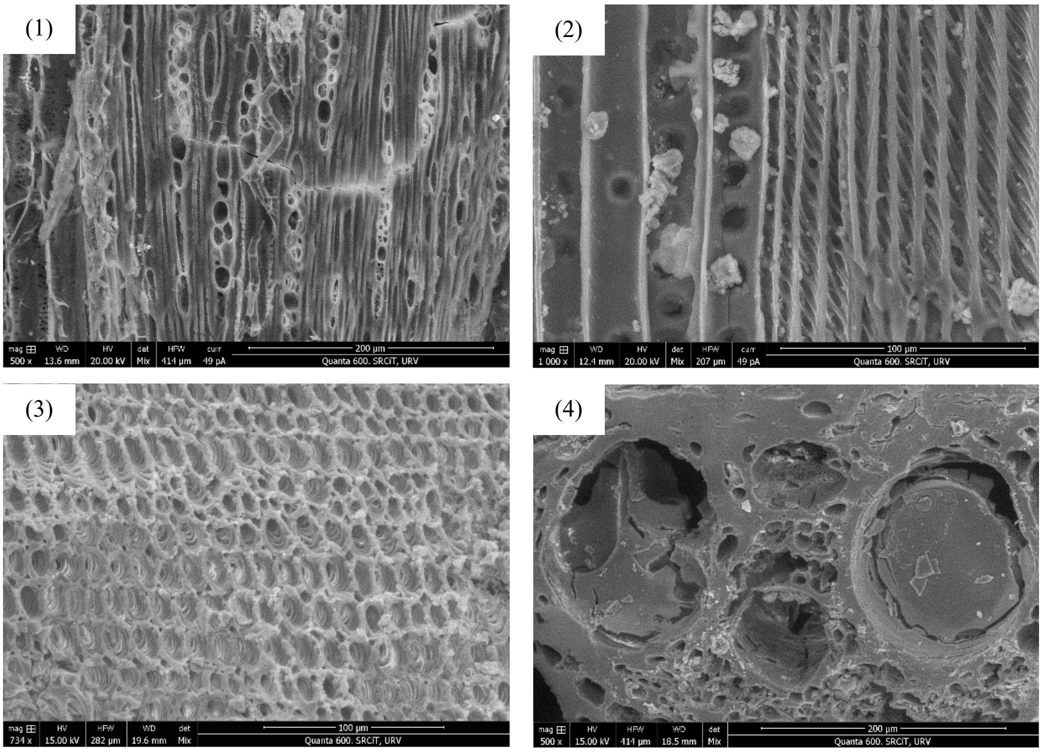


Figure 10 Some taphonomical alterations: (1) hyphae into the vessels of Salvia rosmarinus; (2) reaction wood (right parenchyma) on Pinus nigra-sylvestris; (3) cross section biologically altered Pinus nigra-sylvestris; (4) tyloses on Quercus sp. deciduous

5.3.1. Alteration Levels (A.L.)

The results obtained through the application of the A.L. (Henry & Théry-Parisot, 2014) and the variability found when analyzing the results will be covered in this section. To do so, the results will be reviewed by groups or features, with their correspondent equation.

Conifers

$$Ai = ((498*1 + 181*2 + 63*3) / 1373*3) = 0.256$$

The Alteration index (*Ai*) obtained for the conifers/gymnosperms assemblage is of 0.256, within the category of dead wood with mild alterations. Since the softwoods sum for 92% of the identified wood charcoal assemblage, this information is revealing since it would have been expected that this data and the average for the assemblage were close.

The *Ai* for the conifers in combustion structures contexts is of 0.418, equaling rotten firewood. Meanwhile, for the scatter assemblage it remains on 0.239, on the early stages for that dead wood assemblage. Here, a difference exists between the concentred assemblage and the dispersed one.

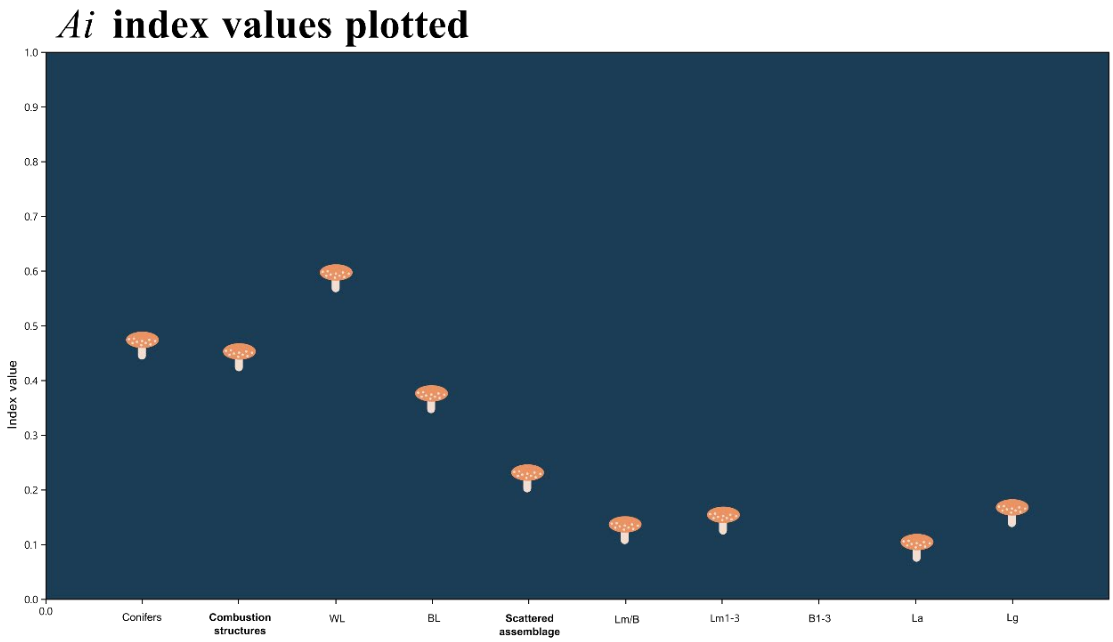


Figure 11 Ai summarized results plotted. There is difference depending on the accumulation type.

<u>Combustion structures</u>

$$Ai = ((99*1 + 54*2 + 25*3) / 203*3) = 0.446$$

The *Ai* obtained for the wood charcoal retrieved from combustion structures, both white and black layers, is of 0.446. This falls within the threshold of dead wood but with pronounced alterations.

Regarding each separated facies, which are the minimum stratigraphic element available for now for Unit XI, it was of interest trying to assess any existing differences. At first it was applied the index differentiating the WL and the BL but including in both of those the samples in which both layers were excavated/cleaned together. Aiming to obtain the clearest possible results, those uncertainties were erased, leaving only the samples where only one of the layers is represented. The results were as it follows:

Only the *WL*:

$$Ai = ((25*1 + 18*2 + 15*3) / 59*3) = 0.599$$

Only the *BL*:

$$Ai = ((50*1 + 21*2 + 3*3) / 89*3) = 0.378$$

It is of great interest the difference within their index values. It must be reminded that both layers represent two different moments and possibly two different occupations. The BL is interpreted as the previous soil on top of which the combustion structure was built and lit, which is represented by the WL. Is in this later one where we must find the remains of the last consumed firewood. What we have here is that the BL shows a high index of dead wood, with ubiquitous alterations. On the other hand, the WL index is already on the rotten wood cluster (> 0.5).

Attending to these results, it was of interest to confirm the specificity of the two hearths where we have more than fifty wood charcoal remains on each (H105-115 and H120). Bearing in mind that the samples are under the minimum count advised, these results should be taken with some caution. In each combustion structure one of the layers presents a very low count. These are represented in salmon color in Table 6, where all the resulting indexes for the combustion structures are featured. Those remarked indexes have little value due to its lack of representativeness.

***Ai* summary of the combustion structures H120 and H105-115**

Combustion structure	*Ai*	*WL Ai*	*BL Ai*
H105-115	0.352	**0.444**	0.333
H120	0.647	0.610	**0.667**

Table 5 Resulting indexes for each one of the representative combustion structures featured. In orange the results statistically not representative.

Always bearing in mind that these results should be treated with caution, here it seems that both combustion structures follow different patterns. Meanwhile H105-115 follows the tendency of the WL/BL defined earlier, representing values of altered dead wood, H120 does the opposite, with values already within the rotten index for both layers. It also shows that H120 is an outlier when referring to the *Ai* index.

Scattered assemblage

$$Ai = ((445*1 + 147*2 + 55*3) / 1300*3) = 0.232$$

When all the samples outside the combustion structures are taken and their *Ai* index calculated what results is 0.232, low signal of dead wood with mild alterations. Considering the numerous existing facies and knowing that they are spatially restricted to certain areas, it seemed of interest to test if there are significant differences between them, and if so, why they may be happening.

Lm1-3 (inner and outer area)

$$Ai = ((91*1 + 14*2 + 6*3) / 335*3) = 0.136$$

These are facies interpreted as contexts for the combustion structures and the main sedimentary component of Unit XI. When all the fragments corresponding with all the Lm and their equivalent outer facies B (rows 9 and 10) were measured the result index was of 0.136, which is within the healthy signal. This result contrasts with the overall measurement of the scatter assemblage, which is over the dead wood signal. It seems clear that there is one context providing those higher values.

B1-3 (outer area, carbonaceous precipitation)

When restricting only the area outside the overhang (rows 9-10), where the postdepositional effects of running water and the alterations by carbonaceous precipitation are frequent, the *Ai* could not be measured. In some of the samples it even could not be recorded due to those postdepositional alterations, and in the ones where it was recorded, they were within the 0 category.

Lm (inner area only)

$$Ai = ((91*1 + 14*2 + 6*3) / 297*3) = 0.154$$

Only measuring the inner facies defined as Lm (row 2-8), without internal dissections following the combustion structures, the overall index is of 0.154. As with the overall extension of the Lm, the contextual sediment of Unit XI, it is within the healthy wood signal.

Lm1-3

$$Ai = ((91*1 + 14*2 + 6*3) / 203*3) = 0.226$$

This category comprehends the sedimentary matrix of Unit XI internally undistinguishable due to the absence of combustion structures which allow for its dissection or due to the impossibility of following laterally the BL. In this case the index is once again into the dead wood category. There are also notes on the presence of postdepositional alterations: brittle texture or rounding. Attending to all the subgroups defined, this one may be the main cause for the increase above the 0.2 threshold. One explanatory reason for this is the intrusions of dispersed combustion materials, which has been giving high values. Since the sediment labelled as Lm1-3 are the combustion contexts but internally undistinguishable, the possibility lays there.

Lm2

The facies Lm2 was defined as the context of H94, H87 and H91, right above H117. Its *Ai* cannot be measured because there is little to no information recovered on the matter. There are notes on cell collapse and overall destruction of the anatomical elements, even highly vitrified fragments, which are the reasons for the lack of information on this facies. Most of these alterations correlate with postdepositional factors or thermal alterations, shadowing the biological agents affecting the wood before being burned.

Lm3

The index for Lm3 is not representative since the total amount of charcoal is too little (0.847% of all the scattered assemblage), and it does not reach the minimum of 80 fragments count. It is also remarkable that there are no notes on any further alteration.

La (all of the facies together)

$$Ai = ((10*1 + 7*2 + 0*3) / 77*3 = 0.104$$

Even though the total count is still under the minimum of 80 fragments (t=77), it is statistically representative since it makes for 5.928% of the scattered assemblage. The result for all those facies of the site is 0.104, a signal of healthy wood. Most of them come from the inner part, where there are some notes on postdepositional alterations. The fragments from the outermost areas (C8) have no signals of postdepositional processes, but there are differences on other indicators, such as the presence of reaction wood, which will be later discussed.

Lg15

$$Ai = ((65*1 + 123*2 + 47*3) / 885*3) = 0.170$$

The last facies to be analyzed is Lg15, which at the same time is where most of the material comes from (68.129% of all the scattered assemblage). Occupying the inner surface of the site, it is the context to most of the combustion structures within the area. It was expected a higher *Ai* since it may be happening that some wood charcoal from the hearths had deposited within the surrounding area, but, in this case, it barely falls within the average alteration values of dead wood. It is also striking because the extension of this facies is really restricted, but it shows the highest concentration of fragments, leading to the first interpretation that it represents an ash dumpster from diverse combustion structures.

***Ai* Summary**

Unit	*Ai*		Wood signal
Conifers	0.256		Dead
Combustion structures	0.446		Dead
Combustion structures WL	0.599		Rotten
Combustions structures BL	0.378		Rotten
H105-115	0.352	*BL:* 0.333	Dead
H120	0.647	*WL*: 0.610	Rotten
Scattered assemblage	0.232		Dead
Lm (inner and outer area)	0.136		Healthy
Lm (inner area only)	0.154		Dead
Lm 1-3	0.226		Dead
La (all)	0.104		Healthy
Lg15	0.170		Healthy

Table 7 Summary of the statistically indexes obtained. The colour code on the column 'Wood signal' is: green for healthy wood, pink for dead wood and dark blue for rotten wood.

5.3.2. Dendroanthracology: growth-ring curvature

What concerns the conifers, the greater number of fragments show little to no curve on the growth rings (*straight* 89.02%). Out of the other defined categories, only the *soft curve* (7.37%) one is statistically relevant, with the *pronounced curve* group not even reaching one percentage.

Another particularity identified in only 7 remains (0.47%) were numerous growth rings – between three and seven–, in fragments with 2-4 mm of cross section. All of them are concentrated in the same consecutive squares (Y3, Z2, Z3) and present homogeneous levels of alteration: straight growth rings, very shiny surface and few deformations in the cell structure due to combustion and low *Ai* (= 0.333).

Following what has been said in the literature, this particularity could be reflecting the presence of *Pinus nigra* (Heinz, 1990). Or, outside of the taphonomical identification, the alteration that could be here represented is *compression wood*, the counterpart of the re-action wood.

5.3.3. Reaction wood

Results reaction wood on conifers

Class	n	%
0	850	61,95
1	353	25,73
2	169	12,32
	t = 1373	100,00

Table 8 Summary of the reaction wood results registered in Unit XI of El Salt

Regarding the presence of reaction wood within the conifers, the results show that all the levels proposed (*none, present* and *marked*) are statistically representative (Table 8). More than 60% of the assemblage shows no signs of reaction wood, meanwhile 25.73% does. In the remaining 12.32% it is highly conspicuous. What these results show is that almost one third of the conifer assemblage, which itself sums up for almost 92% of all the wood charcoal recognized, shows signs of mechanical reinforcement. As it was stated in Chapter 4.4.3, the presence of these indicators aligns with the gathering of branches or leaning stems.

It was of interest to dissect the results by facies and the nature of the assemblages (concentrations and scattered), looking for major differences or particularities. The results are in the following Table 9, where the values are summarized.

			n			%		
Sample	**Total**	**% from T.**	**0**	**1**	**2**	**0**	**1**	**2**
COMBUSTION	145	10,56	56	59	30	38,62	40,69	20,69
H120	7	0,51	6	1	0	85,71	14,29	-
H105-115	71	5,17	8	49	14	11,27	69,01	19,72
SCATTERED	1205	87,76	773	294	139	64,15	24,40	11,54
B1-3	22	1,60	20	1	1	90,91	4,55	4,55
La(all)	74	5,39	63	6	5	85,14	8,11	6,76
Lm(all)	279	20,32	206	69	4	73,84	24,73	1,43
Lg15	827	60,23	482	216	129	58,28	26,12	15,60

Table 9 Summary of the reaction wood results registered in Unit XI from El Salt

What is seen from these results is a clear difference between the combustion structures and the scattered assemblage values. The concentrations barely represent 10% of the total assemblage, meanwhile the dispersed material is what comprises almost 90% of the assemblage. It is of great interest observing that the tendencies are inverted between them:

while for the combustion structures 61% of the fragments display the reaction wood alteration on the tracheid walls, only 35% of the fragments dispersed through the site display it.

This idea is reinforced when the focus shifts onto specific facies or combustion structures. Leaving the H120 behind because it is not statistically representative and keeping in mind that the firewood of this combustion was mainly *Acer* sp., the H105-115 results are more evident. The 89% of the fragments recovered from this hearth display compression wood traits, with almost 20% of them being strongly marked. Accepting that this is the signature for the presence of leaning branches or the indication of sloppy terrain, in this combustion contexts most of the *Pinus* sp. contributions would be coming from branches or from a hill slope.

When we compare the scattered assemblages, distributed by facies, the results are otherwise. The B1-3 facies must be left out from the analyses since it is statistically not representative. For the remaining Lm, La and Lg, always the category *none* (0) is dominant over the ones of presence, above the 60% threshold. It seems that the larger the analyzed sample, more moderate are the results. However, the pattern is always the same: the majority is within the 0 category, followed by the 1 category and lastly the 2 categories. Following what we said for the combustion structures, in the case of the scattered assemblage the main softwood component cannot be associated with leaning branches, displaying a shift in the pattern.

The review of the indicator for the presence/absence of reaction wood has provided further insight into the different assemblage composition from the 'less anthropic' scattered assemblage and the human-curated combustion structures. Two tendencies can be found, relating to its possible human management: the regression pattern, applied in less managed contexts, and the 'branches' pattern, seen into the combustion structures. Even though the H120 is statistically not representative, if we draw its tendency line within the others, instead of following the H105-115 or the *Combustion* ones, it mimics the regression pattern. One explanation for this may arise when paying attention to the origin of those fragments. In this case, most of the conifers from the hearth are found within the BL, which we understand as the existing floor before the burning, what remains from the previous occupations. If this was the case, those fragments would be indeed coming from the scattered assemblage beneath. To test this hypothesis, statistically reliable values for both WL and BL of more combustion structures and to analyze each one separately must be needed.

5.3.4. Thermoalteration or Combustion processes

The combustion process is the main taphonomical agent present in archeological wood charcoal assemblages, since it was the event that led to its formation. The ubiquity of the alteration resulted on the attempts to create classes, degrees or intensities. There are two main alterations usually related to this combustion process: vitrification and the presence of radial cracks in the cross section. The latest, as it was explained in the Chapter 4.4.4, radial cracks tend to also be associated with burning green wood, relating not only to the burning process but also with the state of the firewood before the combustion. In this assemblage it has not been frequently found within the conifers (t=133; 9.7%), however, it is statistically representative. The *Ai* index of this set of fragments is 0.23, a lot higher than what would have been expected. Considering both alterations and how they correlate, maybe the water content of the wood pieces is not directly related to green wood, but due to high moisture values derived from a highly humid environment. This factor of the environmental humidity will be reviewed for other alterations and proxies, with a deeper reflection in the Chapter 6.2, when discussing about paleoenvironment.

Vitrification was registered in 42 fragments, most of which (30) could not be assigned to a taxon due to being heavily altered. The ones that could be identified are all softwoods: Conifer unidentified (3), *Pinus* sp. (1) and *Pinus nigra-sylvestris* (8). Even though the alteration does not reach the minimum for being statistically reliable (only 2.37% from the total assemblage), the signal for the existence of this alteration is there.

It is of interest to take a closer look at the results from the thermoalteration classes established for this study and test their potential. As they were described before, the system is based on four categories, where 0 symbolizes the absence and 3 is for 'overall glossy appearance, unidentifiable or at most to the softwood/hardwood level'. The analysis was divided between the combustion structures and the scattered assemblage like the other alterations reviewed, with the aim of checking for substantial differences between them.

Combustion alteration results for combustion structures										% from the total
FACIES	Total amount	0		1		2		3		
		n	%	n	%	n	%	n	%	
All	*203*	16	7,88	70	34,48	106	52,22	11	5,42	100
H105-115	*71*	3	4,23	29	40,85	39	54,93	0	0,00	34,975
BL	*65*	3	4,62	27	41,54	35	53,85	0	0,00	32,020
WL	*6*	0	0,00	2	33,33	4	66,67	0	0,00	2,956
H120	*52*	2	3,85	18	34,62	27	51,92	5	9,62	25,616
BL	*5*	0	0,00	1	20,00	4	80,00	0	0,00	2,463
WL	*47*	2	4,26	17	36,17	25	53,19	5	10,64	23,153
class % from the total results					34,42		60,09		3,38	100,000

Table 10 Thermal alteration classes proposed and the combustion structures results regarding them.

Beginning with the combustion structures (t=203), the dominant class is 2, followed by 1, 0 and lastly by 3 (Figure 12). The results change when instead of all the combustion fragments the subject is only one of those hearths (see Table 10). The case of H105-115 follows the same trend, with some changes in the percentages with a smaller gap between 1 and 2, and the total absence of class 3. In the case of H120 the trend suffers and exchange: the third group in frequency is class 3, which is almost three times that of class 0. These two combustion structures account for 60.6% of the concentered assemblage and they may be regarded as representative. Even though, several questions arise in this regard considering the striking differences between them and the singularity of H120.

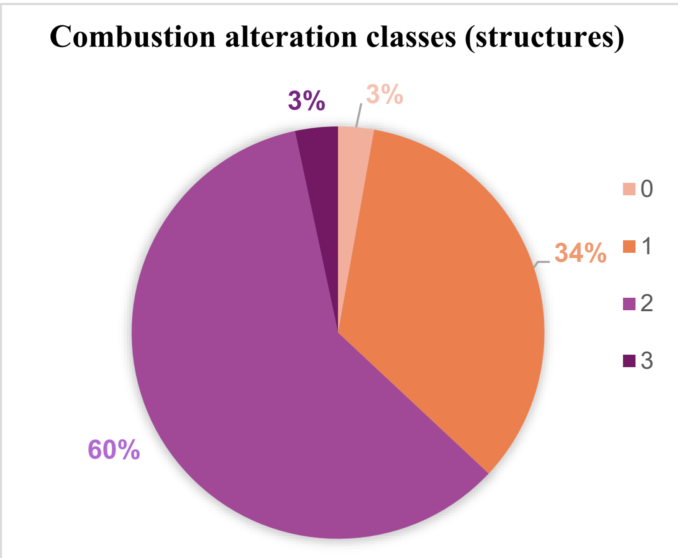


Figure 12 Combustion alteration classes from structures.

It also was of interest testing the WL and BL separately and regard any major difference. The problem here is the representativeness given that H105-115 WL and H120 BL do not reach each the 5% within the combustion structures assemblage, and only analyzing one layer per structure will not provide with more results than one case sample. However, in the Figure 13 both were plotted, and is clear that the class 2 is always the most representative.

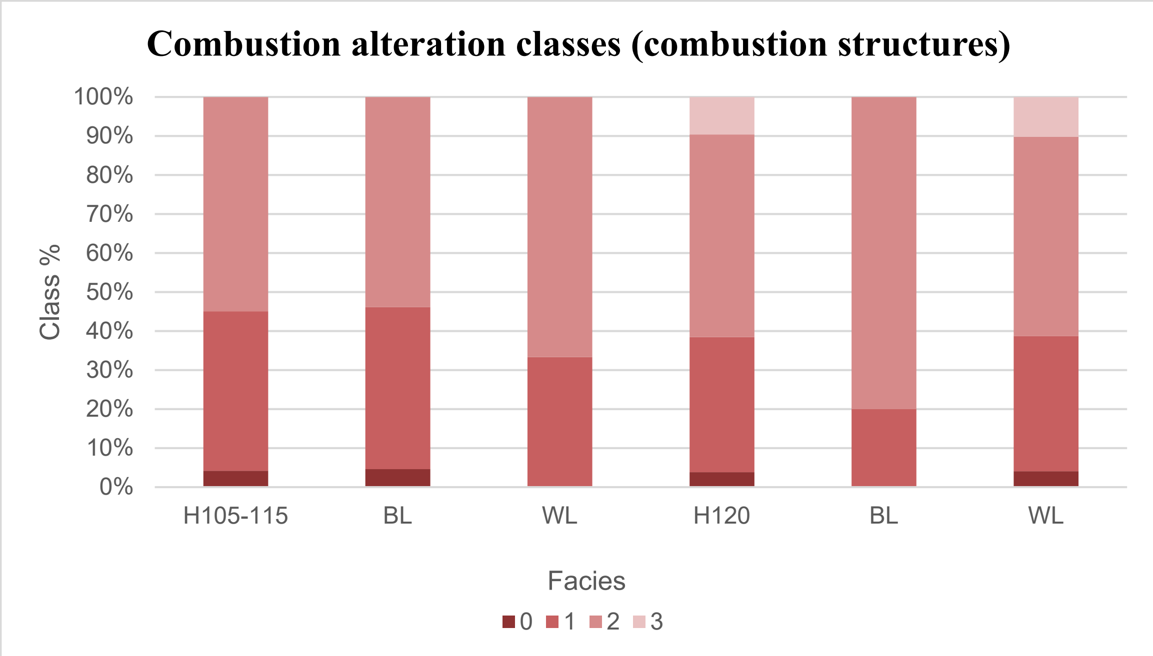


Figure 13 Accumulative bars chart showing the combustion levels from H120 and H105-115, displaying the four categories proposed.

Combustion alteration results for the scattered assemblage										% from the total
		0		1		2		3		
FACIES	**Total amount**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	
All	1299	124	9,55	611	47,04	510	39,26	53	4,08	100
Lm (all)	*335*	47	14,03	165	49,25	111	33,13	12	3,58	25,79
Lm 1-3	*245*	30	12,24	115	46,94	88	35,92	12	4,90	18,86
Lm2	*83*	12	14,46	48	57,83	22	26,51	1	1,20	6,39
Lm3	*11*	5	45,45	4	36,36	2	18,18	0	0,00	0,85
La13-16	*77*	27	35,06	27	35,06	23	29,87	0	0,00	5,93
La13	*4*	0	0,00	0	0,00	4	100,00	0	0,00	0,31
La14	*2*	1	50,00	0	0,00	1	50,00	0	0,00	0,15
La15	*18*	1	5,56	9	50,00	8	44,44	0	0,00	1,39
La16	*53*	25	47,17	18	33,96	10	18,87	0	0,00	4,08
Lg15	*885*	52	5,88	418	47,23	375	42,37	40	4,52	68,13
class % from the total results			22,99		35,66		39,93		1,42	100,00

Table 11 Thermal alteration classes proposed and the scattered assemblage results regarding them

Shifting the focus towards the scattered assemblage (Table 11), the tendency for the whole assemblage (t=1299) is led by class 1, closely followed by class 2, and ending with class 0 and 3. Class 3 would not even be statistically representative, barely reaching 4.1%, markedly decreasing from the structure's results. The main visible change is the dominance of class 1, with generally fragments less altered. Also, the larger the sample analyzed, class 0 gains more weight as clearly seen between the several facies of Lm and in Lg15. The biggest subgroups susceptible to individual analysis are the facies Lm, La and

Lg. In general, they follow the same trend above described, with the difference coming from La. This facies barely reaches 5% of the scattered assemblage, and its results are missing the class 3. When compared with the others, La has an overrepresentation of class 0, which is coming from the results of La16. As is signaled on the Table 10, most of the subfacies are not statistically representative therefore, no further observations can be don done.

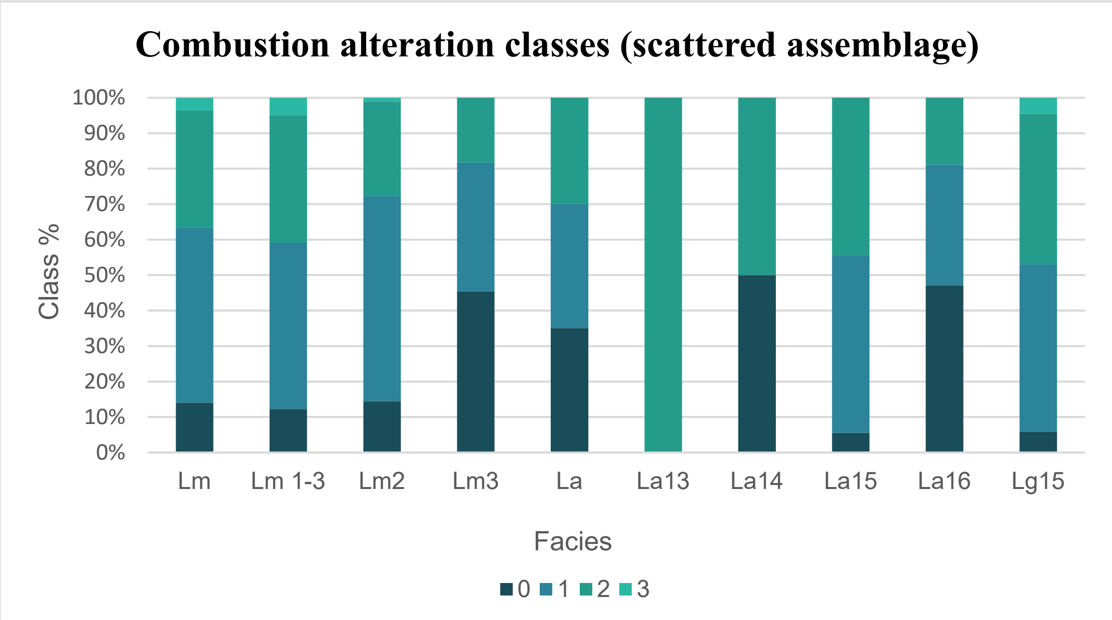


Figure 14 Accumulative bars chart showing the combustion levels from the scatter assemblages, displaying the four categories proposed.

It seems that the main discriminating element between the dispersed material and the one retrieved from the combustion structures is the high values that class 0 has in the first case and the predominance of class 2 for the second (Figure 14). The indicator is different according to the kind of assemblage analyzed, retrieving positive results by the application of this class method. With these results and seeing the graphs, it could be argued that the standardization of a combustion alteration measurement, or even the creation of an index, may prompt the differentiation when identifying and discriminating between these two types of assemblages.

5.3.5. Biological alterations: fungi, bacteria and insects

In this section only the biological alterations that were observed directly on the fragments will be reviewed. The overall state of the wood assemblage has already been explained through the Alteration levels in section 4.4.1. When analysing all the fragments under the microscope, only on five of them it was identified the presence of hyphae or xylophages' channels. Most of them correspond with angiosperms and are in the surrounding area of the H120 structure. These results are indicators of the existence of these elements within this assemblage, even though they are scarce. Probably they are more frequent than what has been identified, but it was not possible to distinguishing them. It is peculiar and noteworthy that most of the fungal and insect attacks were seen in angiosperms, when they do not even make up for 9% of the total assemblage.

5.4. Spatial analysis

The interest and possibilities offered by the spatial analyzes in a site with such rigorous methodology of excavation and water sieving incited and made them possible. Several aspects were reviewed, each one answering to different questions and testing hypothesis proposed through other proxies.

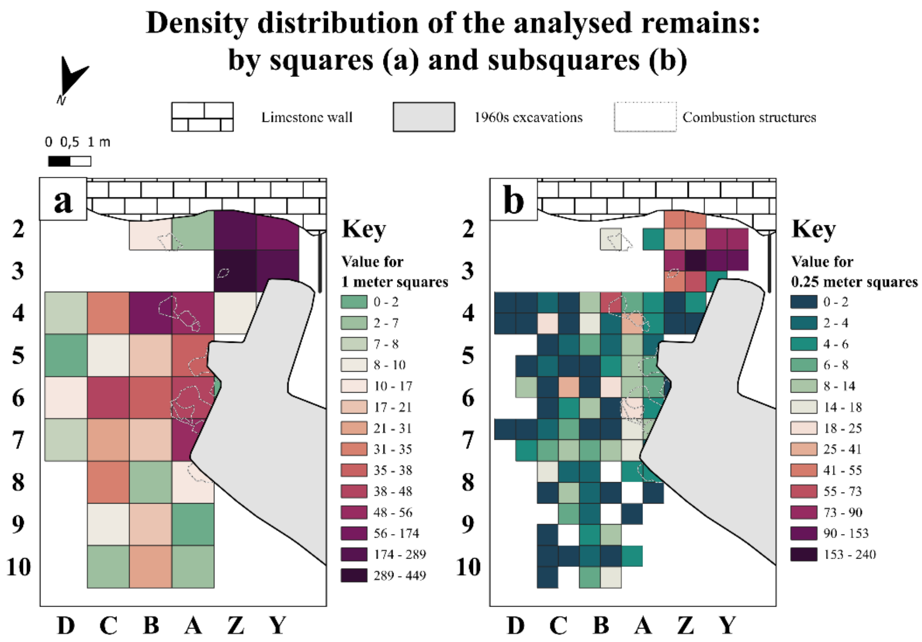


Figure 15 Density distribution of the analysed remains: by squares (a) and subsquares (b).

To start viewing the dispersion of the wood charcoal fragments, all the assemblage was plotted on the grid (Figure 15a). With the first glance there are two main areas of accumulation. Also, the closer to the limestone wall the greater the accumulation is. These two areas may be connected to each other, but the squares to asses that miss any material. The accumulation on Z2/3-Y23 is spatially more restricted and only accompanies one hearth (H120), but it is the largest of the Unit XI (*Accumulation 1)*. The accumulation on rows 4 to 7 (*Accumulation 2*) is the one taking up more space and follows the placement of that area combustion structures. It also seems clear that from the row 8-10, the proposed 'outer area' around the dripline, the material accumulation is much lower.

This diminishing pattern towards the outer area is better recognized when the counting is done onto the subsquares grid (Figure 15b). Using this view is even more striking that in many of those subsquares there is no material recovered. Considering the unfinished nature of the Unit XI, from the excavation to the laboratory process of sediment and material (topic discussed in Chapter 6.4), it seems possible that this area, and more specifically those subsquares are yet to be processed and the image that is reflected on the maps is biased. The columns C/D are also affected by harsh erosion, which may lead to the lack of materials. In this more detailed map, the accumulation on the rows 4 to 7 is much more discrete, with only three subsquares (B4_2, A4_3, C6_2) displaying high values. In contrast, the accumulation on Z2/3-Y2/3 still shows the highest values of the assemblage, being Z3_2 where the denser accumulation occurs (t=274).

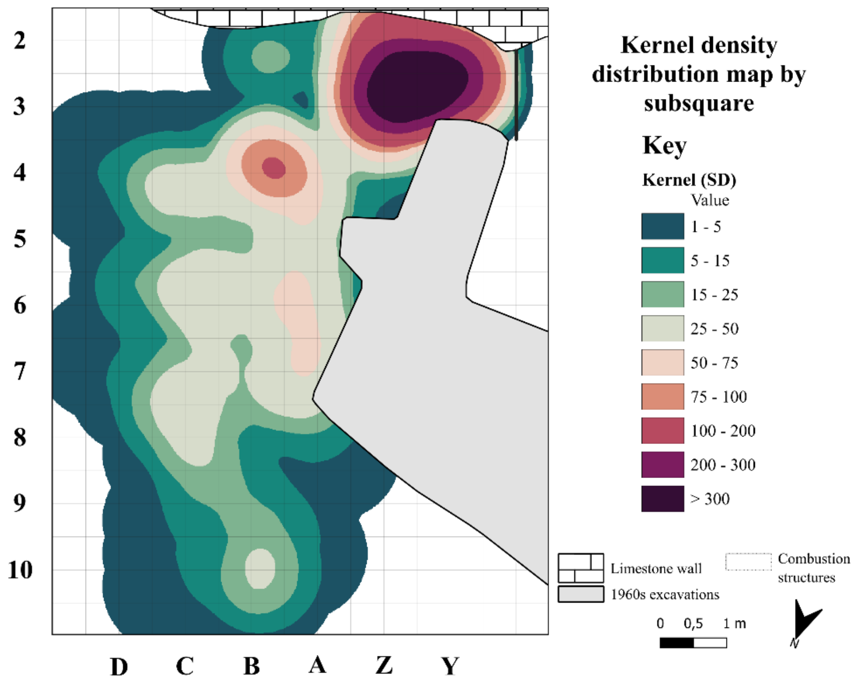


Figure 16 Kernel density distribution map by subsquare.

When the tool Kernel density is applied, the resulting map is Figure 16. The represented areas resemble that of the previous map by subsquares. Here it is clearer that the accumulation on the rows 4 to 7 for the most part shadows the combustion structures and their surroundings. The area of H105-115, H112 and H111 is one of the most complex when referring to combustion structures and the space for the defined as *fire installation*. The heat points that appear on C6_2 and C4_3, isolated and far from any combustion structure may both be caused by few charcoals that broke into several pieces once vacuumed and water sieved, since most of those fragments fall within the same taxa and alterations.

Besides the material density through the grid, it is of great interest to observe the specific dispersal of retrieved wood charcoal. The fragments that were retrieved through mechanical water-sieving are assigned to their corresponding square and subsquare on the grid. With this information they were assigned randomly within each subsquare. By observing each taxon separately, it is easier to find patterns or oddities.

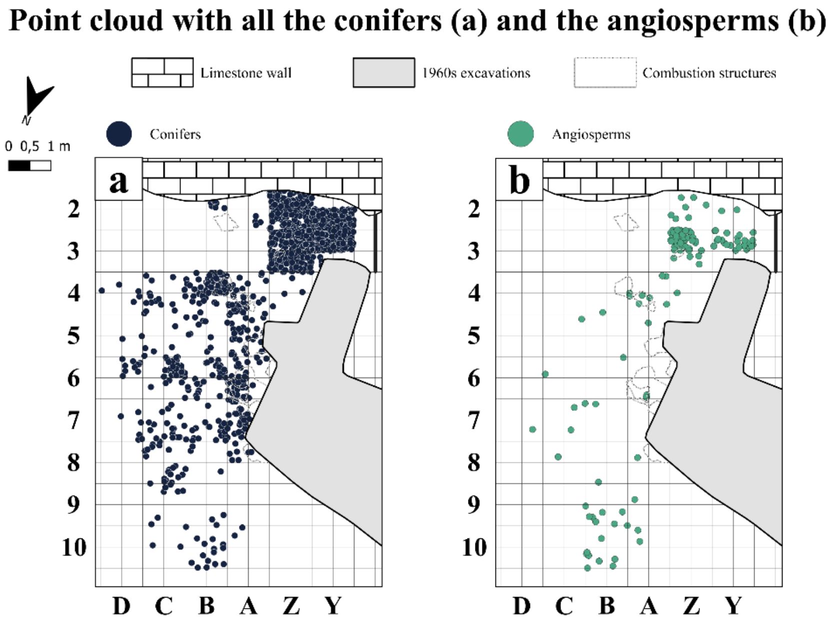


Figure 17 Point cloud displaying all the conifers (a) and the angiosperms (b) identified.

The Figure 17a displays all the identified conifers, from the *Pinus nigra-sylvestris*, *Pinus* sp. and the *Conifers undetermined*. What can be observed in this figure is how being *Pinus nigra-sylvestris* the most frequent taxa, its particular dispersion is what mainly dictates the broad dispersion pattern. Most of the combustion structures display a clear dominance of *Pinus nigra-sylvestris*, which must have been the burnt firewood. When this map is compared with the one resulting from plotting all the angiosperms (Figure 17b), the differences are noticeable. The angiosperms show one clear cluster around the H120 and Lg15, meanwhile the remaining fragments are dispersed through the site in low densities. It seems a second cluster appears on the outer area of the site, around the fallen blocks of the possible ancient overhang.

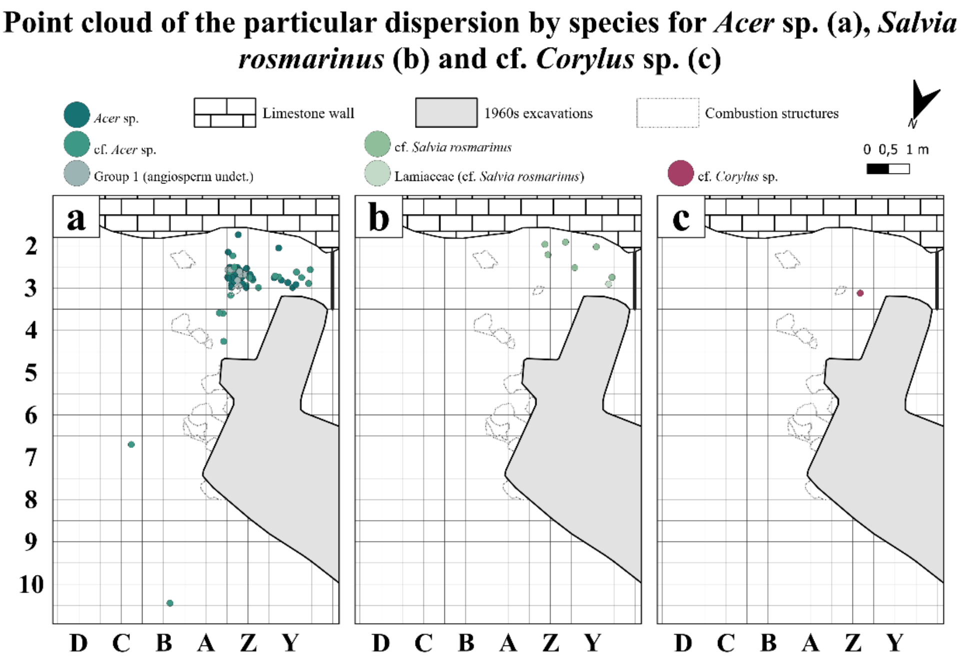


Figure 18 Maps of the particular dispersion by species groups for Acer sp. (a), Salvia rosmarinus (b) and cf. Corylus sp. (c)

The case for *Acer* sp. may be one of the most particular ones. It is found almost exclusively in H120 and its context (Lg15). There are only five fragments scattered over the site, and even so most of them are within this combustion area and the *fire installation* one. This taxa accumulation is clearly linked to hearth 120, whose WL is solely composed by *Acer* sp. The fragments of *Salvia rosmarinus* and the Lamiaceae (cf. *Salvia rosmarinus*) appear condensed into the Lg15 and the surrounding area of H120, right to the wall, nowhere else on the site. For the only fragment of cf. *Corylus* sp. the results are the same, being registered where most of the elements appear.

The opposed dispersion pattern is followed by *Ilex aquifolium* and cf. *Ilex aquifolium* (Figure 19a). These fragments are only present within the scattered assemblage, with some alone and dispersed through the inner-middle area, and with a discrete accumulation by the entrance (B9_3, 4). The same is happening with *Buxus* sp. and cf. *Buxus* sp. (Figure 19b), even more accentuated. This taxon is almost exclusively found on the scattered assemblage from the outer area, around the drip line. The accumulation of *Buxus* sp. is separated from that of *Ilex aquifolium* by less than a meter.

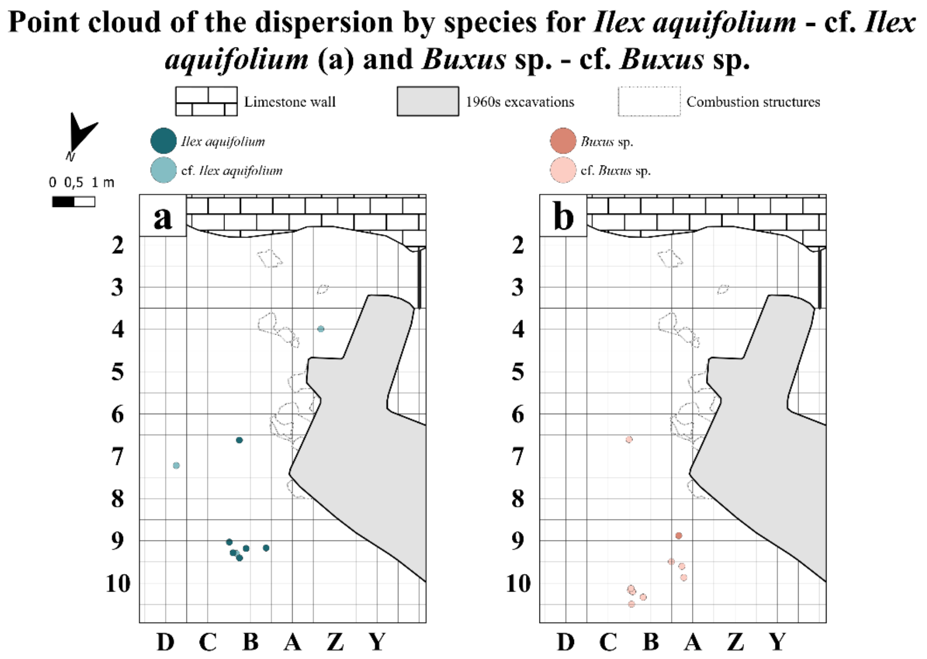


Figure 19 Maps of the particular dispersion by species groups for Ilex aquifolium - cf. Ilex aquifolium (a) and Buxus sp. - cf. Buxus sp. (b).

The five fragments of cf. *Hedera helix* show a special patterning (Figure 20a), since they only appear into the context of the combustion structures from the *Accumulation 2*. There are no remains on the *Accumulation 1*, contradicting the normal pattern and what would be expected. Regarding the *Quercus* spp. Group (Figure 20b), there are little differences between *Quercus* sp. *evergreen* and *Quercus* sp. *deciduous*, all of them happen in scattered assemblages. However, some differences can be observed; first that most of the *Q.* sp. *evergreen* are on Lg15, and secondly, that all of them are towards the inner area. Meanwhile, *Q.* sp. *deciduous* seems to be more linked to combustion structures contexts.

The category of *Undetermined* (Figure 21a) is composed of wood charcoal fragments without a specific assigned taxa due to its state, making impossible even allocating them as softwood or hardwood. These fragments are dispersed through the site's surface, mostly associated with combustion structures. There are three main areas where it accumulates: the *Accumulation* 1, as scattered assemblage in Lg15; the *Accumulation 2*, mainly gathered around the combustion structures and the heat points on C6_2 and C4_3. The third discrete gathering is on the outer area. It seems coherent since in those areas is where most of the fragments were recovered, and the probability of finding undeterminable ones is higher.

The category *No charcoal* (Figure 21b) includes all the undetermined that for their morphology and traits cannot be surely defined as wood charcoal. The main hypothesis is that those are charred trabecular bone. This result is only partial and biased, since the faunal studies from all the remaining bones recovered on site and during laboratory processes are still ongoing. What this assemblage represents is the smaller fraction infiltrated on the flotation due to its low porosity. Its main interest will be later discussed when referring to the fuel sources (Chapter 6.3).

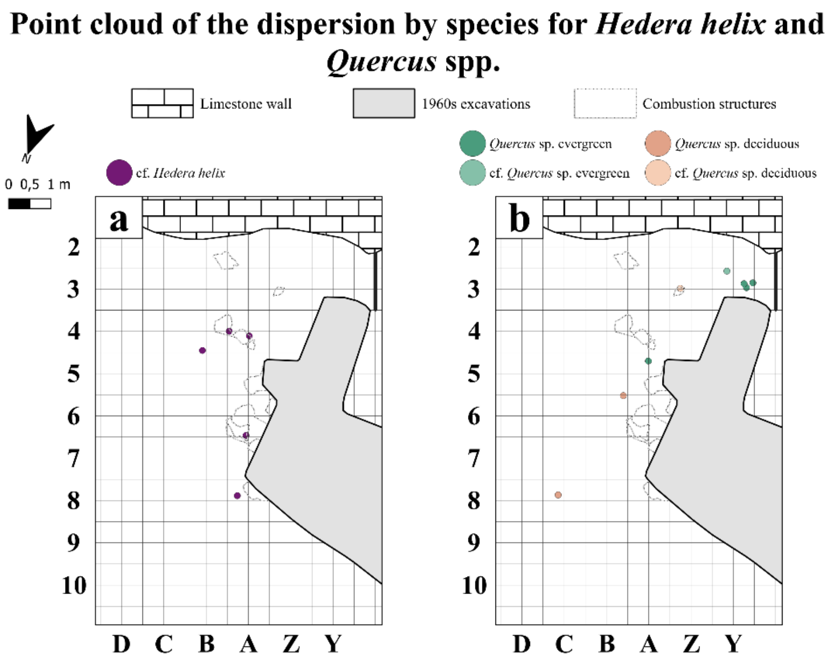


Figure 20 Maps of the particular dispersión by species groups for cf. Hedera helix (a) and Quercus spp. (b).

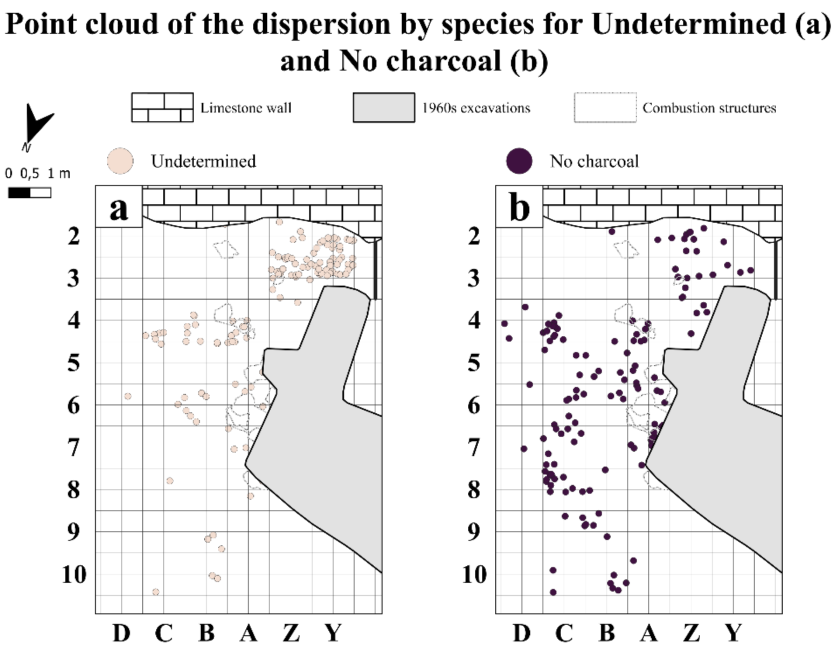


Figure 21 Maps of the particular dispersion for the Undetermined (a) and No charcoal (b) taxons.

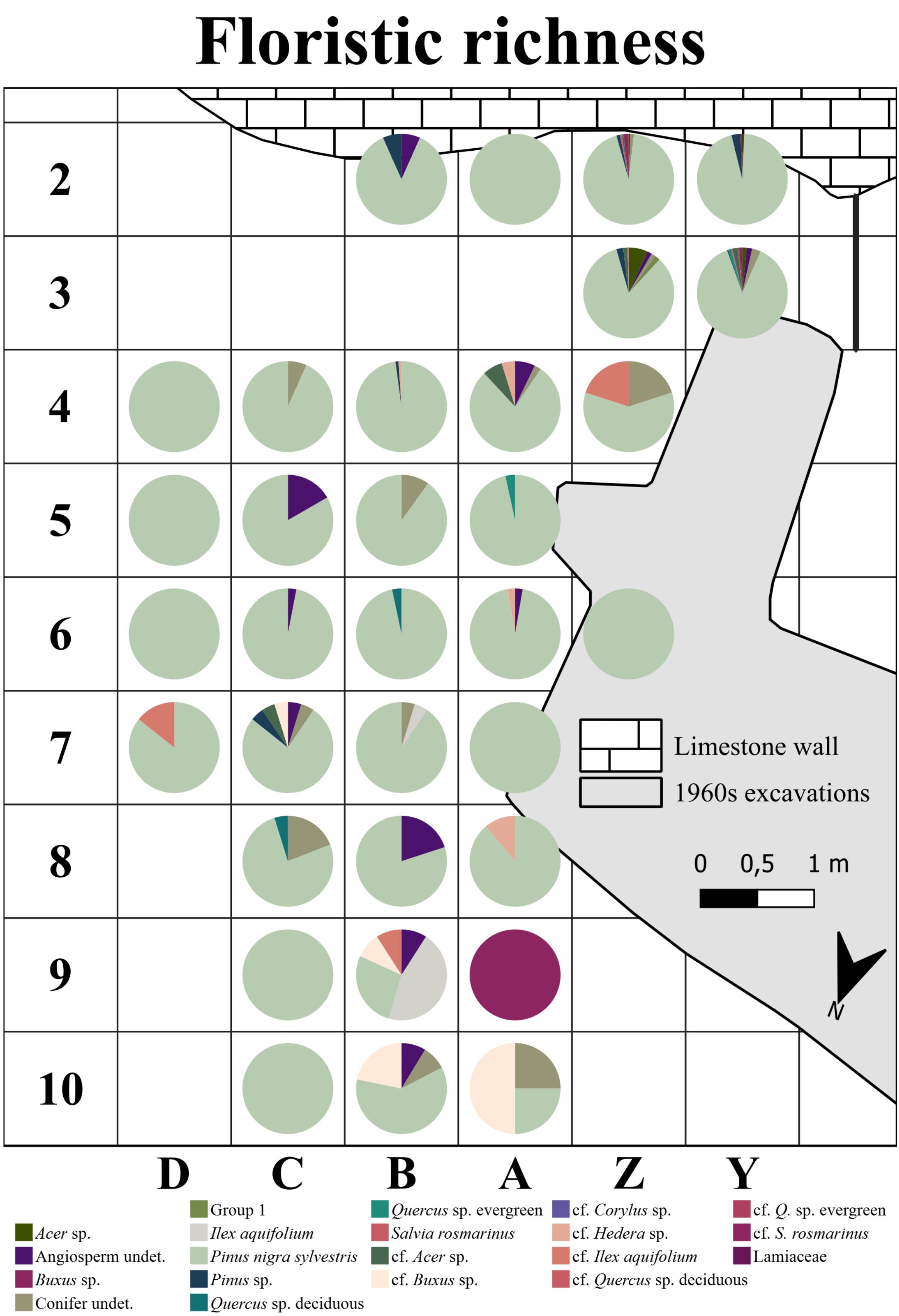


Figure 22 Map showing the floristic richness of each square and the taxa distribution though pie charts. The taxons No charcoal and Unidentified are not contemplated.

Another possibility to represent the results of the species distribution by squares is through pie-charts (Figure 22). The *No charcoal* and *Unidentified* taxa were erased from the count to obtain a more accurate image. When doing so, in the resulting map some interesting behaviors can be seen. The most noticeable is the dominance of *Pinus nigra-sylvestris*, which sums more than three quarters in almost all of them. The square A9 is the only one where there is no *Pinus nigra-sylvestris* and the only species present is *Buxus* sp. The explanation is that there is only one fragment in that square, what is creating that overrepresentation. Another reality that can be easily seen through this representation is how the squares richest in taxa are the ones on the Lg area. Meanwhile for the other squares the maximum number of taxa is 5, the Lg area triplicates this cipher, with difficulties to count them.

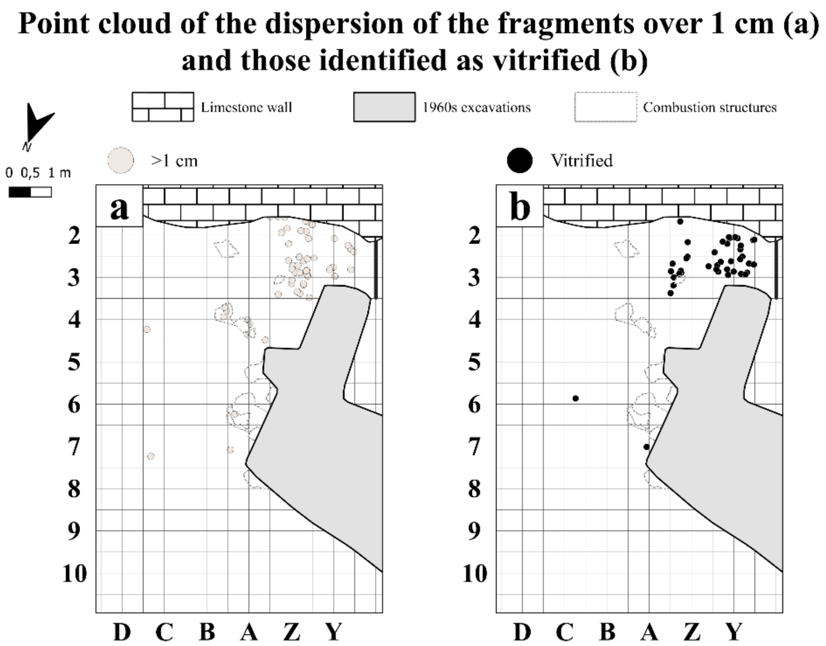


Figure 23 Maps showing the distribution of the fragments over 1cm (a) and those identified as vitrified (b).

Besides the taxa distribution, other aspects of the assemblage can be seen with the aid of spatial tools. One of them was to check how the fragments over 1cm behaved (Figure 23a). The distribution map shows a preferential accumulation on Lg15 and around the *fire installation*. The remnant dispersed material tends to happen within other accumulation areas, but not always directly relates with some combustion structure. When plotting the vitrified fragments instead (Figure 23b), the largest fraction is clustered on Lg15, with only two fragments outside, which at the same time are within combustion structures context.

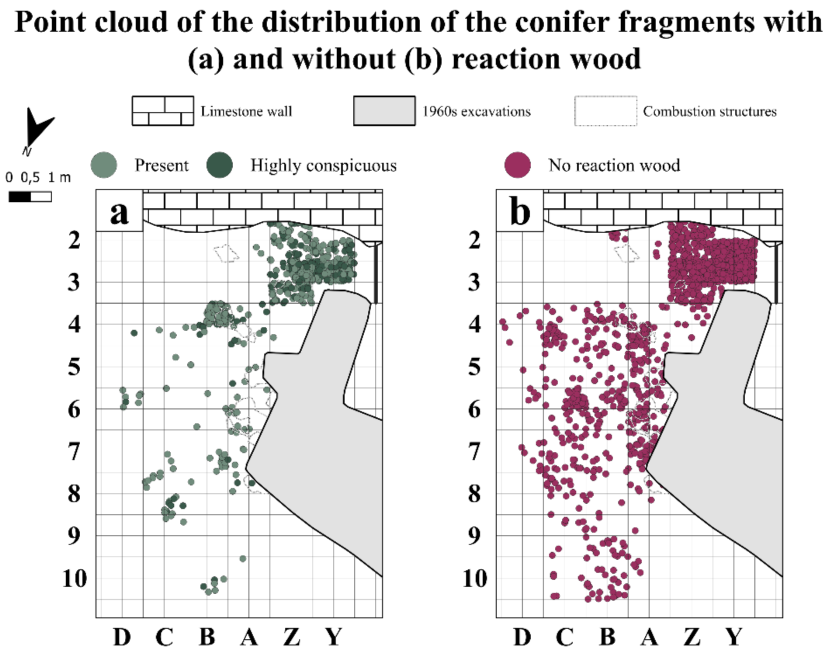


Figure 24 Maps showing the distribution of the conifer fragments with (a) and without (b) reaction wood.

There was another alteration analyzed that, due to the results retrieved, it was of interest plotting those fragments onto the grid. This is the presence and absence of reaction wood on conifers (Figure 24). The statistical analyzes showed that this alteration presence was more notorious in combustion structures than on the scattered assemblage. For the hearths there is one big plot into H105-115. The remaining ones only show some presence of them. The remaining ones are concentrated on Lg15 or dispersed through the surface, concentered where the overall accumulations are. When the fragments without tension wood are the ones being plotted some changes are noticed.

- First, it is dominant on the *fire installation* (H111, H112) and in H89, while it is more conspicuous on the remaining combustion areas.
- Second, in Lg15 it is dominant, and the same goes for the remaining little concentrations through the site surface.

Considering this, it seems possible that not all the hearths fuelled by *Pinus* sp. were consuming the same tree elements. Further analysis using dendroanthracology might throw light on this aspect.

These spatial analyses may also be done through other ways. In the following Table 12 the contexts in which the different species (and their cf.) happen, reviewing any potential particularity. For this, the conifers (t=29; 1.93%) and angiosperms (t=24; 1.60%) undetermined are not considered. These observations are expected to complement and help understanding the results obtained through the software.

Archeological contexts of the taxa	
Pinus nigra-sylvestris	Due to its absolute dominance of the assemblage, we can find it in every area and context.
***Acer* sp.**	They appear mostly in combustion structures near the travertine wall (lines A-Y), or in the scattered assemblage just surrounding them. Only two fragments are found towards the outside area, near the overhang.
Group 1 (Angiosperm undet.)	They only appear within the WL of the combustion structure H120.
***Buxus* sp.**	This species only appears in the facies B1-3, which equals the facies Lm1-3 in the outer area of the site, after the hypothetical overhang (rows 8-9).
cf. *Corylus avellana*	Within the scattered assemblage of the inner area (Lg15).
cf. *Hedera* sp.	It appears only in combustion contexts, both for the WL and BL, and all of them in the middle area (lines A-B, rows 4, 6 and 8, within the facies Lm).
Ilex aquifolium	Only present on the scattered assemblage (facies Lm1-3 and B-1-3), in the outer part of the site (mostly B9).
Quercus* sp. *deciduous	Only in the scattered assemblage of the middle part of the site (Lm).
Quercus* sp. *evergreen	Scattered assemblage but mostly into the inner area, the ashy context (Lg15).
Salvia rosmarinus	Scattered assemblage, the inner area and ashy context (Lg15).

Table 12 Summary of the contexts (dispersed/concentrated) where each taxon was found. When there is the species identified and its 'confer' group, both are grouped.

Overall, the concentrations found in situ –like those of combustion structures– will tend to contain fewer taxa given its nature of short-lived contexts, compared with long-term contexts –scattered assemblages–, its continuous use allows for a greater accumulation of material from several events.

In the following Figure 25 the taxa richness by facies was summarized. The *Unidentified* and *No charcoal* are included on the count. This figure illustrates how variability and floristic richness is correlated with the extension of the facies: the two largest (Lm1-3 and Lg15) are at the same time the richest ones. The average facies richness is 4, down to 3 if those two outliers are erased. The graph shows how in almost all the facies there were fragments not recognized as wood charcoal or others that could just be defined as that, not reaching further taxa identification. This diminishes the floristic richness of the assemblage, ending up with only 1 or 2 taxa in most of the facies. Another element of interest from this same paragraph is the upper area, where the ‘rare taxa’ happen. It is of interest how they appear and, besides cf. *Hedera helix* that is in both concentrations and dispersions, most of the 'rare' taxa are only in one of them (see *Buxus* sp. or *Ilex aquifolium*).

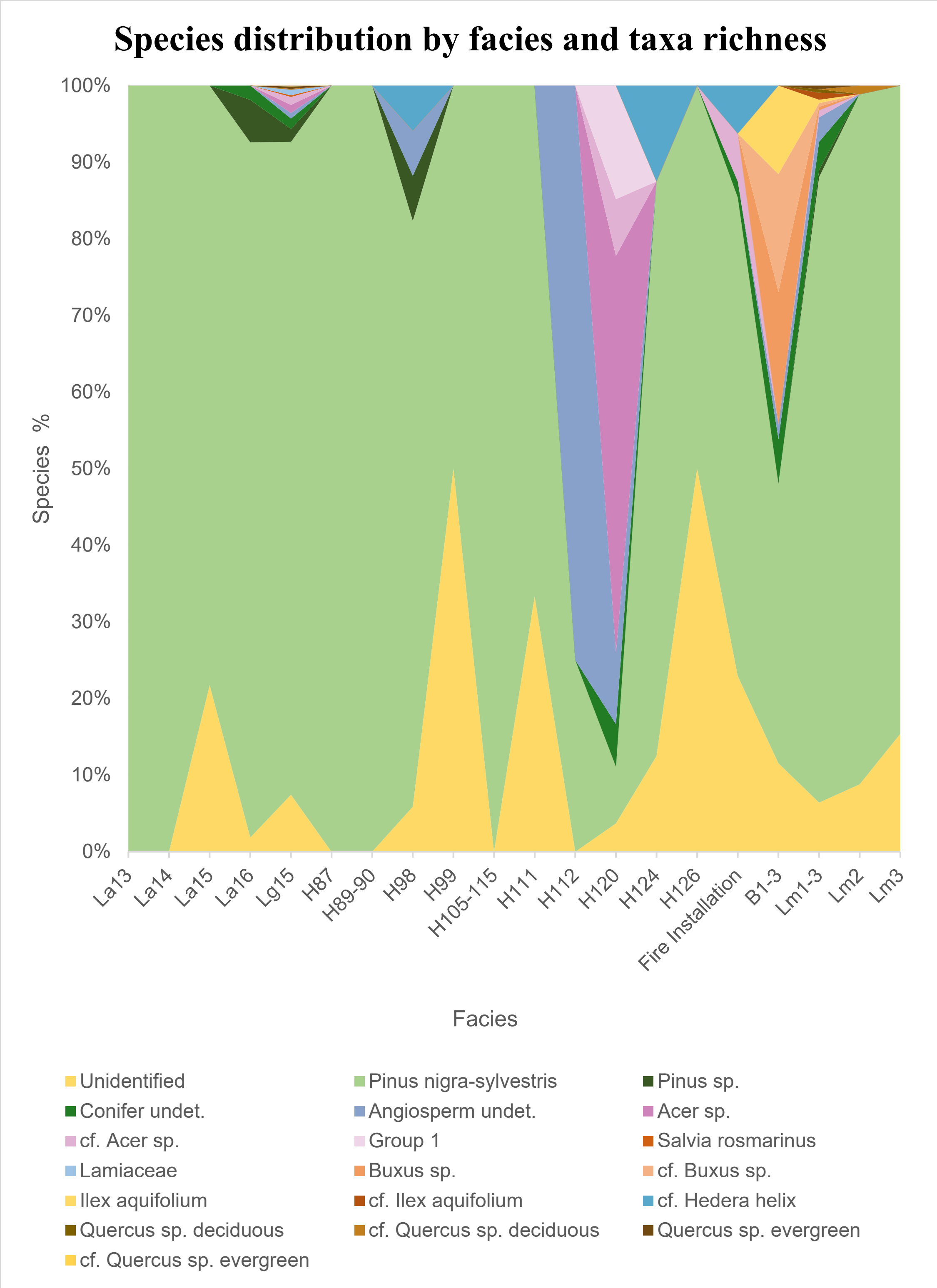


Figure 25 Accumulative graph by facies, with the distribution of the species and with the possibility to asses taxa richness for each one of them.

6. DISCUSSION

6.1. The anthracological sequence from El Salt, from Unit V to Unit XI: an integrative summary

After all the analysis done on the anthracological material recovered from Unit XI until the field season of 2024, this assemblage can be correlated with the results from the previous Units studied by Vidal-Matutano (2016). Preliminarily, Unit XI wood charcoal remains come primarily from cryophilous pines (91.2%), with punctual appearances of about another eight angiosperm species. The total flora richness measured through the number of taxa present is high given its Middle Paleolithic context, following the site trend. On the previous levels there were also numerous taxa identified (Figure 26).

Regarding more specific and particular data, there are two elements worth of review and further discussion. The first one is the facies Lg15, where almost 60% of the assemblage is coming from. Its small extension (condensed into $4m^2$) does not correlate with its importance. The definition itself of the sedimentary matrix of the facies describes this charcoal richness, tinting the sediment in a greyish tone. Is significant that this is the floristically richest area, where some species (*Salvia rosmarinus* and Lamiaceae*, Quercus* spp., *Acer* sp.) are exclusively or almost-exclusively condensed. Its position, right by the limestone wall, and for now the register of only one combustion structure (H120) rise the doubts over its formation process and the origin of all those wood charcoals.

Some possible explanations are given. The deposition being from anthropic origin, due to cleaning and maintenance activities, dumping the remains from the combustion structures there, creating an ash-dump. This scenario would be supported by the preferential vertical orientation of the archeological materials (bone fragments, lithic remains) on this area (C.F. Hernández personal comm.). At sites like La Roca dels Bous, France (Martínez-Moreno *et al*., 2004) and Kebara, Israel (Meignen *et al*., 2001), with the possibility of De Nadale Cave, Italy (Livraghi *et al*., 2019) joining the list, these ash dumps had been found. They tend to be pit features filled with homogeneous ashes, almost white and lacking charcoal remains (Knight, 2024), a description that does not match what there is at El Salt. However, micromorphological analyzes are needed to discard this phenomenon coming solely from biological-originated postdepositional alterations (burrows), and to check if microstratigraphic sorting of the layers exists.

It is also plausible that the charcoal accumulation in this area and facies is redeposited through bioturbation (trampling, burrows) or under erosion (Knight, 2024). It seems that these levels were more humid than the subsequent (see Chapter 6.2 for the paleoecology discussion). Mineralization and carbonate were registered on some of the fragments, and other alterations related to high humid levels show equifinality problems with other biological alterations (see Chapter 6.4 for further discussion). Within karstic contexts and for slopes <1%, 7-55% of charcoal from recent fires is eroded by rainfall (Rumpel *et al*., 2009). These fragments could be coming from the dense combustion area located three meters further north. But there are conflicting elements, like the accumulation there of all the fragments over 1cm, the vitrified ones and the existence of some species only found at certain spots (inside this facies or by the outer area). Once again, there is no way to shed more light into this problem until other proxies are analyzed and the results crossed.

The other particular element is the combustion structure H120. As it was referenced and described on the results section, even though it has nothing special on its morphology, it is unique regarding its fuel. The white layer is composed almost exclusively by *Acer* sp. (and other defined groups very similar: cf. *Acer* sp. and *Group 1*), with little presence of conifers, which are considered to possibly be coming from the below black layer due to postdepositional effect (i.e., trampling). This unusual firewood employed becomes of more interest when seeing that all the fragments of *Acer* spp. are related to this combustion structure, pointing towards a unique moment in time when this species was brought in and burned, possibly, for a specific purpose. Also, because almost the totality of A*cer* sp. fragments was within the altered group, indicating dead wood with mild alterations as its firewood.

This 'captured moment' and its assemblage gains in interest when reviewing the previous levels. In Unit Xb it was defined a similar case to that of H120, the H57 (Y3). In this combustion structure, with little post-depositional disturbances, almost 100 wood charcoal fragments were recovered from the WL. The morphology was unique to all the sequence: located close to the wall of the rock shelter, it was composed by a small ashy layer and a black one surrounding that central area. Some part of this structure was affected by the excavations from the 1960s, but the number of charcoals retrieved from the WL and the 253 charred maple seeds gave great interest for its particular study (see Vidal-Matutano *et al*., 2017 for the study).

To study the palaeoeconomical side of the structure H57 the taphonomical method of Alteration Levels and *Ai* (see Henry & Théry-Parisot, 2014 for the experimental assemblages) was applied to the conifers. For the angiosperms only the presence/absence of alteration was defined, resulting in the clear dominance (70-90%) of the altered group. The resulting assemblage with more than 80% of altered fragments suggests dead wood gathering strategies. More specifically, the presence of alteration (A.L. 1) was recorded in 90% of the *Acer* sp. assemblage, being it composed by degraded wood. The high taxonomical diversity displayed by this combustion structure could be additional evidence of this orientation towards specific state of the wood when gathering, as proof against species-driven selection (Vidal-Matutano *et al*., 2017).

In accordance with what Vidal-Matutano *et al*., (2017) already described, the paleoeconomical implications of using degraded wood as preferential fuel by Neanderthal groups may be mainly related with the hunter-gatherer way of life. The high mobility around the territory, with seasonal occupations would derive in the high value given to dead/decayed wood: 'easily accessible, readily useable, inexpensive to gather and capable of meeting all the group's fuel needs' (Vidal-Matutano *et al*., 2017: 118).

For the H57 the hypothesis of a smoking related function was proposed (Vidal-Matutano *et al*., 2017) due to the gathering of biodegraded black-Scots pine and maple branches. This state of decay in the wood makes it prone to easily absorb soil and atmospheric moisture, with the outcome of slower burning and greater smoke production. The localization of H57 very close to the rock shelter wall may be another indicator of a different function to those classically associated to the hearth-related accumulations (Vaquero & Pastó, 2001). For the H120 in Unit XI it is accepted this possibility of a smoking hearth. The main difference with H57 is the mono-taxa WL and the clear difference existing with the BL, which is almost only composed by conifers.

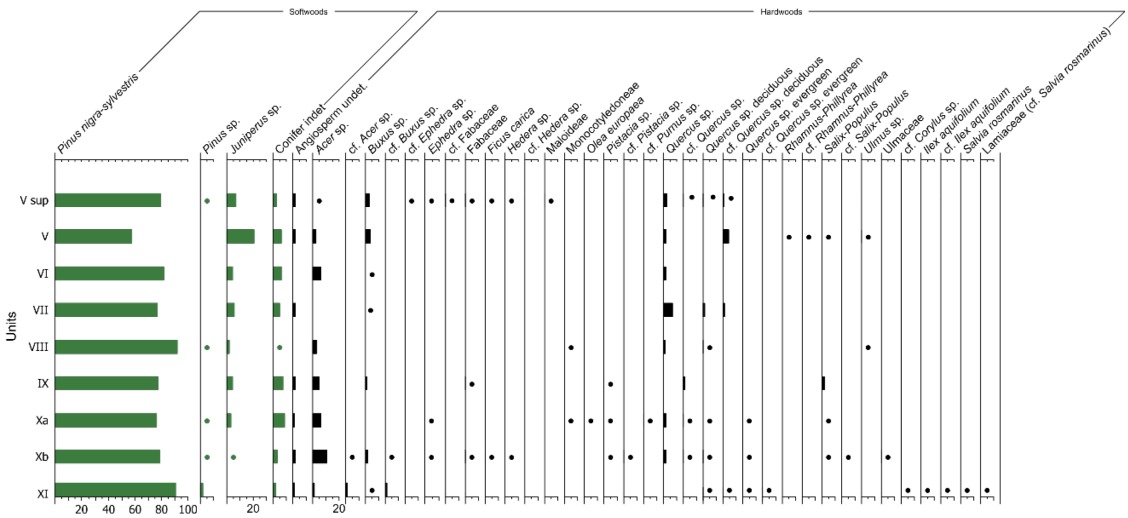


Figure 26 Accumulative graph of the species distribution through the archaeosedimentary units. . In green, the conifers. The dots represent those species with <1%.

Of great interest is to compare what was recorded in this Unit XI with the previous levels. This was only done with the scattered assemblage results because these were the data available from the previous studies (taken from Tabla 4, pp. 275-276, Vidal-Matutano, 2016). The data from Unit XI was adjusted as so, resulting in the Figure 26. When seen altogether, *Pinus nigra-sylvestris* is the predominant taxa through all the sequence. The values of Unit XI are, altogether with Unit VIII, the highest. *Juniperus* sp. is not recorded in Unit XI, the first one where that happens but, at the same time it seems that follows a disappearing trend that began on Unit IX. The second (*Acer* sp.) and third (cf. *Buxus* sp.) taxa, apart from conifers, are present in most of the units. The genre *Quercus* spp. has also a decreased presence in this last Unit, which could be read as a retraction of the mixed forest cover. Despite Unit XI being rich floristically, its record is not that high when compared with the previous units. This could be argued not only on the unfinished excavation process, but due to only reviewing the larger wood charcoal fraction, not analyzing the <2mm ones.

Resuming the idea of the effort invested and the results obtained after analyzing all the fragments above 2mm, coming back to the Figure 8 is of aid. In this it can be observed that the last new taxa (cf. *Quercus* sp. evergreen) appeared on the fragment 1326. It is worth taking into consideration that the analysis was done facies by facies, what explains the step-like appearance of the curve and that the taxa spatially gathered happens at the same time. 95% of accuracy was reached by the nineteenth taxa, just by the Lamiaceae (cf. *Salvia rosmarinus)*, on the fragment 1012. By half of the assemblage sixteen taxa were defined, which is already highly representative. However, the effort into analyzing all the fraction above 2mm was rewarded with high number of 'rare' taxa even without analyzing the smallest fraction of 1mm and below.

One question that arose once all the analysis was done and with the anomalous lack of material from some combustion structures is: how much of Unit XI was analyzed and is it representative? From all the combustion structures and subsquares dug but whose material never got to the analysis process, the reason lies on those bags still being stored at the warehouse and so there is no way that the wood charcoal could have reached the laboratory? This was not the only possibility proposed, but the easiest one to solve and discard. To do so, the following Figure 27 was created and may be of help with this problematic. The combustion structures here are included within the outlined occupation areas and their position in the current stratigraphy, which is still under development and revision. Take into account that all the combustion structures in pale green are those without material in each of the cases.

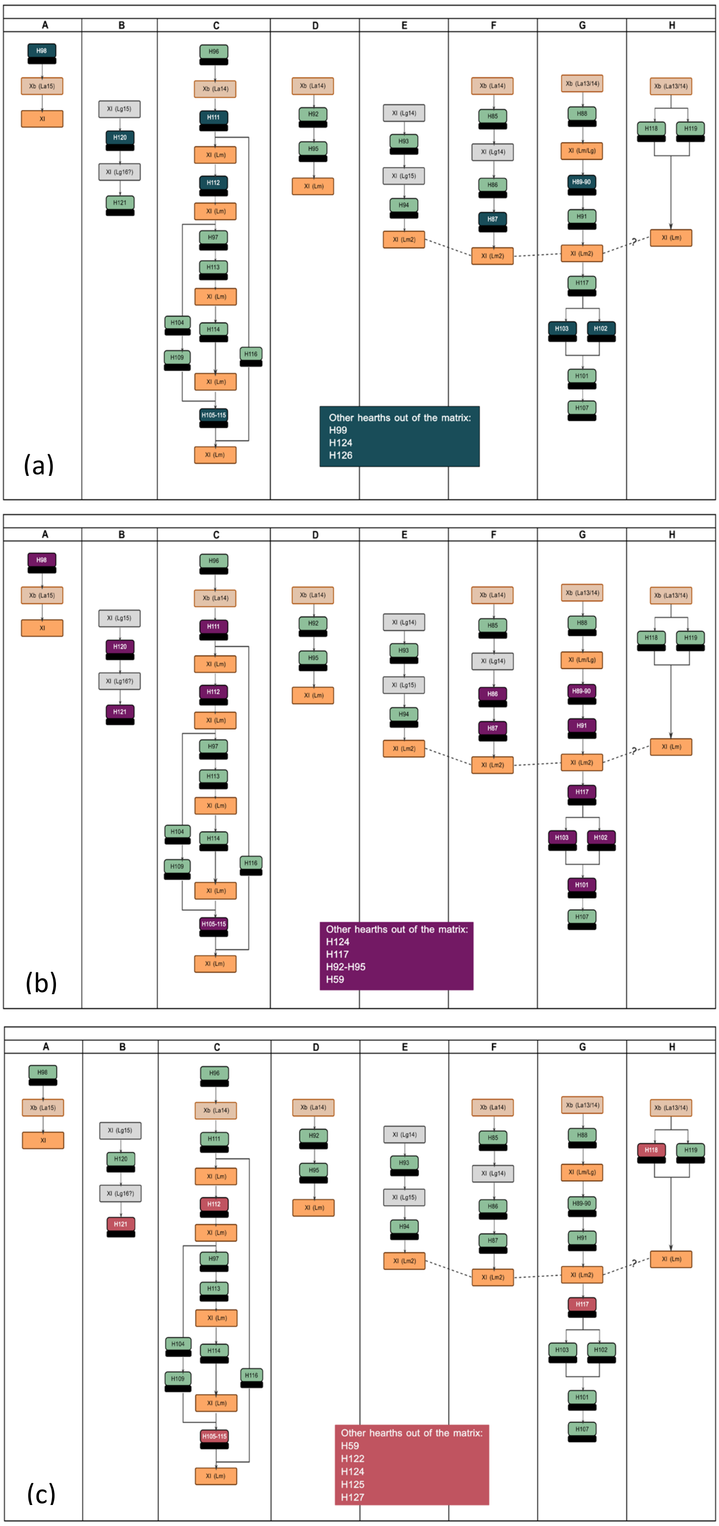


Figure 27 Provisional Harry's matrix of Unit XI, with eight accumulation areas defined (A-H) and the combustion structures comprised on each one. Each case reflects a particular scenario: (a) for the material analysed, (b) for the hearths with material that went through flotation, and (c) the sediment excavated but yet to be processed.

In the Figure 27a there is the representation in dark blue of the combustion structures from which wood charcoal was analyzed and is comprised in this work. The Figure 27b shows in purple the hearths that at some point their sediment went through the flotation process. When compared, not all the hearths match, and some of the ones that were water sieved did not make it up to the wood charcoal analysis. This problematic is partly due to the ongoing excavation and sediment processing of the Unit XI, but several possible scenarios must be considered.

Recovering the scenario where they had not gone through the flotation process yet, to try dismissing it all the bags of sediment stored in the warehouse to be water-sieved were reviewed one by one. Resulting from this is the Figure 27c, where the ones in pink are those which are yet to be processed. Comparing the three figures and only taking into account the combustion structures within the matrix, what results is: H121 and H117 have some remnant bags stored, and some others were already water sieved, but no fragments were analyzed. Also, H112, H86, H87, H91, H101, H102 and H103 went through water sieving, there are no remnants in the warehouse and no material arrived for analysis.

It can also happen that the WL was not conserved, diminishing the possibilities for charcoal preservation. The Table 4 already summarized this information. Other possibility is that the BL, where most of the wood charcoal fragments tend to be recovered, was thin or eroded, downgrading the possibilities for their preservation. May be that the fraction retrieved from those bags were under the 2mm threshold, and it is not that there was no wood charcoal, but it was not analyzed. If this was the case, the solution would be going back into the laboratory, finding those bags and review them for smaller samples.

The last case-scenario proposed is that, in fact, there were no wood charcoal remains in those combustion structures, proposing the possibility for the use of other fuels: bone, dead leaves, grasses, etc. To test it the anthracological record is not enough. More proxies are required such as micromorphology, phytoliths and even lipid analysis to obtain further information on the matter and get to some conclusion. This idea will be brought back in Chapter 6.3.

Returning to the question of how much of Unit XI was analyzed and if it is representative, the impression is that this work may be compiling about half of the materials from the Unit. Considering the ongoing excavations, how much is yet to be dug until reaching Unit XII in the whole surface, and the bags stores in the warehouse that need to go through the flotation process, this is the estimation. If that is correct, the assemblage of this work is already representative of the Unit XI, and almost the totality of its upper section.

6.2. Paleoecology: initial approximation

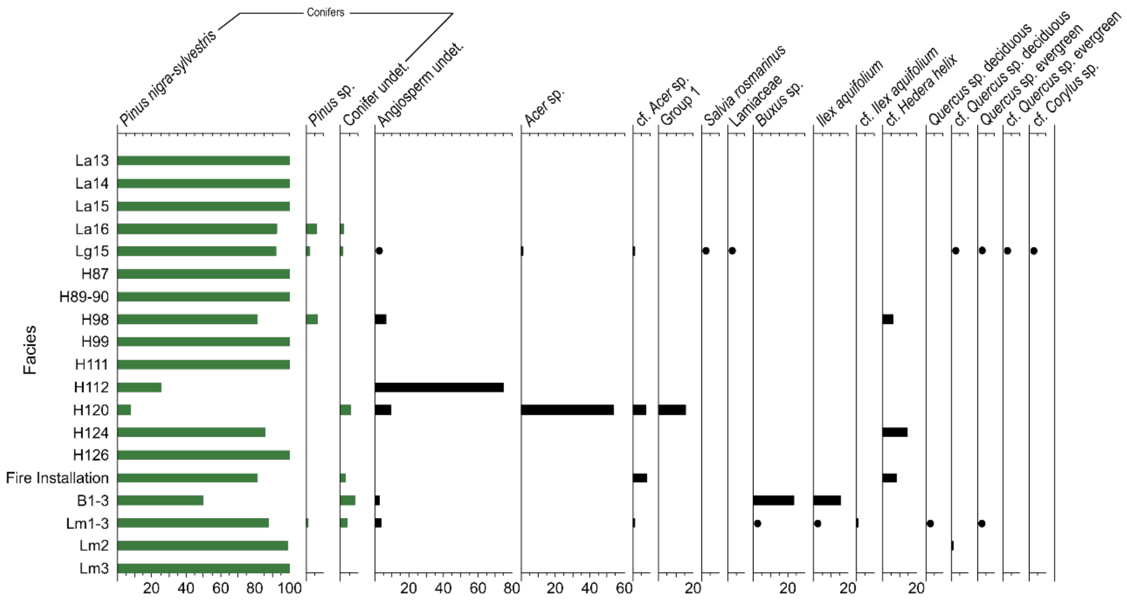


Figure 28 Bar graph representing the species found in each facies of Unit XI for paleoecological interpretations. In green, the conifers. The dots represent those species with <1%.

Following the resulting floristic list (Figure 28), the surrounding area when these Neanderthal groups were occupying the site of El Salt had an important representation of cryophilous pines, which were the main firewood used. Within the Mediterranean climate, it cannot be stated specifically which bioclimate. The percentages obtained from the analyses are not considered to be equaling the actual ecosystem. *Pinus nigra-sylvestris* must have had an important representation on the surrounding area, but it is not expected that it was the main component or the dominant species of the arboreal mass. Given the area where the site is located, the possibility of these being *Pinus nigra* instead of *P. sylvestris* was pointed by other authors (Vidal-Matutano, 2016; The rest of the species identified may have had greater presence on the landscape, and the percentages obtained at the site should not be interpreted as the paleoenvironmental reality. What this floristic list provides is a relation of a series of existing woody taxa which, for one or another reason, were brought into the site by the groups inhabiting there.

Further information about ecology may be seen from the type of environments (i.e., humid, cooler, poor soils, etc.) where this species grow. What is seen is a predominance of taxa requiring high humidity, in need of more precipitation than the current regime or coming from a very humid area. Some of these species are *Betula* sp. or *Ilex aquifolium*. This last one is also an indicator of cooler temperatures, nowadays preferring northern latitudes, reducing its place to the mountains when descending. Also, most of them tend to prefer hill slopes or the bottoms of the valleys to grow, matching the surrounding area. These species were growing nearby the site or within their habitual hunting/gathering routes.

This possible higher humidity rate may be one of the plausible explanations for the visible presence of hyphae on some fragments. However, this must be taken with caution, and more experimental work must be done on the matter to test its possibility. When wood charcoal fragments are left, after carbonization, in a place with very high humidity rate (70-90%) and high temperatures, where there is no bark, it is not infrequent for hyphae to develop on them. Considering this possibility, it could be that constant presence of water and reigniting the fire on the same spots created the environment needed for this phenomenon.

There are three potential species identified in this unit that never were defined on El Salt. The first is *Salvia rosmarinus*/Lamiaceae, bushy family recorded here for the first time. This taxon was already present on Unit IV of Abric del Pastor, another MIS4 site only 4km away from this site (Vidal-Matutano, 2016). Striking not only to find it very restricted spatially (Lg15), but due to its nowadays frequent use for culinary or medicinal properties, all of them give off great odor. Other possible new species is cf. *Corylus* sp., which would be the first both for this site and also for Abric del Pastor. It is particularly interesting how also this taxon requires a lot of humidity. The last one is *Ilex aquifolium*, a species not found until now and whose few remains are very condensed on the outer area.

For a correct paleoenvironmental reconstruction, models of species distribution should be done with the floristic list. With that, more specific data could be given about ecology. Due to the time and scope of this work it was not possible to do so, but it may be of interest in the future when all the levels are analyzed. When that time comes, an approach through multi proxy analysis will be of great interest. The contributions of short range/local materials (anthracology) with other of regional scale (micromammals or pollen) will provide the broadest picture.

6.3. The woody plants, gathering patterns, and the relationship with Neanderthal groups

All the wood charcoal fragments studied are the remains of the fuel used during the several occupations of the site to feed the numerous combustion structures on them all. The anthropic origin of the assemblage, both the primary accumulations as well as the dispersed materials, is the first bias regarding the paleoecological representativeness. But what this provides is the paleoeconomical perspective, the potential reasoning behind the selection of each of the species.

Following the literature, and after analyzing the assemblage, it seems that typically the species was not the main factor behind the selection of one or another wood fragment as fuel. This may be best seen over the combustion structures, where this ‘preferred wood’ or ‘good fuel’ should be reflected. It could be stated that *Pinus nigra-sylvestris* was the one taking this position, but the *Ai* is way greater on these primary accumulations, with signals for decayed wood, even when other taxa are being used as fuel (case of H120). What seems like the determinant factor in gathering strategies is the state of the wood and it being already available to be burnt. When there is a desired and specific utility for one of the combustion structures the fuel may be chosen bearing that in mind. This may be the case of H120 (Unit XI) and H57 (Unit Xb), proof of the knowledge that these groups had of the arboreal resources and their responses.

Even though wood charcoal is the material analyzed through anthracology and the most commonly interpreted as fuel (Solé *et al*., 2013), there are sites with evidences for other sources, including bone, non-woody plants and other residues (Albert & Cabanes, 2007; Albert & Weiner, 2001; Albert *et al*, 2012; Aldeias *et al*., 2012; Allué, 2002; Allué *et al.,* 2012; Asouti & Austin, 2005; Berna & Goldberg, 2008; Cabanes *et al.,* 2007; Courty *et al*., 2012; Goldberg *et al*., 2012; Madella *et al*., 2002; Mallol *et al*., 2013; Sandgathe *et al*., 2011; Théry-Parisot, 2001, 2002a; Théry-Parisot *et al*., 2009; Yravedra & Uzquiano, 2013).

Up to 7.7% of all the analyzed fragments could not be defined as wood, which were interpreted as trabecular bone fragments. If they were actually small, charred bone fragments, its abundance and dispersion may lead to the question about alternative fuels being used. A debate exists about the use of bone as fuel and its utility, if it is being used as additional and alternative fuel, for some specific tasks or if it is just product of cleaning and maintenance of the site surface (Braadbaart *et al.*, 2020; Costamagno *et al.*, 2009; Gabucio *et al.*, 2014; Théry-Parisot, 2002b; Yravedra & Uzquiano, 2013).

Bone as fuel provides temperatures of c. 540ºC (Glazewski, 2006), but it needs an already burning fire to ignite, unlike wood which can start it. No fire could be 100% bone-fuelled (Knight, 2024). Its proposal as an alternative fuel for the Unit XI of El Salt must be contrasted and discussed with the fauna and micromorphology studies, checking if it could be the case with possible cleaning function, or if these fragments are probably wood charcoal fragments vitrified.

However, this is not the only proposed as possible alternative fuel, with special focus on grasses and dead leaves. During the micromorphological study of combustion structure H89-90 by A. Dinçal (in preparation) almost no presence of wood charcoal was registered, and, for the WL, its main component seemed to be coming from grasses or leaves. Phytoliths on anatomical position within those samples seem to point towards the same vegetal elements. At least some of the retrieved sediments from this combustion structure were already water sieved, and the wood charcoal analyzed. It was appealing to verify that only one remain was recovered from that sample. This discovery led to further revision and to setting out the possibility that other vegetal fuels (i.e., grasses) were used in other combustion structures for which almost no wood charcoal fragments were recovered, or even no one.

About the catchment areas what can be said is inferred from the taphonomical analyzes. Humans tend to rely upon a circumscribed number of species gathered in an area around their location, so called the catchment area. Consequently, the catchment area represents an anthropogenic species-area relationship (O'Connor & Evans, 2005; Roper, 1979). The species-saturation curves for woody taxa must show, overall, the human-managed surroundings. Other anthropic factors to take into consideration are cultural preferences and fuel quality, which can distort the reality of abundance and taxa distribution in the area.

Furthermore, the curvature of the growth rings showed that the assemblage was composed by straight ones, only the category of soft curve reaching the statistically representative level. Of greater interest is the presence and absence of reaction wood within the softwood. Up to one third of the assemblage displays this alteration, and it is differentially distributed between concentered and dispersed materials, with a clear tendency towards the combustion structures. Considering the ecological and biological-stress induced implications that arise from its presence, the case scenarios could be or the presence of strong winds, the accumulation of snow for prolonged periods or crooked branches or leaning stems growing over hills. Attending to the mountainous landscape and knowing the high rate of dead wood production by *Pinus* spp. the last is the most possible.

With that said, the catchment areas of this mountain pines would be the surrounding hills, maybe taking advantage of hunting or gathering trips and routes. Whatsoever, there is even the possibility following what was said for previous units (Vidal-Matutano, 2016), that species like cf. *Hedera helix* were brought attached to other branches, tangled with them. Another case scenario that could be proposed is that, following the current situation at the site, the cf. *Hedera helix* grew attached to the limestone wall and fell from it when dead. Those dead remain over the surface would have been collected and used by the groups once there, maybe for clearance of the area. The other possibility is that those fires were lit over these remains, getting burnt by accident.

In a very recent work about Abric Romaní level Ra (Fernández-Iriarte, 2024) it was also noted a high level (77.7%) of 'compression wood', revealing its presence in most of the charcoal fragments. After the application of the Alteration Levels, the resulting indexes pointed towards the range of dead wood, with light to medium alterations. For this assemblage the percentage is much higher than for El Salt, and similar gathering practices are proposed. In this same site the presence of hyphae has been interpreted as a post-depositional process. The hyphae's structure is preserved due to the high presence and accumulation of water, which is saturated in minerals coming from the limestone walls (Fernández-Iriarte, 2024). This post-depositional origin is also the hypothesis considered in El Salt Unit XI assemblage. It comes from the fact that most of the fragments found with hyphae were angiosperms, and mainly bushy species.

Following Henry & Théry-Parisot (2014), they propose that the assemblages dominated by conifer environment and very high *Ai* are ought to be investigated together with other proxies (heart's shape, burned remains, use-wear analyzes) to formulate hypothesis regarding the possible different hearth functions. At the site of El Salt more proxies are being integrated to do so, and they will be coming out during the next years: soil micromorphology, phytoliths, biomarkers (lipids), archaeomagnetism and pollen sequences.

Through the study of charcoal assemblages not only the management of wood species and habitat space may be represented. Other essential but frequently forgotten aspects can be discussed, like the gathering of the resources and their incorporation into daily life. Bearing the interplay of culture, the economy, technology and the environment, as the decisive factors on the decisions taken, these studies allow for greater and further view on the Neanderthal relation with the arboreal mass.

6.4. The 'palimpsest problem', the organization of the habitat area and the troubles within the methodology for the approach

For the assemblage of Unit XI this palimpsest dissection is still ongoing altogether with the field works. It is shown on the numeration given to the facies and combustion structures. The results here obtained, mostly through the *Ai* and the proposed alteration levels may be other tools to consider for this disentangling of the facies. However, the help provided by the anthracological analysis will be better applied and discriminated once the Unit has been completely excavated and other proxies have been analyzed. The paleoeconomical information coming from anthracology, jointly with that coming from other proxies such as lithic tools or faunal remains, between others, will be useful to define the trends, continuities and changes through the recorded assemblages.

As said the formation of this combustion structures is solely anthropogenic, meaning that they can be understood as direct transmitters of cultural behavioral information (James, 1989; Mallol *et al.*, 2013a). This is said after it was recorded in several Middle Paleolithic sites evidence of regular and intense fire use represented by hearths, sometimes stacked and associated with ash-dump areas for site maintenance (i.e., Hayonim and Kebara in Israel (Goldberg & Berna, 2010) or Roc de Marsal and Pech de l'Azé IV in France (Aldeias *et al.*, 2012; Goldberg *et al.*, 2012)). Like any other artefacts, combustion products and residues reflect physiological and cognitive skills in problem solving as well as communicative and learning capacity on technical knowledge. These passing of the ideas and techniques is what underlies as culture (Allué *et al.*, 2022). To recognize cultural processes involved in the formation of archeological sites is necessary to typify them spatially (Polo-Díaz *et al.*, 2016; Vaquero & Pastó, 2001; Vaquero *et al.*, 2004).

The cultural approach to the anthracological assemblages is coming from the anthropic decisions made during the gathering process and the pyrotechnological tradition, if it exists. To try distinguishing it, the recurrence of phenomena is one of the ways. In El Salt, further from *Pinus nigra-sylvestris* always being the main firewood used, the recurrent position of the combustion structures over the same areas and spots or even the apparent frequent use of degraded wood could be interpreted in these cultural terms. The more particular case of combustion structures H57 and H120, which are in different units but share a lot of traits and particularities may also be read in those terms. Also, the cases where some species are found only at a specific point of the site surface, with distinguish between the inside area (see *Salvia rosmarinus* and cf. *Corylus* sp.) and the outer area (see *Buxus* sp. or even the distribution of *Ilex aquifolium*). These differences regarding their location may be due to dissimilarities in how they were brought into the site (anthropic or natural origin, maybe), or after their use or purpose. There are several elements from the record to be interpreted as cultural behavioral information, what will be one of the multiple pieces of the puzzle when this is interpreted from a holistic perspective.

However, there are several methodological problems with the conservation of the assemblage, its representativeness and even the methods developed to address the alterations. The first method where it is seen that some distortion may be occurring is the Alteration levels. As it was lengthily reviewed, the highest values of the assemblage are found on the combustion structures, which simultaneously are the samples that suffered the greatest number of alterations. This is considering that at least the materials from the WL were brought to be intentionally burnt. Another result that follows from the separate analyzes of the layers is that through taphonomical studies on Alteration levels, it may be possible to differentiate one from another. When the excavation process and the sampling method has been done cautiously and with rigor, maybe the possibility of assessing a missing WL undefined during the excavation process could be argued and tested with experimentation and the comparison with other sites. This is what can be concluded after analysing this assemblage and the site of El Salt, where the priority starting from the excavation method defined and followed is palimpsest dissection.

Despite this results, one concern arises regarding the accuracy of the *Ai* method when studying combustion structures materials attending to the difficulty of differentiating between some biological and combustion alterations. Considering this far higher indexes obtained for the primary accumulations and that originally the scattered assemblage is assumed for the most part to be coming from previous fires, the existing variance has to be result of an unknown process. After this comes the proposal of the possibility of an overrepresentation of the *Ai* caused, indeed, by the thermoalteration, which exacerbates it, leading to this dissimilarity.

The methodological greatest problematic faced is the representativeness of the final assemblage in connection with the initial deposition. There are several factors that may be diminishing it, like the phonological state of the materials themselves and the sampling method applied. Arranz-Otaegui (2017), between others, already warned about the diminishing of the fragments in poor state of preservation when water-sieving methods are applied. This scenario and possibility were also expressed by other authors who applied the Alteration levels (Vidal-Matutano *et al*., 2017) with the classes for the highest alterations apparently underrepresented or directly missing. This may also be happening in the assemblage here analyzed, where for a lot of facies or structures the group 3 is inexistent. The diminished poorly preserved fragments may create a distorted image, all of it resulting from this phenomenon.

The other operating factor is fracturation. Lengthily studied and experimented, for this assemblage two key elements during the excavation and processing of the samples may be increasing it. The first one, and following the previous discussion, applying water for its recovery. The second one would be the vacuum cleaners used on the excavation process, which at the same time that allow for the recovery of the maximum amount of wood charcoal, may aid on the fragmentation process suffered. This recent fragmentation of the assemblage components can be seen mostly on the *Pinus nigra-sylvestris* fragments, where the fractures of the sections were fresh and had the tendency towards the same pattern and morphology (see Chapter 5.1).

Other problems of equifinality stem from thermoalteration, and the difficulties to measure and define them for the overall scientific community becomes another obstacle. The classes in this work proposed gave new insight when reviewing the results, and its potential usefulness can be argued. It is prompted the possibility of a systematic series of experimental works that, altogether with the results and comparison of archeological assemblages, lead to the proposal of a measurement system which assesses combustion alterations and intensity.

Additionally, attending to the ‘rare taxa’ with under 1% presence, as well as the similar alterations within each taxon, reservations exist over the possibility for most of these cases of coming from one original sample, fractured over the process of retrieval. Subsequently and knowing that several taphonomical agents and processes are happening, concerns regarding the representativeness of the resulting assemblage in comparison with the total original burnt firewood arise. This problem comes from the method and methodologies applied, and further review and experimentation on the matter is needed to properly address it, but it should be taken into account when coming into conclusions.

7. CONCLUSIONS

Reaching the conclusive chapter of this work, an overall view of what was presented here is coming forward. El Salt Unit XI, even though still on the excavation process, has provided encouraging initial results, being this the only analyses completed for the archeological unit. The dense palimpsest nature is still present, with up to 33 identified combustion structures, assessing for recurrent occupation moments of Neanderthal groups during MIS 3.

The followed anthracological method, with the identification of the fragments up to the species level when possible, and the taphonomical assessment were effective. However, numerous problems of equifinality exist with taphonomy, and they are assessed in the respective chapters. The results obtained are promising, providing further insight on the economic management of these groups over the arboreal cover. Extended works on this and other sites may help to further define and summarize the strategies and preferences on this region.

Future perspectives covering the study of El Salt are, first and foremost, to finish the study of Unit XI. For this, some years are expected to be needed due to its ongoing excavation. It will be of interest seeing if the results presented in this work are representative of the unit or if they follow its overall trend. Once this finished, the comparison with the previous archeological units will be once again reviewed. With all those results, the anthracological contributions can be considered another proxy for several studies: paleoenvironmental reconstruction, gathering and management of the site resources and their possible catchment areas. Of great interest and value would be reviewing with the team the possibilities for other more specific group-projects, like the proposed for the alternative fuels or to test with lengthier experimental work the suggested classes of combustion alteration. The special attention given to reaction wood and the results retrieved are positive for future studies on the matter. It would be delightful to work with other colleagues and sites, outlining the presence and rich information that taphonomical alterations like this one offer. It is also expected to put out a publication derived from the present work and continue working with Prehistoric anthracological assemblages during the next years.

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