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(Unidade Departamental de Arqueologia, Conservação e Restauro e Património)

Erasmus Mundus Internation Master in QUATERNARY AND PREHISTORY

Master Thesis:

The Use of Space Among Neanderthals: Anthracological Spatial Taphonomy of the Charcoal Assemblage in Abric Romaní Level Ra

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Abstract

The presented work has, as main objective, the characterisation of the formations processes of the charcoal assemblage level Ra from Abric Romaní site. This well-known Middle Paleolithic site is characterised by remarkable good preservation conditions. The assemblage was studied using the anthracological methodology including taxonomic and taphonomical observations. The data generated was compared with previous levels and studied using statistical methods, mainly descriptive analysis, correlation and clustering. Afterwards, there were applied spatial analysis to improve how assemblage formation processes interacted in the space.

The results that we present are contextualised in the beginning of MIS 3, where there was an immediate environment composed mainly by *Pinus sylvestris* type conifers. Temperate taxa were in the nearby areas though, since we found more *Prunus* sp than in other levels, which could be related to the expansion of arboreal taxa occurred around 58ky BP. Taphonomical studies showed that the post-depositional processes were low or moderated, and affected discrete areas in the surface. There are two main areas that could correspond to the in and out of the dripping line areas (dripping line has not been established yet). The outer area could have slightly heavier mineralization effects, although there were not detected movements. As in other levels, the distribution of the materials seems to be mainly caused by human action. We found clear differences in the charcoal distributions of the northern and southern section of the excavation surface. In the first, the clusters of charcoal fragments were overlapped, bigger in accumulations and directly associated with hearths while the southern section has discrete clusters, with lower accumulation and not direct association to the hearths, excepting few individuals. The interpretation is that in the northern section there is more palimpsest effect with more intensive use of the area, such as in other levels. However, the southern section could be representing waste-management events. These clusters can be interpreted in different ways (primary or secondary refuse), more data from other materials is necessary. considering the location of the southern cluster it seems that the actions were related to the reuse of the hearth structures. We consider that spatial studies on charcoals can be a great insight to complement the spatial studies of other materials and shed light on the hearth-related assemblage formation and the evolution of domestic spaces.

Keywords: Anthracology, spatial analyses, taphonomy, domestic spaces, Middle Paleolithic.

Structure of the work

This work is structured in in seven chapters that are described as following:

Chapter 1 Here there are presented the main questions that guide the work, the hypothesis and the epistemological baseline from what we start.

In chapter 2 we introduce the paleoenvironmental context of the site. The approach goes from general to particular, focusing on the Iberian Peninsula first and the regional context later. Subsequently, is made the introduction to the site, here we present the Abric Romaní, the history of investigations and the current situation.

Chapter 3 is devoted to the methods that we applied. Here are described the history of anthracology and spatial analysis in archaeology. Then, we explain how the charcoals were studied using the anthracological methods. Afterwards are presented the traits that were used for the identification of taxa and the taphonomical characterisation. how the data generated was subsequently used for spatial analyses.

Chapter 4 shows the result of the analysis presented in chapter 4. Firstly, are discussed the taxonomic identification and the taphonomical characterisation. Then, the statistical and geostatistical results are presented.

In Chapter 5 the results are discussed and interpreted. The structure of this chapter is based on the characterization of paleoenvironmental context, postdepositional formation processes and the behavioral context. First there is a paleoenvironmental characterization, considering the anthracological data related to the information provided by the literature published. Then, there is a characterization of the postdepositional assemblage formation processes. Subsequently there are discussed the cultural formation processes based on a behavioral interpretation. Finally, there are discussed the results in the context of Middle Paleolithic and the emergence of modern behavior.

Chapter 6 closes the work pointing out the main conclusions that this work has reached, and the future perspectives that brings to the study of Middle Paleolithic assemblages.

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1.1. Introduction

The study of the past of humankind is a domain that comprises the specialized analysis of diverse materials and investigation lines. These lines are necessarily interconnected and are interdependent. To progress in the reconstruction of past human groups it is a necessary condition that investigation in different disciplines develop together, creating a basis of common understanding. Among these disciplines there can be mentioned paleoenvironment, geology, sedimentology, zooarchaeology, archaeobotany, genetics, technology and so on. In addition, there are constrains that condition the way in which the sciences developed throughout history. Among these, there can be mentioned the methodological traditions that each country or region have, the materials to be studied and their availability, conservation and other factors that can affect the accessibility to the scholars.

Another important factor that affects how *things* are studied is the theoretical-methodological background. In archaeology is quite interesting to study how the shift in theoretical approaches affected not only the methodological aspect, but also how questions are formulated. In this sense, the development of Prehistory is a clear case, where the shift from historic-cultural approach to processualism, and in some degree to post-processualism, changed the way that problems are formulated and studied (Shanks & Tilley, 1987). The topic of behavior evolution and its reconstruction is the consequence of the summarized investigations in different materials such as the above-mentioned zooarchaeology, geoarchaeology and so on, but also it requires a higher level of inference based on the integration of the data provided by all these investigation lines. In this sense, the ability to detect evolutionary tendencies in the behaviour of *Homo* genus relies on the acknowledgment and interpretation of significative differences in temporal and spatial variability of the archaeological remains. Sometimes these great tendencies are difficult to characterize due to the different materials considered and the progressive nature of the evolutive trends. When studying the evolution of modern behaviour, scholars agree that the use of fire is a turning point in the human evolution that is related to the emergence of the domestic spaces, which in turn will create a synergy in the cultural and social evolution (Clark et al., 2022; MacDonald et al., 2021). Domestic spaces are product of the structuration of the use of the space, these spaces increased they archaeological visibility in the Middle Pleistocene (MacDonald et al., 2021) and this visibility was in part due to the pyrotechnology, which allowed the emergence of hearth-centred domestic spaces (Clark et al., 2022; Kuhn & Stiner, 2019; Roebroeks & Vill, 2011).

From an anthropological and ethnographic perspective, the house-societies have their cultural and social relationships organized physically and conceptually around the household, which acts as a locus from where the society is established, maintained, and organized (Clark et al., 2022; Lévi-Strauss, 1982; Lévi-Strauss & Willis, 1987). Then, the spatial organization could be considered the reflection of the social or systemic relations. Considering this topic from systems theory is useful the application of the "feedback" concept to the hubs or locus. The retro alimentation that the feedback of recurrent activities in the hub or loci provides over the social activities could create an increasingly complexity. The cumulative culture is then understood as the part of the process but also as a result (dynamic and static perspectives). This process is a cultural niche construction where synchronic conditions of the system affect the diachronic conditions, raising pressures in the way that individuals adapt ontogenetically to their cultural environment throughout learning, social transmission innovation and so on.

This work aims to contribute to the understanding of the spatial organization of the hearth-centered structures in the Ra level using the charcoal analysis. The determination of cultural formation processes is important considering that the Abric Romaní has several occupation layers where spatial distribution is assigned to human action. Also, this will be the first spatial taphonomy analysis in the charcoal assemblages from Abric Romaní. The spatial anthracology could contribute when combined with spatial analysis of these materials to the understanding of the dynamics of the site in the context of Middle Paleolithic and the emergence of modern behavior. The Abric Romaní site is a privileged location for the study of topics that aim to reach interpretations close to the ethnographic time. The study of hearth-related assemblages considering the distribution of charcoal remains is a new approach that could contribute to the knowledge of the emergence of behavior associated to the domestic spaces. Also, the anthracological study is the main source of information of the fuel source strategies which is related to the knowledge of the environment and likely representative of the paleoenvironmental conditions of the immediate areas of the site as has been proposed in previous works (Allué, 2002b; Allué et al., 2017; Allué et al., 2009).

1.2. Problematic

The characteristics of the archaeological inquiry impose the necessity of understanding first the sedimentary environment and the processes that affected the archaeological material for being able to propose hypothesis about cultural formation processes. Even if cultural processes are the ones that formerly create the conditions for the deposition of materials, these are found by archaeologists after the effects of post depositional processes. Cultural formation processes would be able to be evaluated in the case that it can be supported that the post depositional processes did not affect significantly the behavioural informative traits of the remains. The spatial distribution of charcoal might be random or patterned, being a whole range of possible distribution between these two extremes. Following the definition of an activity proposed by Schiffer (1972) (described bellow), it will be expected to have non-random patterned remains plus randomizing post-depositional processes. The effects of the post depositional processes could be non-random as well but would the summatory of different pre- and post-depositional processes should randomize distributions if the post depositional processes affected the location of materials. Spatial analysis of charcoal alterations would be useful to dissect the processes in order to have a clear view of the assemblage formation and thus, being able to make pertinent inquiries.

1.3. Objectives and research questions

The main objectives of this work are:

1) To characterize the charcoal assemblage of level Ra of Abric Romaní site.
2) To understand the paleoenvironmental context of the occupation level, considering other information sources such as the pollen record.
3) To propose an explanation of the cultural and natural processes that created and modified the assemblage.

To address the specified problematics there were proposed different research questions that are concatenated. The descriptive analysis of the assemblage made possible to describe taxa and taphonomical traits in a database. The research questions are mainly about the formation processes, and the human-environment interaction: Can we discern the pattern of human activities from post-depositional disturbances? What can be inferred from the assemblage regarding the paleoenvironment? How can contribute this study contribute to the understanding of human behavioral evolution.

The basic idea is that, to answer questions about cultural behavior it is important to understand first the natural formation processes. Regarding the factors that affected the charcoal, taphonomical alterations were difficult to assets considering the problem of equifinality. In this sense there were developed a first set of hypotheses related to understand these processes assuming that, if these were strong enough, the later processes would be more present than the former. This set of hypotheses were treated statistically and spatially.

Regarding the cultural processes that affected the formation of the assemblage, it is assumed that activities have a spatial pattern (Schiffer, 1972; Vaquero & Pastó, 2001). As a consequence, the distribution of charcoal and its alterations will be analysed spatially, evaluating the distribution and its relationship with activities of the human agents.

1.4. Assemblage formation processes

The temporal sequences of the events that affects the state and distribution of the charcoal can be discontinue. For instance, activities like cleaning or preparing the area for tasks can redistribute the studied materials. In this sense, the processes were divided thinking in fitting with the hypothesis tested in the work since one of the main concerns was to define and differentiate temporally the processes that affected the assemblage.

The processes affecting the materials during the occupation events are inside the systemic context and can be natural (biological alterations) or cultural (combustion alterations). In contrast, the processes affecting the materials during the sedimentation processes, when the site is not being occupied are the archaeological context (post depositional alterations).

The systemic context:

As already mentioned, the systemic approach understands culture as a behavioral system. However, it is necessary to understand culture as being part of a larger ecological system. The processes that made up the assemblage includes those related to the ecological constrains and those related to the social actions. The former would be studied with the focus on natural phenomena, in this case, by studying the biological alterations and the later by studying the combustion alterations.

Cultural assemblage formation processes:

The way that these materials arrive to the archaeological sites is due to being part of a sequence of actions in the socioeconomic system of past human groups. There is a necessity of the energy income that combustion gives in order to achieve different activities such as lighting, cooking, heating, smoking and so on. Because human activities are defined in the space, charcoal are in general not randomly distributed in the archaeological sites.

Fire is the main alteration that, indeed, creates the studied materials. Fire produces changes in the chemical, morphological and physical properties of the materials. The effects of fire can be different depending on the oxygen availability (Braadbaart & Poole, 2008) . The charcoal existence is due to the partial carbonization of the organic materials. Shrinkage, fragmentation, and cracks are the main effects that combustion has on the charcoal remains. Carbonisation also might causewood cell deformations.

The archaeological context is composed of those processes that are part of the sedimentary history. In Abric Romaní site is remarkable the presence of slow waterflows and dripping, both charged with minerals. Some other processes such as trampling or remotion of the sediments (by cultural or other origin) could affect the assemblages, but there are no specific methodologies for measuring these processes.

1.5 Theoretical background

The approach chosen for this work is based on the nomothetic (Carl Hempel, 1955, 1966; Carl G. Hempel & Oppenheim, 1948) as well as inductive probabilistic methods (Carnap, 1955). These methods, developed in epistemology during the 20th century, are useful in the context of natural and inductive sciences, The nature of the field determines some characteristics of the approach. In this case, natural sciences are meant to be inductive in their general orientation, especially when the problem to be inquired it is not enough developed to have general principles or laws, in contrast to exact (physics) and abstract (math) sciences.

The problematic presented in this work is, in the broad sense, derived from observation of the archaeological record and the inquiry about its formation. The materials that are being studied are the result of the activity of two “realms”. The first one is the culture, understood as a behavioral system that is self-regulating and self-maintained, composed by a series of subsystems, that keeps homeostatic state by exchange of energy, matter, and information with the environment (Schiffer, 1972, p. 3). The second realm is composed of those processes that affect and *create* the archaeological record that includes even the archaeological work.

In this case, the component subsystems of cultural systems have variables which their values are maintained between ranges by the aforementioned exchanges. Following this reasoning, an activity is a transformation of energy that might be (directly or indirectly) related to homeostatic conservation throughout the modification of one or more variables. Also, this modification is non-random, this is, patterned (Schiffer, 1972; Leslie White, 1959). In this sense, systemic perspective allows us to understand the charcoal assemblage as the result of interactions from factors arbitrarily called "social" or "natural" (Théry-Parisot et al., 2010, p. 145).

An example of this is the use of combustion fuel for two main purposes: heat conservation and cooking (among others). In both cases the use of fire is related to the modification of one or more in order to conserve more important variables in their respective tolerated ranges (temperature and energy catchment). The consumption of fuel is meant to liberate energy contained in the matter, making it part of the *consumable* elements that are part of a system (Schiffer, 1972, p. 3)

Activities of this kind are detectable by archaeologists not only because they leave material remains but because they are spatially organized, being associated with the pattern of the activity. This identification often is not straight-forward due to the palimpsest nature of most of the archaeological sites (Bailey, 2007; Donald Henry, 2012; Schiffer, 1972) Recent studies have made efforts to dissect sections in occupation surfaces using different methods such as microstratigraphy, bone, and stone tool refitting (Clark et al., 2022; Gabucio et al., 2018, 2023). In this sense spatial archaeology studies are a whole subfield of archaeology studies developed in the last decades. In the case of charcoal studies this is especially interesting if we consider charcoal as a *primary refuse* when the occupations are short (M. Vaquero & Pastó, 2001). This is why the geostatistic and spatial methods are useful for this topic. The duration of the occupations for level Ra is still unclear, but in previous levels studies have pointed out the similarities of hearth-related structures of hunter-gatherer´s short occupations and those of Abric Romaní (Vaquero & Pastó, 2001; Vallverdú et al., 2010; Vaquero, 2012;

Vaquero et al., 2012). This is, if the occupations are short or, at least, there are no palimpsest, the refuse elements of the 'fire' activity are expected to be located where the activity took place, unless post depositional processes have affected their distribution.

Domestic areas are a topic of interest in the evolutive studies of modern human behavior (Clark et al., 2022). Spatial relations between remains can be informative about different aspects of these features such as amount of people in a site, the synchronicity between activities, post depositional processes, the presence of wind and its direction and so on (Donald Henry, 2012). The approach that has been chosen for this project is related to understanding relations of different components that made possible the existence of the assemblage as it was found.

Assemblage formation processes are related to cultural and natural processes. To understand natural processes, experimental investigations have showed that some effects are related to the state of the wood before being burnt, although they also remark the variability depending in the species for specific alterations (fragmentation and compression resistance) (Chrzazvez et al., 2014). Also, experiments are in general restricted to very specific conditions and traits. For the Abric Romani site, there is no experimental-based knowledge on how the post-depositional conditions affect the assemblage. The sedimentary environment is characterized by a fast travertine mineralization which possibly implies the presence of water streams and temporal accumulation of water (Solé et al., 2013; Vallverdú-Poch et al., 2012; Allué, Bischoff, Burjachs, Vallverdú Vaquero, 2013). Because of this, the state of the art in charcoal taphonomy shows that still there is not a specific developed methodology for understanding the effects of the post-depositional processes on the remains in this site (Allué, 2002b; Allué & Mas, 2020; Allué & Solé, 2009; Chrzazvez et al., 2014; Théry-Parisot, 2001; Théry-Parisot et al., 2010; Vidal-Matutano et al., 2020).

2. Paleoenvironmental Context in the MIS 3. From a Global Perspective to the Abric Romaní Rock-shelter

2.1. Quaternary climate at the Iberian Peninsula

Quaternary period is characterized by the climatic oscillations ranging from glacial and interglacial periods. The main reasons for the oscillations are the Milankovitch cycles. These phenomena are composed of three types of cycles that are:

1) Eccentricity: Is the change of Earth's orbit shape around the Sun. The shape of the path that the Earth makes around the Sun can be more rounded or more ellipse shaped. The distance to the sun is then changed and with it the energy received from the star. When the orbit is more elliptic the differences in solar radiation between the nearest point to the sun and the farthest one is around 23%. This cycle last for 100.000 years.

2) Obliquity: Is a property of the Earth's angle between the axis of rotation with respect to the Earth's orbital plane. This angle ranges from 22.1 and 24.5. This phenomenon is responsible for the seasons, when the angle is greater, the seasons are more extreme due to the increase in the hemispheres of solar radiation in summer. Larger tilt angles favoured deglaciation periods. This cycle has a duration of 41.000 years.

3) Precession: Gravitational influences from the Sun and Moon causes tidal forces that affect the axis of the rotational movement of the Earth. By increasing the degree of axial precession, one hemisphere seasons become extreme than the seasons in the other hemisphere. The span of this movement is around 25 ka.

During the last 25 years, oceanic cores taken in the Atlantic façade of Iberian Peninsula where the main rivers deposit their sediments has been proposed to be representative of the vegetation in the Western Iberian Peninsula (Sánchez-Goñi & d'Errico, 2005, p. 117). These cores have shown differences between the assemblages in Northern and Southern iberia, reflecting the variability of biogeographic conditions and their correspondence with terrestrial and lacustrine cores suggest its value as reliable information (Sánchez-Goñi & d'Errico, 2005). The new insights revealed interesting information about Upper Pleistocene climatic conditions. In first place, the presence of abrupt changes of temperature that generated reactions in the flora.

The immediate period that concerns us, the end of MIS 4 and beginning of MIS 3, includes the H6 cold event, which has been characterized as a cold period with maximum extension of ice in the Northern Hemisphere. Sea level reached around a hundred meters lower level and the superficial temperature was 10º lower than the current. However, between 63 and 61 Kyr BP, the average superficial temperature of water raised, reflecting a climate improvement. In the South of Iberian Peninsula this process generated dryness as can be seen in the 30% raising of *ephedra* pollen percentage (Sánchez-Goñi & d'Errico, 2005). The Daansgard-Oeschger cycle 18 (D-O 18) may be the general context of this first climatic improvement, as the Heinrich Stadial 6 (HS6) may be the explanation for the subsequent dryness. In the beginning of MIS 3, climatic fluctuations are related to warm Isotopic Stages 16th and 14th.

2.2. Paleoenvironmental context at Abric Romaní during the MIS 3

In contrast to the tendencies showed by oceanic cores, paleoenvironmental analyses in specific regions in local scale can show how the general processes affected to the local biomes and how these reacted to them. The analyses of micromammals from different sites in North-Eastern Iberia have been used to establish the characteristics of ecological associations throughout the Late Pleistocene. Using sequences of Abric Romaní, Teixoneres, Cova dels Xaragalls, Cova del Gegant, Galls Carboners and L'Arbreda cave it has been posited that North-Eastern Iberian Peninsula maintained patches of forested areas during the MIS 3. During the coldest phases, temperatures were lower than present while, at the same time, there was more moisture and rainfall (+ 70/ +170 mm)(Fernández-García et al., 2018) In this period woodland forest would have retracted but still were able to support populations of *A. sylvaticus* and *E. quercinus* and other Mediterranean species such as *M. duodecimcostatus* or *I. cabrerae* (Fernández-García et al., 2016, p. 716). In support of micromammal samples, pollen analyses data showed that, during interstadials, depending on the regional climatic conditions, forest recover was remarkably quickly (Sánchez-Goñi & d'Errico, 2005). The presence of woodland forest during the sequence of occupations in Abric Romaní is also related to the preservation of conditions of higher ecological diversity, making this site a suitable location of Neanderthals occupations.

Using pollen analysis from samples taken in the site Abric Romaní, scholars determined that the climate during the glacial period of MIS4 and MIS3 was not uniform. In the palynological sequence of Abric Romaní, *Pinus* is the dominant species. According to Biltekin et al., (2019) the palynological sequence of Abric Romaní is divided in 5 zones. Zone 5 corresponds to the range between 69.5 and 48.8 kyr BP. This zone is subdivided in Zone 5a and Zone 5b (Figure 1). In the species representation *Pinus* has a major role, reaching up to 90% in the upper levels of subzone 5b (which is the sub-layer containing archaeological level Ra). *Quercus* is present in 5a and increases in the bottom of the next subzone 5b. However, for the MIS3 the presence of *Quercus* is subject of fast increase-decrease events (Figure 1). In this period *Artemisia* increases up to 47.1% while other arboreal taxa such as *Salix, Corylus, Alnus, Fagus, Ulmus, Betula, Juglans, Fraxinus, Viburnum, Olea and Quercus ilex/coccifera* remain in the region in low percentages. Also, *Cosmarium* increases in zone 5a and decreases in zone 5b.

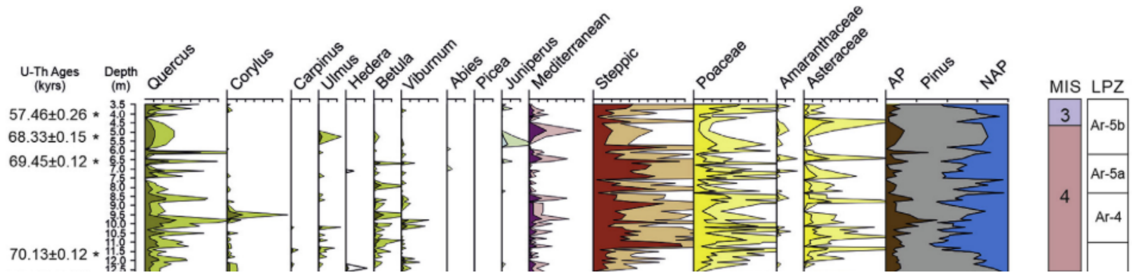


*Figure 1 Graphic section from (*Biltekin et al., 2019) *"Simplified percentages of characteristic pollen taxa from Abric Romaní for 55-110 ky BP. The pollen profile of Carpinus reflects C. orientalis and C. betulus. The pollen percentage curve of the Mediterranean trees including Olea, Quercus ilex/coccifera type, Pistacia and Coriaria and the pollen profile of steppic mainly including Artemisia with Ephedra distachya. The Asteraceae curve composes of Asteroideae and Cichorioideae families. On the right, AP: arboreal pollen; NAP: non-arboreal pollen; MIS: Marine Isotope Stages; LPZ: local pollen zones with superzones (based on cluster analysis)."*

In terms of climatic events, the previous time range witness the presence of warming events during the MIS 4. The first event is the GI 19 that goes from 70 to 67 kyr BP and the GI 18 goes from 65 to 63.5 kyr BP. These events, especially the GI 19, allowed the expansion of pine forests with mesothermophilous elements such as *Quercus* and *Olea-Phillyrea* as well as arboreal taxa (AP values) (Burjachs et al., 2012,). When glacial conditions recovered, these mesothermophilous species did not disappeared, being able to expand again when favourable conditions allowed it in GI 18. Still, during the glacial stadial, cold adapted species belonging to families such as Asteraceae and Poaceae (grasses and herbs) and *Artemisia,* increased their presence, indicating steppe environment and cold and dry climate (Biltekin et al., 2019a; Burjachs et al., 2012a). *Pinus* was still present in high densities and other arboreal taxa remained in smaller percentages. Among these, we find *Betula, Corylus* and *Viburnum.*

From 63 to 61 ky BP occurred the cold event HS6 (Figure 2), where the reduction of arboreal cover was around 40% (Burjachs et al., 2012). MIS3 was characterized by colder climates than today (around –7.5 MAT) but higher moisture (350 mm/y higher MAP), this is supported by the evidence from layer O Abric Romaní micromammals (Burjachs et al., 2012).

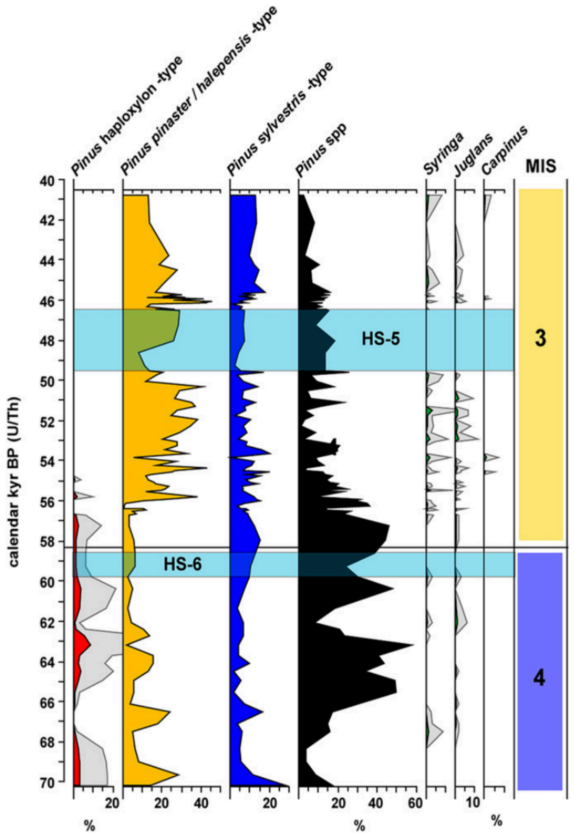


Figure 2 Synthetical graphic showing the evolution of Pinus and extinct areboreal taxa (Burjachs et al., 2012)

2.3. Geographical and geological setting of Abric Romaní site

Iberian Peninsula is a geographical unit characterized by several accumulative orogenic episodes. As a result, there is a great diversity in the topography along the peninsula. In the first place the Variscan orogeny that was active during the Late Paleozoic (Devonian-Permian). This orogenic process modified the continental crust of Western Europe and the North and Northwest Africa during 80 million years in what it was the supercontinent Pangea. For the Iberian Peninsula to "appear", it was necessary to wait until the Cretaceous when the Bay of Biscay and the Pyrenean line was opened. The convergence of the African and Eurasian plates reworked the variscan materials in the Betic Range, Pyrenees, Iberian Range and Demanda Range. Some of these mountain ranges are aligned East-Northeast to

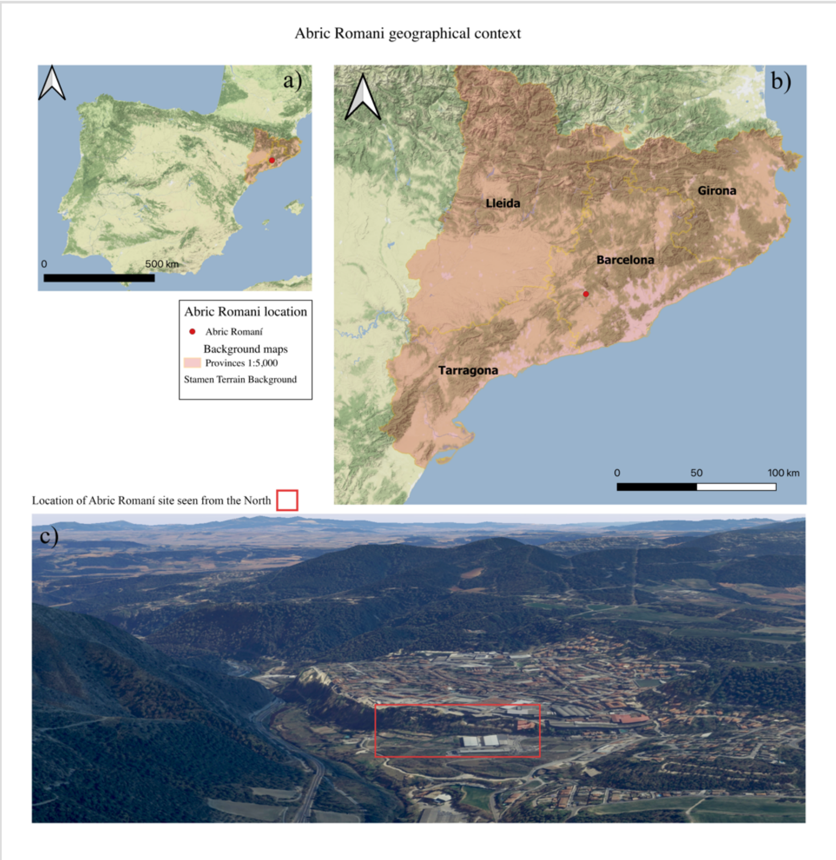


Figure 3 Abric Romaní location at different scales.

West-Southwest (Cantabrian Range, Ancares, Montes de Leon, Central System and the Portuguese Serra da Estrela, Sierra Morena), this is the result of the convergence of the abovementioned tectonic plates (Benito-Calvo et al., 2009). The high level of folding of different geological layers allowed a great diversity of ecosystems due to altitudinal differences. This characteristic has important implications for the evolution of the biota and thus, the distribution of the genus *Homo s*ince this diversity allowed the existence of refugees as well as the presence of different resources in close regions.

Capellades area opens towards the Conca d´Òdena (Ódena Basin), an erosional marginal basin created by the Anoia River in the Eastern Ebro Basin in its course towards the sea. The Anoia River, created the connection between the Penedès Depression and the Ebro Basin (Figure 4). Capellades, 50 km away from Barcelona, is the locality where there is a travertine cliff named *Cinglera del Capelló*, in the nearby of Anoia river, that runs in direction N-S. Is in this location where Abric Romaní is. The karstic condition of the *Cinglera del Capelló* allows the creation of rockshelters. This geoform has 1 km of longitude and 60 mts of

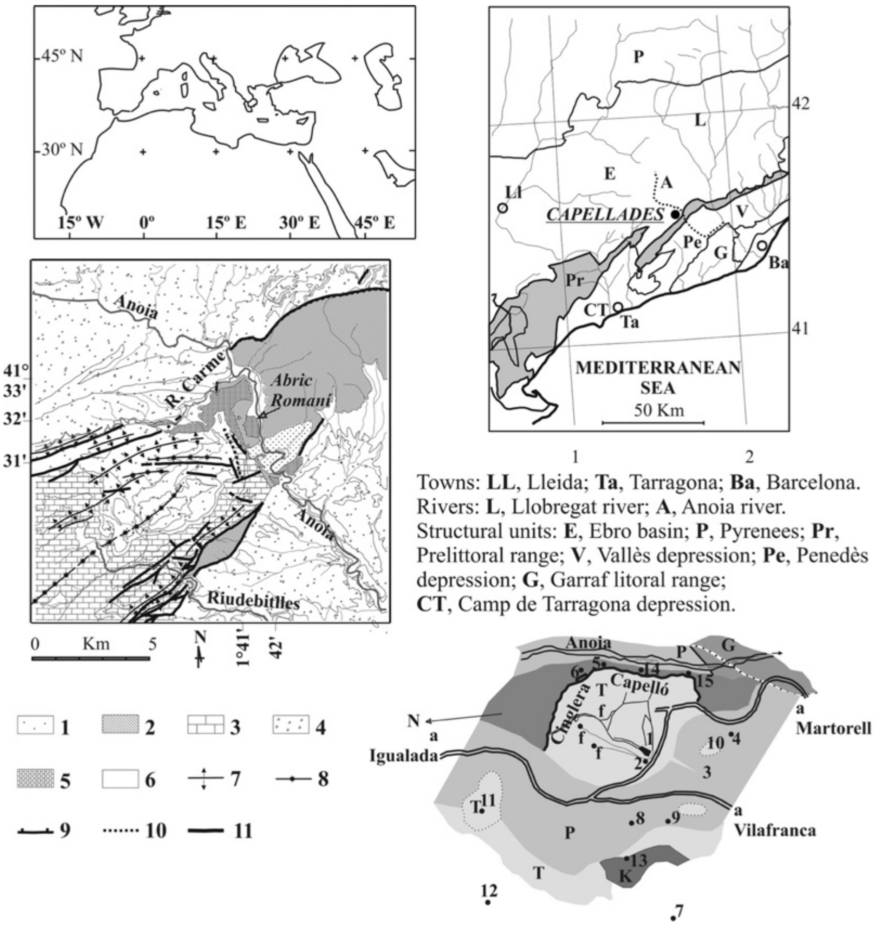


Figure 4 Geographical location and main geochronological units of the Capellades region *Legend (IGME 1975): 1 Plutonic intrusions. 2 Paleozoic. 3 Mesozoic. 4 Cenozoic. 5 Quaternary travertines. 6 Quaternary. 7 Anticline. 8 Syncline. 9 Normal fault. 10 Inverse (thrust) fault. 11 Fault. At the bottom right, geological outline and water sources in the vicinity of Capellades (Vidal 1911, p. 111): G granites; P slates; T tuff; K travertines; 1 Bassa or Font Gran; 2 Font Petita; 3 Font Cuitora; 4 Font del Llargandaix; 5 Font de la Reina; 6 Abric Romaní; 7 Font de Riudacost; 8 Pou del Cardús; 9 Mina del Artigues; 10 Travertí del Cementeri; 11 Turó de Torre Nova; 12 Font de Frígols; 13 Terreres de la Garc.*

thickness. It is made of tufa in its west side, where Abric Romaní is placed. Its coordinates are UTM (ETRS89) are 390566E y 459874N and its altitude is 310 m. asl. There are different cavities located in the cliff and some of them have archaeological remains of middle and late Paleolithic, Mesolithic and Holocene. Geographically, the Abric Romaní site is in the natural corridor called *Congost de Capellades*, which connects three geomorphological units: the pre-coast Catalonian Mountain range, the Ebro Depression, and the Penedès Depression. The subsidence of the Penedès Depression and the uplift of the Prelitoral Range and Ebro Basin are both attributed to the Vallès-Penedès normal fault. This morpho structural frame enabled the incision of a new hydrological network that captured the Ebro Basin, reversing the direction of the Pleistocene drainage that had previously existed (Gallart, 1981) The Anoia splits the Prelitoral Range in the Capellades region into two distinct lithological regions: the Paleozoic materials to the east and the Triassic materials to the west. The Paleozoic formations are made up of dark, glossy, gray-blue Silurian slates that are interspersed with quartz ledges and a few porphyry dikes (García Rodrigo, 1957). There is a plutonic outcrop between Capellades and Cabrera d'Igualada formed by intrusive granitic rocks, which has resulted in a phenomenon of regional metamorphism in contact with the Paleozoic. The Bundsandstein materials, which are largely of fluvial origin (Anadón et al., 1979), are the first Triassic formations west of the Anoia. Dolomitic limestones are separated by red clays to produce the Muschelkalk. The Keuper is finally formed by gray marls, yellowish clayish dolomites, and sporadic gypsum strata at the summit of the formation (García Rodrigo, 1957).

2.4. The excavations of Abric Romaní site.

The site has been excavated since the early 20th century. The excavations of the site can be divided in three main periods: the Amador Romaní excavations, the Eduard Ripoll excavations, and the current excavations (Vallverdú-Poch et al., 2012). During the first thirty years, excavations were developed in the *Cinglera del Capelló* by Amador Romaní, who settled the bases of the understanding of the site. He was an industrialist from Capellades interested in the archaeological potential of the *Cinglera del Capelló.* The prospections of Amador Romaní discovered several archaeological deposits in the rock shelters, mostly from the Pleistocene period. The Abric Romaní site was used as a cemetery during the 19th century, being this the reason for calling it *Balma del Fossar Vell* (Old Grave Rock shelter)

(Vallverdú-Poch et al., 2012), which affected the conservation of the first four levels. The first excavations were made with the sponsor of the Institute for Catalan Studies (IEC) and directed by different archaeologists which were accompanied by Amador Romaní. In the first years it was Norvert Font i Sagué who directed the excavations and gave the current name to the site. After the passing of Font i Sagué, the direction was assumed by Luís Marià Vidal, who published the results in 1911 and 1912. The diary of Amador Romaní is the other main source of information of the first excavations. In the 1911 the contract with the IEC finished and the excavation stopped, being intermittently continued only by Amador Romaní. During this period, there were excavated levels A to D, and other levels were partially excavated. The firsts years a surface of 6 x 6 m (Pit 2) was excavated. In the western part, near the wall of the shelter the deepness reached currently level J (13-14 in Romaní sequence), while in the rest of the pit was deepened 12 layers in the Romaní stratigraphy. A circular well was made by Romaní, adding knowledge of eight meters more of sequence. Subsequently, the excavation surface was extended towards the East. The excavation reached the currently rows M-V and columns 43-60.

The first stratigraphic descriptions made by Vidal and Romaní, stressed the presence of calcareous sands interbedded with thin layers of black sediment and thick travertine strata. The 31 layers of Romaní had 12 with evidence of human occupation. A considerable part of the sequence was made using Romaní's well. Regarding the rest of the sequence, there were documented between five and nine archaeological layers in the Romaní well. There are some discrepancies between the sequence of Amador Romaní and Vidal, where in the second layers 8, 10 and 12 are equal to layer 9, 11 and 13 of Amador Romaní (Vallverdú-Poch et al., 2012). This first period, due to the excavation methods, although well documented, unnoticed layers D, H and F-G, which were very thin layers with low density of findings. The characterization of cultural sequences identified Layer 2 to Aurignacian and the remaining layers were assigned to Magdalenian.

The next investigations period started in 1956 after the instability of political and economic conditions for the science tasks that the war brought with it. The team was headed by scholars from France and Spain. In the Spanish team it was Eduard Ripoll the responsible of the investigations, while George Laplace, Henry de Lumley in the French team (Vallverdú-Poch et al., 2012). This excavation period is characterised by the implementation of the theoretical-methodological approach of the historic-cultural school. In terms of excavations, the methodologies are not well known, opposed to what happened in the previous period. They made various trench and pits in different areas of the surface, unaware of the places where Amador Romaní excavated first. However, they made a characterisation of the stratigraphy and the processes that create the sediments comprising three main sets. The first one composed of fallen block of cryoclastic origin and 1.5 metres thick. The unit is divided in two subunits where layer 12 (upper) has bigger blocks and the Layer 13 (lower) has smaller angular clasts. The sediments were characterised as the result of freeze-thaw cycles and the falling of blocks in a cold and humid period likely associated with the end of Würm II (Vallverdú-Poch et al., 2012). The second unit was characterised as travertine layers (11 and 12) with different facies and silt and sand lenses. It was correlated to the interstadial of Würm II-III due to the high humidity, but the hearth 2 was attributed to initial Würm III due to the presence of Upper Paleolithic assemblage. The third unit was composed of red silty sands (Vallverdú-Poch et al., 2012). This period provided an interpretation of the archaeological assemblages from an historical-cultural approach. G. Laplace analysed the lithic materials and assigned them to other assemblages classified as Protoaurignacian. The Mousterian levels were characterized by Ripoll using the Bordes type-list and later attributed to Denticulate Mousterian (Perelló & de, 2008).

The final and current excavation project started in 1983 under the direction of Eudald Carbonell, Artur Cebrià and Rafael Mora. The project has been focused in the *Cinglera del Capelló* sites, including Abric Agut, Balma dels Pinyons and Balma de la Costa de Can Manel (Vallverdú-Poch et al., 2012). During this new period, it was decided that the excavation should be extensive. This is a key insight to understand the site, its importance and uniqueness. Few Middle Paleolithic sites are known with small palimpsest effect and such a great conservation state, moreover, these characteristics make the Abric Romaní a perfect site for the spatial understanding of human activities, which needs extensive excavation for its study. After finishing the remains unexcavated of levels, A-D, large surfaces excavated reaching 315 m^2. From level K onwards few disturbances were detected, while Levels E to J were altered.

This new approach to the site was greatly influenced by the New archaeology ideas focusing on achieve a paleoethnographical interpretation of the site (Chacón et al., 2012; Vallverdú-Poch et al., 2012; uerouero, 2008; Vaquero et al., 2012). Spatial distribution has been since the beginning of this period a prime concern for the scholars who have been working in Abric Romaní. All the artifacts, bones and charcoal are three-dimensionally documented (Allué et al., 2017; Vallverdú-Poch et al., 2012). The large number of hearths is considered a main feature of the site which should be studied carefully in order to shed light on behavioural, organizational and taphonomical aspects of the site. The study of the site is addressed from a multidisciplinary work organization considering sedimentary dynamics, paleoenvironmental processes (Arteaga et al., 2001; Bischoff et al., 1988; Giralt & Julià, 1996; Mora, 1988; Vallverdú Poch et al., 2005) behavioural inquires where addressed combining taphonomy, zooarchaeology (Aimene, 1998; Aimene et al., 1996; Cáceres et al., 1998; Cáceres & (voc.), 2002; Rosell Ardèvol, 2001) archaeobotany (Allué, 2002b; Cabanes et al., 2007; Carbonell et al., 1992, 1996), lithic studies (Bischoff et al., 1988; Martínez et al., 2005; Morant & García-Antón, 2000; Vaquero Rodríguez et al., 1997) and spatial organization (Chacón et al., 2012; Gabucio et al., 2018, 2023; Romagnoli & Vaquero, 2016; M. Vaquero, 1999; Manuel Vaquero, 2008; Manuel Vaquero et al., 2012, 2017).

2.5. Current stratigraphy and sedimentology of Abric Romaní and layer Ra

The stratigraphic sequence of Abric Romaní is composed of two main units that are: the sequence 0 and the basal unit. The former is three metres thick and is composed of silts and sands of aeolian origin. The basal unit has a thickness of seventeen metres and is mainly composed of tufa, tufa gravels, carbonatic sands and silts (Bischoff *et al*., 1988; Carbonell *et al*., 1994; Giralt & Julià, 1996 in Vaquero, 2013). In the sequence revealed by extensive excavations in the Co*rveta Nord* outcrop and published by Vaquero et al (2013) there were differentiated the following units:

Unit 4: (2 m thick) It is composed by gravels and tufa domes. *"Bellow the cornice and beyond the dripline, conglomerates and sands alternate with gravels"*. In this Unit is located the level L.

Unit 3: (2 m thick) Moss-generated tufa interbedded with thin gravel lenses. There is a discontinuity in the upper third part of this unit, representing erosion processes.

Unit 2: (2.5 m thick) In the bottom of this unit there is two beds of carbonate sands interbedded with gravels and fallen blocks. The upper part becomes thinner as is closer to the dripline and dips towards the wall. The upper part presents loess. This unit contains the archaeological layers E, F, G, H, I, Ja-Jb.

Unit 1: (3 m thick) This unit contains fallen blocks covered with massive domal laminated tufa near towards the shelter wall. The upper part of this unit contains cemented and stratified gravels, carbonatic sands and tufa. It is covered by the layer of Unit 0 and contains the archaeological layers A, B, C and D.

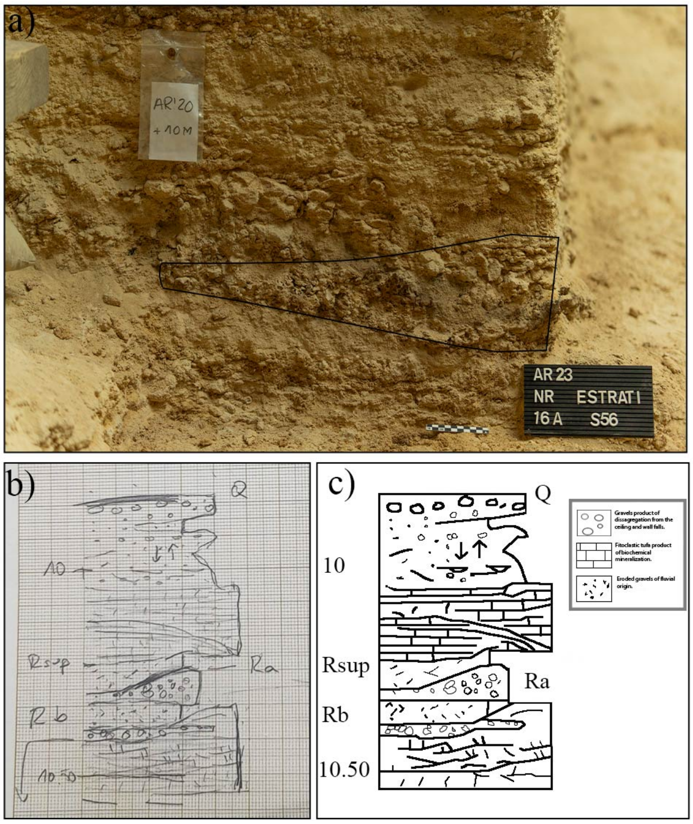


Figure 5 a) Image of the section with the Ra level marked inside the black line. b) Scheme of the section made in the field work by Josep Valleverdú. c) Digitalization of the section with the legend.

The region where Abric Romaní stands is in the border of a Pleistocene lacustrine tufa, that are superposed over a Paleozoic basement. The origin of the tufa is related to the activity of a water aquifer and host different shelters like the Abric Romani site. In this sense, lithofacies are useful for determining general sedimentary conditions. Vaquero et al (2013) established four main lithofacies for the deposits in the Capelló system that are: *"a) moss-generated tufa and algal mats (stromatolites); b) gravels and fallen blocks that are found in poorly stratified discontinuous beds; c) conglomerates, carbonatic sands and silts appearing in graded and horizontal discontinuous beds; and d) red silts and sands of aeolian origin that form irregular and massive stratified beds. these lithofacies provide some clues to the climatic context."* While lithofacies a) and c) are related to dry and humid conditions with dripping water as an important factor, d) are result of dry and arid conditions where the springs were inactive. The sedimentology of the level Ra is characterised by three main origin processes. Firstly, small and slow waterflows emerging from the wall of the rock shelter would be related to small cross stratified structures. The stratigraphy can be appreciated in Figure 5. The second process is the biochemical mineralization caused by the dripping processes over vegetation, creating a layer of dripping originated tufa that incrust photosynthetic organisms. In this process the biological tissues charged with water of the organisms are slowly accumulated with Ca^{2+} until they are completely mineralized.

Finally, chemical mineralization occurs when the water that carries minerals does not discharge its minerals in the vegetation but in a flat soil surface, creating horizontal layers. The separation between sterile layers is made by layers originated from the second and third processes, which are representing wet periods where the site was not occupied. Another process that creates sediments is the disaggregation of the ceiling and walls of the rock shelter. This forms a white-yellowish sediment of fine grain. Also, blocks from the ceiling where registered in the sequence, as well as domes and stalagmites and stalactites. The sediments of level Ra are composed mainly by the disaggregation of walls and ceiling materials, the materials from fluvial origin and the incrustation of organic materials (J. Vallverdú, personal communication).

2.6. The archaeological assemblage of level Ra

The archaeological assemblage of level Ra is composed of bone, lithic, charcoal, wood casts and hearths and malacofauna. Regarding the faunal assemblage of Level Ra, the current information available points to a low species variability, being considered even monospecific (P. Saladié, personal communication). The main species is *Cervus elaphus* but also rabbits have been documented and a unique bird bone was identified (IPHES, 2021). Currently, no paleoenvironment information can be obtained from the faunal assemblage, and micromammals have not been analysed yet for level Ra. There were found in the 2021 field season three deer masts anchored to the front bone. This finding is informative about the occupation period, which could have been in autumn/winter when the males fight for mating and then they are weak (IPHES, 2021). The limbs and skull were carried into the shelter, causing the good representation of the skeleton of these animals.

The lithic assemblage of Abric Romaní layer Ra shows a different percentage of raw materials compared with the other levels. Along the sequence, chert is in general the most represented material, generally above 70% (Table 1). In level Ra, until the excavations of 2021, this proportion drops slightly, while speleothems, quartz and limestone increase their percentages. Scholars have noticed that Neanderthals may have been used the speleothems as raw materials. The sourcing of flint is likely made in the siliceous outcrops of San Martí de Tous, which has been recognised also as the main sourcing place in previous levels (Gómez de Soler et al. 2020a). Also, there were recognised other sources of flint for this level (Panadella -PAN-, Sant Quintí de Mediona -Guixera series-, Valldeperes -VLD-, etc.), showing variability in the knowledge and routes used by neanderthals. The speleothems were recollected from the Abric Romaní travertine formations and the Capello cliff, the field season of 2021 recovered different materials of the *Chaîne opératoire* such as nuclei and retouches. However, the functionality of these objects is still un. In the area where Abric Romaní is, there is also accessibility to limestones and sandstones pebbles from the Anoia River, as well as quartz and schists which are present in the pre-coastal mountain range in front of the site (IPHES, 2021) (Table 1). The typological analyses shows that the objects in general are small despite the raw materials. There are scarce objects of large dimensions, and these are made of limestone, used as percussors or for fracturing bones (IPHES, 2021 Combustion structures (hearths) are associated to level R and for now, considered contemporaneous independently of the sublevel since it was not found evidence of stratification. The size of the combustion structures shows that those located near the wall are larger in size and that these are distributed in a band following the contour of the wall. Some of the hearths were very small (W51 and U50, Figure 6) and the authors proposed that they may have been used for specific purposes such as lighting (IPHES, 2021).). The rest of the materials have been probably introduced as part of “toolkits” (IPHES, 2021).

Table 1 Absolute and relative frequencies of lithic materials of layer Ra from Abric Romaní (IPHES, 2021).

Lithic materials Ra 2021		
Material	**Level Ra**	**%**
Silex	736	69.5
Quartz	63	5.95
Stoneware	25	2.36
Speleothems	118	11.14
Limestone	108	10.2
Esquist	8	0.76
Porphyry	1	0.09
Total	1059	100

The combustion structures might have a carbonaceous stratum and a rubefaction. In general, their thickness is between 1 and 3 centimetres. The diameters of the estimated carbonaceous lenticular strata have a mode of 0.20 cm (IPHES, 2020). Most of the lever R combustion structures are grouped in a semicircle, some of them contain burnt rocks. Their distance is around 1 meter, although their contemporaneity cannot be totally assured (IPHES, 2020).

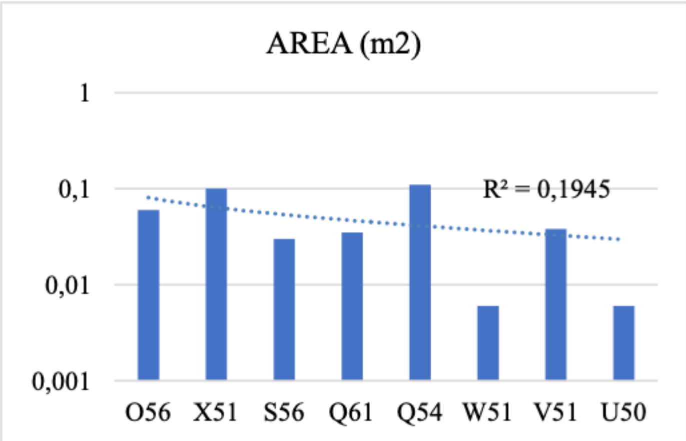


Figure 6 Size of the areas of the Ra level Combustion structures exhumed in 2021 field season (IPHES, 2021).

During the field seasons from 2018 to 2020 there were recovered135 wooden imprints in both levels R and Ra. Some of these were distributed following the contour of the wall and the topographic limits of the stalagmite domes (IPHES, 2020). The imprints have been classified by their clustered or isolated distributions. There were identified accumulations formed by small imprints that differs from other accumulations containing small and medium imprints, that have been interpreted as firewood accumulations bundles. Also, it was proposed that some of the grouped imprints could have been related to woodworking (IPHES, 2020).

3. Material and Methods

3.1. Anthracology

3.1.1. State of the art of anthracological studies

Charcoal, material that anthracology studies, is the product of the incomplete burnt of wood, generally, because of its use as fuel. Some scholars have made the distinction between charring and carbonization, where charring is the product of combustion with limited air supply and carbonization occurs when there is no oxygen (Braadbaart & Poole, 2008). The settings of the combustion activity such as heat source, temperature, time of exposure and heating rate, plus wood properties including taxon, size, porosity and thermal conductivity, affect the morphological, physical and chemical properties of charcoal (Braadbaart & Poole, 2008). The presence of wood charcoal in archaeological sites is generally due to its use as a fuel supply by human communities. The spatial distribution of charcoals is then, related to its use (plus their subsequent alterations) in the context of the exploitation activities of the resources as a medium to satisfy necessities related to homeostasis (Schiffer, 1972) The discipline that studies the archaeological wood charcoal, is called anthracology or charcoal analyses, which has a well-stablished methodology for analysing the materials (Lucie Chabal et al., 1999). The analysis of charcoal remains is based on the identification of different traits that are used to identify taxonomical categories and taphonomical processes that affected these materials. The study of taphonomical processes is informative regarding on the ecological and local conditions, including its consumption, that affected the state of the materials (Alcolea-Gracia, 2017, p. 68) Thus, the information generated by anthracological analysis is a key source to understand human woodland management and site and assemblage formation processes.

As a discipline, anthracology has developed its niche in archaeological studies focusing on incompletely burnt woody parts, to inquiry about past environmental conditions, vegetal landscape transformation, intra-site organization around hearths, plant consumption as fuel and firewood/fuelwood human management strategies (Allué et al., 2017; Lucie Chabal & Heinz, 2021; Vidal-Matutano, 2017; Vidal-Matutano et al., 2015, 2020). Charcoal analysis, or anthracology, studies the anatomical and taphonomical traits of the woody parts of the plants, to answer different inquiries related to archaeological questions. The anatomical traits are originated from the growing of the secondary xylem, from the cambium that has the function to conduction and support. The taxonomical information is gathered from the analysis of diagnostic traits that can be consulted in specialized bibliography such as Schweingruber (1990). The taphonomical traits are originated from different events that can be summarized in biological processes, combustion processes and postdepositional processes(Allué & Solé, 2009).

The systematic application of anthracology was not equally developed as for other materials such as lithics or bones. Also, it has not been equally developed in different regions and specialties in archaeology. While some countries have standardized practices for different types of materials whatever is the historical context, in other regions the application of anthracological methods is related to specific context such as Prehistory or Paleolithic archaeology.

The history of this discipline can be divided into three distinct time periods. The first range from middle 19th century and the first half of 20th century, the second ranges from 1950 to 1970, the third one goes from the 1970 decade to the present. The first attempts to recover charcoal remains were made in the late 19th and early 20th centuries. Initial investigations into charcoal analysis were conducted by archaeologists and botanists. Among these can be mentioned the works of Kunth (1826) Heer (1866) in Switzerland, Prejawa (1896) in Germany, and Hollendonner (1926) in Hungary (Alcolea-Gracia, 2017, p. 67; Matutano, 2016, p. 84) In France is remarkable the case of Breuil, Capitain and Fliche (Matutano, 2016, p. 68) that, when, in the beginning of the 20th century, they started to apply more systematic techniques of excavation, recovering the remains from hearths and identifying the taxa in the sites of Mas d'Azil, Meije and Teyjat (Ernestina Badal, 1987; Breuil, 1903; Matutano, 2016, p. 68) Moreover, Breuil hypothesized about past environment conditions using charcoal from Mas d´Azil (Breuil, 1903).

The second stage is the time lapse between 1950 and 1970. After the World War II the discovery of the C14 method gave to charcoal remains the first level of importance to be widely recovered. The application of exact dating methods allowed archaeologists to stablish sequences based in other ways than biostratigraphy or cultural typological sequences (Taylor, 2009). The theoretical and methodological improvements in the 60s (New Archaeology) boosted the environmental studies and the application of actualism to reconstruct past processes using the already developed techniques for reconstructing past environments (palaeontology, geomorphology, palynology) combined with a systems theory approach and the use of analogies obtained from the application of middle-range theories in zooarchaeology and technology studies (Binford, 1972; C. Renfrew & Bahn, 2007; Colin Renfrew & Bahn, 2005). In this context of interdisciplinarity investigations, anthracology gained relevance as a specialization for inquire themes such as the abovementioned (fuel supply, paleoenvironment reconstruction, and so on), although it will be fully consolidated in the next period. An anthracological example of this period can be mentioned in the work of Momot (1955), who used Late Palaeolithic hearth structures to study charcoal remains and reconstruct past climate patterns. Santa (1961) used charcoal from hearths to reconstruct past woodland landscapes. Couvert posited the uniqueness of charcoal data in the information that brings information about synchronous vegetation in relation to human occupations. Also, his work allowed to make interpretations about past environments and how they differ from actual conditions by changes in the climate conditions (Couvert, 1968, 1969) . Couvert's investigations in Algeria took into consideration of the spatial distribution of past and modern vegetation, modern rainfall values, and topographic relief. During these decades the investigation of charcoal assemblages was based on thin slices. This procedure was expensive and difficult to achieve for each individual charcoal fragment, which reduced the representativity of the studied assemblages.

The following period witnessed the consolidation of the methodology. The use of thin slices was abandoned and, during the period from 1970 to 1990, Vernet (1973) stablished the use of optical reflection microscope, which is faster and easier to use, allowing more representative analysis and interpretations of the assemblages both in number of sites and number of samples per site (Alcolea-Gracia, 2017; Ernestina Badal, 1987; Lucie Chabal et al., 1999; Matutano, 2016). Regarding the analysis of the charcoal, this methodology, as the previous one, allows the observation of the three wood anatomy sections: transverse, radial and tangential. Vernet also was the director of the *Palèoenvironnements, Anthracology et Action de l´Homme laboratory at* the university of Sciences et Techniques du Languedoc in Montpellier (France), which in turn, influenced the careers of many scholars who received training. During these years, the palaeoecological orientation of the anthracology was highly developed both in theoretical and methodological aspects, for instance, there are several works complementing anthracology and palynology (Krauss-Marguet, 1980; J. L. Vernet et al., 1987; Jean-Luis Vernet, 1973). Vernet supervised several works and doctoral thesis contributing with the consolidation of the discipline (E. Badal, 1984; Ernestina Badal, 1991; L. Chabal, 1982; Figueiral, 1987, 1990; Grau, 1991; Heinz, 1983, 1990; Machado Yanes, 1994; P. Uzquiano, 1992; Paloma Uzquiano, 2002). Finally, specific corpus of anthracological knowledge was developed related to field sampling, lab work and statistics (Lucie Chabal, 1992; Lucie Chabal et al., 1999).

The *Palèoenvironnements, Anthracology et Action de l´Homme laboratory* favored the expansion of the field throughout the publication of thesis that affected regional studies in the Iberian Peninsula, France and Italy (Alcolea-Gracia, 2017; Vidal-Matutano, 2016). Since then, the anthracological studies in the Iberian Peninsula have increased, as well as the thesis made in Spanish investigation centers. In the 80s, charcoal analysis was done for the first time in Spain, from Fuente Álamo and Cueva del Toll sites, as well as other sites from Valencia and Alicante such as Cova de l´Or, Cova de Llop, Cova Recambra and Cova Ampla (Vernet et al., 1983). In the North-East of Iberian Peninsula, the anthracology studies were firstly developed by Maria Teresa Ros, who published investigations of Catalonian charcoal assemblages during the 80s and the 90s (María Teresa Ros, 1988; Maria Teresa Ros, 1992, 1996; Serrano Endolz et al., 1997; Teresa & Mora, 1987). The 90s decade witnessed an increase in the anthracological studies in northeastern Iberian Peninsula comprising different chronological spans (Allué, 2002a; Piqué i Huerta, 1991; Buxò i Capdevila, 1997; Piqué, 1998; Pique & Pique, 1992; Piqué & Piqué, 1992).

Finally, the last decades were represented by a consolidation of the anthracological methods but also by a diversification in the approaches to charcoal studies. Experimentation protocols started to be proposed and executed in order to understand better how the characteristics of the tree species, the state of the wood before charring the carbonization, and the postdepositional processes affected the charcoal remains (Alcolea-Gracia, 2017; Chrzazvez et al., 2014; Kabukcu, 2018; Kabukcu & Chabal, 2021; Lancelotti et al., 2010; Théry-Parisot et al., 2010) Another branch-related to anthracological investigation that has been growing is dendroanthracology. Incipient works were made to establish differences between species that are difficult to identify by their woody parts. The investigations started to give attention to specific traits such as the number of cells of the rays (Marguerie & Hunot, 2007). After that studies started to develop tools based on detailed information for the species differentiation using morphometric information plus statistical analysis, as well as digital images.

Other scholars agree that studies on living societies are a key insight in the understanding of criteria for selection and management of fuel supply (Picornell-Gelabert & Servera-Vives, 2017). This research is based on different approaches including ethnoarchaeology. Among the topics addressed from ethnoarchaeological research focused in anthracology there are interests in diverse points such as enlighten of the "blind-points" of theoretical assumptions and the interactions between factors that include social dynamics and environmental elements (Picornell-Gelabert et al., 2011; Picornell-Gelabert, 2020). Some approaches are also related to the taphonomical and paleoenvironmental studies, complementing the information coming from different lines of investigation (Berihuete-Azorín, 2013; Auréade Henry & Théry-Parisot, 2014). Dendrochronology and dendrology lines of investigation made advances in the generation of information related to past variations in temperature and precipitations, and the part of the tree that could have been selected as fuel (branches, twigs, trunk) (Alcolea et al., 2021; Bianco et al., 2023; Carrión Marco, 2007; Caruso Ferme & Villalba, 2011; Dufraisse, 2008; Dufraisse et al., 2022; Marguerie & Hunot, 2007; Picornell Gelabert et al., 2020).

3.1.2. Taxonomic identification

The first approach in working with charcoal is the taxonomic identification with the maximum accuracy possible. The technique used for the examination of the charcoal does not imply the use of any preparation allowing their use for radiocarbon dating.

Generally, anthracological analysis relies on anatomical characteristics observed across the three wood anatomy sections (Figure 7). Charcoal fragments are manually fractured to obtain fresh and clean transverse, tangential and radial sections of the wood (Chabal et al., 1999). The cutting of the charcoal fragments needs to be done in the more accurately way possible to avoid distortions or deformations (Arévalo et al., 2020). The transverse section is perpendicular to the branch or tree, is the section that the loggers make when they fell a tree. In this section it can be appreciated the sequence of growing rings and the rays that are perpendicular to them as well as the pores (Arévalo et al., 2020). The radial section allows to appreciate the rays as lines running across the surface and, as well as the tangential, gives information about anatomical traits and structure (Arévalo et al., 2020; F.H. Schweingruber, 2008) The charcoal identification was made considering specially the sections that have the diagnostic anatomical features. To compare the material, we have used the reference collection of carbonised wood from the IPHES-CERCA. Also, it was used specialized bibliography in vegetal anatomy (Schweingruber, 1990). I this study we used the taxonomic categories of species (*Pinus sylvestris* type) and genus (*Prunus* sp.). We used "type" to refer to a category that includes three species but that cannot be differentiated anatomically. The identification of *Prunus* sp was made using the dichotomic table of Schweingruber (1990). The accuracy of the taxonomical identification depends on the conservation state and other factors. It is common that taxa are grouped in broader categories when diagnostic traits are shared and thus unable to be differentiated, being used categories such as "types", cf., (Chabal, 1997). Similarly, to the applications of other works (Allué & Mas, 2020; Allué & Solé, 2009; Mas et al., 2021), including this thesis where *Pinus sylvestris* type comprises *P. sylvestris, P. uncinata* and *P. nigra ssp. salzmannii.*

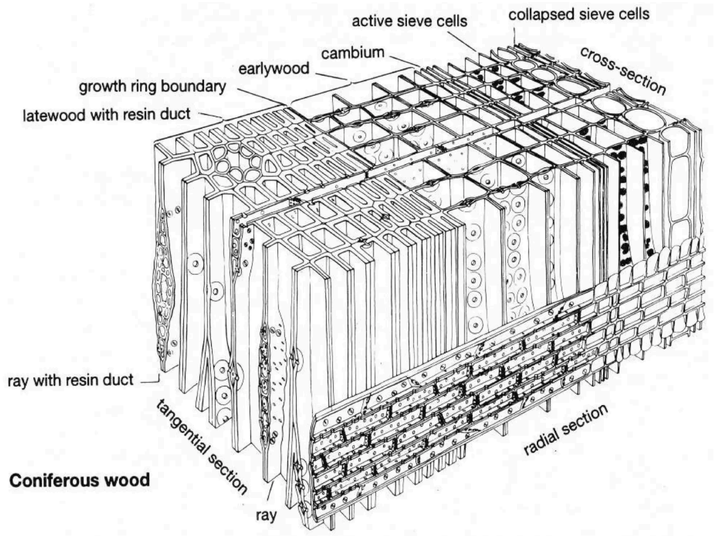


Figure 7 wood sections used in anthracology for identifying taxa.

The genus category *Prunus* sp. is used since more accurate identification is not possible in several cases (Heinz and Barbaza, 1998; Ntinou and Kyparissi-Apostolika 2016; Allué 2016; Allué et al., 2018). In those cases where identification cannot be achieved different categories have been used including "undetermined" and "unideterminedconifer", in the cases that the traits of *Pinus* cannot be recognized.

3.1.3. Charcoal taphonomy

In its original definition, taphonomy deals specifically with the processes that affect the organisms after their death and during the sedimentation process in their passing from biosphere to lithosphere (Behrensmeyer, 2020). However, the study of charcoal taphonomy has a significant and particular development in recent decades, encompassing both theoretical and methodological approaches. In the former, some authors have broadly use charcoal taphonomy to understand pre and post depositional events (Allué et al., 2017; Allué et al., 2009; Théry-Parisot et al., 2010; Vidal-Matutano et al., 2020). The reason is that the modifications of the wood anatomy structure observed in the charcoal remains can be related to processes that occur throughout a sequence of events or filters, including the human selection, the combustion, the post-depositional processes, and the sampling methods(Kabukcu & Chabal, 2021; Théry-Parisot et al., 2010). Other studies focused on themes such as the presence of fungus and microorganisms affecting the preservation of the anthracological assemblages (Caruso Fermé, 2013; Fermé et al., 2013; A. Henry, 2011; Auréade Henry & Théry-Parisot, 2014; Matutano, 2016; Théry-Parisot, 2001). Also, there were studied the processes that are related to the mechanical fragmentation of the charcoal and the use of bone as a fuel (Théry-Parisot, 2001; Théry-Parisot, 2002; Théry-Parisot et al., 2004; Théry-Parisot & Costamagno, 2005).

In this study, the taphonomical alterations were assessed considering categories related to the events that created those traits, which are, combustion alterations, biological alterations and postdepositional alterations.

As a process, combustion is the alteration that creates the charcoal that we study. However, *per se* it can comprise different traits and create overlap situations (Allué, 2002b; Lucie Chabal et al., 1999). It encompasses various traits that can lead to overlapping observations. In this study, we aimed to classify those alterations related to the fire activity such as cracks, vitrification, and combustion alterations.

Vitrification can be described as "fluid-like", glassy form where the bounds between cells cannot be appreciated. Partial vitrification is often the most common situation in charcoal remains (Allué et al., 2009). Its origin can be related to the combustion process but still is not totally clear its genesis (Allué et al., 2009). However, it has been shown that there is more presence of vitrification in close environments such as kilns or wildfires. (Allué & Solé, 2009; Aura et al., 2005; Py & Ancel, 2006; Scheel-Ybert et al., 2008). There are some factors that have been proposed but experimental investigations have not reach conclusive results. Carrión (2005) has suggested an origin related to the accumulation of substances in the surface of the wood cell structure due to the lack of oxygen and low gas liberation during the combustion, while other scholars posited the presence of resins or the combustion of green wood as the origin of this trait (Allué et al., 2009).

Finally, cracks (fissures) can be appreciated in transverse section as a longitudinal aperture of the tissues (Figure 8). It is caused by the fast expulsion of gases and water during early stages of combustion. Is related to the contraction that the wood suffers during this process. The state of the wood is related to the presence of cracks since green wood contains more water, as well as the temperature raised.

Biological alterations are originated from different sources and include the environmental conditions that may affect the growing of the tree and the effects of other living organisms

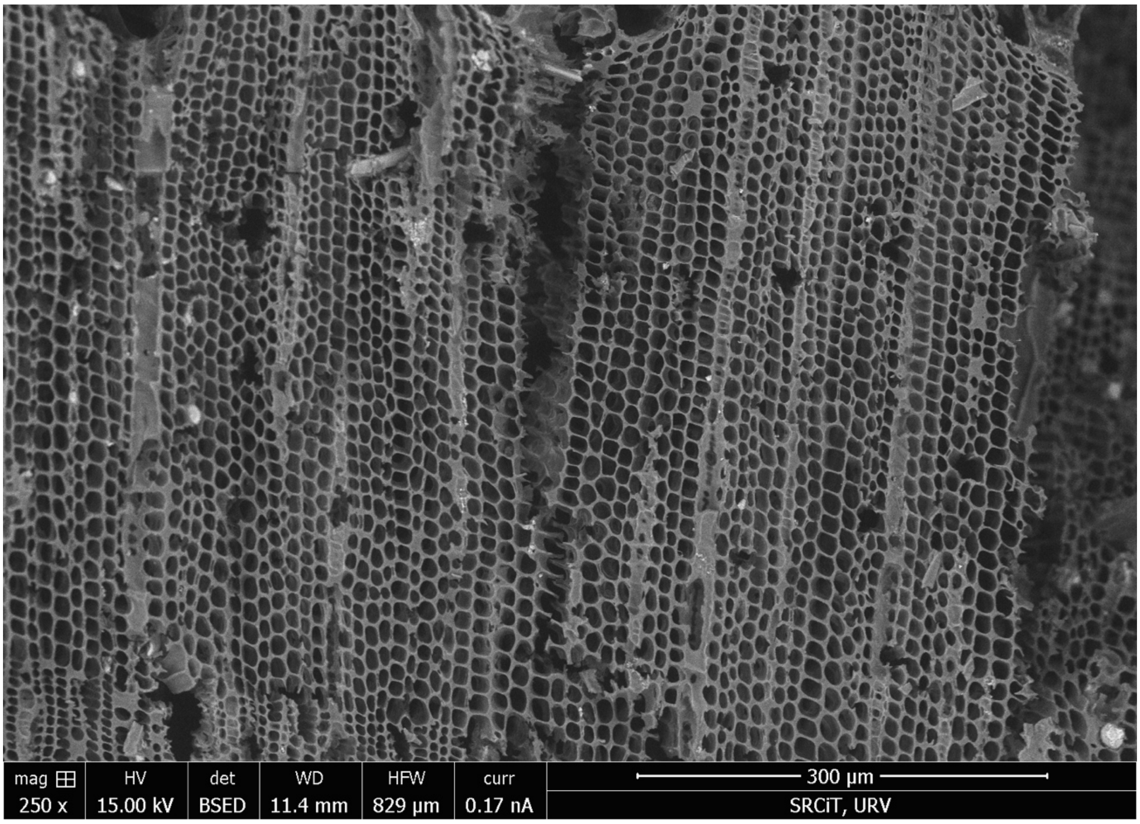


Figure 8 Image of the cracks from a Pinus sylvestris type.

such as fungi and decomposers or insects. The biological processes that affect the charcoal assemblage processes include the compression or tension wood, that affects the traqueids of the wood tissues and it is related to the stress that the tree may suffer in its adaptation to slopes or snow. Cell collapse is an alteration seen in the late wood of conifers where the fibers are more fragile and then they contract irregularly (Figure 9). The origin of the cell collapse however can be due to the growth of the tree, the state of the wood or the combustion(Allué et al., 2009). Also, the presence of hyphae that, along with the alteration index, is related with the decomposition process that affects the tissues.

- Compression Wood (in conifers): These traits are generated during the growing of the tree and are related to the stress. The traqueids walls grown in helical thickening-like pattern. It has been observed in the branches but also in trees growing on pronounced slopes (Schweingruber, 1988; Allué & Mas, 2020, p. 3).
- Cell Collapse: this variable is problematic since it can be caused by different agents, including not biological agents. Fibres are more fragile in the late wood and the contractions have stronger effects over these cells. Its origin has been related to the

state of the wood previously to been charred, for example by the action of fungi, also to the growing process of the tree. In the database this variable was registered when the overall structure in transversal plane was in good state and there was collapsed cells at the end of the rings (Allué et al., 2009).

- Insects: Xylophages are insects that eat and live in alive or dead wood. Their larvae's damage the wood by making galleries and, when they are adult, they leave the wood letting observable holes in cross section. The areas affected by these alterations are, in general, in the late wood (Carrión, 2005; Allué & Solé, 2009).
- Spores: This variable was created during this investigation after observing in some the charcoal remains a series of accumulations of very small red dots with their centre with clearer colour. They were catalogued as "spores" as an apriorism with the aim of recollecting more information in the bibliography and to test their composition in the SEM. Finally, it was shown that they were iron formations, so their values were added to "concretions" variable.
- Hyphae: Decomposers usually attack the wood introducing their mycelium in the plant tissues throughout the inter-vascular structures. They severally affect the walls making them thinner and less consistent (Allué et al., 2009; Moskal-del Hoyo et al., 2010) The walls acquire a curvy or undulated aspect. In this variable there were marked all those cases where hyphae were noticed.

Post-depositional processes include those variables related to sedimentary and other processes alterations. Is divided into deposition of sediments and concretion or mineralization, which is an important process in the environment of Abric Romaní site due to travertine. There are several processes that can affect in archaeological context the state of the charcoals. These processes affect the structure of the cell by trampling, water erosion, frost-thaw, sediment pressure, roots, carbon fungi, and microorganisms. In consequence, fragmentation and hyper-fragmentation can lead to higher number of fragments. The degree of the effects of these processes are, however, determined by the previous state of the wood. Decayed wood is much more fragile and vulnerable to hyper-fragmentation than a healthy drywood since its cells are weakened. The study of these process in the charcoals was made by considering the mineral inclusions and concretions that appeared in the tissues (Chrzavzez, 2013).

After the abandonment of the site, charcoals are affected by different agents. The main agents are of natural origin including trampling, water, frost-thaw, sediment pressure, roots and microorganisms. As result, there are higher levels of fragmentation and fissures (Allué et al., 2009), also changes in the state of the charcoal. In this work, there were studied those alterations related to the presence of minerals.

- Concretion or mineralization: This variable represents the mineralization product of the arriving minerals carried likely by water; this same process also affects the colour of the cells (Allué 2002). Post-depositional mineral accumulation: In the context of Abric Romaní is common to find carbonate depositions of different sizes product of the sedimentary context (Allué, 2002b). In this work there were differentiated the concretions from the mineral depositions.

Other variables

- Alteration Index: The alteration index is a measure developed by Henry and colleagues (2014) in order to analyse relations between the microscopical and macroscopical state of the wood. Depending on the state of the cell and tissue structures, each fragment was catalogued from 1 to 3 in a state of alteration. In level 1, the tissues are recognisable and not modified at all; in level 2 there are modification in the cell's walls such as perforated cell walls; cell deformation, voids, etc., in the stage 3 there are collapsed cell walls, cellular deformations and voids, the intensity is higher and affects the ability to identify the taxon (Auréade Henry & Théry-Parisot, 2014)

  To create the link between the macroscopical and microscopical features of the wood, the authors developed an experimental protocol using different stages of microscopically characterized wood (healthy, dead, and rotten) to classify the previously selected wood. The development of this index is useful for closed contexts where there are no multiple events of charring. However, considering that the preliminary archaeological works suggest a fast sedimentation of the human occupation of level R, we consider that it is worth to test the application of the alteration index. There is also possible to calculate the alteration index of the assemblage by applying the formula proposed by Henry and, which is:

Ai= ((nA1x1 + nA2x2 + nA3x3) /(nTOTx3)

In this formula there where added all the charcoals from each alteration stage, and then divided by a “theoretical maximal Alteration of three on each fragment. Lastly,

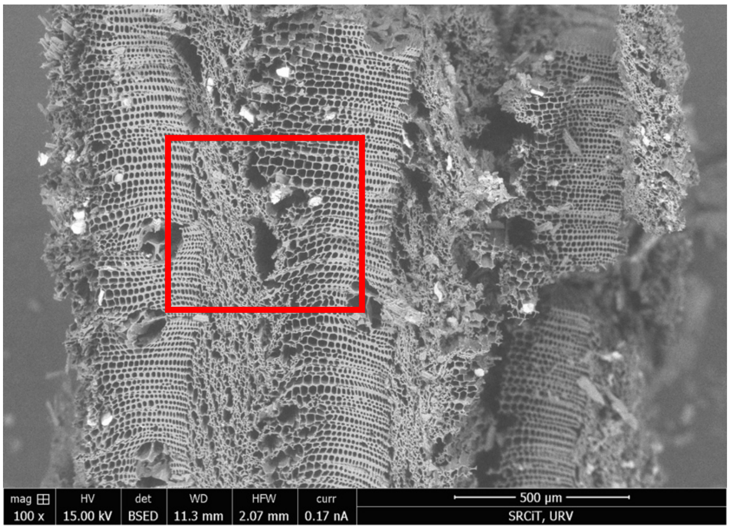


Figure 9 Cell collapse from a Pinus. Red square collapsed area.

they are multiplied by the total number of fragments studied.

- Section fractures: This variable was developed during the observations since there were several cases of fragments that were able to be fractioned following tangential or radial planes. However, so far there are no similar characterizations in the bibliography of charcoal taphonomy, which make it difficult to link a causal phenomenon of this trait. According to my observations it is most probably due to the presence of water without movement or with low movement.

3.1.5. Quantification

The materials studied in anthracology are charcoal fragments product of the incomplete charring. As a process, Chabal posited that the charcoal fragmentation is not dependent of the taxa and that the size is an indicator of the combustion degree that affected the wood (Chabal, 1987; Lucie Chabal, 1992) Other authors proposed that charcoal fragmentation is dependent of the carbonization, the caliber of branches, physio-chemical properties of wood and the type of combustion structure(Piqué, 1999). This, in turn, imply questions about the ecological representativeness of the assemblage, which is of prime importance for the information to carry out these interpretations (Chabal, 1987; Lucie Chabal, 1992; Garcia, 1992; Lancelotti et al., 2010; Piqué, 1999). Therefore, there were developed different measures to evaluate this representativeness such as the "counting" and "weighing" (Lucie Chabal, 1992). In this work, the charcoal assemblage was counted. However, in the case of Abric Romaní as the sampling is carried out manually the fragmentation occurs due to the fragility of the charcoal.

The management of the assemblage was based in the methodology proposed by different authors (Lucie Chabal et al., 1999; Kabukcu & Chabal, 2021). The quantification method is based in counting the fragments. The minimal number of charcoal fragments study is of 250, although there were made the totality of the charcoals in the level Ra. Then these are measured and analyzed, identifying the taxa and the alterations.

3.1.6. The anthracological sample from Abric Romaní (charcoal sample and taphonomy data set)

Charcoal remains were recovered during the fieldworks of 2019 to 2022. All sample was measured with cartesian coordinates using a Total Station. All charcoal fragments were hand-picked which allows to avoid spoilt, and hyper-fragmentation or destruction of the most fragile fragments, which could have consequences for taphonomical analysis (Allué et al., 2017, p. 8; Arranz-Otaegui, 2017). The total sample was composed by 645 charcoal fragments.

The analyses made in this work were developed in the facilities of the Institut Català de Paleoecologia Humana i Evolució Social (IPHES-CERCA). Charcoal analysis was conducted using a reflected light microscopy, both bright- and dark-field (Olympus BX41), with magnifications of x50, x100, x200, x500. To achieve stability of the charcoal fragments, a support system utilizing amaranth seeds was employed. To support the identification reference materials provided by the reference collection of modern charred wood from IPHES-CERCA were used as well as the wood anatomy atlas of Schweingruber (1990).

The Environmental Scanning Electron Microscope (ESEM Quanta 600 FEI) from Servei de Recursos Científics i Tècnics Universitat Rovira i Virgili was used to achieve higher definition levels for specific tasks, such as to recognize small features that cannot be appreciated in the optical microscope and to illustrate the alterations. Images from the ESEM were used to complete information about taxa and alterations. The information was stored in a database using Excel software.

3.2. Statistical methods

The first approach on the raw data once finished the data recollection was to make it readable and easy to understand in order to identify trends. To achieve this, there were made different frequency tables organizing the information in existing categories (for instance, the archaeological squares, alteration stage) and in new variables made up to categorize the data. For example, length was classified in two ways in order to compare tables. The first table summarized the 359 variates of this value (ranging from 0,5 to 18 mm) in equal intervals of 3 mm. As result there were made 6 categories. The second table classified the length in three categories: <6mm; 6-10mm and >10mm. As well as with the length, it was categorized the variable "zinfo" in order to address if there were differences in the concentrations of traits depending on the deepness. There were made categories for each 10 mm. In a second attempt there was made another classification with three categories: 1) <5; 5-10, >10.

The alterations variables were summarized in types according to their origin, this is, biological alterations (Tension wood, Cell collapse, Knots, Insects and Hyphae); Fire-Related alterations (Combustion alterations, Cracks and Vitrification) and Postdepositional alterations (Concretions and mineral depositions). Also, there were created three categorical variables that represent from the maximum to the minimum possible alterations in each type of alterations. There were made Frequency tables using the following criteria:

Table 2 Frequency tables designed.

Frequency tables designed		
Frequency table	Variable	type
1	Rows: alteration index (0,1,2,3) Columns: alterations (presence-absence)	Ordinal, count
2	Rows: "overall length category" Columns: alterations (presence-absence)	Categorical, count
3	Rows: Archaeological squares Columns: alterations	nominal, count

4	Rows “Square” + “alteration index” Columns: alterations	nominal, ordinal, count
5	Rows: “Deepness” categories Columns: length category.	categorical, categorical

In some cases, the tables revealed different N for each case. For instance, in the frequency table 1, the N of alteration state 1 is 397 while alteration state 2 is 119 and Alteration state 3 is 116. The frequency tables made able the possibility of evaluating differences between the groups to see if they were significatively different. Previously, it was necessary to check the normality of the distributions in order to choose the correct method to evaluate the differences between groups.

Frequency table one is composed of the variable “alteration index” which is ordinal was tested normal and then it was applied Kruskal-Wallis. Frequency table two was created using categories of 3 mm each one, except the bigger, which includes all possible sizes from 18mm onwards. It was tested normal and then applied ANOVA and Kruskal-Wallis. Frequency table three has no normal distribution, then it was applied Kruskal-Wallis test. Frequency table four was divided in three tables, each one using the different alteration index. All were tested following the same steps of frequency table three. Finally, the frequency table five was tested no-normally distributed and the applied Kruskal-Wallis.

Differences between groups have been tested using three main statistical tests, which are ANOVA, Kruskal-Wallis and Chi-square. The analysis of the variance is a straightforward method based in the F-distribution. The expectations that the method requires is normality, with no significant variance between groups. It is a useful method for comparing means, in this sense it can be used in expeditive ways, to know how the data behave, but also in well-defined hypothesis testing (Vanpool & Leonard, 2011).

The Kruskal-Wallis is a ranking-based test (Vanpool & Leonard, 2011a) that that was used to compare groups from the frequency tables in those cases where parametric methods cannot be applied (i.e., normal distribution and variance homogeneity). The usefulness of the Kruskal-Wallis test is in the ability of manage more than two groups and the type of variables accepted, such as ordinals or no-normally distributed. For the frequency table 3, it was used the Kruskal-Wallis method since it does not have the conditions to use ANOVA and to compare more than two groups.

Chi-square: the chi-square test reflects the combined total of all of the chi-square values created by comparing the observed and expected values. Rejecting the null hypothesis indicates that at least some of the expected and observed values are significantly different, but it doesn't specify exactly which ones these are. (Vanpool & Leonard, 2011) The assumptions of this test are, in first place, the necessity of nominal or ordinal data. Also, the variables must be independent. The third assumption is the sample size, which should be big enough (Vanpool & Leonard, 2011, p. 248).

3.2.1 Inferential statistics

Following the idea that the postdepositional processes would affect the representation of processes occurred before there were designed a series of hypothesis expecting that there would be a negative correlation between the later processes (Postdepositional and Fire-related) and the earlier processes (Biological). A test employing correlations was constructed to assess the hypothesis regarding the post-depositional processes. The method used is the Kendall´s Tau correlation: This method consists in a classical correlation assuming two dependent variables (Vanpool & Leonard, 2011) using ordinal categories (that were provided by frequency table 3). It was planned to, in case of having strong correlations, applying regression.

There were carried out different tests by contrasting variables isolated and grouped. The formers allowed to gain more detailed information about what variables were the ones with stronger correlations, while the later enabled more general information about the overall interactions between temporally differentiated processes. Correlations were made using the software PAST. To make the tests the database was copied and pasted in the software deleting those cases with errors and filling with "?" the missing values.

Cluster analysis has been performed to identify statistical clustering that can correspond to the spatially observed in order to have a support for the observations and a "double" path to support interpretations. The method used was the hierarchical clustering with paired group algorithm and Jaccard similarity index. Three types of constrains were tested to compare their results (none, stratigraphic and groups). The data used was the frequency table 3, where the rows are the squares and the columns the alterations.

3.3. Spatial analyses

3.3.1 Spatial analyses in archaeology

Archaeologists have been concerned with space from early stages of the development of the discipline, although from different perspectives and approaches. The diffusionist schools such as the Austro-German anthropo-geographers, attempted to show diffusion processes in relation to culture zones, which were bounded in space. These representations were used to study cultural history in terms of diffusion, direct contact, or acculturation (Clarke, 1977; Wheatley & Gillings, 2002). The ecological approach that raised in the US with the anthropology of J. Steward and its later application to archaeology of G. Willey developed a particular interest in the study of spatial patterns of settlements and its adaptation to environmental context (Wheatley & Gillings, 2002). The adaptational view on culture renewed the interest in studying the human adaptation to the environment. Cultural ecology prompted several works considering the landscape as a key aspect in determining or influencing behaviors such as technology, location, routes, alimentation and so on (Eriksen et al., 2013). The main methodology was to represent sites in distribution maps, but the analysis was still rather intuitive. However, by the second half of the 20th century, scholars started to shift their approach both theoretically and methodologically towards more systemic and quantitative approaches. The archaeological record was conceptualized as the result in the space of different processes that affected the materials, and thus, the main concern started to be about *relationships* between the components of the systems. An important concept that changed was the idea of culture, that started to be understood as a system, composed of sub-systems that tended to homeostasis with the environment, where change was buffered throughout feedback between components of the system (Bateson, 1972; Schiffer, 1972). From the 60s onwards, the New Archaeology made the first analyses using quantitative methods to analyze the intuitively recognized patterns of previous schools (C. Renfrew & Bahn, 2007). Variability in the space started to be explained from a systemic and functional perspective, preserving the idea of cultures as adaptations to the environment of the cultural ecology. Methodological innovations focused on statistic and probabilistic approaches, along with the application of the nomothetic method (Carl Hempel, 1955, 1966). In consequence, there were created null hypotheses (for example: distribution of x variable is random) were to be contrasted with the desired hypotheses (the distribution of x variable is clustered) in order to be statistically tested. In case a hypothesis was rejected, it could be modified and tested again. This contrast with previous inductive approaches first, there was a search of patterns and after a hypothesis designing in relation to the observed patterns.

During the 70s, intra-site analysis emerged as a way of studying patterns of distributions of archaeological remains such as lithics and bones inside excavated areas (Clarke, 1977). The models to study distributions came from different sources. Among these there were ethnoarchaeology, and taphonomy. Several statistical methods were taken from geography, economics, and plant ecology (Wheatley & Gillings, 2002, p. 6). Among these are remarkable the nearest neighbor, density estimation such as Kernel Density estimation(Wheatley & Gillings, 2002). In general, assemblage formation processes were divided into cultural and natural formation processes, where both include pre and post-despositional processes. The statistic approach studied the dispersion of findings in point dispersions with cartesian coordinates (X-Y-Z). One of the firsts methods that were applied in archaeology was the method of the *Nearest Neighbour algorithm* (Whallon, 1974). The improvement of computational and statistical methods and their applications to archaeology during the 90s derived in an ascent in the number of publications using GIS and geostatistics. From these works raised the methodological innovations of autocorrelations of continuous variables. An example of this is the use of Ripley's K and Kernel density estimation(Castillejo, 2012), the latter has been used in this work.

Regarding Paleolithic assemblages, the use of GIS in intra-site context has been applied mainly to lithic and bone assemblages. Among these, the studies have focused on themes such as the recycling of lithic materials, the refitting of stone tools and their relationship with combustion structures (Arteaga-Brieba et al., 2023; Machado et al., 2017; Neruda, 2017; Romagnoli & Vaquero, 2016) Regarding Abric Romaní site, there have been studies on the spatial analysis of hearth-related features by Vaquero (2001), who suggested that the spatial areas from levels H, I, K and L had similarities with domestic areas recorded in Upper

Paleolithic sites, although smaller than those from modern hunter-gatherer groups, but not far from the range of short-term camps. Other works focused on study the spatial structure of the remains in order to identify activity areas and synchronicity of events inside levels (Gabucio et al., 2018, 2023). Finally, there are investigations that have focused on the spatial identification of sleeping areas by studying the distribution of objects and empty spaces in the occupation surface (Vallverdú, 2010, 2012).

In the 90s there published the first papers focused on charcoal spatial distribution, (e.g., Thiébault, 1995). However, the use of GIS was allowed scholars to use larger datasets combining different types of information and apply more complex analysis to see how variables interact in the space (Wheatley & Gillings, 2002).The refinement of this method is related to the selection of an appropriate sampling technique, that also needs to suit the characteristics of the sedimentary context. The use of spatial analysis software enables the manipulation of data marked by spatial references, thereby facilitating the computation and visualization of a wide array of datasets. This technological proficiency expedites the methodical exploration of inquiries relevant to spatial utilization, incorporating the evaluation of material culture's location-based usage, the examination of palimpsest dissection, post-depositional processes, and more (Mas et al., 2021; Out et al., 2021; Vidal-Matutano et al., 2017). The possibility of studying the assemblages from spatial hypothesis opened a new way of approaching the interpretations that relates the distributions of charcoal materials with the particularities of the site and with other materials. Also, allowed the creation of simulations useful to test models (Marston, 2009), and the exploration of activity distributions and the reconstruction of past plant communities (Lucie Chabal & Heinz, 2021).

3.3.2. Archaeological grids

The spatial distribution in this thesis has been made based on the software ArcMap from ArcGis 10.8. The environment was created from the sections of the excavation provided by J. Vallverdú. The procedure was based on Mas (2018) using the archaeological level as a unit.

The first task was to delimit the workspace and its coordinates. To do this, it was mandatory to create the space in which the archaeological layers occur and stablish the coordinates (WGS1984) for referencing the document and all the objects projected. This system consists in a reference ellipsoid, reference coordinate system, altitude data and a geoid. As standard

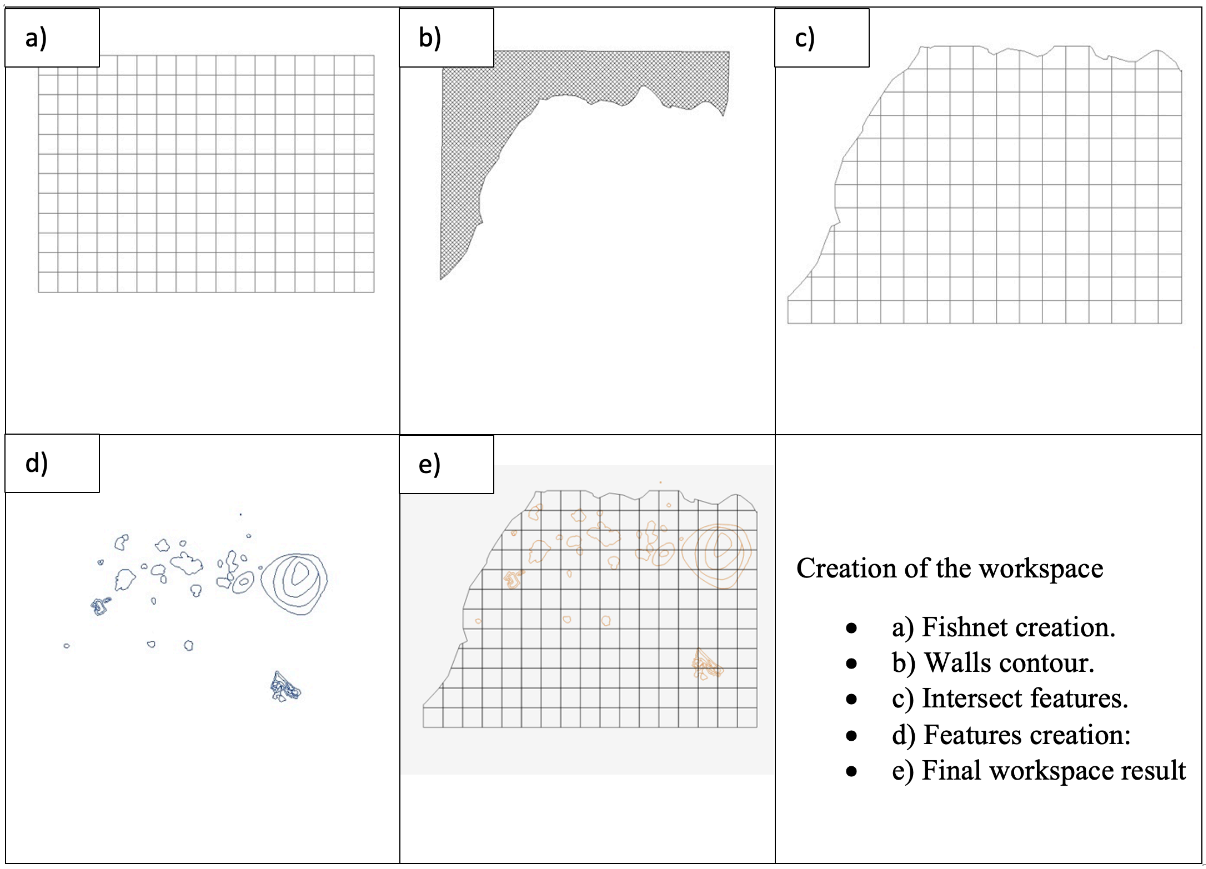


Figure 10 Steps for the workspace creation.

coordinate systems it was choose the special reference EPSG 4326.The second step was the fishnet creation to establish the archaeological squares, specifying the point zero in the left-bottom square and the number of columns (17) and lines (12). Subsequently, it followed the introduction of the archaeological map of Abric Romaní as a raster image in the project and georeferenced it. Then, there were reproduced the features that affect the squares such as the stalagmite, the witness, and the walls. This was made using the linear vectors editing tool after the creation of a new shapefile specific for these traits. Finally, it was erased the intersection between the fishnet and the features of the wall, resulting the in the layer representing the excavated surface (Figure 10).

3.3.3. Sample distribution

The following stage consisted in the introduction of the elements in the project. The excel file containing the data has, in the columns, the X and Y assigned in the excavation to the elements. This data was transformed using the following formulas:

1) XGIS= (x/100)+n
2) YGIS= (y/100)+n
3) ZGIS= z/(-100)

N is the value assigned in the ArcMap project to the column or row counting from the bottom-left corner (the archaeological point zero). Each point has a former value ranging from x to 100 and other ranging from y to 100. The first indicates the column and the second value that indicates the rows, that are coded in letters. For instance, the coordinates 94,67; states that the point is inside the square U57. From the window "catalogue" was selected the excel file with the data prepared for ArcMap. For this step it was necessary to create a shapefile from the table and then add it as a layer in the project. The same steps were made for creating the profile, although instead of YGIS, it was used the variable ZGIS and it was selected only one archaeological row: for instance, all the charcoals from row "U", determined the *x* axis, and the ZGIS determined *y* axis.

3.3.4 Heat maps

This type of representation uses statistical information displayed in polygons by graduated colours. In this case, the heat map was used to represent the average number of biological and fire-related alterations in each square. Post-depositional alterations were not represented since the maximum accumulation is two, and then the variability is low to be represented in the squares. To represent the heat map, it was created a new column where the average was calculated. Then, the column was added to the shapefile containing the points. Finally, in the properties of the layer, it was chosen the "categorized" option and selected the average variable. Once the charcoals were plotted, there were made different categorizations in order to look for tendencies, particular distributions and hypothesis testing. There were plotted those variables considered in the hypothesis presented being these the grouped alterations and the different alteration stages. Also, there were plotted the different categories of length and deepness. The taxa were represented as well.

3.3.5 Geostatistical analyses

Kernel Density Estimates (KDE) was used to calculate quantitatively how grouped are items in a particular area (Wheatley & Gillings, 2002). KDE is based on an estimation that instead of showing a circle for every point, like in simple density estimations, replace this for a function of density. In order to represent clustering more clearly, it was used the kernel spatial analysis to obtain the concentrations in gradients and thus evaluate differences in the different variable's concentrations. In the KDE the radius of the estimations around the points can be changed, allowing to control the smoothness(*Spatial Technology and Archaeology*, sem data, p. 166). In this work it was used a small radius (0,034) in order to have smooth representations of the concentrations. The calculations of the KDE were made using the archaeological squares as "processing extent" giving an output cell size of 4,79999999999997E-02. The classification used the tool Jenks natural Breaks and, in general, there were used 9 categories, except in those variables with less accumulation such as Posdep = 2, because 9 categories made at least two categories starting from 0.

Kernel steps: The first step was to introduce the excel file in "Catalog" using the variables XGIS and YGIS as coordinates to create a shapefile. Then, go to "add data" and choose the shapefile to see the representation in the map. Subsequently, is necessary select in the "tools" section the Kernel density function, open the menu, and choose the layer and the variable to see represented in amount in the field "population field". The next step is to delimit the extension of the analysis, select the layer that will be the limit (in this case is "planta") in the window "environment" and submenu "processing extent". Finally, save the file and press "ok" to see the representation.

The Geographically Weighted Regression (GWR) is a test designed to measure the relations between different variables in the space. Is based in a regression model that works over every feature studied . Also, it is not necessary to assume that the relationships are stable in the whole area. The test can be applied in ArcMap software, and it works by evaluating a local model of the variable to be predicted by fitting a regression equation to other features in the dataset. GWR constructs separate equations using a dependent and explanatory variable (it can be used one or more explanatory variables) falling within the neighborhood of each target feature (ESRI, 2023).

In ArcMap 10.8 the neighborhood model assumes a gaussian distribution. We used this test to inquire how different alterations interact in the space (archaeological grid) and if the presence of one alteration (usually later events) could be used to predict the presence of another alteration.

To make the test, it is necessary to have datasets with several hundred features. The input features "Dependent Variable" and "Explanatory Variable(s)" should be numeric and have a range of values. In the case of the dataset used, the variables did not have spatial autocorrelation individually, but from the summarized variables used (biological, fire-related and postdepositional) autocorrelation occurred in Biological and post depositional alterations.

"Statistically significant spatial autocorrelation of the regression residuals or unexpected spatial variation among the coefficients of one or more explanatory variables suggests that your model is incorrectly specified." (ESRI, 2023)

Spatial autocorrelation is a test designed to evaluate quantitatively how are the objects distributed, spatial autocorrelation exists if the objects at one location helps us to guess values of nearby points, and this correlation may be positive or negative (Wheatley & Gillings, 2002, p. 118) . The test was applied *"ad hoc"*since the results of the GWR were giving low R2 values. Since this measure explains how much the regression is fitting well in the description of the relation between variables, higher R2 indicate that the independent variable explains a larger proportion of the variation in the dependent variable (ESRI, 2023) In the tests made, the R2 was 0,6 and 0,1. In consequence, it was applied spatial autocorrelation to test if the variables were autocorrelated instead of inter-correlated.

Moran´s index test was used. This test evaluates spatial autocorrelation from -1 to 1 where -1is maximum negative spatial autocorrelation and 1maximum positive spatial autocorrelation (Wheatley & Gillings, 2002, p. 118). This test is designed to inquire about the distribution of objects in the space, if the values of. The types of distribution are dispersed, aleatory or random and clustered. Random distributions cannot be predicted while dispersed conserves more or less equidistant spaces between features and clustered distributions have groups with more or less defined limits.

In the database there was introduced the layer and the features to be analyzed. The Moran´s Index is one of the options inside the standard tests available in ArcMap10.8. The result is a table with the Moran´s Index, a Z-score and P-value. Moran´s index ranges from -1 to 1. Positive numbers indicate clustered distribution while negative indicates dispersed. The Z-score indicate how many standard deviations the calculated Moran´s index deviates from the values expected assuming no spatial autocorrelation. When the z-score is greater than 1.96, the spatial autocorrelation is statistically significant at a 95% confidence level. The P-value represents the probability of obtaining a Moran´s Index similar as the one observed under the assumption of no spatial autocorrelation.

4.Results

The results are presented following the different records analysed including taxonomy, taphonomy and spatial distribution. Different aspects are considered according to the methodology presented in chapter 3. The frequency table 1 is made using the alteration index as classificatory variable; the frequency table 2 is made with the length categorisation plus the alteration stage; frequency table 3 classifies the cases by their archaeological square; frequency table 4 adds the alteration index to the columns of frequency table 3; frequency table 5 is made using the variable "deepness category" and the columns represent the charcoal length categories.

4.1. Taxonomic identifications

The analysed sample from layer Ra of Abric Romaní corresponds to 640 charcoal fragments. The anthracological analyses shows that *Pinus sylvestris* type is the main fuel used, being around 75% of the anthracological record (Table 3). There is only another category, *Prunus* sp. with a percentage of 2,64%. The rest of the charcoal correspond to undetermined conifers and undetermined fragments.

Table 3 Anthracological results from layer Ra of Abric Romaní.

Anthracological results of Ra level		
Taxa	**%**	**Count**
***Pinus sylvestris* type**	75.63	484
***Prunus* sp.**	2.66	17
Undetermined conifers	13,44	86
Undetermined	8.28	53
Grand Total	100	640

4.2. Taphonomical analyses

The results from the taphonomical analyses have provided information on the biological, fire-related and post-depositional alterations (Table 4). The most common and significant are those related to biological and fire-related alterations followed by the post-depositional alterations. The biological alterations, which are "compression wood" (77.7 %); "cell collapse" (48.8 %); "hyphae" (15.70%) and

"knots" (1.7 %), provided results among which "compression wood" is the most significant. Regarding combustion alterations, the analysis yielded higher results for "cracks" (75.7 %), followed by "fire-related alterations" (53.3 %) and "vitrification" (21.9%). Lastly, the postdepositional alterations, composed by "mineral inclusions" and "concretion", yielded higher results for "mineral inclusions" (47.6 %) than "concretion" (13.8 %).

The study of alterations revealed that most of the charcoal fragments have compression wood, and cracks (more than 75%), 15% of the charcoal have combustion alteration, cell collapse and mineral inclusions. Lastly, vitrification is present in 20% of the charcoal, followed by hyphae and concretion (15% and 13%) and knot (1%).

Table 4 Percentage of alterations in the sample.

Charcoal alterations				
	Type of Alteration	**Total**	**Total charcoal sample**	**Alterations**
Biological alterations	**compression wood**	501	77.70%	21.84%
	cell collapse	315	48.80%	13.73%
	hyphae	101	15.70%	4.40%
	knots	7	1,10%	0,31%
	Insects	0	0,00%	0,00%
Postdepositional alterations	**mineral inclusions**	307	47,60%	13,39%
	concretion	89	21,90%	6,15%
Fire-related alterations	**cracks**	488	75,70%	21,28%
	combustion alteration	344	53,30%	15,00%
	vitrification	141	21,90%	6,15%

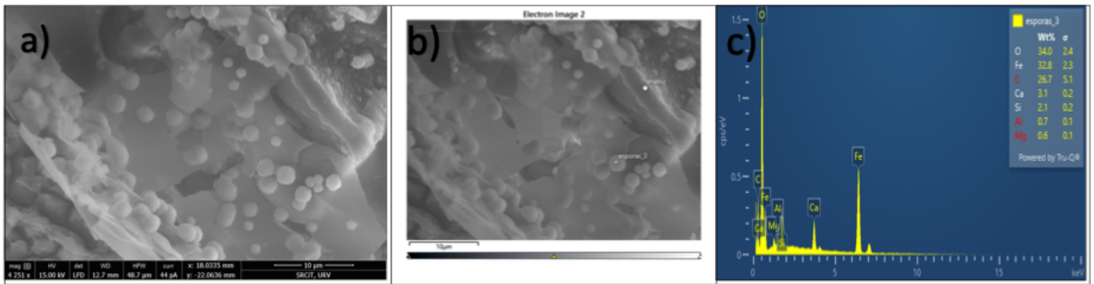
The Alteration Index has been calculated using the formula Ai= ((nA1x1 + nA2x2 + nA3x3)/ (nTOTx3) from Théry-Parisot (2014). *"The formula is: (5*1+114*2+108*3)/ (618*3) =**0.300431***

Table 5 Alteration index states. Modified from Henry & Théry-Parisot (2014).

Alteration index				
Alteration level	Microscopic traits	Wood state	Intensity	Index
A.L.0	No micromorphological signs of decay	Not affected	None, or very localized A.L 1	<0.5
A.L.1	Cavities in cell walls; minor cell deformations	Not affected	Low intensity	0.2-0.34
A.L.2	Perforated cell walls; cell deformation and/or localized voids in cellular structure	Slightly affected; taxon remains identifiable	Medium intensity	0.35-0-5
A.L.3	Collapsed cell walls; major cellular deformations and/ or important voids.	Affected taxon might be unidentifiable.	High intensity and generalized alterations	>0.5

The results falls inside the range of dead wood, which has signals of light to medium alterations (Henry & Théry-Parisot, 2014) (Table 5).

The analysis of alterations using the ESEM revealed that one of the variables considered in a first moment, “spores”, was indeed, a post-depositional concretion of iron. The traits observed were small reddish balls located in groups on the charcoal cell structure usually in high alteration state and with hyphae (Figure 11).



a)	b)	c)
ESEM image of a charcoal fragment from Abric Romaní layer R showing the features identified as "spores" reclassified as post-depositional concretions.	*Detaille image with ESEM of a charcoal fragment from Abric Romaní layer Ra U58 n38 showing the traqueids and specific features.*	*Analysis of the elements in picture b.*

Figure 11 ESEM images and element analyses of concretions from a charcoal.

4.3. Statistical analysis

To compare the data organised in the frequency tables there were developed different tests to understand if the differences were significant and then, able to be compared. The tests made were: 1) Normality tests; 2) Depending on the normality or not, the comparison tests used varied from ANOVA, chi2 or Kruskal-Wallis. All the tests results are presented in tables 9-18 in appendix I.

Frequency Table 1:

After the results of the normality test, which for the alteration index 2 did not almost showed strong support of normality, it was applied the Kruskal-Wallis method to inquire for significant differences between groups. The results showed a probability of being equals of 0.013 whereas Chi-square gave results of 91.82 (chi-square) and <0.000001 for the probability of non-association (Table 7). The Chi2 and Kruskal-Wallis indicate that there are significant differences between the Alteration index 1, 2 and 3 medians distributions and that there are associations between row values (Alteration Index) and columns (accumulation of alterations).

Table 6 Description of the frequency tables and their tests used in this study.

Frequency tables				
Frequency table	Variable	Type	Normality test (S-W)	Method
1	alteration index; number of cases in each stage of alteration and crossing them with specific alterations.	ordinal, conteo o discreta	normal	K-W/chi2
2	Rosw: "overall length category" index: columns: alterations accumulation	ordinal, conteo o discreta	normal	anova/K-W
3	Archaeological squares to classify the frequency of alterations	Ordinal, conteo o discreta	No normal	K-W
4	"Square" and "alteration index" to classify the number of cases of alterations.	ordinal, ordinal, discreta		
5	"Deepness" categories to analyse possible non-random dispositions according to the deepness and other variables such as the length category.	ordinal, ordinal, discreta	No normal	K-W

Table 7 Summarised results of tests applied to frequency tables.

Tests applied to frequencies tables						
	It is normally distributed?	**ANOVA**	**P(same)**	**Chi-square**	**P(association)**	**kruskal-wallis P(same)**
Frequency table 1	Yes, although not very much for A.i. 2	x	x	91.82	<0.000001	0.01309
Frequency table 2	Yes, although not very much for A.i. 2	substantial evidence for equal means	0.5317	x	x	0.7449
Frequency table 3	no	x	x	x	x	1.37E-33
Frequeny table 5	no	x	x	x	x	0.009378

Frequency table 2:

Frequency Table 2 was tested for normality, and then both ANOVA test and Kruskal-Wallis test were applied to asses differences between groups. The ANOVA test yielded a probability of similarity of 0.531, whereas the Kruskal-Wallis test resulted in a probability of similarity of 0.74. The normality test showed that the distributions of the alterations are normal although Postdepositional alterations are near the significance level (Table 7). After, there were made tests to test if their differences were significant and both ANOVA and Kruskal-Wallis supported that there are no significant differences between groups. The distribution of charcoal by size is represented in figure 12, that shows a slightly skewed distribution.

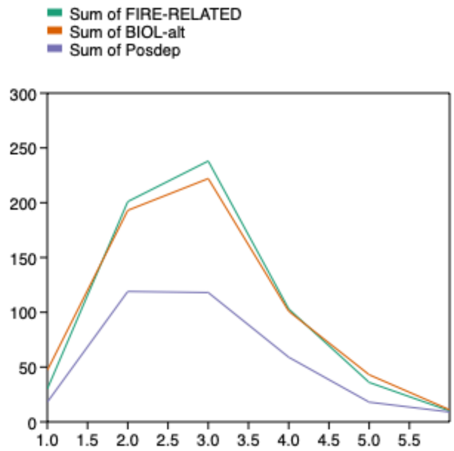


Figure 12 Distribution of the alterations by their length category.

Frequency table 3:

The normality test for Frequency Table 3 resulted in a Non-normal distribution (p.normal= 0.00000002597)(Table 7). To assess the differences between groups, the Kruskall-Wallis test was conducted. The Kruskal-Wallis test showed significant differences between medians (p-value= 1.365E-33) and the ANOVA test yielded a probability of being the same of 5.17E-16. The results show that the alterations had no normal distributions. Kruskal-Wallis test supports the differences between the distributions of alterations in the squares.

Frequency Table 5

According to the normality test, Frequency Table 5 does not follow a Gaussian distribution. To assess the differences between groups, d Kruskal-Wallis tests was employed. Kruskal-Wallis test resulted in a p-value for similarity to 0.009378. These results indicate that there are significant differences between medians of length categories according to deepness based on the Kruskal-Wallis test.

4.4. Statistical correlations

To test the correlations of the taphonomic data, different methods of organizing the data were used (see Chapter 3 Methods). Using the database, the correlations were weak in general. Only two of the correlations were higher than 0.25. Additionally, there were more positive correlations (23) than negative correlations (10) (Figure 13).

The Non-parametric method of Kendall´s Tau was used to assess correlations. In the study, post-depositional alterations showed positive correlations with most of the variables, except for Knots and Hyphae. Specifically, the correlation between Hyphae and Concretions showed a p-value= 0.05, indicating a possibility of being uncorrelated P(uncorrelated). However, with the rest of the biological alterations, the correlations were positive and deemed reliable. Similarly, correlations with fire-related alterations were positive, but the p-value for uncorrelation P(uncorrelation) reached significance levels, indicating a higher level of

Table 8 Correlations of post-depositional alterations: Blue: positive correlations. Red: negative correlations

Correlations of postdepositional alterations		
Kendall´s Tau	**Concretion**	**Posdep**
Vitrification	0.12014	0.030752
Combustion Alteration	0.23078	0.1396
Cracks	0.067138	0.14319
Tension wood	0.15206	0.16409
Cell Collapse	0.13969	0.08078
Knot	-0.076514	-0.14989
Hyphae	-0.020206	-0.19192
Concretion		0.21907

confidence in these correlations (Table 8). Overall, the results suggest that post-depositional alterations, biological alterations, and combustion alterations exhibit significant positive correlations with most of the variables. The exception is identified for the specific case of Hyphae and Concretions, where the correlation might be weaker or non-existent.

Fire-related alterations had positive correlations with almost all the alterations except Knots and Hyphae (Table 9). Regarding the confidence of the tests, those of vitrification with tension wood, cell collapse and post-depositional, combustion alteration and compression wood and Hyphae, and cracks and concretions were not significative (Table 10).

Table 9 Correlations of fire-related alterations. Blue: positive correlations. Red: negative correlations

Correlations of fire-related alterations			
Kendall´s Tau	**vitrification**	**combustion alteration**	**cracks**
Vitrification			
Combustion alteration	0.22088		
Cracks	0.075191	0.34391	
Compression in traqueids	-0.0014058	0.0033591	0.17347
Cell collapse	0.11765	0.28012	0.16754
Knot	0.052823	-0.08422	-0.12155
Hyphae	0.076414	0.016591	-0.081352
Concretion	0.12014	0.23078	0.067138
Posdepositional	0.030752	0.1396	0.14319

Table 10 P of uncorrelation of combustion alterations. Blue: positive correlations. Red: negative correlations

P of uncorrelation of combustion alterations			
P(uncorrelated)	**vitrification**	**combustion alteration**	**cracks**
Vitrification			
Combustion alteration	6.32E-17		
Cracks	0.0044337	1.01E-38	
Compression in traqueids	9.58E-01	0.899	5.59E-11
Cell Collapse	8.49E-06	2.95E-26	2.29E-10
Knot	0.12318	0.013978	0.00038918
Hyphae	2.46E-02	6.26E-01	1.67E-02
Concretion	5.23E-04	2.68E-11	5.26E-02
Posdepositional	0.35834	3.05E-05	1.89E-05

Biological alterations showed more negative correlations than other variables, but the main negatively correlated variables were Knots and Hyphae, which were constant in similar results in previous tables. Hyphae has significant values for uncorrelation with Combustion

Table 11 Correlations of biological alterations. Blue: positive correlations. Red: negative correlations.

Correlations of Biological alterations				
Kedanll´s Tau	**compression wood**	**cell collapse**	**knot**	**hyphae**
Tension wood				
Cell collapse	0.13905			
Knot	-0.15742	0.10275		
Hyphae	-0.084244	-0.05573	0.062172	
Concretion	0.15206	0.13969	-0.07651	-0.020206
Posdep	0.16409	0.08078	-0.14989	-0.19192
Vitrification	-0.0014058	0.11765	0.052823	0.076414
Combustion alteration	0.0033591	0.28012	-0.08422	0.016591
Cracks	0.17347	0.16754	-0.12155	-0.081352

alteration. Cell collapse, knots and tension wood has significant values for uncorrelation with

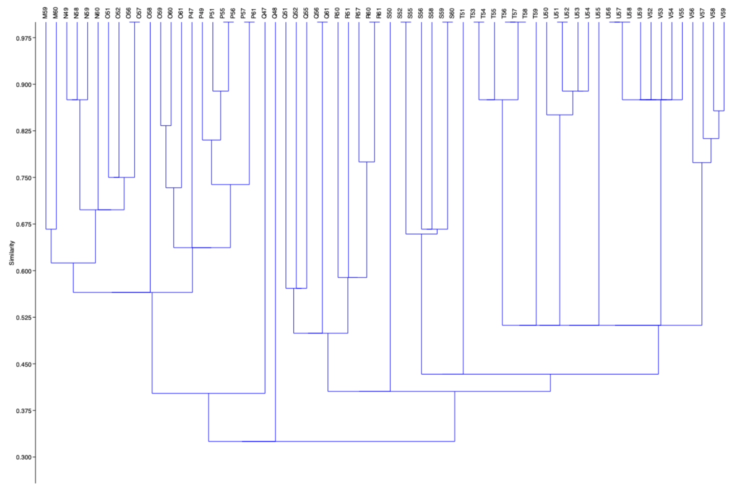


Figure 14 Cluster analysis of archaeological squares classified by their alterations. See bigger in appendix II

vitrification and Combustion alteration and Knots with Vitrification (Table 11 and figure 13).

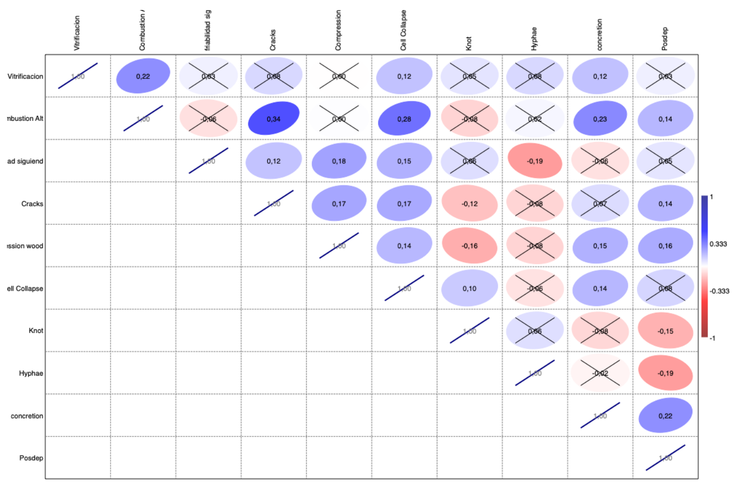


Figure 13 Correlations of alterations using Past software.

The results of the hierarchical clustering using the alterations variables as classificatory values and the stratigraphical constraints are shown in.Figure 14 where two main groups can be observed. These groups correspond to differentiated areas of the level Ra. On the one hand, the group with squares from M59 to Q47 are those in the southern excavation area. On the other hand, those from Q51 to V59 are those in the northern excavation area (Figure 14).

Within these groups there are differences, the northern group has more squares than the southern one and it is composed by more defined groups due to their more separated branches than those of the southern group.

4.5. Spatial analysis

The spatial arrangement of the charcoal remains has been used to represent the spatial distribution of charcoal *per se* but also different variables. The first representation aimed to examine how the charcoal fragments were distributed. The results showed that the charcoal fragments were clustered, indicating Non-random pattern and that some of these clusters were in places without the hearth-related modifications in the sediments. Notably, these clusters were smaller compared to those associated with hearths.

Alteration Index categories and length categories showed no significantly different distributions. This is, there were made Kernel density estimations for every Alteration Index category and the results overlapped between them (Figure 18).

Regarding taxa representation in the space, a cluster of *Prunus* sp. was identified in the squares R60 and S59 (Figure 15). However, since there were some isolated occurrences of *Prunus* sp. in other squares, the Moran´s Index indicated a dispersed distribution for this taxon.

Table 12 Moran´s index of Fire-related alterations.

Fire-related Moran´s index	
	Charcoal
Variable	FIRE_RELAT
K Nearest Neighbors	KNN = 1.0
Morans-I	0.01978
Expected Value	-0.00156.
Z-score	0.43176.
P-value	0.6659180255868438.

The results indicate that there is a weak tendency for similar values of "FIRE_RELAT" for clustering together in space. However, it is important to note that this spatial correlation is not statistically significant (Table 12). In other words, the observed clustering of "FIRE_RELAT" might be due to random chance rather than a systematic spatial pattern.

Table 13 Moran´s index.

Moran´s index of Biological alteraitions	
	Charcoal
Variable	BIOL_alt
K Nearest Neighbors	KNN = 1.0
Morans-I	0.10164
Expected Value	-0.00156
Z-score	2.0875
P-value	0.03684325045739878

The positive Moran's I value (0.10164) and significant z-score and p-value (2.0875 and 0.0368, respectively), provides strong evidence of statistically significant spatial correlation in the variable "BIOL_alt" (Table 13). This indicates that there is a meaningful spatial pattern in the distribution of biological alterations of archaeological charcoal across the site. In other words, areas with similar biological alterations are more likely to be found close to each other.

The results indicate that there is a strong tendency for similar values of "Posdepositional",

Table 14 Moran´s index of Post-depositional alterations.

Moran´s index if Postdepositional alterations	
	Charcoal
Variable	Posdep
K Nearest Neighbors	KNN = 1.0
Morans-I	0.28863
Expected Value	-0.00156
Z-score	5.86995
P-value	4.36E+07

which are related to postpositional processes, to cluster together in space. Moreover, this spatial correlation is highly statistically significant. It suggests the presence of a systematic spatial pattern for the variable "Post-depositional alterations" (Table 14).

The GWR test (Geographically Weighted Regression) was conducted using two different layers. In the first case, the layer used was the polygon layer (.shp) representing the squares, with the charcoal fragments as attributes of the polygons. This means that each square had associated attributes of the charcoal recovered within it. In the second case, the layer used was a point shapefile (.shp) comprising the individual locations (X, Y, Z) of the charcoal. In both cases, the explanatory variables of the biological alterations were the Fire alterations and the Post-depositional alterations.

The results show that average R2 is lower for the individual points than the polygons (Tables 15 and 16). This measure represents the goodness of fit of the regression model. In the raster layer created there is a specific local R2 for every point or polygon.

Table 15 Summarized information of the GWR of the polygon shapefile.

GWR polygon Shapefile			
OID	**VARNAME**	**VARIABLE**	**DEFINITION**
0	Neighbors	30	
1	ResidualSquares	175.61113	
5	R2	0.613694	
6	R2Adjusted	0.472376	
7	Dependent Field	0	Biological
8	Explanatory Field	1	Posdepositional
9	Explanatory Field	2	FIRE_RELAT

The second GWR results showed similar lower results for the adjustment of the model (Table 16). In the appendix there are available the graphics showing spatially these measures (figures XIV-XIX). Using the charcoal points to test the spatial regression the results showed that the residuals do not have a visible pattern. Most of the values are between -0,73 and 0,96 although.

Table 16 Summarized information of the GWR of the point shapefile.

GWR point shapefile			
OID	**VARNAME**	**VARIABLE**	**DEFINITION**
0	Neighbors	639	
1	ResidualSquares	371.68183	
5	R2	0.139241	
6	R2Adjusted	0.130433	
7	Dependent Field	0	Biological
8	Explanatory Field	1	Posdep
9	Explanatory Field	2	FIRE_RELAT

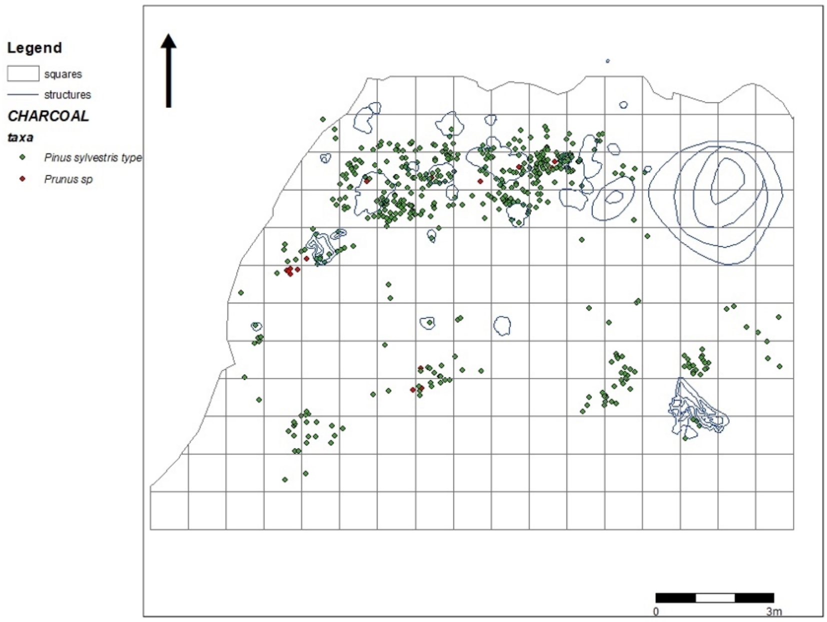
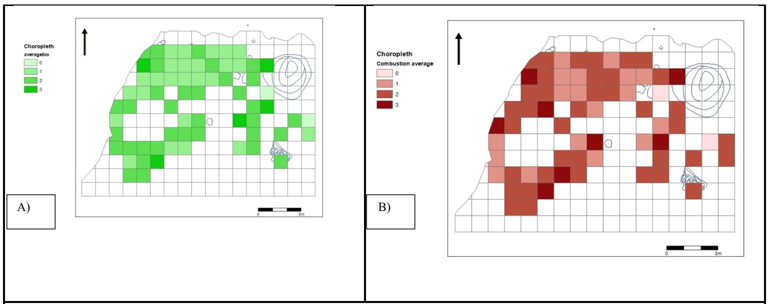


Figure 15 Charcoal representation by taxa See appendix II Figure II.

The spatial distribution of charcoal by taxa and alterations are presented in Figure 15. Distribution by taxa allows to define concentration of charcoal remains and to identify the location of Prunus sp. fragments which are concentrated in two specific areas (Figure 15). The spatial distribution of the accumulation of alterations are showed in figures 19 to 21. These were separated by alterations and accumulations of them. There were maintained in possible similar number of categories of clusters, eight in most of the cases, to improve de comparisons.



A) *Choropleth maps represent the average accumulation of biological alterations in every square*

B) *Choropleth of combustion alterations.*

Figure 16 Choropleth maps. See VI and VII in appendix II

The choropleth maps show where there are higher average of alterations. In both cases there are not clearly distinct patterns considering the alteration (Figure 16). Indeed, in both figures their higher accumulations are in the same squares. To evaluate distribution using different variables we used Kernel Density Estimation (KDE). The variables used were the charcoal per se, the Alteration index and the levels for each alteration category. KDE distributions showed clusters in the squares associated with hearths mainly on the rows T and U. However, there are clusters in the southern area of the excavation, between M and Q rows. The charcoal distribution shows that the main concentrations are in the squares U53, T57, T54 and U56

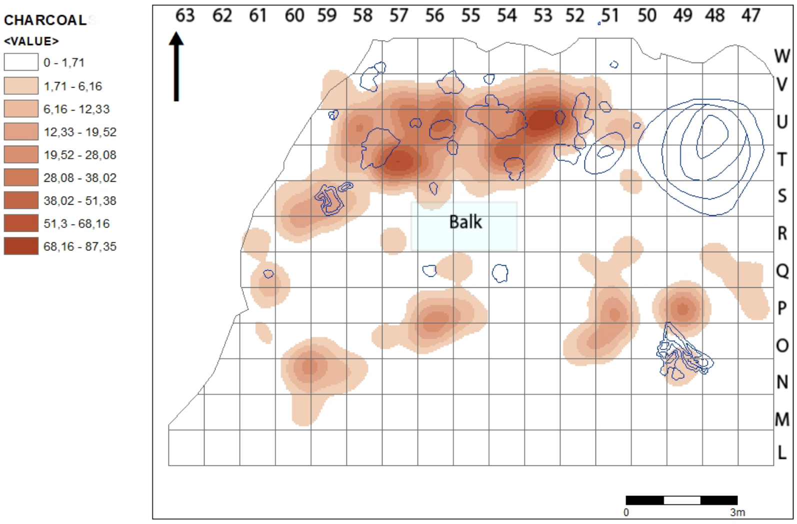
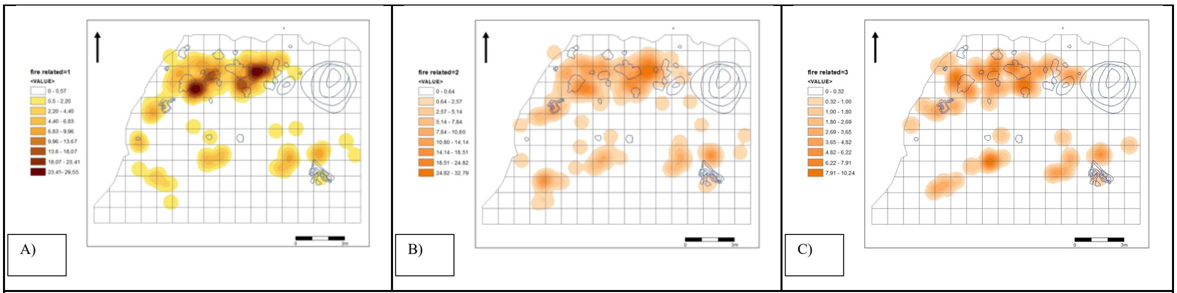


Figure 17 charcoal distribution of level Ra. The main clusters are in the squares U53; T54; T57; U56; P49 ;P56; P51 and N59.

reaching a maximum of 68-87 charcoal per unit (Figure 17). These clusters are related to a greater group that goes from U51 to U59 including part of rows T and V. The southern part of the surface has smaller clusters both in size and number of charcoal reaching in P49 a category that goes from 51 to 68 charcoal per unit.

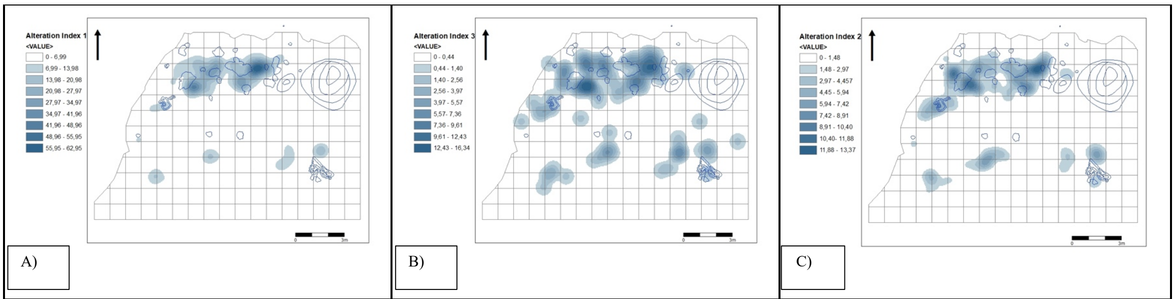


A) *Kernel Density Estimation of fire-related alterations with 1 accumulation. The main clusters are in the squares U53; T54; T57 and U56.Kernel Density Estimation: Alteration index 2: The main clusters are in the squares U53; T54; T57 and U58.*

B) *Kernel Density Estimation of fire-related alterations with 2 accumulations. The main clusters are in the squares U53;T54; T57;U56; N60; P49; U57 and U58 (in decreasing order).*

C) *Kernel Density Estimation of fire-related alterations with 3 accumulations. The main clusters are in the squares T54;U56; U57; U58; T57, O56 and P49 (in decreasing order).*

Figure 19 Kernel Density Estimation of fire-related alterations See appendix II VIII, XIX and X.



A) *Kernel Density Estimation: Alteration index 1: The main clusters are in the squares U53; T54; T57 and U56.*

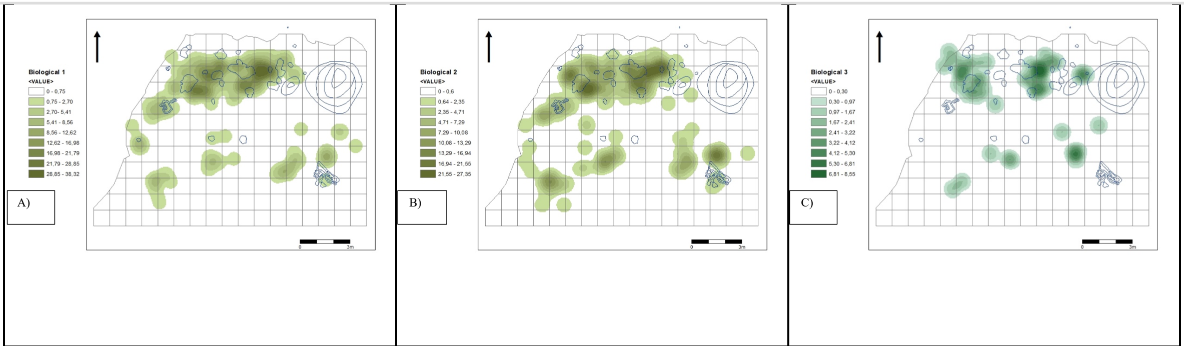
B) *Kernel Density Estimation: Alteration index 2: The main clusters are in the squares U53; T54; T57 and U58.*

C) *Kernel Density Estimation: Alteration index 3: The main clusters are in the squares U53; T54; T57;U58 and U57.*

Figure 18 Kernel Density Estimation of Alteration index See appendix II figures XI, XII and XIII

Categories of alterations were used to represent different accumulations of the alterations, in general higher number of accumulations have similar distributions although more concentrated in the northern areas.

When comparing the distributions classified by their alterations (Figure 18; 19, 20, 21), it can be appreciated that the distributions are similar in general, clustering mainly in squares U53, T54; T57; U56; U57; U58; P49; P56 and P51. The main clusters of Fire-related accumulations are in squares T57 and U53, they are next to hearths and near the wall. The Biological alterations with 2 and 3 accumulated alterations show a cluster near the wall, in U59.

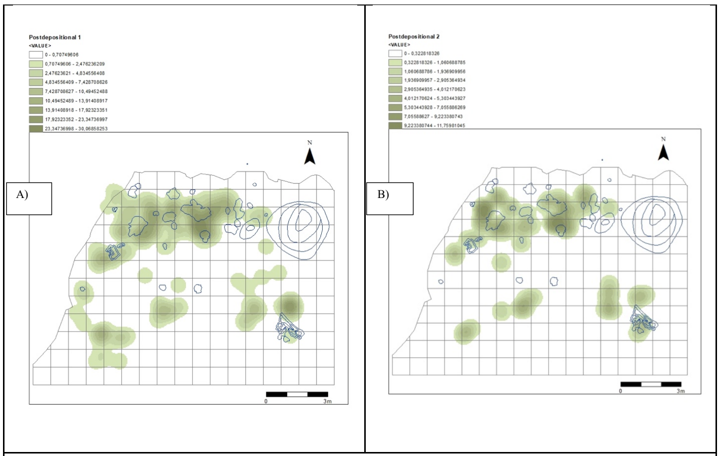


A) *Kernel Density Estimation of biological alterations with 1 accumulation. The main clusters are in the squares U53; T54; T57;U56 (in decreasing order).*

B) *Kernel Density Estimation of biological alterations with 2 accumulations. The main clusters are in the squares U53; T54; P49; N59; U58; T57; U56; O56 (in decreasing order).*

C) *Kernel Density Estimation of biological alterations with 3 accumulations. The main clusters are in the squares U53; U58; P51 and T53 (in decreasing order).*

Figure 20 Kernel Density Estimation of Biological alterations. See appendix II Figures III;IV and V

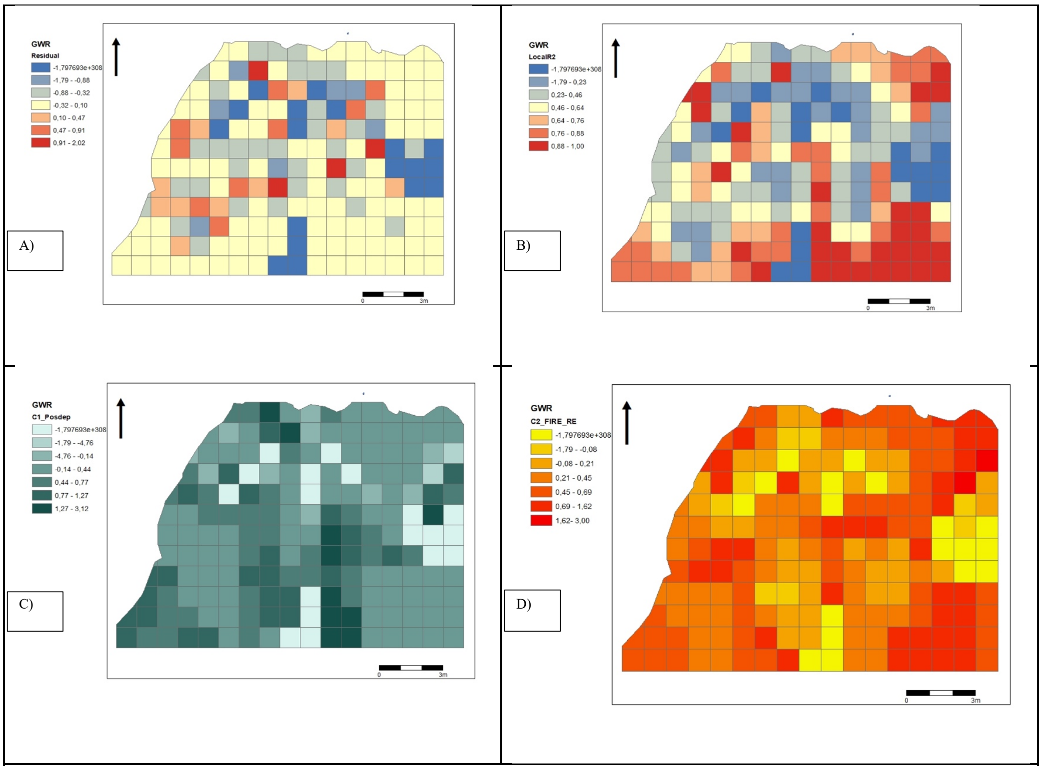


A) *Kernel Density Estimation of Post-depositional alterations with 1 accumulation. The main clusters are in the squares T54; P51; O56 and T57 (in decreasing order)*

B) *Kernel Density Estimation of Post-depositional alterations with 2 accumulations. The main clusters are in the squares T54; U58; T57 (in decreasing order).*

Figure 21 Kernel Density Estimation of post-depositional alterations

GWR (Geographically Weighted Regression) results represent different variables that inform about the applicability of the method and the hypothesis tested. The residuals are the differences between observed and predicted values for each location. In the Figure 22, the distribution of residuals in squares follows a pattern where the higher and lower values are in those squares with more charcoal remains representing that the test does not fit well with the data. The local R2 represents the goodness of fit for each local regression model at every location. Figure 22,b) shows that there are low values, explaining lower proportion of variation in those squares with more archaeological charcoal. Lastly, coefficients of each independent variable represent the local regression coefficients for each variable at every location. Figures 22 c) and 22 d) represent that Post-depositional and Fire-related alterations have the lower results where they overlap with the same squares in which there is the lower R2. This means that the negative correlations are not explicative since the R2 is in its minimum.



A) Geographical Weighted Regression: Local residuals.Choropleth of combustion alterations.

B) Geographical Weighted Regression: local R2.

C) Geographical Weighted Regression: Coefficient of Post-depositional alterations

D) Geographical Weighted Regression: Coefficient of fire-related alterations.

Figure 22 Geographical Weighted regression using squares plus charcoal points.

5.Discussion

5.1. The paleoenvironment during level Ra Neanderthal occupations

The presence of *Pinus sylvestris* type is recurrent and in coherence with the rest of the sequence, being the main represented taxa. This category "*Pinus sylvestris* type" regroups three species: *Pinus nigra* ssp. *salzmannii* (black pine), *Pinus sylvestris* (scots pine) and *Pinus uncinata* (mugo pine or mountain pine) (Allué et al., 2017; Allué & Mas, 2020). These cannot be differentiated by their wood anatomy. Indeed, the *Pinus sylvestris* type category is widely used because the differences between these species can be problematic (Carcaillet and Vernet, 2001; Schweingruber, 1990; Postigo-Mijarra et al., 2017). Some suggestions were made to distinguish *Pinus sylvestris* from *Pinus nigra*. For instance, the former has rectangular and elongated fenestriform cross-fields, while in the second are more rounded (Mas, 2018; Postigo-Mijarra et al., 2017). However, this division was not performed in this work. These species are adapted to cold and dry climates. Currently *Pinus sylvestris* type lives in altitudes higher than 600 meters (*P. nigra* from 350 to 2,200 m. asl) and their extension in the Pleistocene was likely wider than today (Postigo-Mijarra et al., 2017). Their extension nowadays is huge, ranging from the Iberian Peninsula to East Russia and from sea level to 2,600 meters (San-Miguel-Ayanz et al., 2016). Consequently, there are different types of associations that *Pinus sylvestris* type species can have with other taxa (Mas, 2018).

The compression wood observed in pine's tracheids is often related to environmental stress, which could be associated with the growing conditions of the trees in environments with snow, wind or in sloppy areas (Fritz, H. Schweingruber, 1990). Each one of the causes of compression wood could be interpreted differently: the growing in slopes could be considered an indicator of the area of recollection, probably in the surroundings of the site. If the compression wood is due to snow stocked in the branches of the trees, the environment could have annual periods with snow deposition that last for months or the necessary time span to affect the cell structure of the wood. Also, wind can be the cause of the compression wood, being informative about the climate regime of the site.

The presence of *Prunus* sp. in this layer has reached a percentage of 2.66, representing a higher value compared to both other levels and woody taxa representation (Allué et al., 2017). This higher presence could be related to a climatic environment with more arboreal taxa, in the context of warming periods or patchy/refugee environments. The mosaic characteristic of the environment near to the site has been marked by different works (Biltekin et al., 2019b; Burjachs et al., 2012; Vaquero et al., 2013).

Regarding the species determination of the identified *Prunus* sp, there is a categorization, several traits can be shared by the different species, being difficult to be classified. However, the Ra examples have ring or semi-ring porous (cross-section), and the rays are homogeneous in the (tangential section) and multiseriate from 3- to 5-seriate rays, although there are some cases with more than 5 multi-seriate rays (Fig. 6.3). Considering the specialized atlas of wood anatomy (Schweingruber and Landolt, 2005), there are three main possibilities for the identification of the *Prunus* sp. (Fig. 6.3): *P. amygdalus (syn Amygdalus sp.), P. spinosa or P. mahaleb*. Considering the cross-section, the Ra example is like the *P. amygdalus*, but the tangential section could also correspond to *P. spinosa* type (see pictures in Figure XXII in appendix II).

Prunus species are highly variable in their environmental preferences, they are thermophilous and pioneers, and commonly they have tree or shrub structure. In any case, most of the studies determine these taxa as *P.* cf. *amygdalus* or including types such as Prunus spinosa/ mahaleb (Allué et al., 2018; Ntinou and Kyparissi-Apostolika, 2016). Only in specific cases in which the ring porosity is clearly observed the identification is more precise (Caracuta et al. 2021; Kabucku and Asouti 2022)

Prunus spinosa (blackthorn) is a deciduous, shrub, that produces edible plums. It has a size from 1 to 5 meters tall with a dense canopy and spines. Is common to find it in forest margins and openings with direct sun, also in rocky slopes, river valleys, ravines, and plains with different altitude values (San-Miguel-Ayanz et al., 2016). *Prunus mahaleb* is a deciduous tree or shrub that can achieve 10 meters and its habitat can be open woodlands, forest margins and riverbanks. It has widely used fruits and seeds. Its habitat can be warm, sunlight and dry slopes at middle elevations. At the same time, it has resistance to frost (San-Miguel-Ayanz et al., 2016).

Considering the presence of this taxa we can suggest that the immediate forest around Abric Romaní was mainly composed by *Pinus sylvestris* type, although more specific identifications are difficult to achieve. Other species were probably in the nearby areas, likely in the riverbank, but also in different altitudinal levels. The higher presence of *Prunus* than in other levels could be related to the increase in the percentage of temperate trees recorded by pollen analysis in the first millennia after 59 Ky bp (Figure 23). This suggests an environmental condition of climatic improvement that allowed the rapid expansion of wood species that were reduced to refugees in the previous climatic conditions.

R level is located between "Abric 1-c" (57.37+-0.24) and "Abric 2" (68.33+-0.15) in the age-depth model from Biltekin (2019a). However, personal communication during the seasonal excavations with Dr. P. Vallverdú, led to the conclusion that the occupation is after the Heinrich 6 (H6) event (64-62 kyrs BP), in the final moments of the MIS 4 or likely the beginning of the MIS 3 (figure 23). The H6 event was a cold phase that occurred in northern Europe, although its impact on the northeastern Iberian Peninsula was moderated. Indeed, the arboreal taxa were reduced only in 40%, allowing the forest to survive and rapidly expand in the next period (Burjachs et al., 2012a). The research published involving the time span where Ra level is mainly related to pollen analysis. Pollen results have pointed out the incremental proportion of deciduous *Quercus* and its reduction around 57ky (Biltekin et al., 2019a), after that it has peaks likely associated with OIS 16 (Vallverdú, personal communication). During the MIS 3, there was an initial warm phase (GI 17) characterized by pine forest and a presence of 25% warm temperate woody species (Figure 23). Subsequently, in GS 17 phase, which was analyzed for its micromammal assemblage in level O (Burjachs et al., 2012b), the Mean annual temperature (MAT) was approximately 7.5ºC lower than the current temperature. This was accompanied by a higher Mean Annual Precipitation (MAP) in mm/y compared to the present conditions.

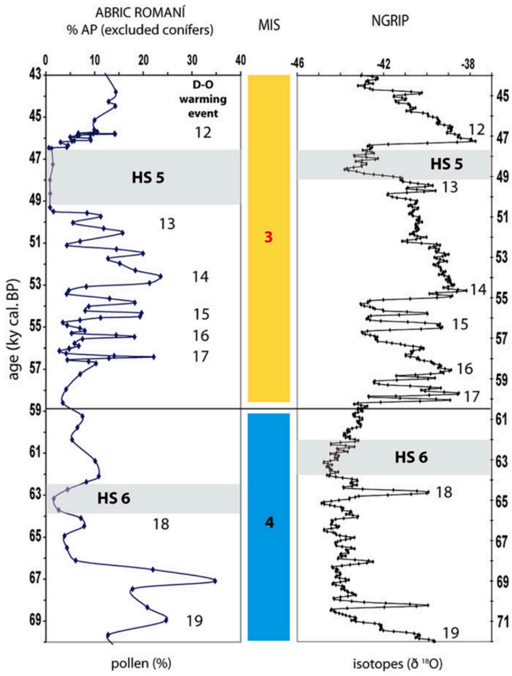


Figure 23 Comparison between isotopic ice curve NGRIP (NGICP, 2004) and Arboreal Pollen (AP) (Biltekin et al., 2019a).

It is important to note that there is still some absence of data for level Ra specifically, since there are no Ur-series dating the level or publications about the faunal and lithic assemblage. Moreover, while some alterations can be easily discerned like those post-depositional, others have the problem of equifinality. This is the case of cracks for instance, that can be produced by fire or by post-depositional compression. In addition, it is important to consider that the effects of alterations are in some cases overlapped, making it impossible to discern the agents that affected the charcoals giving their final aspect.

5.2. The archaeological context: post-depositional alterations and their spatial distribution

The processes that formed the charcoal assemblage have been studied bearing in mind the temporal sequence of events. The reconstruction from later to former processes has been important to understand relations between these processes. The spatial analysis allowed the interpretation of distributions considering the characteristics of the studied events. This conceptual scheme is the structure used in this research to analyse the involved processes (see Chapter 1).

Before starting with the sequential division, it is important to consider some general results from the analysis. The taphonomical studies revealed that the main alterations affecting the state of the assemblage are those related with the combustion processes, followed by the biological alterations including compression wood and cell collapse. Compression wood was the most recorded alteration, followed by cracks and combustion alterations.

Cell collapse variable is problematic since it can be generated by different processes, this is, due to equifinality (Allué et al., 2009; F H Schweingruber et al., 1978). However, as it was registered it was systematically differentiated the cell collapse as a biological alteration when healthy tissues were together with cell collapse in transversal section. Regarding the spatial distributions, the clustering and non-random distribution of charcoal highlight the presence of meaningful spatial patterns that are indicative of formation processes. Moreover, the absence of randomized distributions can be interpreted as representative of post-depositional processes that are not very intensive, though not inexistent.

The charcoal assemblage is divided in two main groups distributed in the northern and southern parts of the excavation surface. The northern section is near the shelter wall and is associated with the distribution of hearths. Also, it is the largest comprising more clusters that overlap between each other and have more charcoal. Furthermore, the higher degree of alterations is reached in the northern section, which is an indicator itself of the processes that support the differentiation of the two groups. However, in proportional terms the differences are not so marked, conserving the same proportions, except for the presence of hyphae (Fig ure 24).

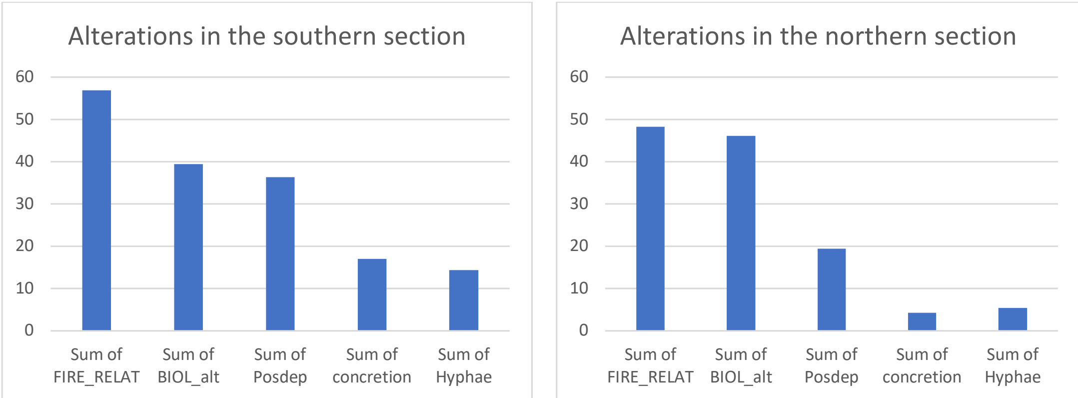


Figure 24 Comparison between charcoal assemblages from different sections.

The results showed that the post-depositional alterations were not specially marked in the assemblage (figure 25). Post-depositional alterations comprise mineralization and concretion of minerals. However, the presence of hyphae could be related to a post-depositional process, being its mineralization part of the post-depositional concretion (Vallverdú, personal communication). Inside the post-depositional alterations, the mineral inclusions were present in 47% of the assemblage, meaning a significative contribution to the final aspect of the charcoals. Concretions were present in 13.8% of the assemblage, being a reduced and likely localized alteration of the charcoal (see resjults section and tables therein). The spatial distribution of the post-depositional alterations is proportional to the number of charcoal fragments in each cluster or group of clusters. This is, in the northern clusters there is an amount of 489 charcoals while in the southern part there are 153. From these, the northern part has 63/489 concretion and 222/489 mineral inclusion cases, while in the southern part the proportion is 26/153 concretion and 85/153 mineral inclusions (Figure 24).

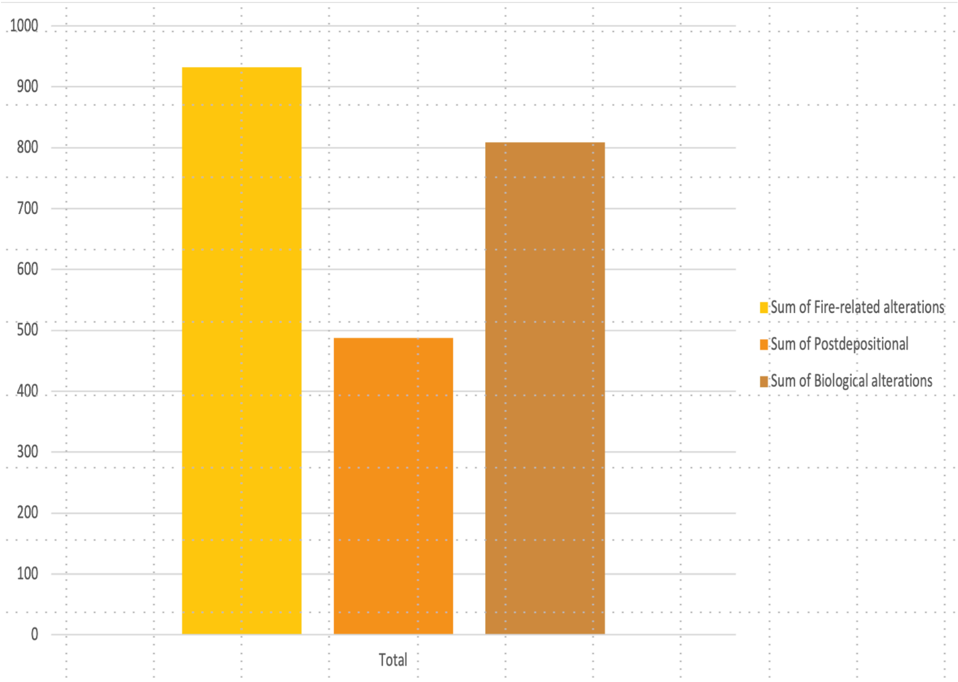


Figure 25 Bar graphic of charcoal alteration accumulations

The presence of hyphae has been interpreted as a post-depositional process that could have affected the cell structure of the charcoal (Figure 26). The structure of the hyphae has been preserved thanks to the saturation of minerals from the water coming from the walls and ceiling of the rock shelter. The condition for this process to occur is the availability of Ca^{2+} ion and water (Verrecchia & Verrecchia, 1994).

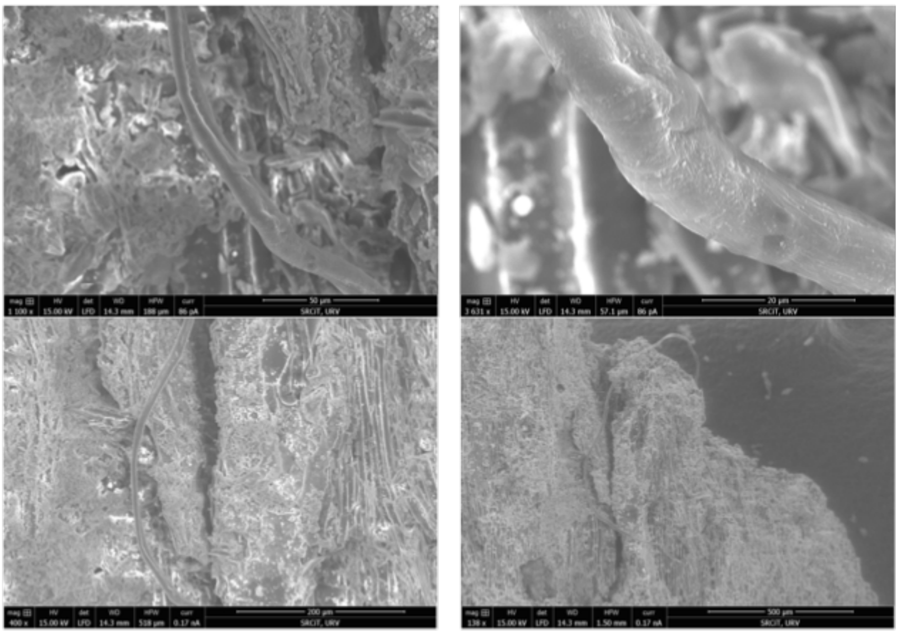


Figure 26 Hyphae mineralized at different magnifications.

Comparing the data between northern and southern areas, the post-depositional variables are significantly different in their mean and median considering squares accumulation. The squares with a higher accumulation of alterations cases are near the wall, in squares T54, U58, T58 and T57, probably due to the presence of water flows carrying dissolved minerals and pieces of sediment. The maximum presence of these alterations in the southern part is three, while in the northern is nine. Spatially, the accumulation of post-depositional alterations is autocorrelated as has been showed by the Moran´s Index. Moreover, this spatial correlation is highly statistically significant.

This autocorrelation is probably because of the processes affecting the charcoal located in discrete areas of the surface. This autocorrelation may be related to the fact that the correlations were positive in general with the other variables. This is the opposite of the expected negative correlations under the hypotheses that assumed that later alterations would mask alterations from previous processes. However, the correlations did not reach high levels (maximum is 0.2), meaning independence between the alterations.

5.3. The systemic context: Cultural formation processes based on the spatial analysis of combustion alterations and biological alterations.

The systems network in which the occupation of level Ra occurs is composed by the social behavioral system and the ecological system. The combustion alterations are informative about the use of fuel by humans, this is, about the behavioral system. The biological alterations are informative about the behavioral system because the woody plants are socially filtered (Auréade Henry & Théry-Parisot, 2014; Théry-Parisot et al., 2010), but also, they are informative about the ecological system.

Combustion alterations were the most present alterations in the assemblage. Cracks were present in 75% of the assemblage, while combustion alterations almost reached 50% of the assemblage and vitrification was present in 20% of the assemblage. It may be interesting to notice that, although in the southern section of the excavation surface there are small hearths (in squares Q54, Q56 and Q61), the charcoal fragments are not clustered around them such as in the northern section, only isolated charcoals are inside them. This may be due to the total carbonization of the charcoal in those hearths in the southern squares, but also to the waste-management of charcoals coming from the north area.

The accumulation of biological alterations also showed spatial autocorrelation, which may be related, on the one hand, to the similar environmental conditions where the trees were growing and, on the other hand, to the spatial relation produced by the selection and use of wood. This is, most of the accumulations of biological alterations (not particular alterations) showed distributions following cluster organization. This is, if selection of fuel occurred in the near areas of the site, as it has been proposed by Allué (2017), and this was organized by discrete "packs" of branches or wood trunks, it might be expected that the clustering of traits already present in the wood before selection was preserved in the charcoal spatial relations. The archaeological consequences of these actions could be evaluated by the clustering of alterations or other traits.

As in other layers, the main remains are related to *Pinus sylvestris* type, that is accompanied by other taxa, in this case, *Prunus* sp. The most abundant species in the surroundings of the site is likely the main fuel used (e.g., *Pinus sylvestris* type) and the variation in the sequence of other species could represent changes in the vegetal communities associated to climate change, but also to human selection for specific purposes. In the sequence of Abric Romaní there were found storage unburnt woods, which, along with the absence of riverside species, related to the procurement of nearby dead wood (Allué et al., 2017; Solé et al., 2013).

The clustering of *Prunus* sp., in the case of fuel use, supports this behavioral interpretation, represented in this case by a species, not an alteration, as well as raising questions about the use of this species for specific purposes. The clustering added to the low frequency of this species is interesting. There are possible explanations for this cluster but none of them could be tested with the actual knowledge. The data suggest that the clustering could be related to one episode of burning a piece of *Prunus* sp. and not the consequence of several combustion events, which it is unlikely. The presence of *Prunus* wood could be related to the extraction of one or more specific resources, such as resin, fruits recollection, wood for tools and so on. In this regard, the archaeological and ethnographical documents show a great variability in the possible uses (Martinoli & Jacomet, 2004; Menendez-Baceta et al., 2017; Quave et al., 2012; Svanberg, 2012; Timbrook, 2012).

An alternative explanation for the distribution of *Prunus* sp. could be that the cluster is representing a burnt object as has been proposed for similar cases by Allué et al. (2017), although in this case there are more than one or two fragments in the cluster. Another possible explanation can be related to its use as fuel for specific purposes, such as starting the fire. It has been posited that *Prunus* sp. fuelwood has good characteristics as fuel (Zapata, 2001). However, the distribution should be more homogeneous in the space, or should have clusters associated to the hearths. A third possible explanation is the recollection for its fruits, however there is no evidence yet of the edible parts of this plant (fruits or seeds) in this assemblage. In case that the occupation was in autumn or winter as proposed by the scholars due to the presence of deer masts anchored to the front bone (IPHES, 2020), then the only possible taxa that may have fruits available is *Prunus spinosa* (San-Miguel-Ayanz et al., 2016).

The application of the alteration index was found useful for different reasons, although it was designed for closed combustion environments (Henry & Théry-Parisot, 2014). In the first place, the descriptive possibilities that brings are accurate and easy to apply. Secondly, even if the problem of equifinality remains, is a great advance the link between macroscopic state of the wood and microscopic features. Thirdly, since the sedimentary environment of the Abric Romaní favors the quick burial of the materials, and the preservation of levels with a relatively slow "palimpsest effect", we consider that its worth to try the applicability of the index. The result of the alteration index suggests that the fuel collection was based on dead wood in a variable conservation state, although not rotten. The high rates of deadwood production of *Pinus sylvestris* provided enough amounts of fuel to support the maintenance of short occupations type (Allué & Mas, 2020; Cañellas et al., 2000). The strategies of fuel collection would be then attached to the nearby areas of the site, where branches, trunks or twigs were likely available, as has been already suggested (Allué et al., 2017; Solé et al., 2013). Although this could be a focused sourcing, it may be caused by relative low diversity in the immediate forest composition, mainly by pines. However, the presence of a *Prunus* sp. cluster could be interpreted as a spatialized collection, which, in turn is representative of the combination of generalized (opportunistic) and specialized strategies (Roberts & Stewart ,2018).

Although we believe that the Alteration index could be useful to be applied, the discovery of the presence of post-depositional hyphae should lead to considerations about the possibility of post-combustion modifications of cell structure that could affect this index. In this sense, more experimental works are needed to test hypothesis related to the specific taphonomical processes that affect the assemblage in the context of Abric Romaní, this is, the experiments should also consider the fast sedimentation and the particularities of the travertine environment.

5.4. Reconstruction of the behavioral systemic context

Other layers from the Abric Romaní show similar sedimentary environments. Lithic and faunal remains from layer O suggests that the assemblage is mainly the result of human behavior and not of post-depositional processes (Gabucio , 2023). The same conclusion applies to the layers M, (Romagnoli & Vaquero, 2016) and P (Marin et al., 2019) as well as the rest of the sequence (Carbonell, 2012, 2002; (Gabucio et al., 2014; Marín et al., 2017; Modolo & Rosell, 2017). The spatial results of different clusters throughout the sequence have led to the identification of different types of areas according to the use and the sedimentary processes. The inner area of the rock shelter, near the wall is where the main activity cluster has been identified (Gabucio et al., 2023; Romagnoli & Vaquero, 2016; Vallverdú et al., 2010), corresponding to the distribution of hearth-related assemblages (Romagnoli & Vaquero, 2016; Solé et al., 2013; M. Vaquero & Pastó, 2001) and associated with specific activity areas such as carcass processing (Carbonell, 2012; Gabucio et al., 2014; Marin et al., 2019). The outer part of the shelter also contains activity areas, for instance, there were identified episodes of lithic tool production in level M (Romagnoli & Vaquero, 2016). In addition, there were identified slightly stronger post-depositional processes in this area related to the slope and the weathering (Romagnoli & Vaquero, 2016). The identification of the dripping line is an important information concerning the evaluation of differential preservation. This feature has not been yet identified for the Ra level. However, the inner areas can also have specific weathering related to mineralized water flow and dripping from the ceiling (J. Vallverdú, personal communication).

Level Ra seems to have similar characteristics of the assemblage spatial distribution as other levels. This distribution is mainly due to human activities, as shown by the small effects of post-depositional alterations, as in the rest of the sequence. The most clustered areas in the northern section are between 2 and 0.5 meters away from the wall. This pattern of use of the space shows redundancy throughout all the sequence, associated with a typified use of the space.

The formation processes of cultural remains are interpreted in the space, is the distribution of charcoal, and not their alterations, the main source of behavioral information in this case. The non-random distribution of the northern and southern clusters is interpreted in this work as the management of waste in order to reuse the area of hearths. Here, there are different possibilities that can explain the distributions. It could be the case that a continuous occupation led to the re-starting of the fire after this has been extinguished, but also it could be related to the re-starting of the fire in a different occupation with an undetermined period between them.

If we accept, at least temporally, that waste-management is the reason of the charcoal distribution, then, there is certainty in assume that there are at least two cultural formation processes (CFPs). The first CFP, which is induced from the charcoal distribution is "cultural deposition", which comprises the creation of a refuse area (that could be primary or secondary). The second CFP affects to the hearths (assuming that this charcoal comes from the hearths) is related to the above-mentioned open question about the sequence of actions, if is continuous, this is, inside the same occupational event, the cultural formation processes would be "reuse". If the sequence is discontinuous in time, the CFP is "reclamation" (Schiffer, 1991). To discern if the distribution of charcoal is the product of a continuous or a discontinuous use of the space is a complicated task that requires the integration of studies of different materials from the Ra level. The same problem remains with the differentiation between primary and secondary refuse deposits, which depends on the study of other materials such as bones, or lithics, mainly micro-debris related to cleaning of activity areas (Tani, 1995). Primary refuse occurs when the remains are in the area of use, this would be the case of abandoned hearths, while secondary refuses imply the movement of the materials to a distinct area, different of the use area (Schiffer, 1991). Primary refuse deposits are discrete events related to activity area maintenance, and do not show so much prevision and division of fragments by size as secondary refuse deposits (Tani, 1995). In the case of the charcoal, the northern section seems to fit with the primary refuse, as the charcoal clusters overlap the area of hearths. In the southern section there is a reason that slightly could support the idea of a secondary refuse deposit rather than a primary refuse deposit. However, it could be pointed that secondary refuse deposits are expected to group, under planification, the refuse from different events and activities in a context of waste accumulation, but this idea assumes continuity in the events that create garbage.

In other layers from Abric Romaní, primary refuse structures were suggested for lithics in level M and later retracted (Gabucio et al., 2023; Manuel Vaquero et al., 2012, 2017). In level O there were interpreted *drop* and *toss* areas in sector 6 (Gabucio et al., 2018). Bone cleaning activities were also suggested for level Ob, including burning of these to reduce its mass (Gabucio et al., 2023). Is interesting to note that in level M there was suggested a dump area with burnt bones, this is, a secondary refuse in Schiffer terms (refuse is placed in a location different from the use) plus a secondary depositional process (Gabucio et al., 2018; Schiffer, 1972; schiffer, 1991; Tani, 1995). This would imply more planning of the space administration and refuse management.

The case of the charcoal in Ra should not be directly interpreted using the refuse categories without evaluating their usefulness, because much of the refuse categories were made thinking in materials such as bone, lithics and ceramics (artifacts) and not in charcoal. Charcoal could be considered as an ecofact in Schiffer terms (Schiffer, 1972), since is a consumable element which it is not maintained. In this sense, it would be considered similar to the food, where there is a sourcing-optional storage-consumption cycle without maintenance of the element in its flow. In both cases, it is required not the wood or the food, but the energy obtained from them. The digestion and the fire could be considered equivalent processes in the sequence, transformative processes that allow the liberation of the energy stored in the materials. Moreover, the combustion and the digestion are coupled sequences when the food is cooked.

However, fire can be considered as a product by itself, that can be used for no specific reason but a multipurpose. This is, fire can be used for the light, the warm, to cook, to make lithic production tasks, to smoke, etc. In this sense, its sequential production could have similar structure to that of other products such as lithics (Allué and García-Antón., 2006), but its flow from system to archaeological context might be still different.

The importance of the classification is to explain processes, in this case, the events that form the assemblage of level Ra, but not to classify items *per sé*. In this sense, this study suggests that the clusters of charcoal in the southern section of the excavation surface could be considered secondary refuse in Schiffer terms since these are located outside the use area of use of the charcoal. Spatially, the different clusters and their structure could be considered as a tossing area (Binford, 1981; Tani, 1995). This is, they are delimiting a kind of ring or line when a secondary depositional process would be expected concentrate the waste in reduced spaces after a placing (Tani, 1995). This distribution could be explained by discrete events of cleaning of the hearths to reuse them (could be reuse or reclamation). This is because the hearths are cleaned when needed to be reactivated and not as a general cleaning activity involving all the surface.

In this sense, the discrete charcoal distribution also can contribute to inquire about the duration of the occupation and generate new hypothesis to be contrasted. The differentiation of hearth-reactivation events could put this archaeological remains as time-sensitive objects that could help archaeologists to think in ethnographic times (Manuel Vaquero, 2008; Manuel Vaquero et al., 2012). Then we have two (or more) possible scenarios to explain the assemblage:

Scenario 1: If the southern clusters are considered secondary refuse product of discrete cultural depositions in a continuous time lapse, then, it could be hypothesized that the occupation is relatively (to the scenario 2) long.

Scenario 2: In the case that these events were discontinuous in time, each event should be shorter than the scenario 1 since there is a reactivation of the hearths from previous occupations.

However, these scenarios can only be evaluated from an interdisciplinary analysis, if the charcoal accumulations are accompanied of materials such as burnt and unburnt lithic and bone materials, it should be considered a secondary refuse.

5.5. Abric Romaní's domestic spaces in the context of the emergence of modern behavior

The appearance of modern human behavior is a major topic in archaeology that requires the interpretation of information coming from different proxies. The establishment of domestic spaces and their evolution is directly related to the evolution of human modern behavior, which appears to affect to different *Homo* species (*Homo sapiens, Homo neanderthalensis)*. This topic comprises studies such as spatial analyses, technology, procurement strategies, charcoal taphonomy in this case, and more intangible phenomena such as paleo demography, labor division, social complexification, cultural regional variation, language, and communication studies. From the later Middle Pleistocene and later the Middle Paleolithic (MP) and Middle Stone Age (MSA) (Burke, 2006, 2012; Lalueza-Fox et al., 2012; Mark White et al., 2016) it has been marked that the emergence of hearth-related assemblages is correlated with the development of sophisticated toolkits and the appearance of regional technological traditions (Clark et al., 2022; Delagnes & Meignen, 2006; Mcbrearty & Brooks, 2000; Tryon, 2019; Uthmeier, 2016). Archaeologically it has been documented the increase in the intensity of fire use, structural modification, and waste management (Clark et al., 2022). Delimited sleeping areas, although there are difficult to identify, increase their visibility from the last 100 ky. In Sibhudu Cave there are reported intensification activities of bedding maintenance from 77 ky (Goldberg et al., 2009). Bedding areas have also been proposed for Abric Romaní as has been mentioned above, with distributions of the space like other sites such as Oscurusciuto (Spagnolo et al., 2019; Vallverdú et al., 2010). Oscurusciuto rockshelter located in Italy has shared characteristics with Abric Romaní. First, the levels are delimited yielding "short palimpsest" (Spagnolo et al., 2019). Layer SU 13 was analyzed spatially and, although the site has not been excavated in the total surface, the inner and outer areas were interpreted as clearly distinct. Both areas are divided by sub-parallel bands of hearths to the wall. The inner zone has various hearths with *in situ* knapping and carcass processing associated activities, where in some places there are recurrent activities. Also, they have identified resting/sleeping areas by their low density of remains and considering the distances to the hearths and their spatial ubiquity. The site was likely used recurrently, supporting some spatial comparisons with ethnographic distributions of sleeping areas, although the SU 13 has, what appears to be, the addition of different events superposed (short palimpsests) (Spagnolo et al., 2019). In Abric Romaní there were identified several hearths of small size, that could have been used for lighting or keep warm the individuals (Vallverdú et al., 2012). Compared discard areas from Abric Romaní and Oscuruscioutо site have also showed maintenance of central domestic areas. In Abric Romaní large animal bones were discarded outside the immediate hearth-related area, and in Oscurusciuto there were identified waste-management activities consisting in an aggregate of lithic production waste, exploited cores and large bones localized in a marginal area. This is classified as dumping area (secondary refuse deposit) made as "preventive maintenance" throughout actions such as sweeping away, cleaning the working floors, and dumping accumulation of refuses in specific areas(Spagnolo et al., 2019). Space segregation of activities were also identified in different levels of Abric Romaní (Gabucio et al., 2018, 2023; Marín et al., 2017; Romagnoli & Vaquero, 2016) and Oscurusciuto, where carcass processing was in the southern part of the site but not so the lithic production (Spagnolo et al., 2019). Waste management activities were suggested in level X from Kebara cave, where accumulations of bones inside the cave and middens along the wall of the shelter were identified (Speth, 2006; Speth et al., 2012).

The appearance of larger groups or longer stays creates pressures to the way in which space and materials are managed. Moreover, implies modifications in how social interactions occur. Waste-management is an indicator of some of these pressures, also the synchronic overall diversity of activities can be a proxy of the collaborative work /labor division inside a group (Clark et al., 2022; Kuhn & Stiner, 2006). The intensification of domestic spaces identification in the archaeological context is related to a non-linear increase of the co-evolutionary feedbacks in the systemic context where domestic spaces started to be a hub for human interactions (Clark et al., 2022; Kuhn & Stiner, 2019). From a systems theory perspective is interesting to note that this non-linear increase (or exponential) is likely related to a change in how the elements of that system interact, specially how the transmission of information occurs (Bateson, 1972). The regionalization of technology (for example in MP of Europe (Delagnes & Meignen, 2006) may be correlated to an increase in the innovation rate (this could be a fruitful line of investigation in the future), and this is, again, likely related to the increased social interactions that the domestic spaces as a hub provides. These processes are not monocausal and should be interpreted as a progressive change in the global systemic context where a small change in a variable (buffer) can achieve important consequences in the behavior of that system. In this case, the buffer change is the time shared in domestic spaces, and the increase is in the information flow, which in turn has consequences in the innovative rate, labor division and so on. The complexification of social interactions and the above-mentioned phenomena carries new consequences and pressures for the individuals (Clark et al., 2022). If the systemic context increases its complexity, then the individuals need to be adapted to it, increasing their dependency on learning and knowledge transmission. How can this type of complexification be analyzed from archaeology? Although currently there are not straightforward methods to study this, it could be hypothesized that the higher degree of repeated behaviors not directly linked to adaptation to the environment are the visible trait of the emergence of cultural norms (Clark et al., 2022), cultural "*a priori*", stereotype or standardized behaviors.

In the sequence of Abric Romaní, there is a repeated behavior in the use of space in general terms based in the marked division between inner and outer spaces, which is also posited for Oscurusciuto rockshelter. This feature alone could be considered not necessarily redundant, since it can be determined by the presence of weather protection, but the way that the hearths are located is not attached to this protection and could be considered a redundant behavior. In this sense the remains from Ra level of Abric Romaní are informative about the establishment of the domestic spaces and some of the associated behaviors (waste-management and differential spatial clustering) that characterize the MP and MSA. These behaviors are congruent diachronically with the sequence of Abric Romaní site, where it can be appreciated that there is a continuity, or redundancy, in the way of using the space of the rockshelter. Also, it could be posited that the interpretation makes sense synchronically, since the archaeological signal considering different indicators of these activities increases from the MIS 5 onwards (Clark et al., 2022), being the mentioned sites (Kebara and Oscurusciuto) in this period. It is important to consider that the determination of which species or chrono-culture might be a confusing factor when there is an aim to understand the processes involved (Clark et al., 2022) and that hearth-related assemblages may be universal characteristics of spatial strategies of hunter-gatherer groups. What it is considered is that in equivalent chrono-cultures (Middle Paleolithic and Middle Stone Age) similar behaviors started to happen (i.e., domestic spaces), although progressively. If there are similar conditions in the social system such as demography, information flow, innovation rate, economy, then similar cultural niche construction (Laland & Boogert, 2010; Laland & O'Brien, 2011) processes can happen, being an emergent factor or set of traits. This process could be affected by environmental conditions, but not in a deterministic way. For sure, culture must be adaptive in some degree to the environment from a cultural-ecology point of view (Steward, 2005), or at least not maladaptive, but culture is itself part of the habitat to which *Homo* individuals must adapt in their ontogeny since the lack of genetic adaptation. Then, if the adaptation to this habitat relies in the cultural transmission, it is expectable feedback increasing this relation. This is, adaptation to culture requires cultural learning and transmission, which in turn increase cultural interactions. This incremental dependence, in some point in the Middle Paleolithic became nonlinear increasing the diversity and innovation rate. But how could this reasoning be tested false? Since we are proposing that culture is a habitat which requires adaptation and that the cultural "*a prioris*" could serve to this purpose, exemplified by redundancy in the use of space in Abric Romaní, it will be enough to test if the redundant use of the space is mainly a functional adaptation to the non-cultural environment or not.

6.Conclusions and Future Perspectives

The processes that contributed to the formation of level Ra charcoal assemblage are the product of both natural and cultural phenomena, with a sequence in time that flows from the systemic to the archaeological context. There are reasons to characterize the spatial distribution of charcoal as mainly anthropogenically generated, due to the subtle postdepositional disturbance. This interpretation is a constant in the Abric Romaní sequence (Courty et al., 2012; Gabucio et al., 2018, 2023; Vallverdú-Poch et al., 2012; Allué, Bischoff, Burjachs, Vallverdú Vaquero, 2013; M. Vaquero & Pastó, 2001; Manuel Vaquero, 2008).

Taphonomical processes are mainly related with the sedimentary environment which is characterized by water charged with Ca^{2+} minerals. The spatial study of concretions and postdepositional mineral insertions allowed to understand partially what affects the charcoal fragments when these were deposited. However, the mineralized mycelium raises the question about the bioturbation of these materials. Also, the role of water is only indirectly perceived and not measurable yet. There were not detected disturbance movements both vertical and horizontal.

The way of sourcing, stocking and consuming fuelwood could be the cause of the autocorrelation that accumulations of biological alterations have. The recollection of wood was likely based on the available deadwood that pines produce. The high availability of dry deadwood could have affected the selection of the location of Abric Romaní (Allué, 2002a; Allué et al., 2017; Vidal-Matutano et al., 2015). This is important since wood it is not like other resources that can be recollected several kilometers away from its point of consumption or use. Because of the volume of wood required for several burning events is unlikely that the recollection of wood occurs to far from the site.

The spatial distribution of charcoal clusters seems to be related to waste-management activities. The reuse or reclamation of hearths creates discrete secondary refuse clusters. There is a clear spatial differentiation in the use of the space inside the rockshelter. The northern section has a higher palimpsest effect since there are several hearths that may be product of different events and clusters of charcoal that overlap each other. In this section there is a direct association between the charcoal clusters and the hearths. In opposition, the southern section of the rockshelter has discrete clusters that are not directly associated to the hearths and that have less accumulation of charcoal. This is interpreted as a less intense use, that allows the perception of discrete waste-management events product of the reuse or reclamation of the hearth structures. The characterization of the refuse as secondary or primary refuse is important since allow to characterize the nature of the occupation and the pressures that could have affected the management of the space. However, it is important to consider the complementarity of the spatial studies with different materials.

The collection of fuelwood in the surrounding area of the Abric Romaní rock shelter likely represents, although with some selection degree, the immediate vegetal environment as well as the processes that were affecting these organisms. For instance, the compression wood, alteration affecting the cell structure of *Pinus sylvestris* type is representative of the adaptation to the stress that the trees suffered. This stress could be caused by wind, growing in the slope or snow, although it is difficult to differentiate which of the phenomena could have caused the compression. The pollen analyses showed an increase in the arboreal taxa from 59 Kr BP onwards, which would be related to the expansion of trees species isolated in refugees (Biltekin et al., 2019b; Burjachs et al., 2012a). The higher representation of *Prunus* sp. compared with other levels could correspond to the mentioned improvement of the climatic conditions. However, future analysis of micromammals could deepen the interpretation of the paleoenvironmental conditions. The sedimentation occurred in humid phases of the site, since is related to slow fluvial events and biochemical mineralization, but the occupation might have occurred in drier moments, because otherwise the site maybe would be unable to be used.

This was the first time that spatial taphonomy was applied to charcoal assemblage in Abric Romaní, the complementarity with the spatial analysis of other materials is recommendable though. The processes that create the distribution of materials could have occurred in the same sequence of events, bounding the distributions of the materials together. The identification of waste-management activities it has been considered an important insight in the understanding of intra-site dynamics. From the analysis made arises the acknowledgement of the importance of consider charcoal spatial analysis along with bone and lithics in order to: 1) dissect palimpsests and deepen in the understanding of the occupations events, such as the reuse or reclamation of hearth structures; 2) reach interpretations of events near to the ethnographic time; 3) understand how activities are related between each other, this is, how the hearth-related assemblages are the product of different activities that may occur simultaneously or not.

Another aspect that can be further developed is the spatial taphonomical analysis. It could be interesting to design an experimental work plan based on the sedimentary characteristics of Abric Romaní, this is, considering the waterflows and the mineralization. Also, the hyphae phenomena is interesting since we have based our analysis considering hyphae presence a pre-depositional alteration. Although the literature shows that it is possible to find carbon-eating-mycelium (Moskal-del Hoyo et al., 2010), most of the anthracological works assume that these are predepositional and even consider the fungi alterations as the origin of the charcoal traits, mainly those that creates the "decayed wood"(Auréade Henry & Théry-Parisot, 2014). From my point of view, the design of an experimental program that evaluates the post-depositional fungi alterations could have worthy insights in the understanding of the transition from systemic context to archaeological context. For instance, if the fungi species can be identified and evaluate its rate of growing, some hypothesis regarding the exposition to weathering before sedimentation could be tested. Diachronically focused investigations of the use of the space should also be considered a powerful investigation line in order to identify and reconstruct the processes of niche construction and the evolution of human behavior in its adaptation to cultural and non-cultural environments.

Finally, in a more abstract and ambitious topic, to really grasp cultural evolution from an evolutionary standpoint, I believe it is crucial to consider innovative theoretical-methodological features. This needs a sequential development of research questions and methods to perceive significative information to answer those research questions (Shanks & Tilley, 1987). In my opinion, two basic needed assumptions are: 1) the understanding of culture as part of the environment to which cultural animals must adapt; 2) cultural niche construction as an evolutive process that might or might not share characteristics with organic evolution but likely has emergent properties characteristic of the information-based systems. This is, the evolution of our organic system (i.e., genetic evolution) it is not coupled with the evolution of our cultural system, otherwise, humans should be only genetically adapted to their environment. Understanding the past and evolution of human behavior considering the different levels of adaptation, cultural, physiological and genetic (Frisancho, 1995; Frisancho R, 1995, 2013), will shed light on this gap. Also thinking in these topics (cultural niche-ecological niche, adaptation etc..) from a systemic point of view is important in order to deal with hierarchical categories, this is crucial to make correct hypothesis assuming cause and consequence. Much of the New Archaeology research program has focused in determine adaptation mainly to the environment from a functionalist perspective (e.g (Binford, 1965; Flannery, 1968). In my opinion, the consideration of culture mainly as adaptation to the environment has weakened this approach. Maybe the functionalist approach is useful, but if the adaptive target is wrong, then explanation problems arise.

As final remarks, I want to emphasize the fruitfulness of the spatial charcoal analyses in sites with unique conservation as Abric Romaní. The integration of the spatial analysis of different materials will have to the interpretations of human use of the space and behavior evolution a more holistic perspective.

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Figure Index

Table Index

Appendix I

Table 1 Comparison of the sequences of Abric Romaní and Eduard Ripoll

Stratigraphic sequences from Amador Romaní and Eduard Ripoll

Amador Romaní		Eduard Ripoll	
Layer 0	Human remain from recent burials; lithic implements	Layer 1	Sandy silts
Layer 1	Sterile; reddish sediments	Layer 2	Stratified Calcareous travertine
Layer 2	Upper Paleolithic, not well preserverd, current level A.	Hearth 2	Archaeological level.
Layer 3	Travertine layer	Layer 3	Calcareous crust
Layer 4	Black sediment with charcoals and a rich assemblage. Current level B	Hearth 4	Archaeological level.
Layer 5	Travertine layer	Layer 5	Hardened stratified travertine, rich in plant remains at the bottom.
Layer 6	Black sediments with charcoals and Mousterian artifacts, Romaní documented wood artifacts. Current level C	Layer 6	Hardened stratified sandy travertine.
Layer 7	White sediment only found in a small section of the surface.	Hearth 7	Archaeological level
Layer 8	Travertine Layer	Layer 7	Hardened stratified sandy travertine
Layer 9	Mousterian level with sediments similar to layer 1. Current level E	Hearth 8	Archaeological level
Layer 10	Calcareous sandy sediment with archaeological remains and hyena coprolites.	Layer 8	Hardened stratified travertine, rich in plant remain at the bottom.

Layer 11	Mousterian artifacts although discontinuous. Current level I.	Hearth 9	Archaeological level with great abundance of faunal and lithic remains.
Layer 12	Calcareous sand, with coprolites and malacological remains and empty of other archaeological evidence.	Layer 9	Sandy silts
Layer 13	Black sediment with Mousterian artifacts and 20 cm thickness of archaeological remains.	Layer 10	Complex layer composed of several facies, comprising a "calcareous dust", lenses of lumpy clay and silty sand. There was an upper deposit of hardened and stratified sandy. In the eastern section there was a hardened travertine.
Layer 14	This layer was composed of stalagmitic limestone, with travertine blocks and clasts. Layers 13 and 14 are likely correlated to level J.	Layer 11	Travertine facies and silty clays lenses with a discontinuous archaeological level (Layers 11 and 12 of Amador Romaní).
Layer 15	Travertine layer in the bottom of the Pit 1	Hearth 12	Archaeological level (Amador Romani's Layer 13)
		Layer 12	Travertine fragments in sandy matrix and blocks from roof collapse. (Amador Romani`s Layer 14)
		Layer 13	Small clasts in a yellow Sandy Matrix. (Amador Romani`s Layer 14)

Table 2: A.i= Alteration index; Vit=vitrification; Comb.al= combustion alteration; C.wood=compression wood; Conc= concretion; Min= mineralization.

Frequency Table 1									
A.I.	**Vit**	**Comb. al**	**Cracks**	**C.wood**	**Cell Col.**	**Hyphae**	**Conc.**	**Min**	**N=**
1	55	157	298	324	137	44	29	174	397
2	37	94	101	94	93	22	33	73	119
3	43	89	83	76	77	30	22	57	116
Grand Total	135	340	482	494	307	96	84	304	632

Table 3 A.i= Alteration index; Vit=vitrification; Comb.al= combustion alteration; C.wood=compression wood; Conc= concretion; Min= mineralization.

Frequency table 2				
Size category	**Fire-related**	**Biological**	**Postdepositional**	**N**
1	30	47	18	31
2	201	193	119	114
3	238	222	118	126
4	103	101	59	57
5	36	43	18	22
6	10	11	9	6
	618	**617**	**341**	**356**

Table 4 A.i= Alteration index; Vit=vitrification; Comb.al= combustion alteration; C.wood=compression wood; Conc= concretion; Min= mineralization

	Frequency Table 3								
Row Labels	**Hyphae**	**Conc.**	**Knots**	**Cellco**	**C. Wood**	**Cracks**	**Comb. al**	**Vit**	**Min**
M59	1	2	0	0	2	0	1	2	
M60	1	1	0	0	1	1	0	1	
N49	2	3	0	3	2	4	3	1	4
N58	1	0	0	2	2	2	2	1	2
N59	2	3	0	7	7	9	7	3	6
N60	0	0	1	7	9	9	8	4	7
O51	1	3	0	5	11	10	7	3	6
O52	1	0	0	0	6	6	3	4	1
O56	0	3	0	5	8	11	10	4	5
O57	0	1	0	1	1	2	2	1	1
O58	0	0	1	2	1	2	1	1	0
O59	1	0	0	2	3	2	1	0	1
O60	0	0	0	1	1	1	1	0	1
O61	0	0	0	1	1	1	0	0	1
P47	0	0	0	2	1	3	2	1	0
P49	0	3	0	19	20	21	17	5	20
P51	5	2	0	9	10	9	8	2	8
P55	1	1	1	7	6	4	5	1	3
P56	2	2	1	6	9	8	8	4	7
P57				1	1	1	1	0	
P61	1	0	0	1	3	1	1	0	1
Q47				0	0	2	1	0	
Q48	1	0	1	1	3	0	0	0	0
Q51	0	1	0	2	2	2	2	1	2
Q52	1	0	0	1	1	1	0	0	1
Q55	0	0	0	1	2	2	2	1	1
Q56				0	1	1	0	0	
Q61	0	0	0	0	4	4	0	0	3
R50	1	0	0	1	1	0	1	1	1

R51	0	0	0	1	2	1	0	0	1
R57	0	1	0	2	2	2	1	0	2
R60	2	2	0	6	4	7	5	1	4
R61				1	2	2	2	1	
S50	0	0	0	0	0	1	1	0	1
S52				1	1	1	1	0	
S55	0	0	0	2	1	1	1	0	0
S56	1	1	0	3	4	3	2	2	3
S58	0	0	1	3	2	3	3	2	3
S59	3	2	0	7	12	13	12	2	9
S60	2	1	0	1	3	4	2	2	3
T51				1	1	0	0	0	
T53	4	3	0	6	8	6	7	1	5
T54	3	9	0	14	25	26	15	10	27
T55	0	2	0	6	8	8	6	3	4
T56	1	2	0	3	8	6	3	2	3
T57	4	4	0	28	48	42	25	11	21
T58	3	5	0	9	7	8	7	5	11
T59	0	0	0	0	1	2	1	0	2
U50	1	0	0	1	1	1	1	1	1
U51	3	1	0	2	6	5	6	3	4
U52	2	1	0	10	14	13	7	1	4
U53	16	4	1	27	57	50	36	7	15
U54	2	3	0	20	24	25	14	7	23
U55	0	2	0	7	12	15	9	3	9
U56	4	3	0	7	32	28	17	9	11
U57	2	2	0	11	19	18	12	4	14
U58	10	8	0	15	21	20	14	7	11
U59	1	0	0	1	1	1	1	1	1
V52	1	3	0	6	9	9	5	4	5
V53	4	0	0	7	11	11	12	1	7
V54	2	2	0	3	11	10	3	2	5
V55	1	0	0	1	3	2	1	2	1
V56	0	0	0	5	6	9	6	4	2

V57	4	3	0	8	11	11	9	1	8
V58	1	0	0	1	2	2	1	0	2
V59	2	0	0	2	3	3	2	1	3
Grand Total	**101**	**89**	**7**	**315**	**501**	**488**	**344**	**141**	**307**

Table 5 A.i= Alteration index; Vit=vitrification; Comb.al= combustion alteration; C.wood=compression wood; Conc= concretion; Min= mineralization

Alteration 1									
squar	**Hypha**	**Conc.**	**Knot**	**Cellco**	**C.Woo**	**Cracks**	**Comb.al**	**Vit**	**Min**
N49	0	1	0	0	1	1	0	0	1
N59	1	3	0	6	5	6	5	3	5
N60	0	0	0	3	5	6	5	1	4
O51	1	2	0	3	9	9	5	2	5
O52	1	0	0	0	4	4	1	2	1
O56	0	0	0	2	4	5	4	0	2
O58	0	0	0	1	1	1	1	0	0
O59	0	0	0	2	3	2	1	0	1
O61	0	0	0	1	1	1	0	0	1
P47	0	0	0	1	1	2	1	0	0
P49	0	0	0	9	13	13	9	1	10
P51	2	0	0	3	5	3	2	1	3
P56	1	0	0	3	7	6	5	2	5
P57				1	1	1	1	0	
P61	1	0	0	1	2	1	1	0	1
Q47				0	0	2	1	0	
Q48				0	2	0	0	0	
Q51	0	0	0	1	1	1	1	1	1
Q52	1	0	0	1	1	1	0	0	1
Q55	0	0	0	0	1	1	1	1	1
Q56				0	1	1	0	0	
Q61	0	0	0	0	4	4	0	0	3
R51	0	0	0	1	2	1	0	0	1

R57	0	0	0	1	1	1	0	0	1
R60	0	1	0	0	1	2	1	0	1
R61				0	1	1	1	0	
S50	0	0	0	0	0	1	1	0	1
S52				1	1	1	1	0	
S56	0	0	0	2	3	2	1	2	2
S58	0	0	0	1	1	1	1	0	1
S59	1	0	0	2	8	6	5	0	4
S60	2	1	0	1	2	2	1	1	2
T51				1	1	0	0	0	
T53	0	1	0	0	4	3	2	0	1
T54	1	6	0	8	19	18	8	5	19
T55	0	1	0	3	6	7	5	2	3
T56	1	1	0	2	6	4	2	1	1
T57	2	2	0	13	32	27	9	7	13
T58	2	0	0	3	3	3	2	1	4
T59	0	0	0	0	1	2	1	0	2
U51	1	1	0	0	3	3	3	1	1
U52	1	1	0	4	11	7	2	0	4
U53	12	2	0	16	41	34	18	3	9
U54	0	1	0	13	17	17	7	4	15
U55	0	1	0	3	7	10	5	1	6
U56	1	0	0	3	25	22	11	3	8
U57	0	0	0	3	12	10	4	2	9
U58	6	0	0	3	10	9	3	3	3
V52	0	1	0	3	6	6	3	2	1
V53	2	0	0	3	5	7	7	0	3
V54	0	1	0	2	7	6	2	1	3
V55	1	0	0	0	2	1	0	1	0
V56	0	0	0	1	3	3	1	1	1
V57	1	2	0	4	7	6	4	0	6
V58	1	0	0	1	2	2	1	0	2

V59	1	0	0	1	2	2	1	0	2
Grand Total	**44**	**29**	**0**	**137**	**324**	**298**	**157**	**55**	**174**

Alteration 2									
square	**Hyphae**	**Conc.**	**Knot**	**Cellco.**	**C.Wood**	**Cracks**	**Comb.al.**	**Vit**	**Min**
N49	1	1	0	1	0	1	1	1	1
N58	1	0	0	1	1	1	1	1	1
N59	1			0	1	2	2	0	
N60				0	1	1	1	1	
O52				0	2	2	2	2	
O56				0	0	2	2	1	
O59	1	0	0	0	0	0	0	0	0
P47	0	0	0	1	0	1	1	1	0
P49	0	0	0	4	2	2	3	2	4
P51	2	1	0	4	4	4	4	1	4
P55	1	0	0	3	3	2	3	1	1
P56	0	0	0	0	0	0	1	1	0
Q51	0	1	0	1	1	1	1	0	1
Q55				1	1	1	1	0	
R50	1	0	0	1	1	0	1	1	1
R57	0	1	0	1	1	1	1	0	1
R60	0	1	0	2	1	2	1	0	1
R61				1	1	1	1	1	
S55	0	0	0	1	0	0	0	0	0
S56	1	1	0	1	1	1	1	0	1
S59	0	1	0	1	1	2	3	1	2
S60				0	0	1	1	1	
T53	3	2	0	3	1	2	3	1	2
T54	0	2	0	2	3	3	3	4	3
T55	0	0	0	1	1	0	0	0	0
T56				0	0	0	0	0	
T57	1	0	0	9	8	7	8	2	4
T58	1	3	0	4	2	2	2	2	4
U50	1	0	0	1	1	1	1	1	1

U51	1	0	0	1	1	0	1	0	1
U52	1	0	0	6	3	6	5	1	0
U53	2	2	0	4	6	6	7	2	5
U54	0	0	0	2	3	3	3	2	3
U55	0	0	0	1	2	2	1	0	0
U56	1	2	0	2	4	4	3	3	3
U57	0	1	0	2	2	2	2	1	1
U58	2	3	0	4	4	3	4	1	4
U59	1	0	0	1	1	1	1	1	1
V52	0	0	0	1	0	0	1	1	1
V53	2	0	0	4	6	4	5	1	4
V54	2	0	0	1	3	3	0	1	1
V56				1	0	2	3	2	
V57	3	0	0	3	3	4	4	1	1
Grand Total	**30**	**22**	**0**	**77**	**76**	**83**	**89**	**43**	**57**

Table 6 A.i= Alteration index; Vit=vitrification; Comb.al= combustion alteration; C.wood=compression wood; Conc= concretion; Min= mineralization

Table 7 A.i= Alteration index; Vit=vitrification; Comb.al= combustion alteration; C.wood=compression wood; Conc= concretion; Min= mineralization

Alteration 3									
square	**Hyphae**	**Conc.**	**Knot**	**Cellco.**	**C.Wood**	**Cracks**	**Comb.al.**	**Vit**	**Min**
N49	1	1	0	1	0	1	1	1	1
N58	1	0	0	1	1	1	1	1	1
N59	1			0	1	2	2	0	
N60				0	1	1	1	1	
O52				0	2	2	2	2	
O56				0	0	2	2	1	
O59	1	0	0	0	0	0	0	0	0
P47	0	0	0	1	0	1	1	1	0
P49	0	0	0	4	2	2	3	2	4
P51	2	1	0	4	4	4	4	1	4
P55	1	0	0	3	3	2	3	1	1
P56	0	0	0	0	0	0	1	1	0
Q51	0	1	0	1	1	1	1	0	1
Q55				1	1	1	1	0	
R50	1	0	0	1	1	0	1	1	1
R57	0	1	0	1	1	1	1	0	1
R60	0	1	0	2	1	2	1	0	1
R61				1	1	1	1	1	
S55	0	0	0	1	0	0	0	0	0
S56	1	1	0	1	1	1	1	0	1
S59	0	1	0	1	1	2	3	1	2
S60				0	0	1	1	1	
T53	3	2	0	3	1	2	3	1	2
T54	0	2	0	2	3	3	3	4	3
T55	0	0	0	1	1	0	0	0	0
T56				0	0	0	0	0	
T57	1	0	0	9	8	7	8	2	4
T58	1	3	0	4	2	2	2	2	4

U50	1	0	0	1	1	1	1	1	1
U51	1	0	0	1	1	0	1	0	1
U52	1	0	0	6	3	6	5	1	0
U53	2	2	0	4	6	6	7	2	5
U54	0	0	0	2	3	3	3	2	3
U55	0	0	0	1	2	2	1	0	0
U56	1	2	0	2	4	4	3	3	3
U57	0	1	0	2	2	2	2	1	1
U58	2	3	0	4	4	3	4	1	4
U59	1	0	0	1	1	1	1	1	1
V52	0	0	0	1	0	0	1	1	1
V53	2	0	0	4	6	4	5	1	4
V54	2	0	0	1	3	3	0	1	1
V56				1	0	2	3	2	
V57	3	0	0	3	3	4	4	1	1
Grand Total	**30**	**22**	**0**	**77**	**76**	**83**	**89**	**43**	**57**

Table 8. Frequency table 5: percentage of charcoal fragments by size according to their deepness

Frequency table 5							
cm deepness/ lenght category	**1**	**2**	**3**	**4**	**5**	**6**	**Grand Total**
<990	0,00%	33,33%	33,33%	33,33%	0,00%	0,00%	100,00%
990-1000	11,11%	44,44%	44,44%	0,00%	0,00%	0,00%	100,00%
1000-1010	14,58%	35,42%	29,17%	14,58%	6,25%	0,00%	100,00%
1010-20	7,69%	33,33%	37,82%	15,38%	4,49%	1,28%	100,00%
1020-1030	8,77%	36,84%	45,61%	5,26%	1,75%	1,75%	100,00%
1030-1040	0,00%	40,00%	20,00%	20,00%	20,00%	0,00%	100,00%
1040-1050	0,00%	33,33%	0,00%	33,33%	33,33%	0,00%	100,00%
1050-1060	5,00%	40,00%	30,00%	15,00%	5,00%	5,00%	100,00%
1060-1070	0,00%	0,00%	40,00%	40,00%	20,00%	0,00%	100,00%
1070-1080	0,00%	16,67%	16,67%	16,67%	50,00%	0,00%	100,00%
1080-1090	0,00%	25,00%	62,50%	12,50%	0,00%	0,00%	100,00%
1090-1100	0,00%	0,00%	20,00%	60,00%	0,00%	20,00%	100,00%
1100-1110	0,00%	50,00%	0,00%	50,00%	0,00%	0,00%	100,00%
1110-1120	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%
1120-1130	33,33%	16,67%	16,67%	33,33%	0,00%	0,00%	100,00%
1130-1140	0,00%	12,50%	37,50%	25,00%	25,00%	0,00%	100,00%
1140-1150	0,00%	0,00%	25,00%	50,00%	25,00%	0,00%	100,00%
1150-1160	0,00%	0,00%	25,00%	25,00%	25,00%	25,00%	100,00%
1160-1170	0,00%	0,00%	0,00%	100,00%	0,00%	0,00%	100,00%
1170-1180	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%
1180-1190	0,00%	100,00%	0,00%	0,00%	0,00%	0,00%	100,00%
Grand Total	8,71%	32,02%	35,39%	16,01%	6,18%	1,69%	100,00%

Tests results

Table 9

Frequency table 1 normality test			
Normality TEST	A.I.1	A.I.2	A.I.3
N	8	8	8
Shapiro-Wilk W	0.8977	0.8274	0.9084
p(normal)	0.2754	0.05578	0.3426
p(normal)	0.3345	0.05197	0.3645
p(normal)	0.5989	0.07035	0.1912
p(normal)	0.701	0.5827	0.6587

Table 10

Frequency table 1 Chi-square			
Chi squared			
Rows. columns:	8. 3	Degrees freedom:	14
Chi2:	91.82	p (no assoc.):	<0.000001
Monte Carlo p :	0.0001		
Fisher´s exact			
Cramer´s V :	0.1431	Contingency C :	0.19835

Table 11 Kruskal Wallis test for Frequency Table 1

Kruskal-Wallis test for equal medians	
H (chi2):	19.34
Hc (tie corrected):	19.35
p (same):	0.01309
There is a significant difference between sample medians	

Frequency table 2 ANOVA TEST					
Test for equal means	Sum of sqrs	df	Mean square	F	p (same)
Between groups:	8494.78	2	4247.39	0.659	0.5317
Within groups:	96675.7	15	6445.04	Permutation p (n=99999)	
Total:	105170	17	0.5293		
Components of variance (only for random effects):					
Var(group):	-366.276	Var(error):	6445.04	ICC:	-0.060255
omega2:	0				
Levene´s test for homogeneity of variance. from means	p (same):	0.2472			
Levene´s test. from medians	p (same):	0.427			
Welch F test in the case of unequal variances: F=0.8829. df=9.171. p=0.446					
Bayes factor: 0.2007 (substantial evidence for equal means)					

Table 13

Frequency table 2 normality test			
NORMALITY TEST	FIRE-RELATED	BIOL-alt	Posdep
N	6	6	6
Shapiro-Wilk W	0.8684	0.8894	0.8122
p(normal)	0.22	0.315	0.07542
Anderson-Darling A	0.4111	0.3681	**0.5405**
p(normal)	0.2231	0.2963	0.09417
p(Monte Carlo)	0.2401	0.3321	0.0963
Lilliefors L	0.2569	0.2405	0.2776
p(normal)	0.2475	0.3406	0.1568
p(Monte Carlo)	0.2607	0.3531	0.1666
Jarque-Bera JB	0.7578	0.7112	0.8097
p(normal)	0.6846	0.7008	0.6671
p(Monte Carlo)	0.2619	0.3192	0.2121

Table 14 Kruskal Walllis test for frequency table 2

Kruskal-Wallis test for equal medians	
H (chi2):	1.233
Hc (tie corrected):	1.234
p (same):	0.7449
There is no significant difference between sample medians	

Table 15

Frequency table 3 normality test									
NORMALITY TEST	Hyphae	conc	Knot	Cellco	C.wood	Cracks	Comb.al	vit	Min
N	60	60	60	66	66	66	66	66	58
Shapiro-Wilk W	0.6046	0.7597	0.3739	0.7245	0.6542	0.7038	0.7395	0.785	0.7625
p(normal)	1.90E-11	1.52E-08	1.45E-14	8.11E-10	3.41E-11	3.04E-10	1.71E-09	1.96E-08	2.60E-08
Anderson-Darling A	5.998	4.032	19.01	5.604	6.829	5.928	4.85	4.503	4.479
p(normal)	6.21E-15	3.71E-10	6.45E-45	5.80E-14	6.52E-17	9.58E-15	3.87E-12	2.70E-11	2.97E-11
p(Monte Carlo)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Lilliefors L	0.255	0.218	0.5241	0.2223	0.2345	0.2202	0.2244	0.2352	0.2092
p(normal)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
p(Monte Carlo)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Jarque-Bera JB	779.9	83.84	91.32	120.8	309.5	189.6	193.7	52.23	61.08
p(normal)	4.43E-170	6.22E-19	1.48E-20	5.83E-27	6.26E-68	6.65E-42	8.56E-43	4.55E-12	5.45E-14
p(Monte Carlo)	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001

Table 16

Kruskal-Wallis test for equal medians	
H (chi2):	169.2
Hc (tie corrected):	174.7
p (same):	1.37E-33
There is a significant difference between sample medians	

Table 17

Frequency Table 5 Normality test						
Column1	1	2	3	4	5	6
N	8	14	15	17	11	5
Shapiro-Wilk W	0,7865	0,5857	0,5505	0,4481	0,6274	0,5522
p(normal)	0,02051	3,04E-05	0,000009261	4,84E-07	0,00005586	0,0001
Anderson-Darling A	0,7558	2,366	2,764	3,711	1,717	1,205
p(normal)	0,02832	2,33E-06	0,0000002323	1,01E-09	9,21E-05	0,0008
p(Monte Carlo)	0,0305	0,0001	0,0001	0,0001	0,0001	0,0001
Lilliefors L	0,3078	0,3294	0,3613	0,4078	0,3426	0,4726
p(normal)	0,02537	0,0001	0,0001	0,0001	0,0001	0,0001
p(Monte Carlo)	0,0262	0,0001	0,0001	0,0001	0,0009	0,0001
Jarque-Bera JB	1,944	26,29	37,04	102,7	11,6	1,888
p(normal)	0,3784	1,95E-06	0,000000009035	5,04E-23	0,003	0,3891
p(Monte Carlo)	0,0547	0,0002	0,0002	0,0001	0,002	0,0001

Table 18 Kruska Wallis test for frequency table 5.

Kruskal-Wallis test for equal medians	
H (chi2):	15.75
Hc (tie corrected):	16.97
p (same):	0.009378
There is a significant difference between sample medians	

Appendix II

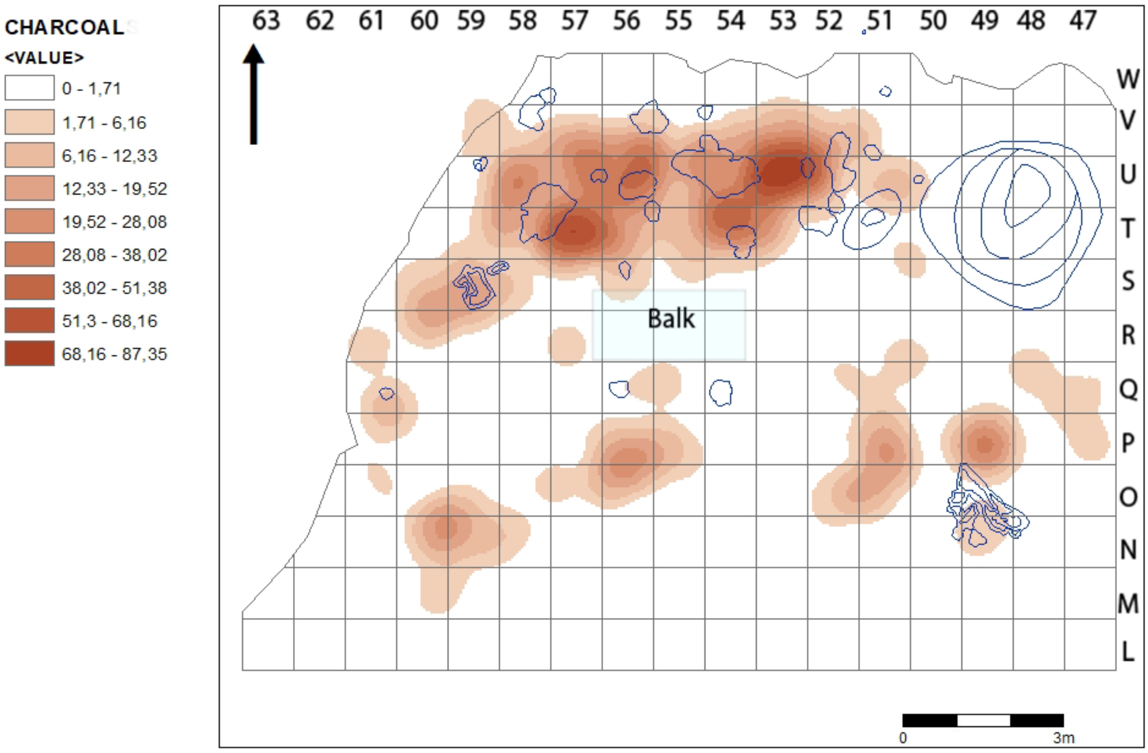


Figure I Kernel Density Estimation (KDE) of charcoal fragments

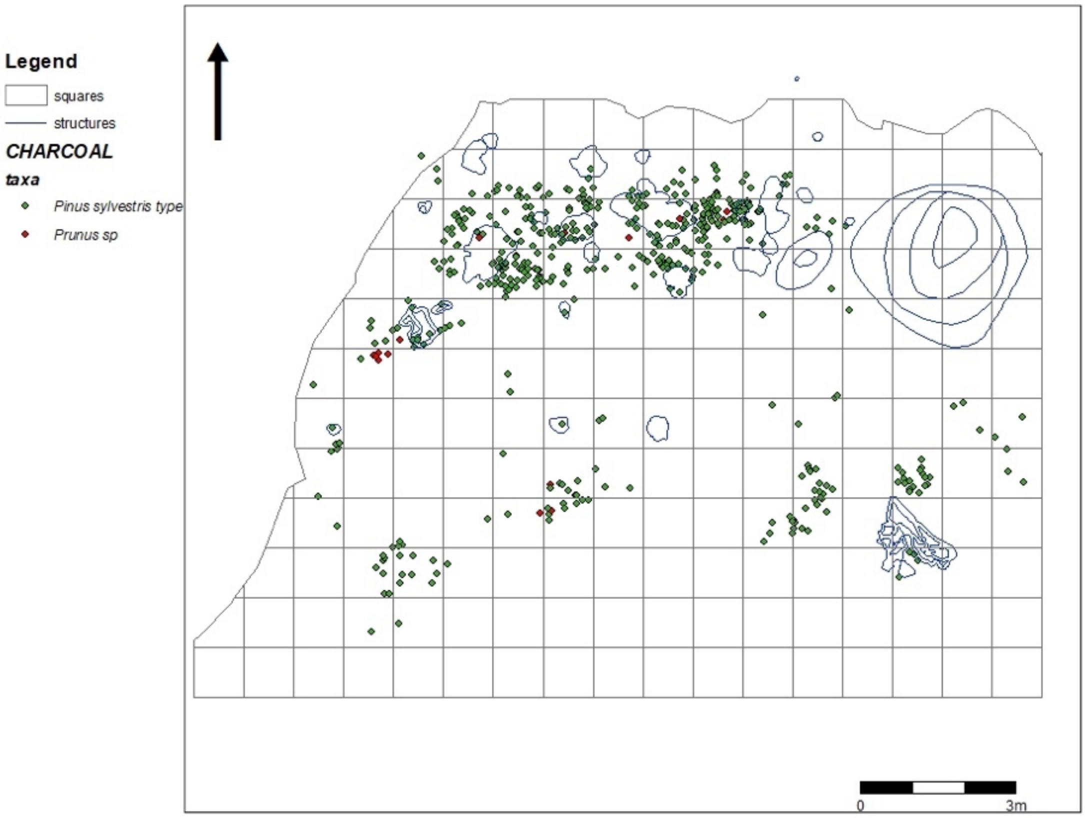


Figure II charcoal fragments by taxa

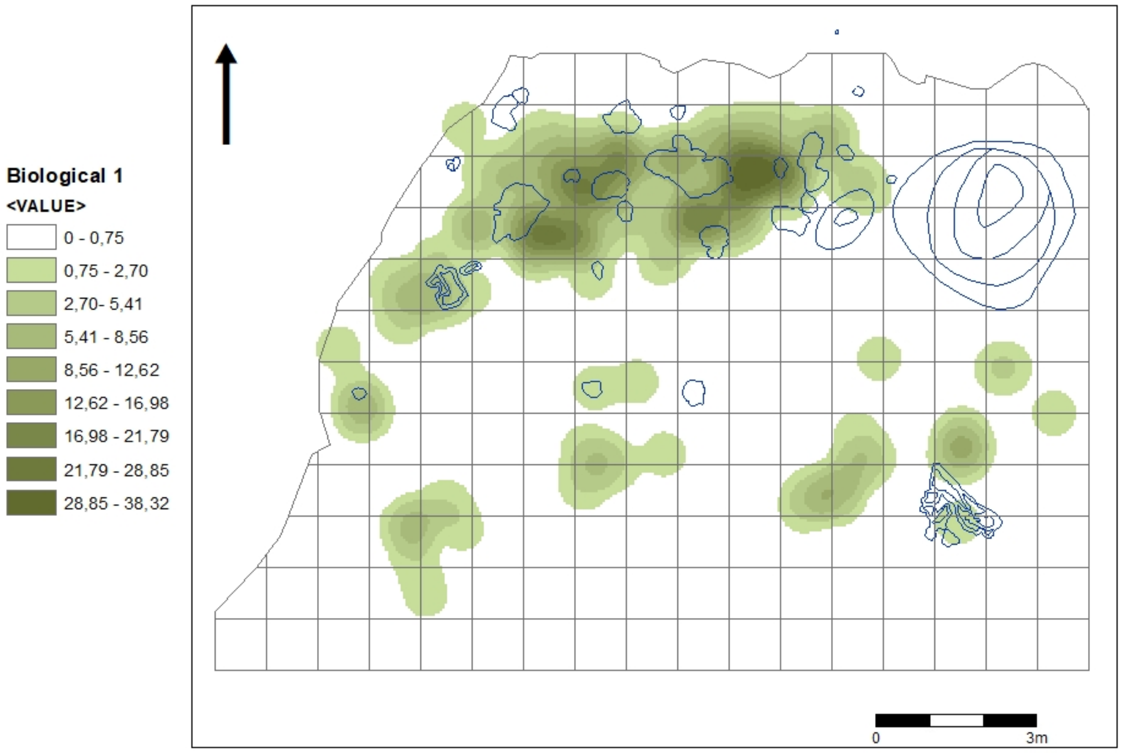


Figure III Accumulation of one biological alteration

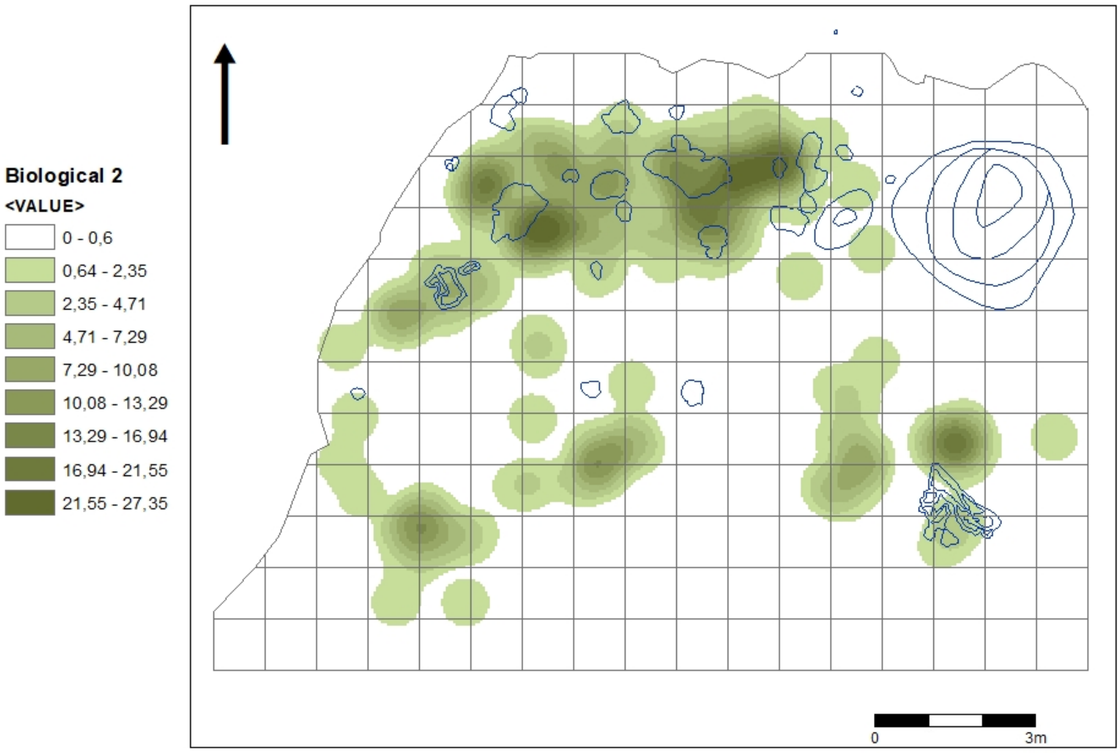


Figure IV Accumulation of two biological alterations

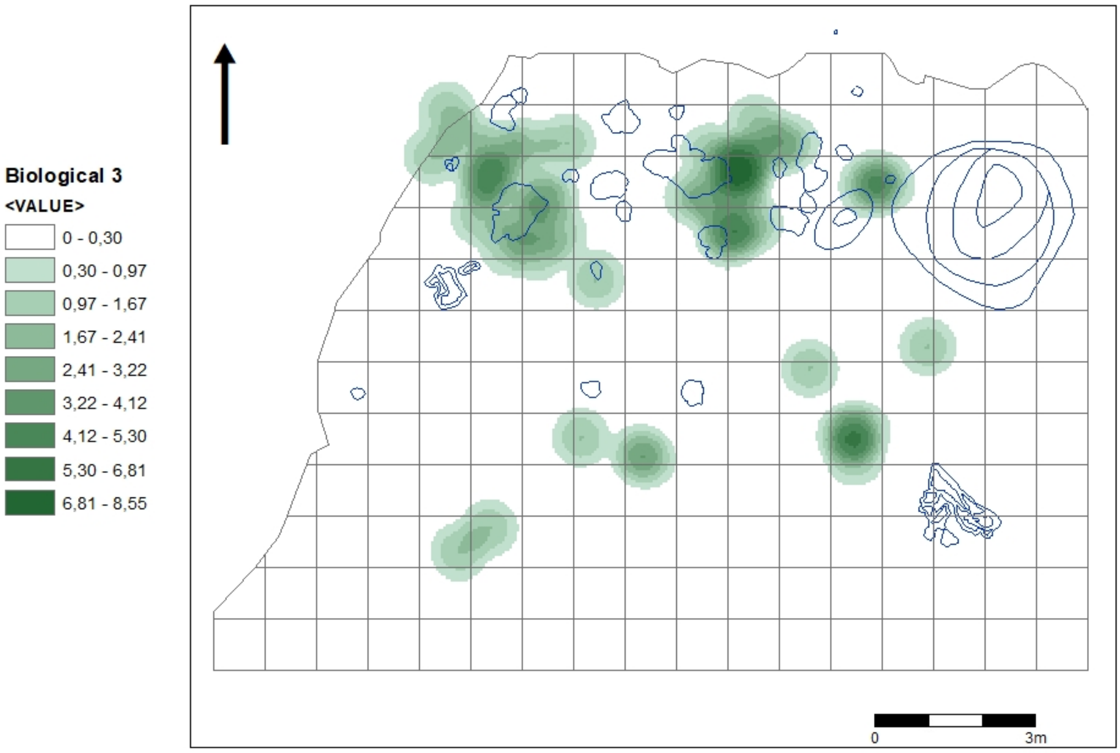


Figure V Accumulation of three biological alterations

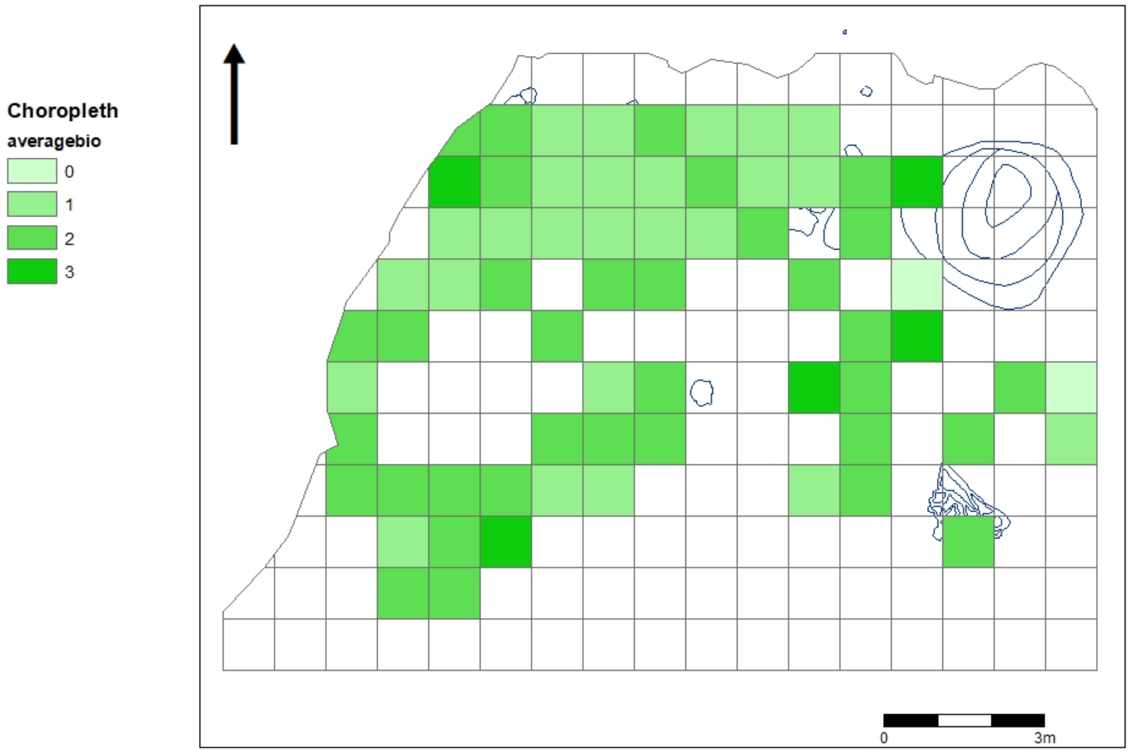


Figure VI average accumulation of Biological alterations

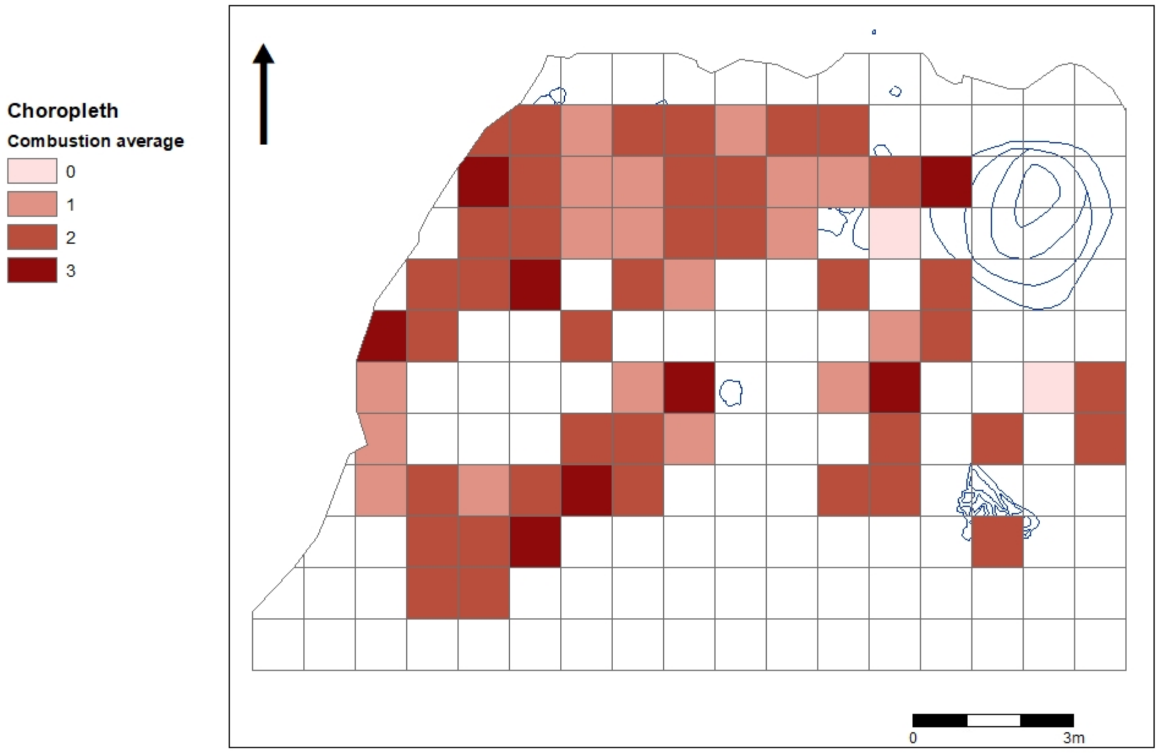


Figure VII average accumulation of Combustion alterations

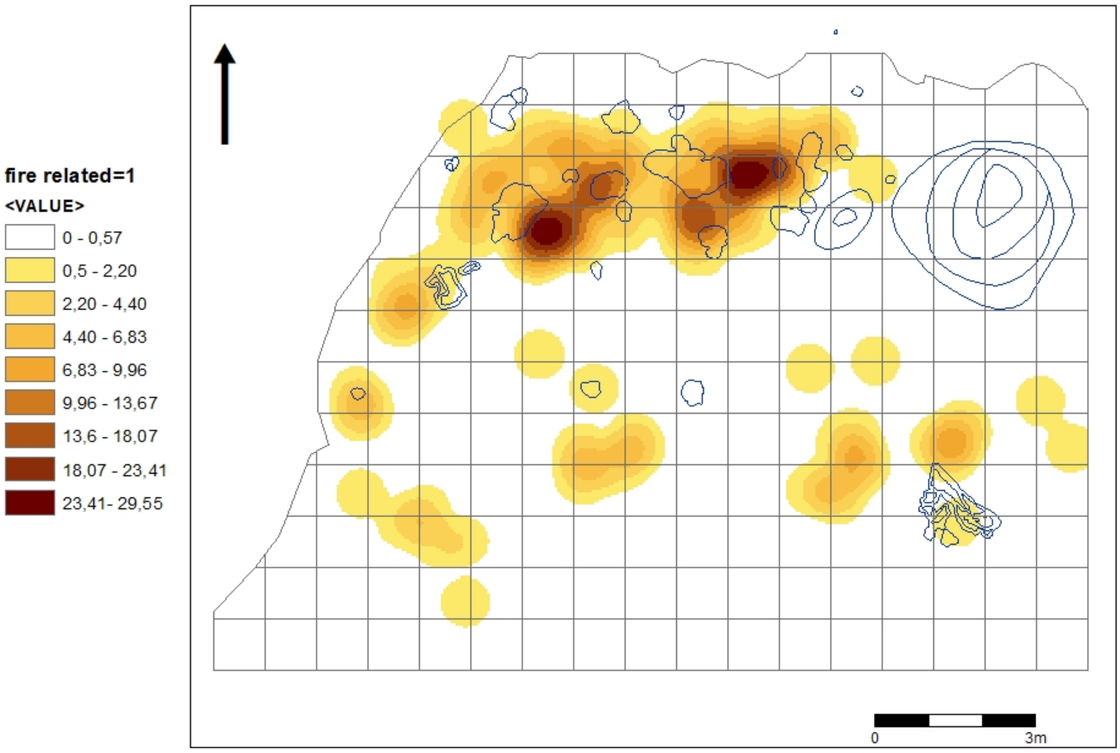


Figure VIII Accumulation of one fire-related alteration

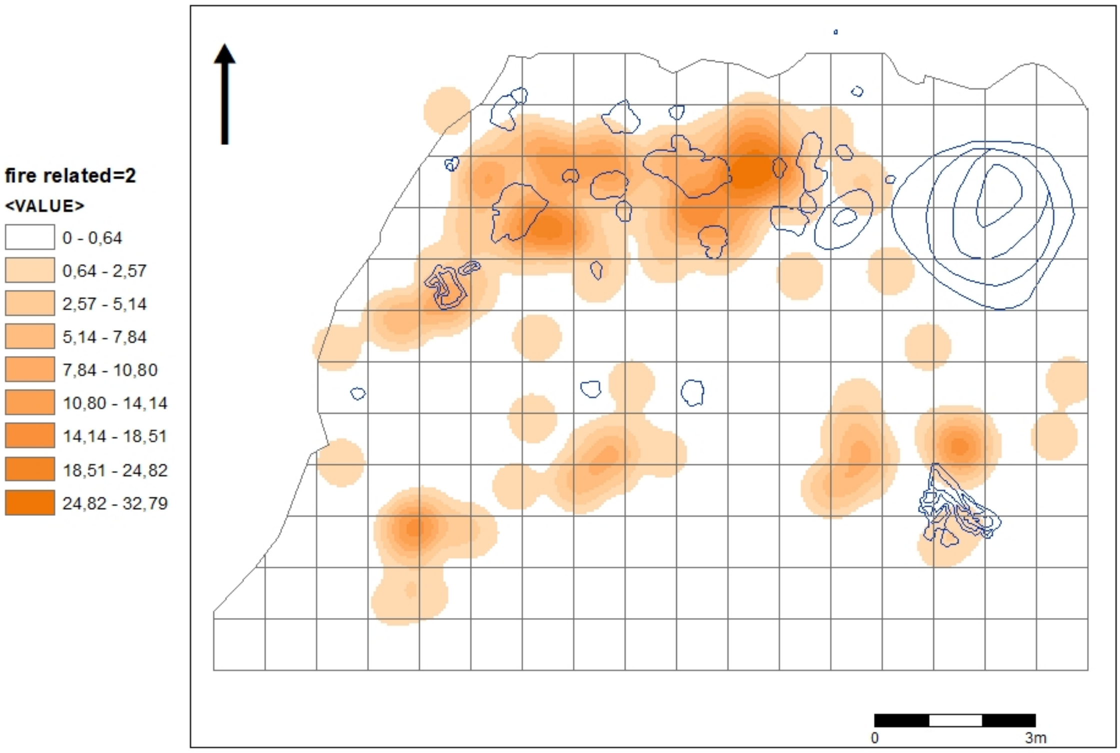


Figure IX Accumulation of two fire-related alterations

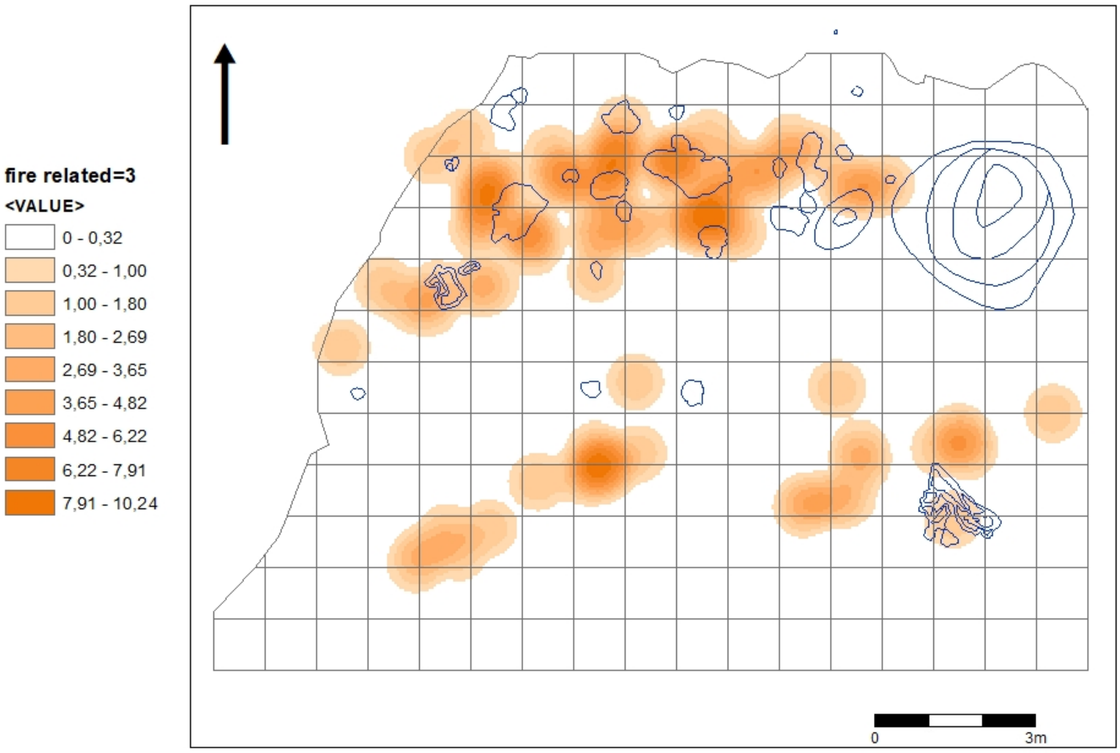


Figure X Accumulation of three fire-related alterations

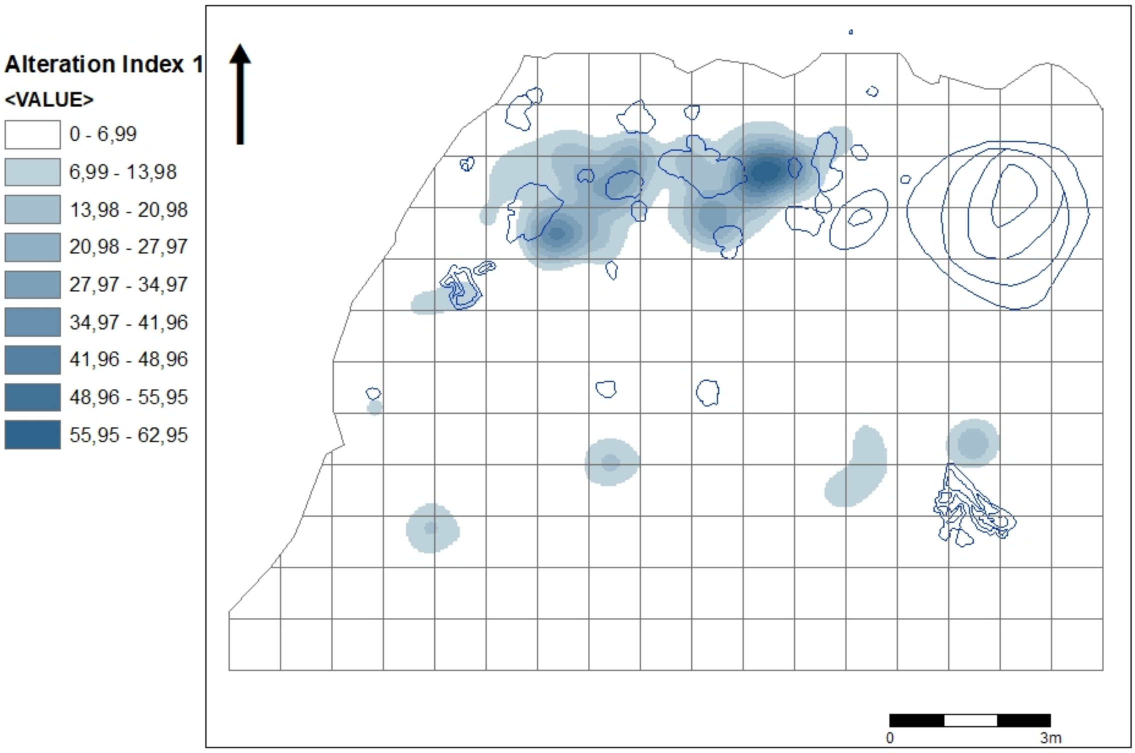


Figure XI cluster of charcoal fragments with alteration level one

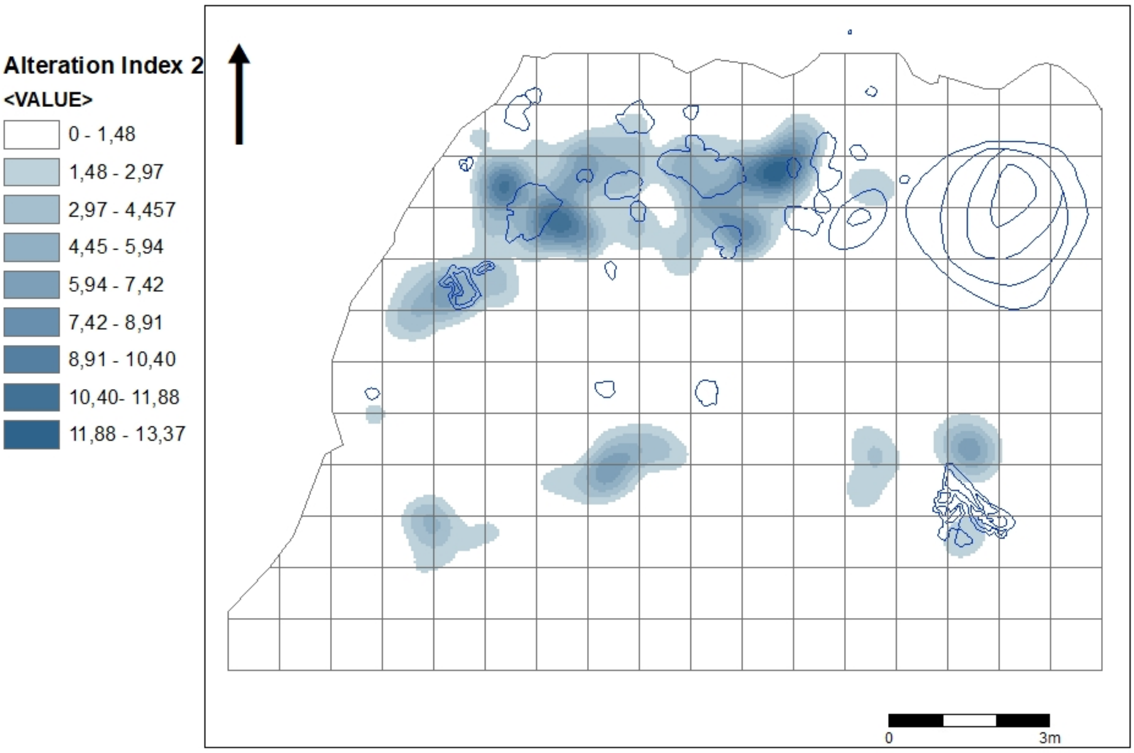


Figure XII cluster of charcoal fragments with alteration level two

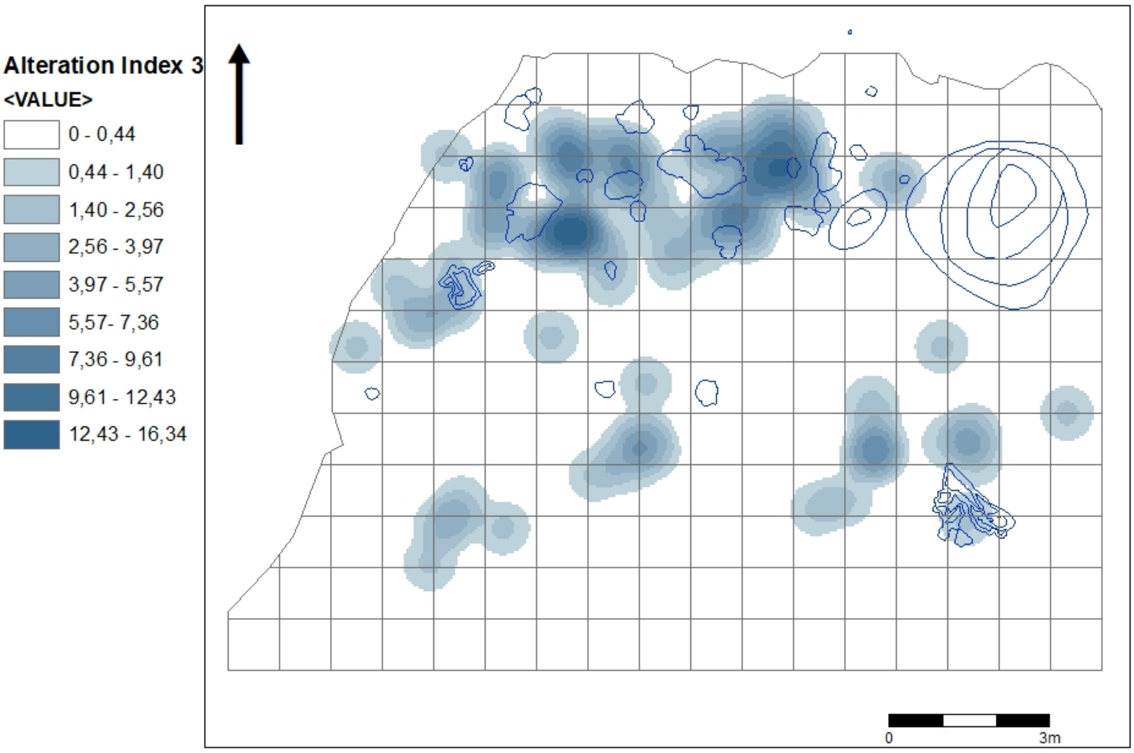


Figure XIII cluster of charcoal fragments with alteration level three

GWR 1 (archaeological squares):

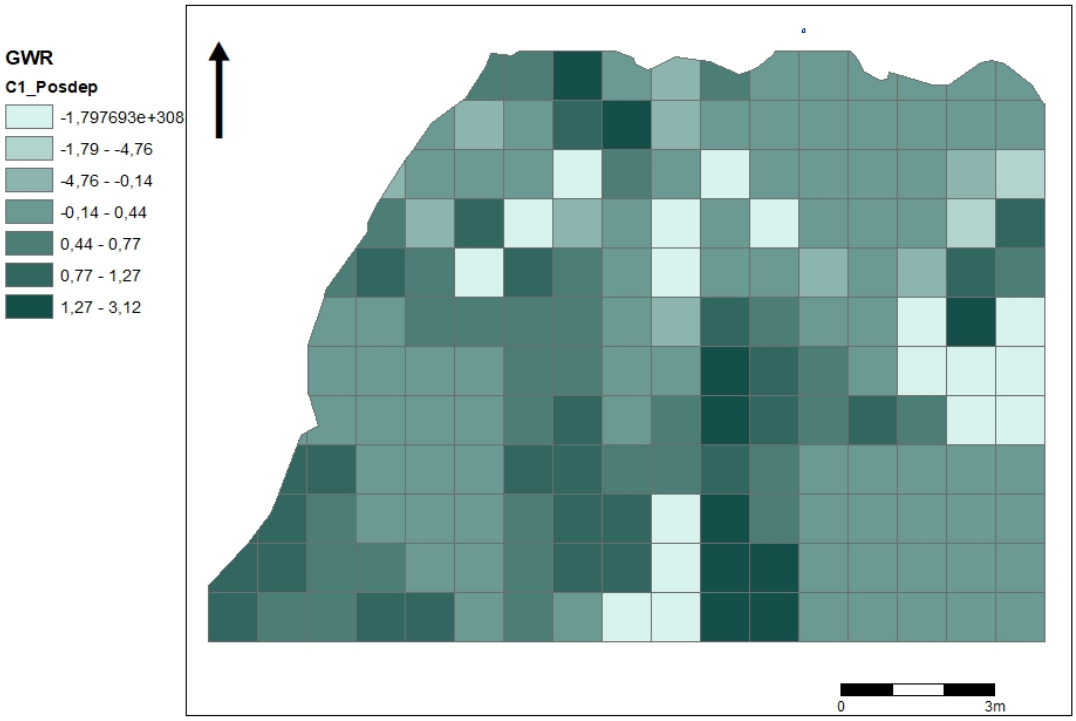


Figure XIV Coefficient of postdepositional alterations

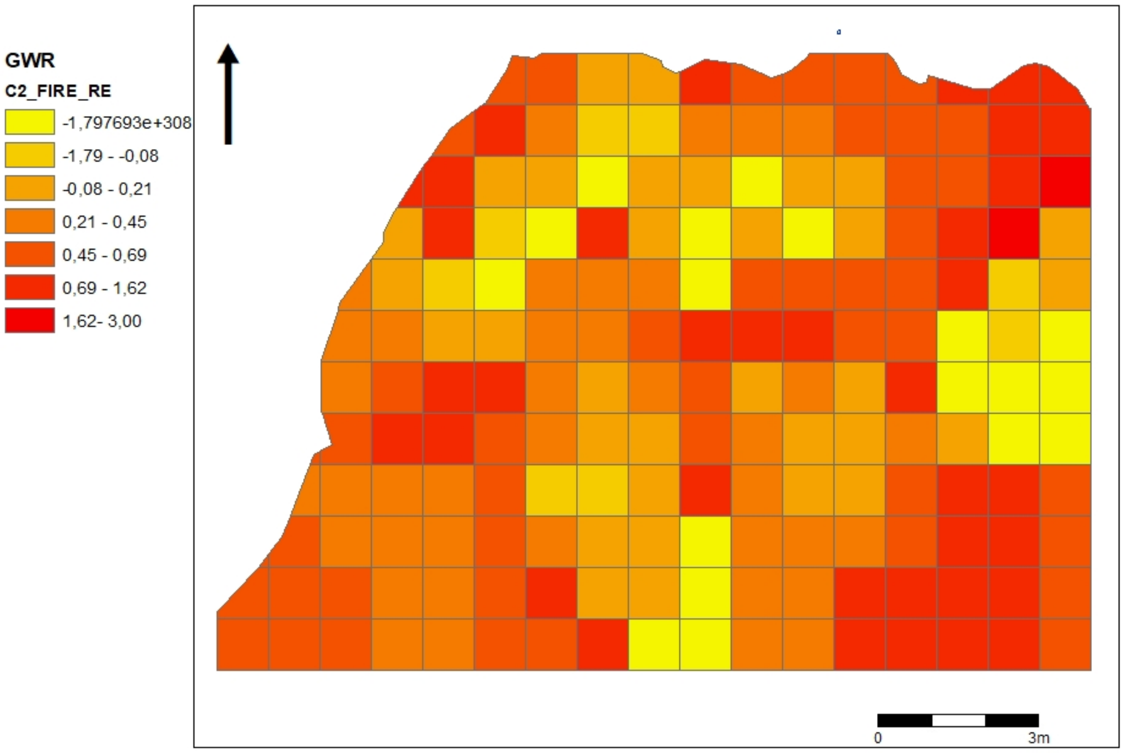


Figure XV Coefficient of fire-related alterations

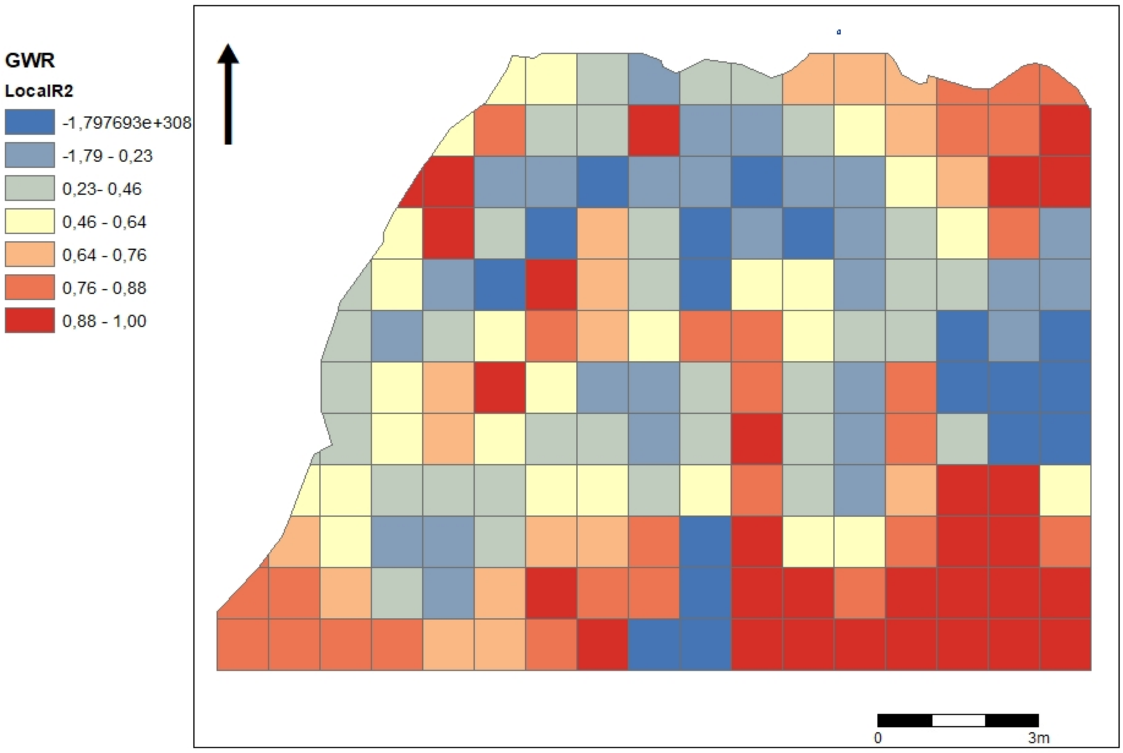


Figure XVI R2 value for the archaeological squares.

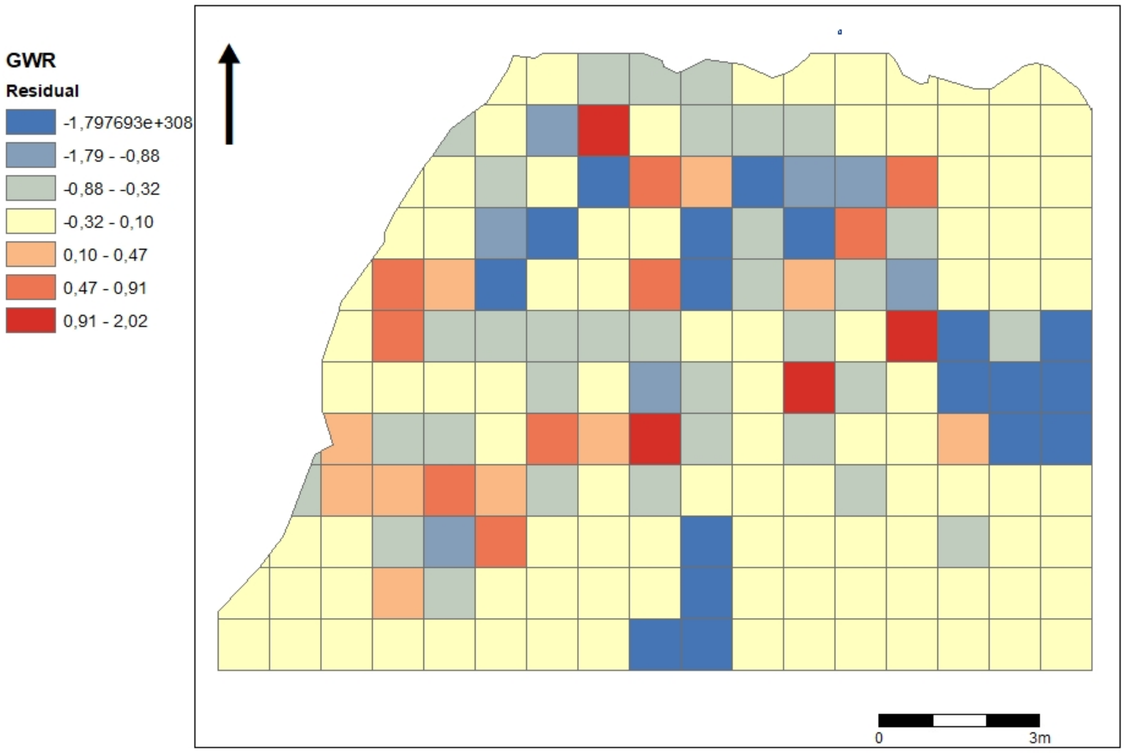


Figure XVII Residual values of the GWR test for the archaeological squares

GWR 2 (points):

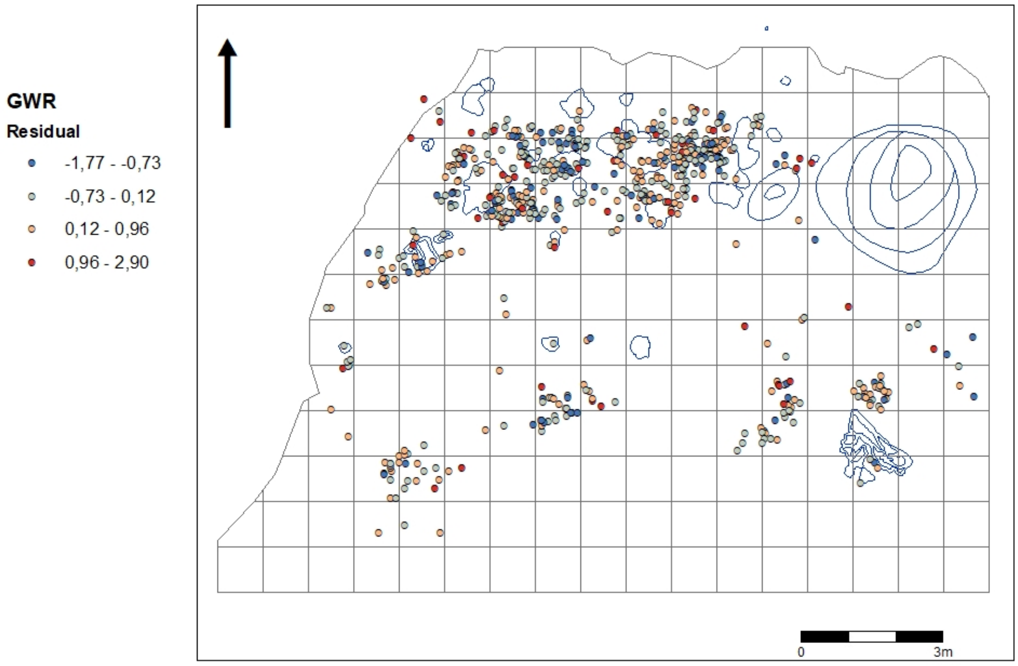


Figure XVIII Geographical Weighted Regression: residuals.

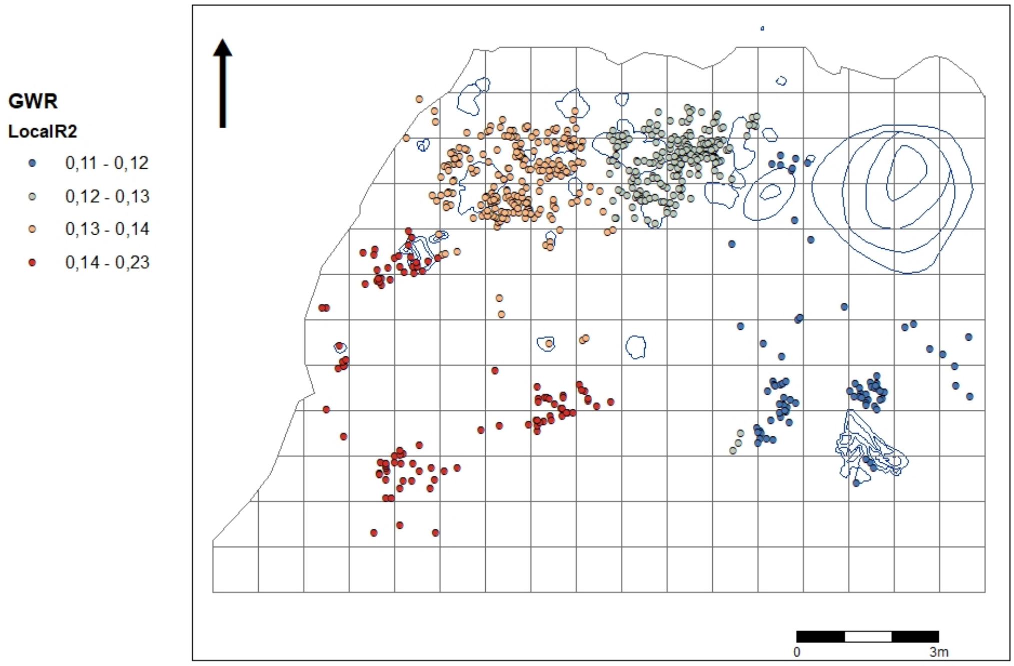


Figure XIX Geographical Weighted Regression: Local R2.

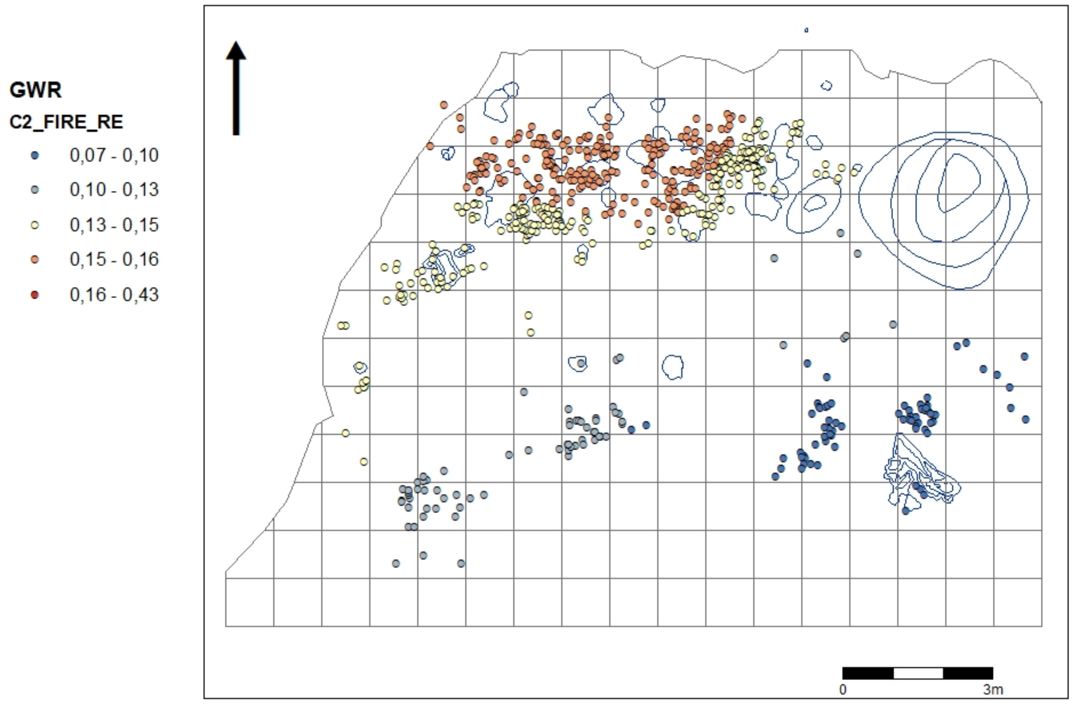


Figure XX Geographical Weighted Regression: Coefficient of fire-related alterations.

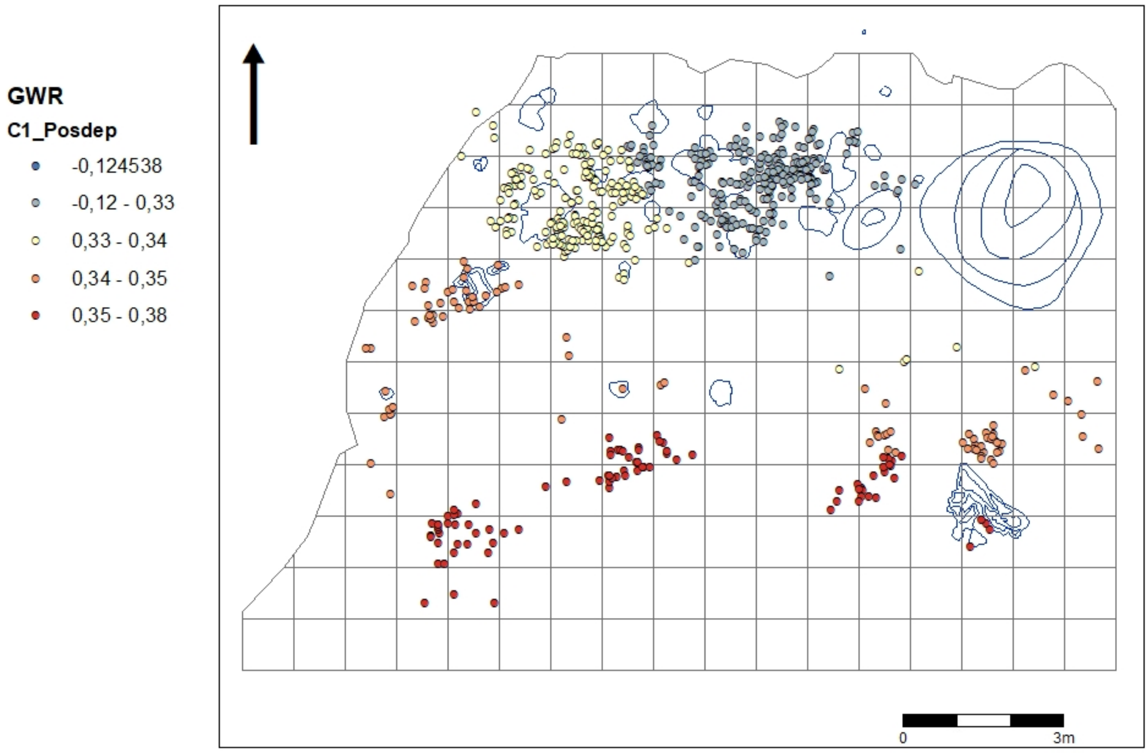


Figure XXI. Geographical Weighted Regression: Coefficient of post-depositional alterations.

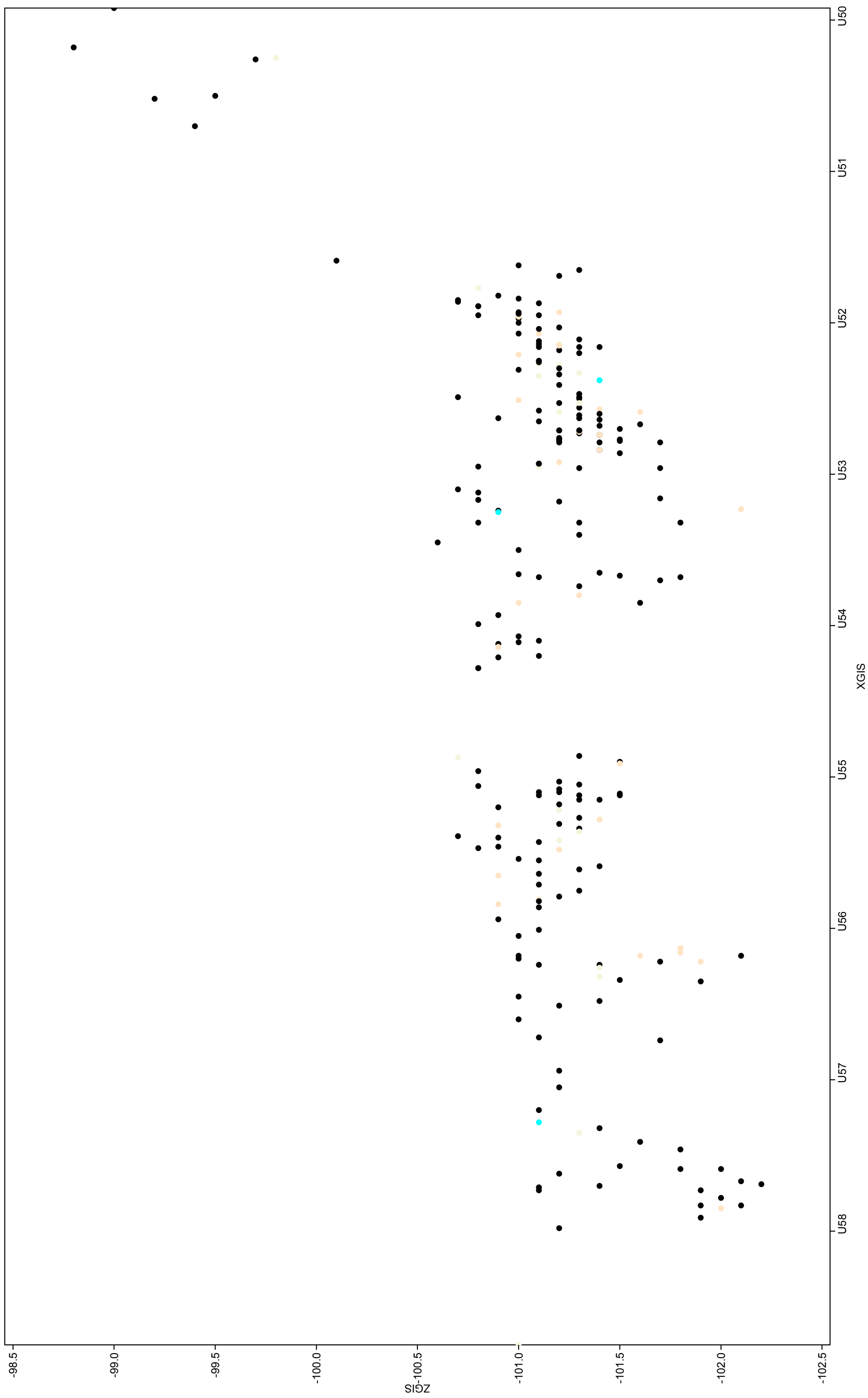


Figure XXII Profile of row U: Black: Pinus sylvestris type; Light blue: Prunus sp; Cream; conifer undetermined;

Dark cream: undetermined

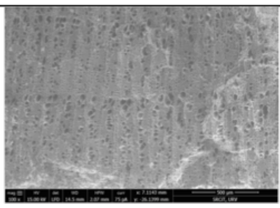
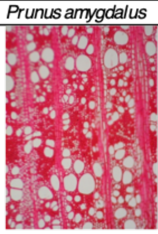
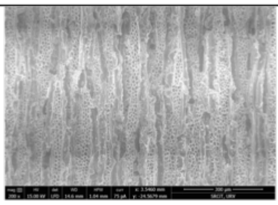
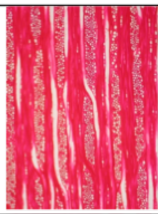
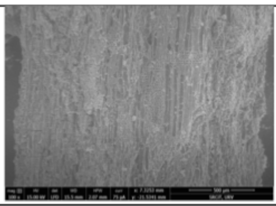
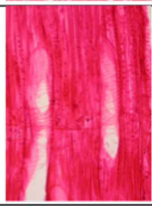
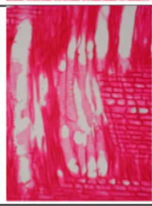
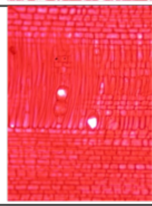
Comparison of different sections of the possible *Prunus* sp				
Section	Ra	*Prunus amygdalus*	*Prunus spinosa*	*Prunus mahaleb*
Cross				
tangential				
Radial				
Schweingruber (2005)		*Distinct rings, semi-ring to ring-porous, vessels solitary, and in more or less radial groups, simple perforation, vessel diameter 50-100μm, with thin helical thickenings, fibers with large pits, fibers thick-walled, parenchyma apotracheal and paratracheal,rays 5-10 seriate with sheet cells, heterocellular with many prostrate and a few upright cells with a few crystal druses in rays*	*Distinct rings, diffuse- to semi-ring porous, vessels mostly in groups and solitary, simple perforation, vessel diameter 40-80μm, with helical thickenings, fibers with large pits, fibers thin- to thick-walled, with tension wood, parenchyma apotracheal, rays uni seriate and 4-8-seriate, heterocellular with many prostrate and a few upright cells*	*Distinct rings, semi-ring porous, vessels mostly in radial and irregular groups, simple perforation, vessel diameter 50-100μm, with helical thickenings, fibers with large pits, fibers thin- to thick-walled, parenchyma apotracheal and partially paratracheal, rays uni seriate and 3-5seriate, homocellular with prostrate cells*

Figure XXIII posible Prunus species from Abric Romaní Ra level.

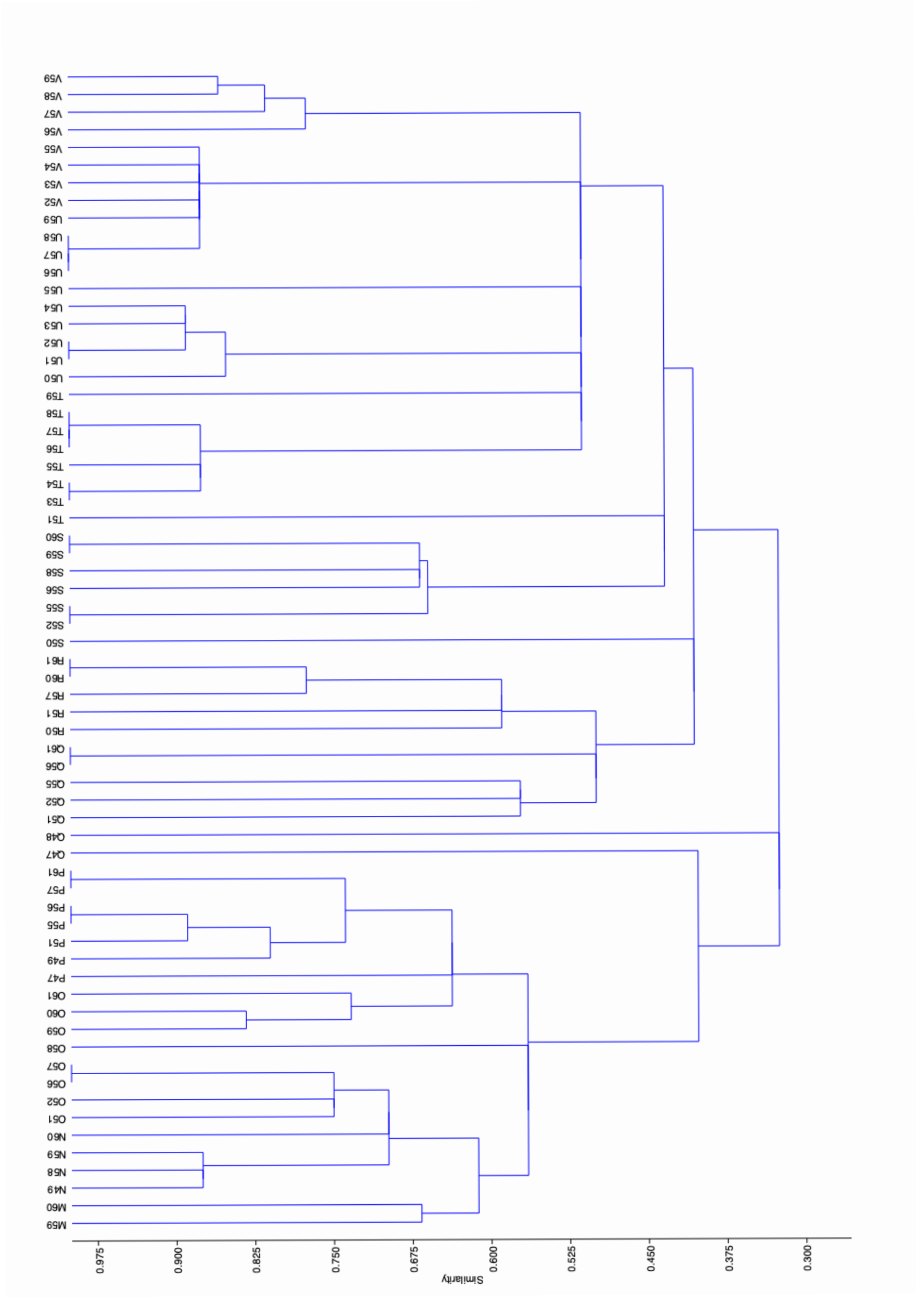


Figure XXIV Cluster analysis of archaeological squares classified by their alterations.