Fire Use & Pyrotechnology

Sumário da Lição

Sumário pormenorizado da Lição apresentada no âmbito das provas de habilitação para o título de Agregado no ramo de conhecimento de Arqueologia pela Universidade do Algarve, de acordo com o Art.º 8.º do Decreto-Lei n.º 239/2007, de 19 de junho, e com o Art.º 4.º do Despacho n.º 2251/2020, de 17 de fevereiro.

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Introduction

The present lecture presents the detailed summary of one of the classes proposed for the course of “*Geoarchaeology of Human-made Deposits”*, specifically lecture # 3 on Fire and Pyrotechnology (see Table 1).

Table 1: Summary of programmatic content of the course “Geoarchaeology of Human-made Deposits”

Lecture #	**Programmatic content**	**Lecture typology**	
		T	P
1	Introduction to Site Formation and Anthropogenic Sediments	x	
2	Preservation of Archaeological Deposits	x	x
3	**Fire use and Pyrotechnology**	**x**	**x**
4	Burials and Inhumations	x	x
5	Stabling and Fumiers	x	
6	Middens, Trash Pits and Latrines	x	x
7	In-class Student presentations		x
8	Earth Mounds and Shell Mounds	x	x
9	Construction Materials	x	
10	Occupation Surfaces and Use of Space	x	x
11	Anthrosols, Dark Earths and Agriculture	x	
12	Abandonment, Site Destruction and Decay	x	
13	Final Exam		

Lecture objectives

The main objectives of this lecture can be summarized as follows in terms of the goals for student’s acquisition of scientific knowledge and concepts:

- Acquire knowledge on the evolutionary and adaptive benefits associated with use of fire by humans.
- Differentiate between concepts of fire use, production/control of fire, and pyrotechnology.

- Know the main types of archaeological proxies for recognizing anthropogenic fire use.
- Identify archaeological case studies of misidentification of fire residues.
- Know different methodological approaches to recognize archaeological fire evidence.
- Understand hypothesis related to the timing of emergence of fire by hominins.
- Acquire up-to-date knowledge on the evolution of pyrotechnology during the Paleolithic.

Methodology

The lecture is structured in a 90-minute theoretical seminar. During the seminar, the fundamental contents of the lecture's topic will be presented to students through an oral presentation supported by multimedia resources. This exposition will be followed by a theoretical-practical 90-minute session with hands-on analysis and discussion of archaeological fire residues in micromorphological thin section analysis.

During the oral presentation, the thematic content of the class will be given to students, while fomenting questions and dialogue related to the exposed content. Concepts already acquired in the previous lectures (namely in the preceding lecture 2) will be integrated concerning the identification of archaeological fire residues. For instance, processes associated with the chemical dissolution of carbonates will be discussed in the context of loss of wood ashes in archaeological sediments under acid pH conditions. This will allow students to see the practical applicability of concepts and formation processes.

The final part of the lecture will allow students to view and analyze microscopic evidence of paleolithic fire features with different degrees of integrity – from well-preserved intact hearths, to dumped ash deposits and poorly preserved burned remains. Similarly, examples of deposits that mimic fire, but that are in fact the result from natural processes will also be analyzed with the support of archaeological thin sections. The necessary samples for this part of the lecture are housed in the Microscopy Laboratory of ICArEHB.

Fire use and Pyrotechnology

The ability to use and control of fire are a behavioral and technological trait associated with the genus *Homo*. Nowadays, all human societies use fire for a range of activities and humans are obligated fire users. Therefore, understanding the origins and how the use of fire developed and changed through time are major research avenues in paleoanthropology.

Despite decades of research, however, when, and how humans started to use and control fire remains a controversial topic. Archaeological identification of anthropogenic (i.e., human-made) fire is far from being straightforward. Several claims for early fire use have later been identified through microstratigraphic analyses as resulting from natural formation processes (Goldberg et al., 2001; Stahlschmidt et al., 2015). Erosion or diagenetic processes can obliterate or substantially distort the original fire evidence. As a result, based on macroscopic observations alone it is often difficult to distinguish between natural versus intentional fire (Goldberg et al., 2001). Another important aspect, and one often less investigated, is when fire started to be systematically controlled and incorporated in the adaptive toolkit of past humans. This differs from research dealing with first appearance and focuses on when humans became proficient in making and repeatedly using fire.

During this class, we will address the theoretical benefits, as well as the costs associated with fire use. We will then focus on the archaeological proxies employed in identifying fire remains from archaeological deposits, and, finally, provide a synthesis of the main archaeological contexts that are associated with the onset of fire use and the evolution of pyrotechnology during the Middle and Upper Paleolithic.

The costs and benefits of fire

Controlling fire offers various benefits, including the provision of warmth, light, defense against predators, and the facilitation of technological advancements. As an external source of heat, fire allows to save energy and maintain the body temperature. As such, early fire use might have contributed to the expansion to Eurasia (MacDonald, 2017), and the exploitation of a broader dietary spectrum. Fire is believed to have played a crucial role in instigating fundamental biological and adaptive changes through the consumption of cooked food. The energetic benefits of fire can be associated with external digestion, that is, that cooked food allows for the breakdown of starch, proteins, and other food components, while eliminating disease-causing pathogens. Wrangham and colleagues (Carmody and Wrangham, 2009, Gowlett and Wrangham, 2013, Wrangham, 2009, Wrangham, 2006) have proposed the ‘cooking hypothesis”, where the ability to cook is the driving force behind early hominin digestive adaptations. Others link the use of fire to enhanced social abilities and perhaps even the development of language (Gowlett, 2006, Twomey, 2013). The control of fire also plays a relevant role as a technology (Goldberg, 2006). The advent of techniques associated with heat treatment improved stone tool production (Schmidt et al., 2013, Brown et al., 2009), as well as the development of glues and tars for hafting (Schmidt et al., 2019, Schmidt et al., 2020, Kozowyk et al., 2017, Rageot et al., 2019). Technology is “cultural” dependent, as such pyrotechnology has the potential to be analyzed in terms of its spatial and temporal variation.

Whereas the benefits of fire use are well established, fewer studies have investigated the costs associated with obligated fire use. One of the costs of fire is the time and energy spent in gathering wooden fuel (Henry, 2017). This energy expenditure in gathering fuel is dependent on the inhabited environment. For instance, in northern latitudes where forests retracted during glacial periods, the costs of collecting wood for burning are necessarily higher than during occupations in forested landscapes where fuel resources were abundantly available. As we will discuss further on during this class, there are other options besides wood for maintaining flames during combustion and we have both ethnographic and archaeological evidence for the use of bones for fuel (Buonasera et al., 2019, Costamagno et al., 2005, Morin, 2010, Théry-Parisot et al., 2005). Relevantly, while modern humans rely on cooked food, there are other processes that produce results like cooking, namely the use of putrid meat. Speth and colleagues (Speth, 2017, Speth and Eugène, 2022) have shown through ethnographic data that the use of putrid meat was widespread not only in communities living in northern latitudes but also in the tropics. The consumption of putrid and rotten meat, fat and fish is a low-cost approach that allows for a pre-digestion and breakdown of proteins in many ways like the benefits given by cooking. This is an area of research that needs to be further explored, as the identification of putrid meat in the archaeological record remains under investigated.

Identifying fire in the archaeological record

When it comes to identify fire in the archaeological record, we first need to consider if the evidence is related to fire – that is, is it burned or not – and if it relates to human-made fire. As we will see later on in this class, there are several natural processes that can mimic and be misinterpreted as burning. The second point deals with the fact that fire is a natural process that exists independently of humans. Natural fires are recurrent in Earth geological record and can, at times, affect archaeological materials spread out over a surface. Natural grass fires can be spatially very extensive, but move relatively fast through a landscape and will not reach high temperatures (see review in Aldeias, 2017). However, the burning of a tree stump will entail temperatures equal to those of a wood fueled hearth and closely mimic it – in this case, the presence of charred underground roots might be an important clue. Therefore, since fire is a natural phenomenon, the presence alone of charcoals or even burned remains does not necessarily equate to human-made fires. In other words, simply identifying an altered (i.e., burned) component is not enough to assign it to human agency. The identification of combustion features must be based not only on the presence of thermally altered materials, but also on their geometric associations in a microcontextual approach (Goldberg et al., 2017). An open campfire will generate a microstratigraphy associated with a superimposition of a white ash-rich layer, overlying a darker organic, often charcoal-rich lens, which in turn sits on top an altered, typically reddened, substrate. A powerful tool to examine pyrotechnology is, then, the use of microarchaeological techniques. A wide range of literature exists on identifying fire in the archaeological record (Mentzer, 2014, March et al., 2017, Goldberg et al., 2017, Mallol et al., 2017) and the analytical approaches to investigate fire remnants are synthetized in Goldberg et al. (2017) and shown in Table 2.

Even when burning has been established, we further need to distinguish between "use of fire" from "control of fire" (Sandgathe et al., 2017). In fact, use of fire is not specific to the genus *Homo*. A variety of animals do use and interact with fires. This is the case, for instance, of "firehawk" raptors in Australia that intentional spread natural fires (Bonta et al., 2017). Savanna chimpanzees from Senegal live in a fire-prone landscape and are adapted to take advantage of recently burned landscapes to forage and travel (Pruetz and Herzog, 2017). Control and production of fire, on the other hand, are only associated with our ancestors, with several ethnographic accounts on methods to start a fire (Sorensen et al., 2014). Surprisingly, however, while we tend to associate control of fire as an essential adaptation for early hominins, ethnographic data also shows several instances where modern humans have lost the knowledge of how to start a fire in a given community (McCauley et al., 2020). Therefore, the ability to produce fire might not be a linear technological know-how, and we can assume that past humans may have been able to start a fire in certain times and in certain communities, but that this knowledge was not necessarily constantly retained (Roebroeks et al., 2021).

Analytical technique, sample type	Type of information/data	Used to identify presence/ absence of heating?	Other information	Key references
Micromorphology: • Oriented blocks of sediment indurated with resin and processed into petrographic thin sections	Visual observation of sedimentary components using a petrographic microscope and different sources of light (plane-polarized, cross polarized, darkfield, fluorescent, reflected, oblique incident)	Yes. Can be used to identify some by-products of combustion based on mineralogical composition and morphology (e.g., ashes).	Allows the analyst to observe the spatial relationship between different components of the feature. Fabric and structure can be used to make interpretations about depositional context. Other components provide information about postdepositional history.	Canti 2003; Courty, Goldberg, and Macphail 1989; Goldberg and Macphail 2003; Meignen et al. 2001; Mentzer, Romano, and Voyatzis 2015; Wattez 1988
FTIR:[a] • Loose sediment samples • Heated lithics and rocks • In situ measurements on intact blocks and thin sections collected for micromorphological analyses using μ-FTIR	Type and strength of molecular bonds; output in the form of spectra	Yes. Certain materials (e.g., clay minerals, bone) can be analyzed to document molecular changes that occur with heating.	Provides temperature ranges of heating for bone and clay minerals; can also be used to identify primary and secondary minerals. Under ideal preservation conditions, pyrogenic calcite can be distinguished from geogenic calcite.	Berna et al. 2007; Forget et al. 2015; Goldberg and Berna 2010; Regev et al. 2010; Thompson, Islam, and Bonniere 2013; Weiner 2010; Weiner and Bar-Yosef 1990; Weiner and Goldberg 1990; Weiner, Goldberg, and Bar-Yosef 1993; Weiner et al. 1995, 1998; Xu et al. 2015
XRD:[b] • Loose sediment samples and artifacts (bone, lithics) • In situ measurements on micromorphological samples using micro-XRD	Spacing and arrangement of atoms in a crystal lattice; output in the form of diffraction patterns	Yes. Certain materials (e.g., clay minerals, bone) can be analyzed to document molecular changes that occur with heating.	Can be used to identify primary and secondary minerals. Can be used to study heat treatment of lithic materials.	Domanski and Webb 1992; Rogers and Daniels 2002; Schmidt et al. 2012, 2013; Weymouth and Mandeville 1975
SEM-EDS:[c] • Loose sediment samples • In situ measurements on polished or carbon-coated micromorphological samples	Elemental abundance for major and trace elements (Na through U); output in the form of spectra	No.	When one mineral phase is present, the relative abundance of elements can be used to estimate the chemical formula and identify the mineral. Used primarily for the study of diagenesis of burned materials.	Karkanas 2010; Karkanas et al. 2002; Schiegl et al. 1996
Phytolith analysis: • Phytoliths extracted from loose sediment samples • In situ observation of phytoliths visible in micromorphological samples	Qualitative description of phytolith morphology; quantitative information from analysis of populations	Yes. Measurements of the refractive index of individual phytoliths can be used to determine heating.	Identification of phytoliths to plant type based on morphology can be used to study the types of fuels in hearths.	Albert, Berna, and Goldberg 2012; Albert and Cabanes 2007; Albert et al. 1999, 2000; Cabanes et al. 2010; Elbaum et al. 2003; Madella et al. 2002; Piperno 2006
Organic petrology: • In situ measurements on polished, resin-indurated block sediment samples (from micromorphological samples) • Other materials (e.g., bones) mounted in epoxy and polished	Identification of microscopic fragments of plants based on morphology, reflectance measurements of tissues and gels, and quantitative fluorescence	Yes. Charred plant tissues have reflectance values that are different from those of humified tissues.	Provides information about fuels and their state of decomposition before burning.	Clark and Ligouis 2010; Goldberg et al. 2009; Stahlschmidt et al. 2015; Suárez-Ruiz 2012
Electron spin resonance: • Measurements on heated bones	Measurement of the g-value of charred organic component of bone	Yes. Heated bones have characteristic ESR spectra.	Can be used to reconstruct heating temperature.	Michel, Falguères, and Dolo 1998; Schurr and Hayes 2008
Luminescence measurements: • Thermoluminescence on heated flints or sediment • Optically stimulated luminescence on heated sediment	Measurement of the amount of radiation damage sustained by a material following a heating event	Yes. Heated materials have a measurable luminescence signal.	Can be used to study heat treatment of lithic materials. Both techniques provide ages for burning events.	Brodard et al. 2012; Mercier et al. 2007; Richter 2007
Magnetic measurements: • Magnetic field survey on buried features (magnetometry) • Magnetic susceptibility on loose sediment samples • Palaeomagnetism on heated rocks	Enrichment in ferromagnetic minerals are visible as magnetic anomalies. Magnetic susceptibility is a measure of the abundance of magnetized grains within sediment. Measurements of remnant magnetism can indicate whether rocks were heated in the past	Yes. Heated sediments have higher magnetic susceptibility than unheated sediments. Iron-bearing minerals in heated rocks record the intensity and direction of the magnetic field at the time of burning.	Magnetic susceptibility measurements can be complicated by soil forming processes with equifinality producing ambiguous results in some cases. Components of magnetization can be used to determine heating temperatures. Paleomagnetic measurements can be used to determine whether burned rocks are in situ.	Barbetti 1986; Bellomo 1993; Dalan and Banerjee 1998; Gose 2000
Organic chemistry: • Gas chromatography mass spectrometry on sediment containing organic material	Identification of alkanes from plants and fatty acids from burned animal tissues	Yes. Charring reduces the relative abundance of long-chain n-alkenes.	May be useful for identifying residues from cooking or animal processing and conditions of heating. Applications are thus far limited to Holocene contexts.	Almendros, Martin, and Gonzalez-Vila 1988; Buonasera 2005; Buonasera et al. 2015; Eckmeier and Wiesenberg 2009; Mallol et al. 2013; March 2013; March, Ferreri, and Guez 1993; Sistiaga et al. 2011
Measurements of stable isotopes of carbon and oxygen: • Loose sediment samples • Quasi in situ measurements on powders drilled from micromorphological blocks	Identification of calcite sourced from wood ashes and its degree of recrystallization in an alkaline environment	No.	Can indicate low- or high-temperature burning in well-preserved samples.	Mentzer and Quade 2013; Shahack-Gross and Ayalon 2013; Shahack-Gross et al. 2008

[a] FTIR = Fourier transform infrared spectroscopy.
[b] XRD = X-ray diffraction.
[c] SEM/EDS = scanning electron microscopy/energy-dispersive X-ray spectroscopy.

Table 2: Summary of analytical techniques used to study archaeological fire evidence (Goldberg et al., 2017).

Generally, evidence for fire can rely on both direct (by-products of combustion) and indirect proxies. When a fire is lit, there are materials and deposits directly produced by the combustion of fuel, such as deposits rich in ashes, charcoals, or calcined bones. The complete burning of wood will result in the production of calcitic pseudomorphs after calcium oxalates, and wood ash is mainly composed of calcite with other minor components, including opal phytoliths (Braadbaart et al., 2012, Albert and Cabanes, 2007, Albert et al., 2000). Opal phytoliths are more abundant in leaves and bark, but preserve poorly in alkaline environments (Cabanes et al., 2011). In domains where combustion is not complete, charcoal fragments will survive, and these provide key information on the identification of the type of wood selection used in ancient fires (Théry-Parisot, 2001). Other by-products of fire are organic compounds that are produced during the combustion of organic fuel, namely polycyclic aromatic hydrocarbons (Brittingham et al., 2019). Bone, particularly spongy bone rich in fat, can also be used as fuel with archaeological examples known from the Paleolithic (e.g., Théry-Parisot, 2002). Experimental work with bone fueled hearths show that these fires have an increase duration of combustion. However because of the relatively high critical heat flux for ignition of bones, the start of the fire needs to use wood or a mixture of wood and bones (Théry-Parisot and Costamagno, 2005, Théry-Parisot et al., 2005).

Lighting a fire also implies a substantial raise in temperature (heat) and indirect evidence of fire are the components that are affected by this heat, such as burned sedimentary substrates and burned artifacts (lithics, bones, shells, organics, etc.). A vast array of studies have established the temperature thresholds for structural changes in burned bones (Bennett, 1999, Stiner et al., 1995), shells (Aldeias et al., 2019, Villagran, 2014), silcrete (Schmidt et al., 2013, Archer et al., 2023), flint (Goder-Goldberger et al., 2017), and other organic and mineral components (e.g., Wadley, 2009). Some natural processes may mimic burning, as is the case of the presence of manganese coated bones, which have previously been misinterpreted as charred bones (Marin Arroyo et al., 2008, Shahack-Gross et al., 1997). Experimental archaeologiy has investigated under what circumstances heat alters underlying deposits (Aldeias et al., 2016, see references in Aldeias, 2017). The alteration of sedimentary substrates underlying a fire often assumes a redden coloration due to the oxidation of iron. These iron oxides are chemically stable and an analysis of their color can provide information on the degree of temperature that lead to their formation (Ferro-Vázquez et al., 2022).

Fire remnants may the subject of dissolution, fragmentation, erosion, and chemical diagenesis. For instance, in several Levantine Middle Paleolithic sites such as Kebara or Hayonim caves, the presence of superimposed combustion features is observed, though in some features, the ashes were dissolved or commonly diagenetically altered to apatite and other phosphate minerals due to guano accumulations (Meignen et al., 2009, Schiegl et al., 1996, Schiegl et al., 1994, Weiner et al., 2002, Albert et al., 2012, Berna et al., 2008). At the sites of Roc de Marsal (France) and Klasies River Mouth (South Africa), thin alteration of the uppermost calcitic ashes is indicative of site abandonment and exposure in a stable surface in cave settings (Aldeias et al., 2012, Morrissey et al., 2023). In open structure deposits, such as those of shell middens, ashes can easily be blown away or reworked by water, with 'invisible' hearths being inferred from the underlying thermal alteration of components such as aragonitic shells (Simões and Aldeias, 2022). Combustion residues can be reworked by a suit of natural processes such as runoff (Goldberg et al., 2007), bioturbation (Madella et al., 2002) or colluviation. Anthropogenic actions related to hearth maintenance activities may also entail the reworking of fire residues (Aldeias, 2017, Mallol et al., 2013, Mallol et al., 2017, Miller et al., 2010). Whereas foot traffic (trampling) will result in the fragmentation of physically fragile components, such as charcoals and calcined bones (Stiner et al., 1995), actions such as dumping or scooping of ashes will effectively disrupt the original microstratigraphy associated with a well-preserved combustion feature (Miller et al., 2010, Mallol et al., 2013). Figure 1 shows the phases of combustion that can affect a hearth feature, both relating to natural and anthropogenic processes.

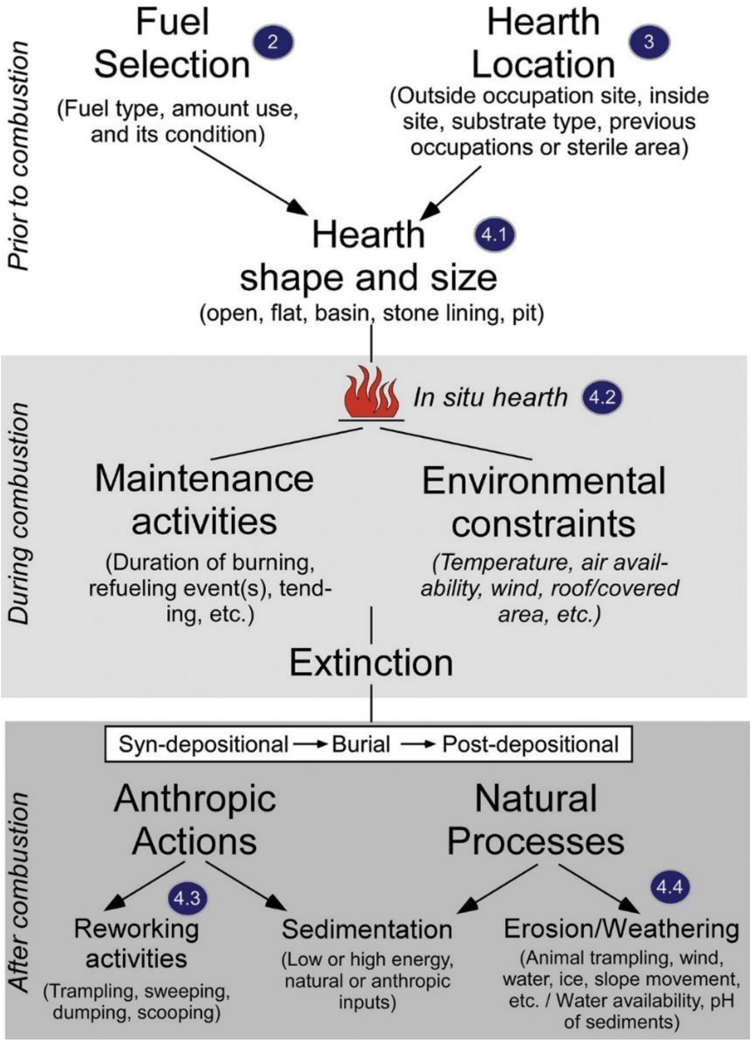


Figure 1: Schematic diagram illustrating the several phases of hearth construction, use, and preservation (Aldeias, 2017).

The evolution of pyrotechnology

As mentioned before, there are long standing debates on the first secure identification of anthropogenic use and control of fire in the archaeological record. Some of the sites initially proposed as showing evidence for anthropogenic combustion features have been proven to be unrelated to fire. Perhaps one of the most illustrative examples of a long-standing claim for early fire use is at the site of Zhoukoudian, in China. At Zhoukoudian the evidence of fire was claimed to be present in Layer 10 dated to ~0.6 million years ago (Ma). Subsequent geoarchaeological research, however, showed that these deposits were the result of water laid organic and loess and not *in situ* hearths (Goldberg et al., 2001, Weiner et al., 1998). Another classic example is that of the German site of Schöningen, where fire was assumed to have played a role in association with

Neanderthal occupations dated to MIS9 ~300 ka. The site is a peat deposit and the presence of organic lake sediments associated with basal reddening was first interpreted as relating to fire use. However, interdisciplinary research using thermoluminescence, organic petrology, soil micromorphology, and FTIR has shown that there is currently no evidence for anthropogenic fire use and that the iron oxides producing the rubification are not related to heating but with the lowering of the water table at the site (Stahlschmidt et al., 2015a, Stahlschmidt et al., 2015b). The following sites have been proposed as early evidence of fire use prior to ~500 thousand years ago (ka), although several of these contexts have certain "caveats" and have been disputed:

- Wonderwerk Cave – situated in south Africa, this large cave has deposits dated to 1.0 Ma associated with Early Stone Age assemblages. Geoarchaeological research of the deposits by Berna et al. (2012) showed the presence of discrete calcitic domains that were interpreted as ash remnants. FTIR analysis on bones demonstrated that several of the bones exhibit colors consistent with heating above 400ºC. Since this original publication, however, some authors have cast doubt on the association of the calcite with ash, as the deposits are rich in calcified root casts (rhizoliths) that can be misinterpreted as calcitic ashes (Goldberg et al., 2015).
- FxJj 20 – is an open air locality in Koobi Fora in Kenya with the presence of reddened patches of sediment. The origins of this rubification as related to fire is still debated (Bellomo, 1994, Hlubik et al., 2017, Hlubik et al., 2019, Clark and Harris, 1985).
- Gesher Benot Ya-aqov – is situated in Israel and the presence of so-called "phantom" hearths have been interpreted based on the spatial clustering of burned flints in layers dated to 800 ka (Alperson-Afil, 2008, Alperson-Afil et al., 2017, Alperson-Afil et al., 2007). However, several authors have casted doubt on this evidence as relating to anthropogenic hearths, since the flint could have been naturally heated prior to use, and the site formation processes at the site are not well established (Stahlschmidt et al., 2015b).

Another important aspect, and one often less investigated, is when fire started to be systematically controlled. This differs from research dealing with first appearance and focuses on when humans became proficient in making and repeatedly using fire. In Qesem cave (Israel) deposits dated to 300 ka have been investigated using micromorphology and FTIR to attest to the presence of a multilayered *in situ* hearth associated with burned artifacts (Shahack-Gross et al., 2014, Barkai et al., 2017, Karkanas et al., 2007). Other archaeological sites in Europe dating to and around 400 ka have also claim to have fire evidence associated with human occupations (e.g., Sanz et al., 2020, Angelucci et al., 2013, and see references in Roebroeks and Villa, 2011). However, based on an extensive review, Roebroeks and Villa (2011), suggest that early European hominins did not habitually use fire before 400 ka ago, whereas clear evidence for pyrotechnology exists in later Neandertal contexts. Conversely, based on the archaeological sequence of two French sites, Sandgathe et al. (2011) argue that although Western Neandertals did use fire, this was not an essential part of their adaptation. In fact, several Neandertal occupation layers do not show direct traces of fire or burned artifacts (Sandgathe et al., 2011). They propose, therefore, that northern latitude Western Neandertals could not start fires during cold glacial periods and used it only opportunistically by harvesting natural landscape fires (Dibble et al., 2018). In part due to these ongoing debates, fire use in Neanderthal is one of the best investigated instances of pyrotechnology (Allué et al., 2022). The available evidence shows that Neanderthal combustion features tend to be flat open structures, though an example of a basin-shaped feature has also been identified at the site of El Salt (Leierer et al., 2020) and instances of stacking of hearths and ash dumping have been identified in several Neanderthal settings (see Allué et al., 2022).

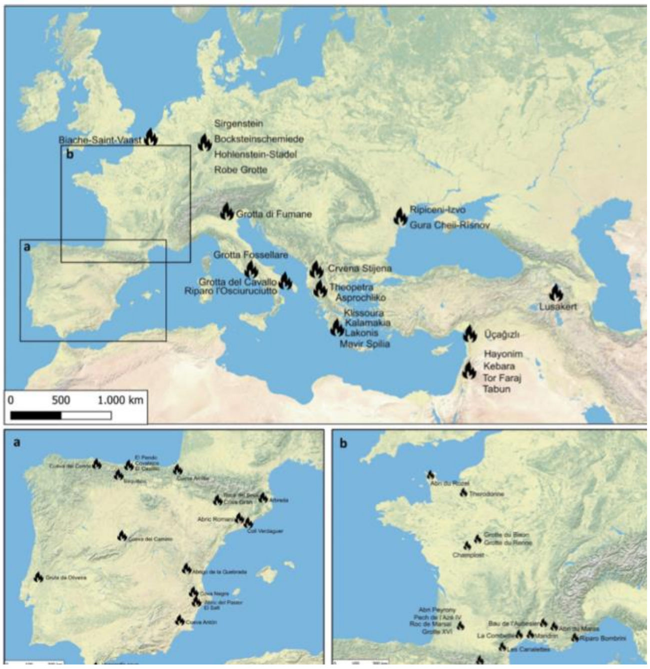


Figure 2: Map of combustion features and fire use associated with Neanderthal occupations (Allué et al., 2022).

Comparatively with Middle Pleistocene Neanderthal evidence, far less research has been devoted to pyrotechnology associated with Upper Paleolithic hominins. It is generally assumed that Upper Paleolithic communities were obligated fire users, but few studies have focused on the pyrotechnology associated with homo sapiens in Europe. A recent review by Murphree and Aldeias (2020) has pointed out that while researchers tend to mention the presence of ‘burned remains’ or ‘hearths’ in deposits of these ages, only a very small percentage of Upper Paleolithic fire remains have been studied in detail. The combined evidence currently available was classified based on the classification system proposed by Mallol et al. (2017), with results showing the emergence of temporal distinctions in the pyrotechnological construction of flat hearths, pit hearths, prepared surface hearths and fire installations (Figure 3). Typological variability on the types of hearths was identified in association with Gravettian occupations, whereas prepared surface hearths were identified in two geographical clusters – in Greece and in SW France – during Aurignacian occupations. Interestingly, records of fire features are low of absence in association with the Last Glacial Maximum, which may relate to taphonomic preservation issues, lack of reporting or an absence of use of fire during cold periods (Murphree et al., 2020).

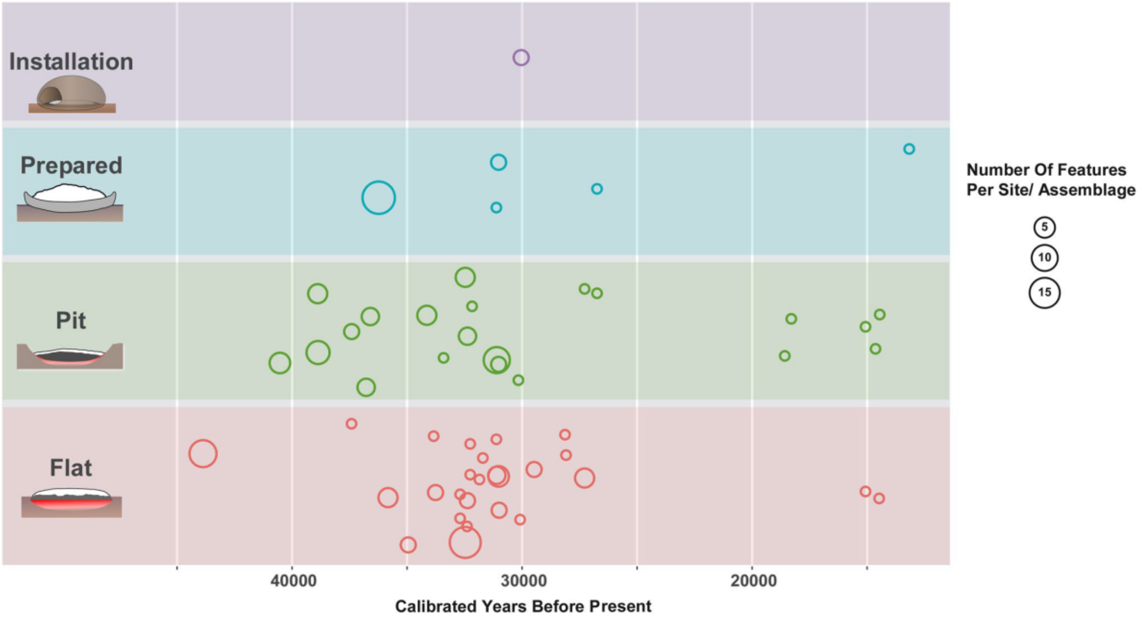


Figure 3: Synthesis of temporal distribution of different contained combustion features associated with Upper Paleolithic contexts in Europe - (Murphree et al., 2020).

Fire Under the Microscope

A set of archaeological thin sections will be analyzed under a petrographic microscope during the practical section of the lecture. Two main case-studies will be shown to students, namely combustion features from the Middle Paleolithic site of Roc de Marsal (France) and from the Middle Stone Age site of Contrebandiers cave (Morocco). These thin sections will provide hands-on experience in:

1. The identification of sedimentary components associated with combustion, namely wood ash, charcoal and burned bones
2. The identification of the microstratigraphy associated with *in situ*, intact combustion features
3. The identification of post-depositional processes that affected fire remnants, namely ash phosphatization and bioturbation
4. The identification of anthropogenic processes interpreted as site maintenance activities, such as ash dump and ash rake out.
5. The identification of naturally laid organic matter that is not related to fire evidence.

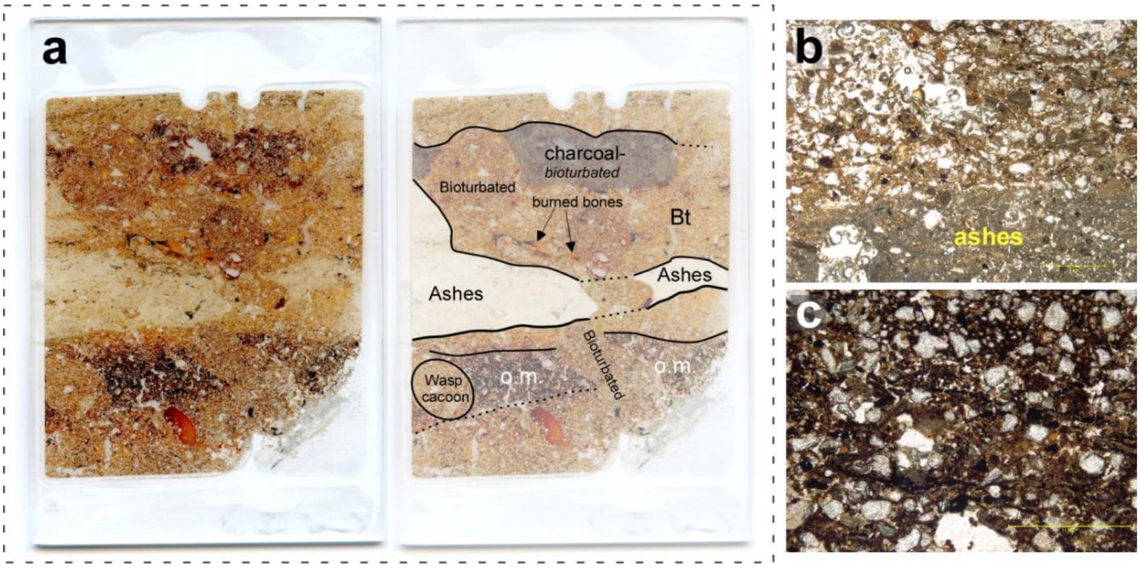


Figure 4: Thin section scan (left) and photomicrographs (right) of poorly preserved ash deposits at the site of Contrebandiers Cave (Morocco) that will be used for students to observe the impact of bioturbation and the presence of organic-rich deposits.

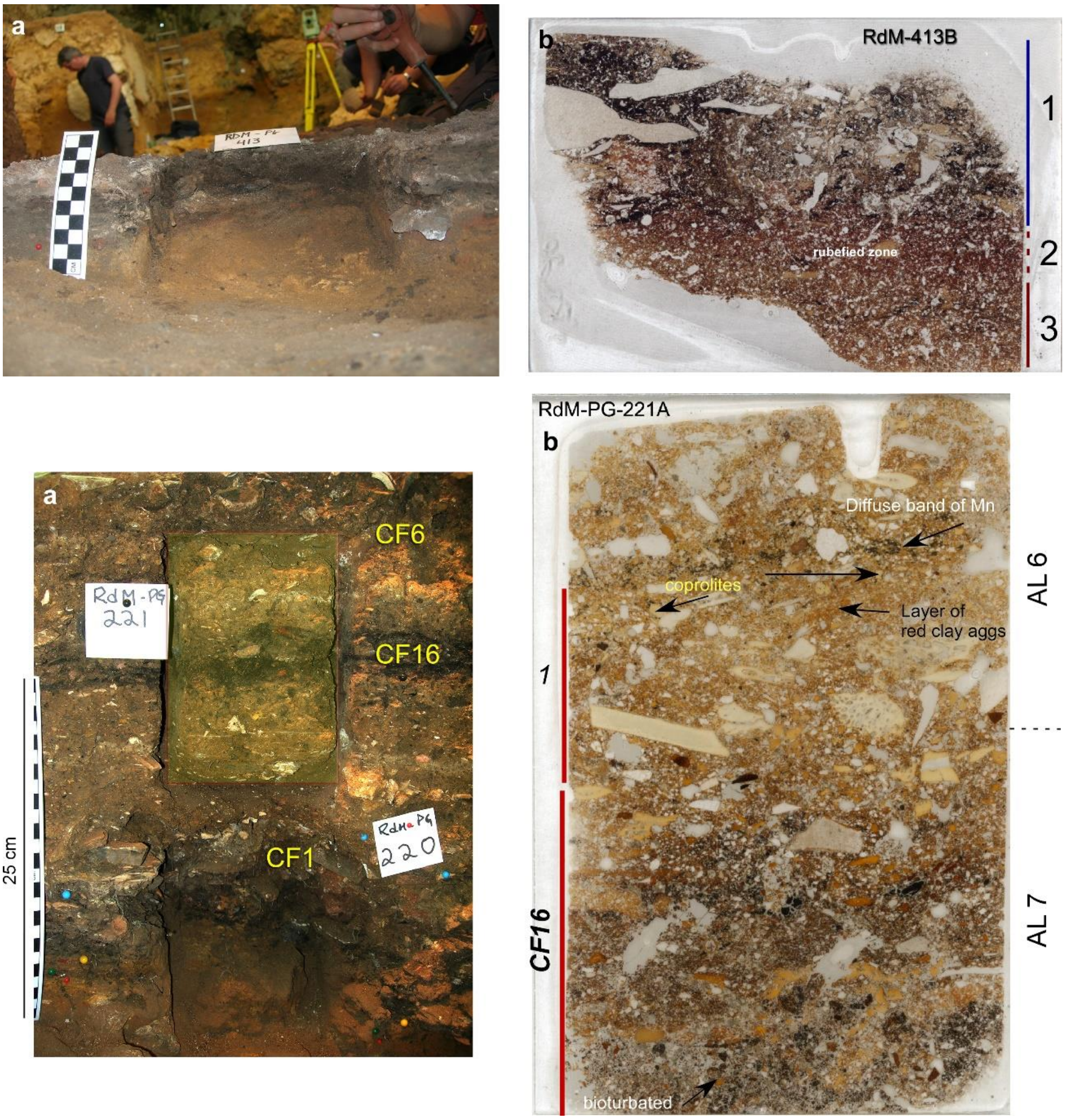
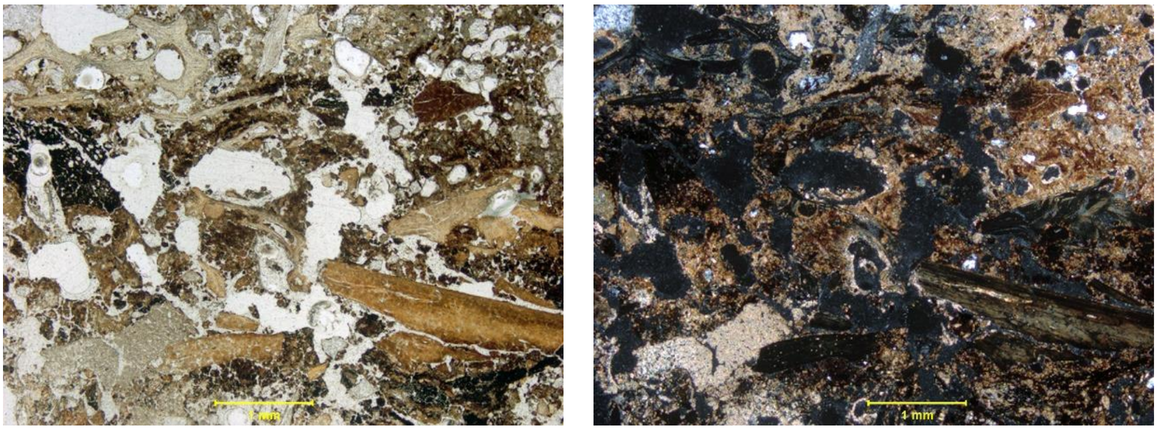


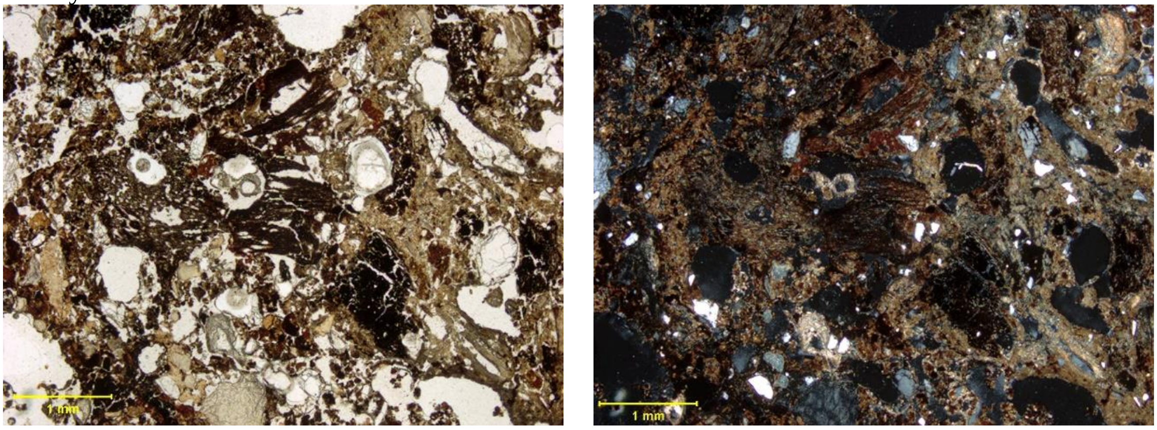
Figure 5: Field (left) and thin section scans (right) of combustion features at the Middle Paleolithic site of Roc de Marsal showing both intact and phosphatized ashes.

Figure 6: Examples of components associated with combustion residues that students will view under a petrographic microscope. PPL: plane polarized light, XPL: cross-polarized light.



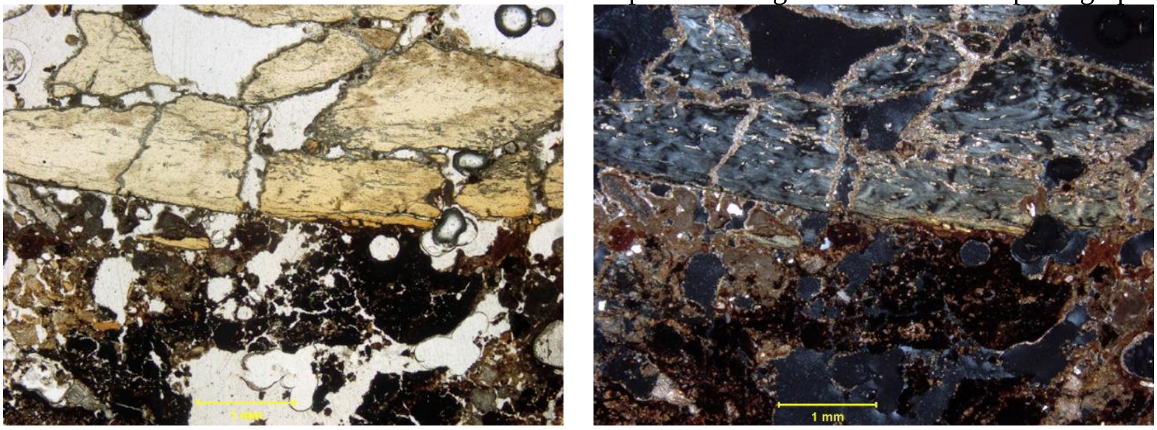
Photomicrograph showing a compacted mass of burned bone, charcoal, and ashes; the latter are locally recemented. PPL.

Same as at left but in XPL.



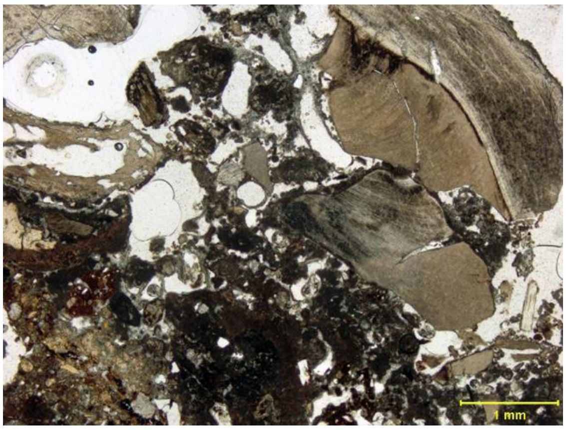
Photomicrograph showing the presence of black charcoal remains associated with ashes. PPL

Same as at left but in XPL. Note how the calcareous ashes, though concentrated at the right-hand part of the photograph, can be seen dispersed throughout the area of the photograph.

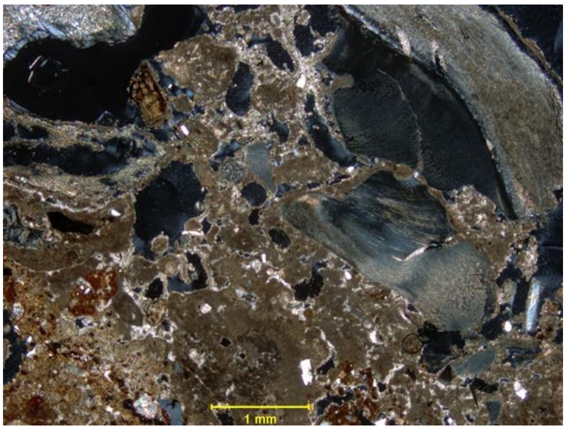


Photomicrograph of crushed calcined bone overlying ashes and organic matter. PPL

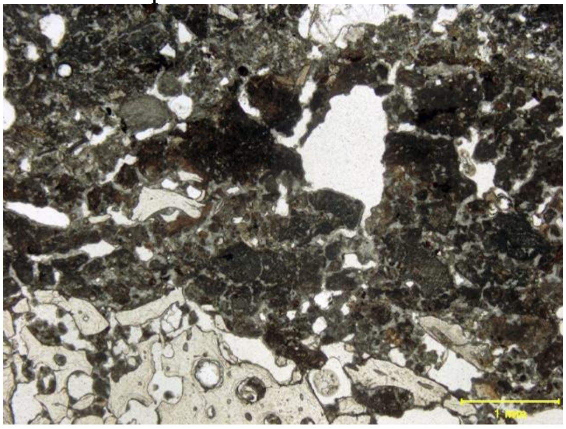
Same as at left but in XPL. Note the secondary calcite cementation in the fissures of the bone in the upper part of the photograph.



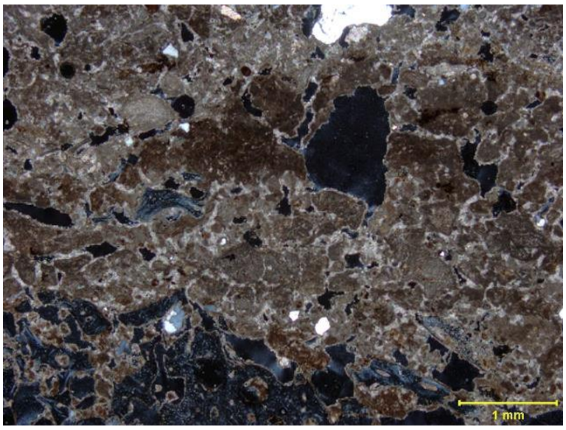
i) Burnt and calcined teeth [upper right] and bone, mixed with cemented ashes, particularly in the lower part. PPL.



This view of the photo at left in XPL shows more clearly the cemented nature of the calcareous ashes.



Rounded grains of cemented calcareous ashes at the top, and cm-size calcined bone at the base of the photo here. PPL.



The aggregated nature of the ashes is somewhat clearer in this XPL of the photo at the left.

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