On the Issues of
Timing Controlled and Habitual Fire Use

Testing the strengths of the short chronologies
with focus on Western Eurasia

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“For man is enabled through his mental
faculties to keep with an unchanged body in harmony with the changing
universe. He has great power of adapting his habits to new conditions
of life. He invents weapons, tools, and various stratagems to
procure food and to defend himself. When he migrates into a colder
climate he uses clothes, builds sheds, and makes fires; and by the aid
of fire cooks food otherwise indigestible”

- Alfred Russel Wallace 1864

1. Introduction

Decades of research on the role and frequency of fire utilization among prehistoric hominin groups have only yielded a blurred understanding of the chronology of anthropogenic fire practice. This predicament has by and large resulted from an ambiguous archaeological record, issues of preservation of fire residues, as well as undefined frameworks for the scientific study of anthropogenic fire. In fact, besides stirring scholarly debates that have in many ways produced more heat than light, very little actual progress has been made in the last decade with regards to the general understanding of when and where various fire practices have emerged. Instead, numerous chronologies have been developed, and different researchers read and interpret the same evidence of fire in a variety of ways. Stated more positively: it is a field that is in the midst of a transition, judging from the intensity and volume of the debate and the large number of papers that appeared on this very issue in the last decade. In the final stage of this thesis, Berna et al. (2012) published a paper on traces of (inferred) hominin fires more than one million years old from Wonderwerk cave in South Africa, again stirring a lot of controversy.

The goal of this master thesis research is to turn some of this heat into light by 1) providing a comparative analysis of the various chronologies, with a focus on testing the strengths and weaknesses of the shorter chronologies against the wider background of fire evidence, i.e. the long chronologies; 2) by examining major challenges hindering any considerable progress in establishing a sound and agreed upon chronological framework for fire use and its subsequent production during the Pleistocene Period; and 3) by providing practical solutions and suggestions on directions for future research.

The importance of studying fire practices in human evolution and sorting some of the muddle regarding fire chronology in human antiquity is manifold.
First and foremost, fire use in and of itself is a uniquely human adaptation that has been used as a yardstick to pinpoint the emergence of more advanced cognitive abilities and the development of culture *sensu lato,* requiring both co-operation and communication to be more routinely utilized (Gowlett 2010; Bickerton 2009; Klein 2009; Rolland 2004; Alperson-Afil and Goren-Inbar 2010). Second, fire utilization brought about numerous benefits during the Palaeolithic (see table 1), as well as in more recent times. Third, controlled or habitual use of

fire is widely seen as having facilitated a ‘release from proximity’ of ecological and geographical constraints, which has consequently led to a more widespread dispersal throughout the old world and has, in particular, played a key role in ‘stabilizing’ colonization of more temperate zones, especially above 50°C north where a continuous source of heat and light together with the benefits of cooking would have affected survival or extinction rates drastically (Gowlett 2010; Wrangham 2010).

Routine use of fire is also argued by some scientists to have played a significant role in the early phases of human evolution as a possible prime mover in the transition from sleeping in trees to building shelters on the ground, as fire would have served as an excellent protection against large terrestrial predators (see Wrangham 2009). Hence, routine use of fire is considered by some to have facilitated a life fully committed to the ground, which in time also led to the emergence of full bipedalism, and the rise of the genus *Homo* (see Wrangham 2009). Given the magnitude of claims on the importance of fire in human evolution and its contribution in shaping the success of the human niche, it cannot be stressed enough that it is paramount to understand when, where and how fire was acquired in human evolution, and how this behaviour transformed and evolved through time.

Examples of Benefits of Fire Use during the Palaeolithic
Warmth
Light
Cooking
Tool for hunting
Protection against predators
Insect repellent
Natural yield of vegetation
Landscape manipulation (e.g. clear vegetation)
Processing of organic material
Production of pigments
Heat treatment of stone

Table 1. Examples of benefits of fire use during the Palaeolithic (note: order of benefits not presented as an inferred chronological order).

2. Methodology

2.1. Research Theme

This master thesis research will examine in which manner the use of various proxies and criteria, such as positive and negative evidence of fire traces, have led to the emergence of various fire chronologies. Moreover, the differences in methods used for developing the various chronologies will be investigated, and the strengths and weaknesses of the individual chronologies will be assessed. In a critical evaluation of the evidence used in the short chronology by Roebroeks and Villa (2011), and the even shorter chronology by Sandgathe et al. (2011), will be tested against the wider background of evidence, i.e. the long chronologies proposed by researchers such as Gowlett (1981, 2010), Wrangham (1999, 2001, 2003, 2009, 2010), and Alperson-Afil and Goren-Inbar (2004, 2007, 2009, 2010). A primary focus will be placed on examining the strength of the core argument of the short chronologies (i.e. negative evidence) in the construction of patterns. The negative pattern of anthropogenic fire in the colonization of Europe will be challenged by a single positive observation point of fire at the gates of the European peninsula at the onset of the Middle Pleistocene Period. In this context, the strength of the positive signal of fire and the controlled and habitual use of fire hypothesis at this one location will be examined in minute detail, and its strength tested against the negative pattern of the short chronologies.

2.2. Research Focus (period, area)

The chronological and geographical focus of this thesis was placed upon the Middle Pleistocene Western Eurasian archaeological record of fire use. The main reason for zooming in on Western Eurasia as opposed to the East was primarily due the character of the Western record, which has a deeper chronological research history that has yielded a more dense distribution of archaeological sites in time and space. This, in turn, has resulted in more and better publication reports that are not only more accessible, but also easier to read as the majority has been published in English (as opposed to Chinese for the Eastern record). Western Eurasia was also opted for due to the commonly held assumptions by the advocates of 'the long chronology' (see Wrangham and Gowlett in long chronology overview below) that controlled/habitual use of fire was a prerequisite technology/behaviour for colonisation of temperate latitudes during the

Pleistocene, as these would have constituted challenging environments with reduced daylight, unfamiliar ecology (e.g. exotic and poisonous plant foods) and constant climatic fluctuations. In this context, it is widely held that controlled use of fire functioned as a sort of a climatic 'stabilizer' facilitating permanent habitation in Western Eurasia during the Middle Pleistocene.

2.3. Research Objectives

The overall objective of this study was to provide a critical evaluation of the various chronologies by testing the strength of the underlying assumptions of controlled and habitual fire use during the Palaeolithic, including assumptions on the interpretation of fire proxies and the strength of negative evidence in the construction of patterns. The second goal of the thesis was to provide a new line of research by instigating a more practical technological fieldwork approach to sort uncertainties involved in the evaluation of negative evidence in the archaeological record. The third objective was to provide an avenue for future work by developing solid, clearly defined criteria for each type of fire practice (i.e. sporadic, controlled, habitual), and encourage the development of a clear and systematic framework for the study of fire proxies, with a focus on separating natural fire proxies from anthropogenic.

2.4. Research Method

The methods applied for this research comprised desk research of primary and secondary up to date sources within the Palaeolithic fire domain, and personal communication with key figures within the debate of prehistoric fire, both in person and via email correspondence. The choice of conducting a literature search for this study mainly stemmed from the method's ability to gather vast bodies of data by fairly quick and inexpensive means. The use of personal communication with scholars allowed for the occasional clarification of what was unclear from studying the literature only, provided me with a good overview of some of the issues within the Palaeolithic fire domain, and aided in determining what particular problems in developing fire chronologies deserved attention. The study was based primarily on a systematic review and evaluation of the evidence used in the various chronologies of controlled and habitual fire use. While the short chronologies were reviewed and evaluated thoroughly, the long chronologies were only briefly discussed apart from a critical review and analysis of the evidence from Gesher Benot Ya'aqov, Israel.

2.5. Limitations and challenges

One of the major challenges in the production of this thesis was the complexity of the subject itself with all the uncertainties involved in the study of fire in human antiquity, especially in dealing with negative evidence. It was also a great challenge to maintain a focused approach to a vast subject covering large time spans, great geographical distances, ecological differences, various settings and perhaps also numerous hominin taxa. The initial strategy was to include a detailed study of the long chronology: it is widely held by influential scientists that fire has been an integral part of hominin behaviour for almost two million years, and that habitual usage played a significant part in the colonization of temperate latitudes (see Wrangham and Gowlett in long chronology below). However, this would have taken too much time, and the thesis itself would have been at risk of potentially becoming too unfocused. Therefore, only a short summary of the long chronology and the arguments supporting it were provided to give some context to the debate on the chronology of controlled/habitual fire use. Focus was instead placed on testing the strength of the models (i.e. chronologies) that challenge the long chronologies of habitual fire use.

3. Long Chronologies (a short overview)

3.1. Introduction

Human fire utilization is commonly believed to have a deep chronology, reaching far back into the antiquity of human evolution, from early supporters in Charles Darwin and Alfred Russel Wallace to more contemporary scientists of the modern era. Numerous scientists believe that fire was first used, tamed and later controlled by hominins on the African continent sometime during the early Pleistocene. It is also commonly believed that *Homo ergaster/erectus* was able to manipulate and control fire on a regular basis and use it for cooking already by 1.9 Ma (see Wrangham 2009, 2010; Gowlett 1981, 2010). However, archaeological evidence for such claims are scant and ambiguous, which in turn has led several authors to cast doubts over such arguments. Roebroeks and Villa (2011) and Sandgathe et al. (2011) have, for instance, challenged such claims by suggesting substantially shorter chronologies for controlled and habitual fire utilization.

Nevertheless, Harvard University biologist and primatologist Richard Wrangham and Liverpool University Professor of Archaeology John Gowlett, two of the most prominent advocates of the ‘long chronology’ of anthropogenic fire utilization argue that fire manipulation was more than just a techno-cultural innovation, namely a significant driving force in human evolution (Wrangham 2009, 2010; Gowlett 2010). While both these researchers supports ideas of routine fire use far back into antiquity, they support their arguments by using different types of evidence.

3.2. Richard Wrangham’s hypothesis

Richard Wrangham bases his arguments of a ‘long chronology’ of hominin fire manipulation on non-archaeological grounds. Instead he uses morphological and biological evidence to substantiate his claims. Wrangham (2009, 2010) argues that the sudden appearance of the extreme morphological characteristics seen in *Homo erectus/ergaster* (i.e. large body proportions, large brain, small gut, reduced molar size and masticatory apparatus) in comparison to earlier and contemporary hominin species (e.g. *Homo habilis, Homo rudolfensis*) at approximately 1.9 Ma in East Africa had been the outcome of a significant change in diet. He further claims this change in diet to be the result of hominins' manipulation with fire where 'cooking' or processing of meat, plant foods and underground tubers on a routine basis would have yielded nutritional and metabolical advantages that in turn would have resulted in an increased energy surplus, thus an allocation of energy distribution from the gut (which then would have been the most energy costly organ) to the brain creating a trade off process, i.e. 'the expensive tissue hypothesis' (Wrangham 2009, 2010). According to Wrangham (2009, 2010), early hominin curiosity and interest towards manipulating fire must have been facilitated by consumption of naturally burned carcasses on the open savannah in Africa, which, if implemented routinely, would have spurred an automatic biological selection process (or craving) for fire processed food. Wrangham (2009, 2010) substantiate claims of an automatic selection for processed food (meat in particular) by his own research on contemporary great apes from the Wolfgang Koehler Research Centre, which when introduced to processed/cooked food, demonstrated a preference towards such foods over raw food (see Wobber et al. 2008; Wrangham 2009, 2010). According to Wrangham (2009, 2010), early hominin contact and active fire utilization would most probably have occurred by collecting burning or smouldering logs from natural conflagrations on which pieces of meat and/or non-lean meat sources (i.e. plant foods) would have been placed and 'cooked'. In his view, hominin groups within Africa would have 'cooked' their food on a routine basis for more than 2 mya (Wrangham 2009, 2010).

3.3. John Gowlett's hypothesis

Next, John Gowlett, who broadly agrees with Wrangham's view on cooking as 'the biological driving force' towards early hominins taming and manipulation of fire, uses archaeological evidence to support claims of a 'long chronology'. Gowlett primarily extrapolates evidence form three sites in Africa that to him provide demonstrable evidence of anthropogenic fire rather than natural combustions. Gowlett (1981, 2010) argues that credible evidence of hominin controlled use of fire by at least 1.5 Ma can be found at the lower Palaeolithic East African sites of Chesowanja and Koobi Fora FxJj 20, FxJj50, both situated in Kenya, as well as the South African location of Swartkrans. The evidence of fire at these localities primarily consist of restricted areas of 'baked' or 'discolored' sediments of various diameters ranging from 5 to 40 cm in diameter, thermal alteration of lithics and charred bone (Clark and Harris 1985; Barbetti 1986; Isaac 1984; Brain and Sillen 1988; Brain 1993). Even though Gowlett (2010) acknowledges the possibilities of natural fires heating the material at these locations, he declares the archaeological circumstances of both *in situ* evidence of hominin occupation at Chesowanja and charred bones in the closed cave setting of Swartkrans to be more conducive to hominins being the agents of the burning than natural conflagrations. In Gowlett's (2010) view, it is wrong to associate hominin control of fire solely with 'hearth features', which is only demonstrated much later in the archaeological record, as hominin fire practice would have been used in a variety of ways, not always leaving archaeological signals at habitation localities. According to Gowlett (2010), it seems implausible to envisage the emergence of encephalization, diet change, colonization of more temperate zones, and cultural capacities such as highly selective transport and management of raw material for stone tools, which in Gowlett's view are indicative of social collaboration and investment of effort for return mindset, already during the early Pleistocene *without* control and habitual use of fire.

In support of Gowlett's view of a 'long chronology' of controlled fire use are two other groups of archaeologists. Bob Brain (1988,1993), the original excavator of Swartkrans - what many have considered as perhaps the earliest and (up until recently) also the most credible evidence for hominins using fire in the Africa during the Early Pleistocene -claim together with Andrew Sillen in their (1988) report the 270 charred bones recovered from the cave to be the earliest direct evidence of hominins using fire in the archaeological record. Brain and Sillen (1988) argue the enclosed setting of Swartkrans, the intense burning of the bones (several heated to campfire temperatures of 300–500 °C and above), and the presence of cut-mark inflicted bones in the same stratum (member 3) as the charred ones, to represent unambiguous evidence of anthropogenic manipulation of fire. The authors have attributed the fires at Swartkrans to either *Australopithecus robustus* or *Homo erectus,* both of which skeletal remains were recovered from the site (Brain and Sillen 1988: 464, 466). Brain (1993) claims the evidence from Swartkrans to favour Gowlett and Wrangham's hypothesis that fire was controlled and used on a routine basis by *Homo erectus* during the Early Pleistocene.

Not far away from Swartkrans at Wonderwerk cave, also in South Africa, Berna et al. very recently (in February 2012) published an article on the discovery of microstratigraphic evidence of *in situ* fires in Palaeolithic deposits one million years old (Berna et al*.* 2012 in press). By means of thin sections from a one-meter section containing archaeology (low densities of bifacial tools and flakes) some 30-meters into the cave of Wonderwerk, Berna et al. (2012 in press) were able to retrieve evidence of fires in the form of a variety of accumulated microscopic charred organic material such as various plant remains and bone fragments. The authors claim the charred remains at Wonderwerk to be *in situ* on the basis of the angularity of the charred bones and the pristine preservation of the ashed plant remains. Hence, they have excluded the possibilities of wind and water transport causing the accumulation of the charred remains inside the cave (Berna et al*.* 2012 in press). Berna et al*.* (2012) argues the microscopic evidence of fire from Wonderwerk cave to be the most compelling evidence to date in favour of Wrangham's cooking hypothesis and a 'long chronology' of hominin fire manipulation.

3.4. A short comment on the long chronology

This being said, the long chronology of controlled/habitual fire use is built on scant and ambiguous archaeological evidence, predominantly from open-air localities (e.g. Chesowanja and FxJj 20E, FXJj 50) at which natural combustions could have easily produced heating of sediments and/or of artifacts and faunal remains. In the case of the charred bones recovered from the enclosed setting (i.e*.* cave site) of Swartkrans, these are *not* primary context as they have been recovered from a gully infill (see Brain and Sillen 1988; Brain 1993) and thus have been reworked into the cave. There are also question marks with regards to the *origin* of the fires at Wonderwerk cave, where the sediments from Berna et al. (2012 in press) thin sections demonstrate an absence of being heated despite having concentrated charred microscopic remains. This suggests the charred material originated elsewhere than on the accumulated spot described in the Berna et al. (2012 in press) report. Hence, one cannot completely write off the possibilities of natural conflagrations producing the charred material outside of the cave, which later became transported into the cave by water or wind.

And although it is not unlikely that hominins *did* utilize fire occasionally during the Early Pleistocene, there is no archaeological evidence from Africa during this time period indicating conclusive evidence for controlled and habitual fire use. As for Wrangham's cooking hypothesis of long integrated fire use in human antiquity fuelling morphological differences seen with the emergence of *Homo erectus/ergaster,* it is a perfectly reasonable explanation, but how can this be proven and/or falsified? The expensive tissue hypothesis coined by Aeillo and Wheeler (1995) pointed out the consequences of the diet shift, which led to large amounts of "meat" in the hominin diet – without fire! Hence, following their argument, there is no need for processed or 'cooked' food to explain a tradeoff between gut and brain size. Alternatively, the increase in brain size demonstrated in *Homo ergaster/erectus* could potentially be explained by an increasing reliance on freshwater and marine food resources that are known to contain fatty acids, thus favorable brain selective nutrients, as opposed to 'cooked food' (see Cunnane and Stewart 2010). Besides, as demonstrated by Navarrete et al. (2011), there is no need to shrink guts to have a larger brain since the evolution of brain size in mammals including the human linage depends more on redirection of resources from growth (adipose fat storage), locomotion and reproduction.

In addition to this, archaeological evidence in support of Wrangham's hypothesis is lacking, as well: all of John Gowlett's sites are dated to much later in time (approximately 1.5 Ma), and display hiatuses of hundreds of thousands of years when compared to the earliest known first appearance date of *Homo ergaster/erectus* at 1.9 Ma (see Klein 2009). Apart from the fact that no hominin fossils have been recovered in direct association with the fire proxies of any of the sites mentioned by Gowlett (1981, 2010), the fossils that have been recovered have been attributed to *Australopithecus boisei* (KNM-CH 304 at Chesowanja and KNM-ER 3220 at FxJj 20E), apart from Swartkrans where both *Australopithecus robustus* and *Homo erectus* remains were recovered. However, these remains have been recovered from strata underlying the charred bones (see Brain and Sillen 1988). In the hominin bearing strata at Swartkrans, there is no evidence of fire at all (Brain and Sillen 1988). Even though Brain and Sillen (1988: 464) have suggested that the discovery of fire at Swartkrans took place in the interval between the hominin bearing strata and the overlying charred bones stratum, the charred bones are, as previously mentioned, in a secondary context (gully infill). Hence, we do not know with certainty the origins of the burning of the bones at Swartkrans, which in turn makes such a hypothesis speculative only. Finally, as discussed by James (1989), archaeological evidence supporting a ‘long chronology’ of hominin fire use is tenuous and very ambiguous, and even with the recent addition of fire evidence from Wonderwerk cave in South Africa one million years ago, James' (1989) view of an absence or negative evidence of controlled and habitual fire use for the Early Pleistocene has not changed.

4. A short chronology of habitual fire use

4.1. Introduction

As discussed in the previous chapter, the scarcity and ambiguity of the archaeological evidence for hominin fire utilization in Early Pleistocene Africa have led to disagreements among archaeologists as to when fire became an integral part of the hominin techno-cultural repertoire. While many scholars agree that fire did play a significant role in the dispersal of hominins into more temperate zones and new ecological habitats, others express more scepticism. Roebroeks and Villa (2011) examined the archaeological evidence for habitual fire use in Europe and concluded that there is an absence of such behaviour prior to the second half of the Middle Pleistocene (400-300 ka) despite evidence of several long-term hominin habitation localities (i.e. long archaeological sequences) from the Early Pleistocene an onwards in both interglacial and glacial periods with good archaeology (i.e. large quantities of well defined artefacts and faunal remains) and hominin remains.

The negative signal of fire use from Europe prior to 400 ka, coupled with the extreme scarcity and ambiguity of fire use in Africa and Asia during the Early Pleistocene and Early Middle Pleistocene, have led Roebroeks and Villa (2011) to opt for a shorter chronology of controlled and habitual fire use. But how strong are these claims and the evidence used in the short chronology?

4.2. Methodology and Dataset

Roebroeks and Villa (2011) reported on six caves, one rock shelter and twelve open-air sites *without* evidence of fire from the European Lower Palaeolithic record, and 125 sites of various settings *with* evidence of fire, of which 27 were reviewed in text, from the second half of the Middle Pleistocene and onwards. Numerous sites with comparable chronologies were omitted due to ambiguity, poor documentation and unpublished material. The authors also excluded several sites from analysis where information on charred bone or charcoal and/or ash lenses was negligible or merely provided in excavation reports with restricted circulation, in theses, and in local journals not easily accessible (Roebroeks and Villa 2011: 5212). The German Early Pleistocene was illustrated as a record hampered by insufficient reporting/restricted circulation and inaccessibility. As a result, the authors choose to omit several rich Middle

Palaeolithic caves with claims by the original excavators on numerous traces of fire such as inferred fireplaces, charcoal and burnt bones (Roebroeks and Villa 2011: 5212).

4.3. Results

4.3.1. Negative evidence of fire use from the early Pleistocene and first half of Middle Pleistocene Europe

Roebroeks and Villa (2011) included in their review a detailed discussion of three long Lower Palaeolithic cave sequences and one rock shelter from southern Europe lacking evidence of fire use despite displaying rich and well-preserved evidence of human occupation in both cold and temperate conditions. Two of those caves are from Atapuerca, Burgos in northern Spain. Here, the earliest presence of humans in Europe thus far has been demonstrated at the cave of Sima del Elefante where evidence of a mandible, tibia and phalanx assigned to *Homo antecessor* in layer TE9 have been dated to approximately 1.2 Ma (Carbonell et al. 2008, see fig 1). This cave site has failed to yield any sufficient evidence of hominins using fire despite displaying a 21-meter thick and 15-meter wide sedimentary sequence (to date) with evidence of human occupation at different levels and an abundance of faunal remains (see Rosas et al. 2006; Carbonell et al. 2008 for further discussion). According to Roebroeks and Villa (2011), the only traces of fire residues that have been reported by the original excavators are small amounts of charcoal *e.g. Pinus silvestris/nigra* in layer TE 19*, Angiosperma* in layer TE 11, and *Acer* sp. and *Quercus* sp from layer TE 9, all of which having been attributed to natural fires (Rosas et al. 2006: 338, 339, 342, see fig 1).

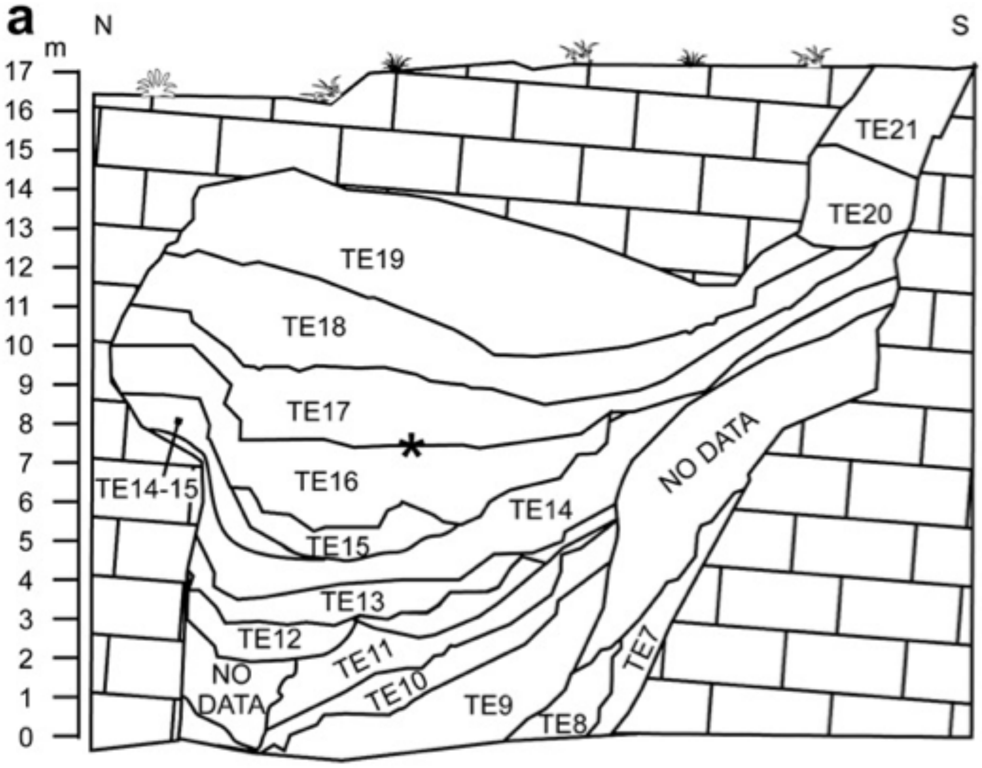


Figure 1. Topographic profile of the Sima del Elefante stratigraphical sequence. The asterisk marks the position of the Matuyama-Brunhes boundary (780ka). Heights are measured from the railway trench floor. Minute charcoal remains in layers TE9, TE11 and TE19. *Homo antecessor* remains recovered from layer TE9 dated to 1.2 Ma. Current status of excavation - 4 meters beneath the railway trench floor and ongoing (from Rodriguez et al. 2011).

Similarly, Roebroeks and Villa (2011) report on an absence of traces of hominin fire use at the cave site of Gran Dolina also at Atapuerca. This site has a 16-meter deep stratigraphic sequence with eleven levels spanning late Early Pleistocene (levels TD1-TD7: 1 mya–780 ka) to (late) Middle Pleistocene (levels TD8-TD11: 780–120 ka), with an abundance of tools, hominin and animal bones at various frequencies throughout the sequence (Falguères et al. 1999, see fig 2). Level TD6 in particular (dated to approximately 800 ka) has not only yielded the richest accumulation of hominin remains within the sequence of Gran Dolina, but also displays the earliest direct evidence of hominin long-term occupation in Europe, spanning some 200 ka of habitation (Falguères et al. 1999). Here, 85 fragmented human remains from different parts of the skeleton from six individuals of *Homo antecessor* have been recovered in association with Mode 1 stone tools and debris from tool manufacturing, as well as cutmarked mammal bone fragments, including hominin ones (Falguères et al. 1999). The excellent preservation, high frequencies of human, faunal and lithic assemblages, and refitting studies have indicated *in situ* archaeology in TD6 with little to no post depositional disturbance (Fernández- Javlo et al. 1999; Diez et al. 1999). In spite of this, no evidence has been recovered of hominins using fire at Gran Dolina. Vallverdu' et al. (2001) report that the only traces of fire that have been recovered from Gran Dolina are in the form of small pieces of charcoal from level TD6 that are not in a primary context (i.e. sediments originate from outside the cave), and which display evidence of low-energy transport.

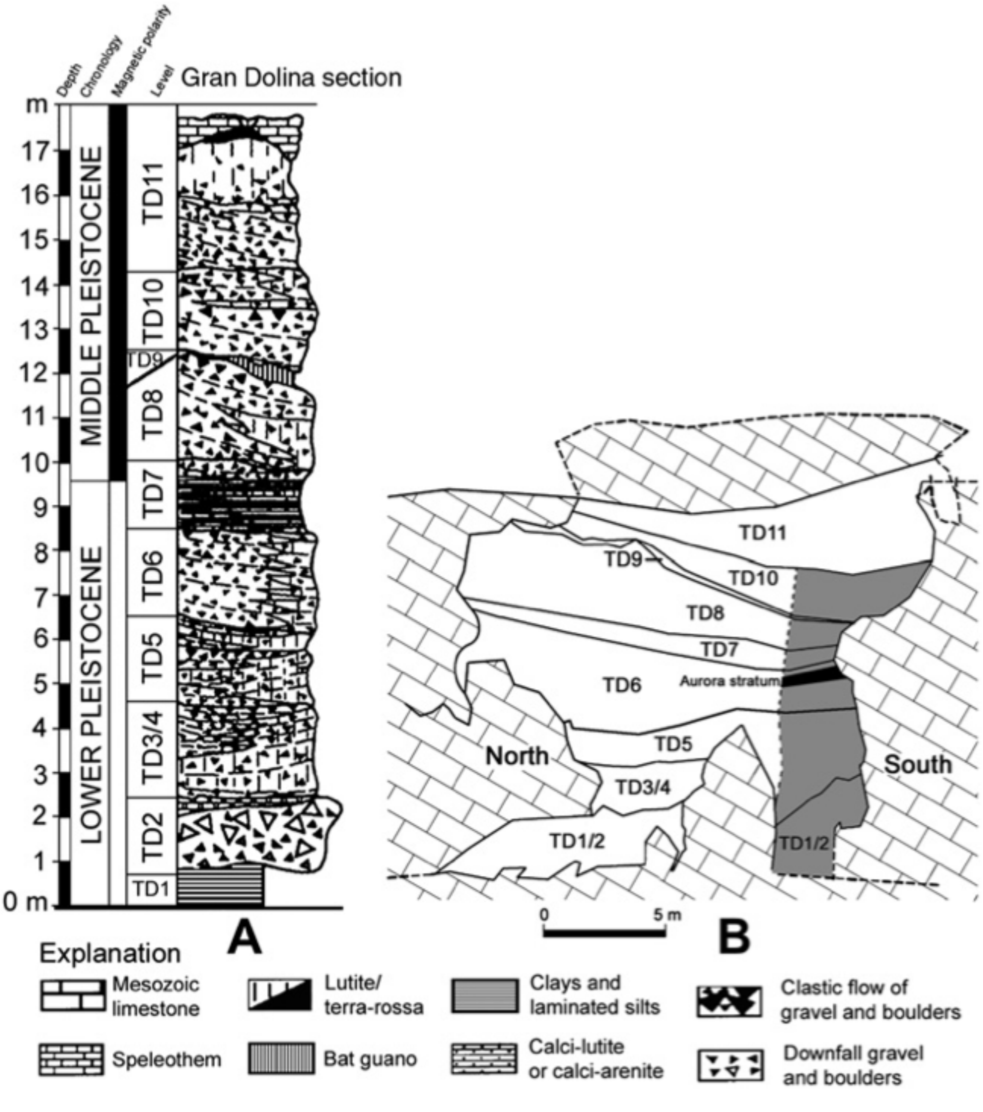


Figure 2. (A) Synthetic stratigraphical sequence of Gran Dolina (Parés and Pérez-Gonzalez 1995 cited in Cuenca-Bescós et al. 2011). (B) Topographical sequence of the infill at Gran Dolina. The black shaded area in level TD 6 (right figure) indicates the Aurora stratum and the location of the recovered human remains, i.e. *Homo antecessor* (Huquet Pámies 2007 cited in Cuenca-Bescós et al. 2011).

Furthermore, two other European Lower Palaeolithic sites with long stratigraphic sequences also lack evidence of hominins using fire according to Roebroeks and Villa's (2011: 5210): the cave site Caune de l'Arago in southern France (dated to 690-325 ka), and rock shelter Visogliano in northeastern Italy (dated to 600-350 ka). At Caune de l'Arago, the original excavators have reported on an absence of fire indications prior to 350 ka, despite a long habitation sequence spanning across hundreds of thousands of years, with human fossils (mandible, teeth assigned to *Homo heidelbergensis*), lithics and faunal remains (de Lumley 2006; de Lumley et al. 1977; 1984, see fig 3).

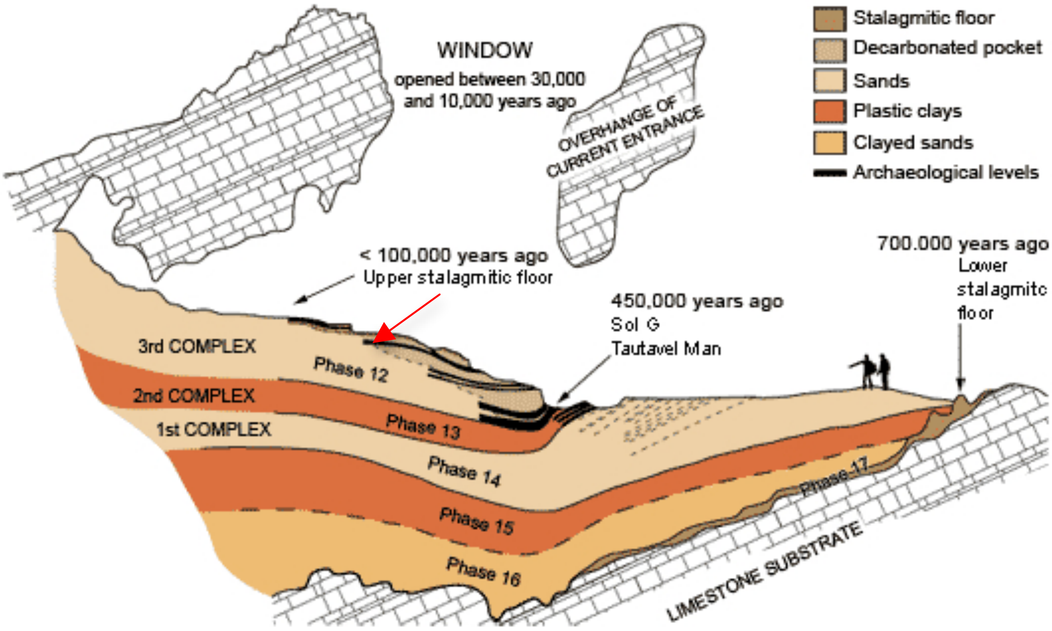


Figure 3. Synthetic stratigraphical sequence of Caune de l'Arago (from Ministère de la culture et de la communication n.d.). Red arrow indicates the earliest evidence of fire in the sequence at 350 ka.

Similarly at rock shelter Visogliano in northern Italy, the original excavators Abbazzi et al. (2000, cited in Roebroeks and Villa 2011: 5210) claim fire traces to be absent despite a long sequence (some 250 kyr) with direct evidence of human presence (i.e. teeth tentatively assigned to *Homo erectus,* see Abbazzi et al. 2000 for further discussion), as well as an abundance of artefacts and rich faunal elements.

Moreover, Roebroeks and Villa (2011) report on two additional Lower Palaeolithic cave sites from Eastern Europe with an absence of fire residues despite displaying evidence of hominin presence in Treugol'naya, Russia, and Kozarnika, Bulgaria. While Treugol'naya has yielded only a small number of lithics and faunal remains that appear to have been accumulated either naturally and/or by carnivores (see Doronichev 2008), the lowest and oldest levels of Kozarnika have displayed a large number of artefacts (Sirakov et al. 2010, cited in Roebroeks and Villa 2011: 5210). However, the oldest and lowest levels at both sites exhibit a complex hominin and faunal habitation history with evidence of stream transport of both lithics and bone at Treugol'naya, and only limited information on contextual and taphonomic data from the artefact bearing layers at Kozarnika (Hoffecker et al. 2003, cited in Roebroeks and Villa 2011).

Roebroeks and Villa (2011: 5210) argue that although both eastern European caves have yielded proxies of human presence and negative evidence of fire utilization, they lack the long habitation sequences and hominin remains seen at the sampled southern European caves - Gran Dolina, Caune de l'Arago and Visogliano. Similarly, contemporary evidence at Sima del Elefante, Atapuerca provides insufficient information on the frequency and duration of hominin habitation history (see Rosas et al. 2006). Roebroeks and Villa (2011) further claim that the deficiency of fire traces associated with human activity at these Lower Palaeolithic cave sites shows a surprising but *strong* negative pattern of fire use given the excellent preservation, rich archaeology and long hominin habitation at many of these sites. It is especially surprising to them that Gran Dolina and Caune de l'Arago lack any evidence of hominins using fire despite being reminiscent of much later Middle Palaeolithic cave sites in central Europe with sufficient archaeological evidences of fire such as Bolomor Cave in Spain, Bau de l' Aubesier Grotte XVI and Lazaret in France, as well as other

Middle Pleistocene caves in South Africa and Israel (Roebroeks and Villa 2011: 5210).

Subsequently, Roebroeks and Villa (2011) also mention five late Early Pleistocene/ Early Middle Pleistocene open-air sites *without* fire in their review. These five open-air sites are Orce in southern Spain, Isernia and Venosa Notachirico in Italy, and Happisburgh and Boxgrove in the United Kingdom. Roebroeks and Villa (2011: 5210) found that although these sites exhibit evidence of hominin presence (e.g. lithics and butchered faunal remains) and are contemporary in time to the sampled cave sites, they do express more uncertainty with regards to the validity of their negative signal of fire use. They deduce that since these sites are open-air localities, there is always a chance of traces of fire (e.g. charcoal and ashes) potentially having been destroyed, erased and/or relocated by water or wind transport. In a similar way, the authors argue these open-air localities to possibly contain the (accumulated) remains of very brief hominin visitations only (Roebroeks and Villa 2011: 5210). That being said, Roebroeks and Villa (2011: 5210) posit that the absence of fire traces cannot be completely warranted by the sites open-air setting, since later open-air sites with comparable settings (e.g. Maastricht-Belvédère, Netherlands and Neumark-Nord 2, Germany) exhibit evidence of hominins using fire. They conclude that if the negative signal of fire at these open-air sites is indeed genuine, then hominin presence above 55 degrees north in the UK at Happisburgh and Boxgrove seems to have occurred *without fire* - with the exception of a few scattered particles of charcoal at Boxgrove (Roebroeks and Villa 2011: 5210). Roebroeks (2012 personal comm.) argues that “If fire was indeed being used at these localities it could have been preserved, but given the ‘extraction’ character of these sites (i.e. raw material procurement and butchery activities), they may reflect short term activity locations only where resources were extracted from the environment and where fire was not a necessity to utilize.”

In sum, the absence of evidence of fire at these eleven Lower Palaeolithic observation points of human presence in various settings and climatic conditions has led Roebroeks and Villa (2011) to conclude that fire was not a requisite for early dispersals and colonisations of Europe.

4.3.2. Positive evidence of fire use from the second half of Middle Pleistocene Europe

In Roebroeks' and Villa's (2011: 5210) view, the earliest evidence of fire with credible anthropogenic affinities and subsequent habitual fire use does not become archaeologically visible until the second half of the Middle Pleistocene, starting from MIS 11-9 with open-air sites such as Beeches Pit in the UK, and Schöningen in Germany, at approximately 400 ka. While Beeches Pit has yielded heated sediments (interpreted as remnants of hearth lenses by the original excavators, see Gowlett et al. 2005), Schöningen yielded some heated flints (mostly natural pieces) and charred wood (Roebroeks and Villa 2011: 5210). The authors also mention two other open-localities from MIS 11-9 in their review providing credible evidence of fire associated with hominin activity in Terra Amata, France (charcoal and a flat lens hearth), and Vérteszöllös, Hungary (small fragments of charred bones) (Roebroeks and Villa 2011: 5210). However, these sites have only been tentatively dated (Roebroeks and Villa 2011: 5210). Roebroeks and Villa (2011) argue that fire proxies such as charred bones, heated lithics and heated sediments become more frequently represented from MIS 11-9 onwards, and state that from MIS 9 onwards there are widespread traces of fire in both open as well as in cave settings indicating more *routine* use of fire.

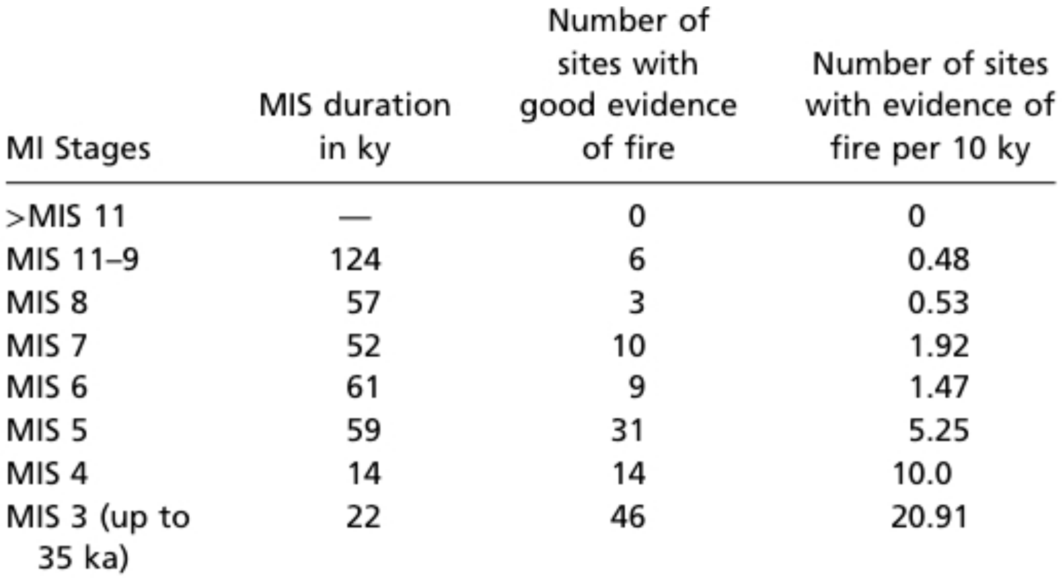
The authors, for instance, report on repetitive evidence of fire use in both cold and temperate conditions from MIS 7-4 at La Cotte de Brelade, Jersey (Roebroeks and Villa: 5210). Here, the original excavators Callow et al. (1986) have described evidence of burning in all levels spanning across three MIS stages (MIS 7-4). The fire evidence comprises multiple high-density accumulations of burned material, mostly charred bone, but wooden charcoal fragments have also been reported (Callow et al. 1986). Callow et al. (1986) have interpreted these dense accumulations of charred bone and wood as fuel used by Neandertals to sustain fires at La Cotte de Brelade.

In addition, Roebroeks and Villa (2011) argue spatial concentrations of heated flints and charred faunal remains to be commonplace occurrences at many Middle Palaeolithic open-air sites across Europe. They also use the earliest discovery of hafted tools thus far (i.e. flint flakes still covered in birch-tar adhesive) from Campitello Quarry in Italy, to illustrate the presence of extensive knowledge and advanced fire practices by the end of the Middle Pleistocene –

perhaps by the beginning of MIS 6 (Roebroeks and Villa 2011: 5210; see Mazza et al. 2006: 8 for further details). Subsequently, Roebroeks and Villa (2011) report that several Middle Palaeolithic sites – both cave and open air sites – display numerous succeeding levels covering long time spans with clear evidence of fire. Roebroeks and Villa (2011: 5210) mention two sites – Abric Romani, Spain, and Ksiecia Jozefa, Poland – exhibiting multiple combustion structures (187 and 29 respectively) throughout their stratigraphic sequences.

The authors also report on other 'clear' evidence of fire below 50 degrees north in France, Italy and Spain where hearth related activities and traces of fire in multiple levels have been recovered from both open and closed settings (although mostly from closed settings) at La Folie (France), El Salt (Spain), St. Marcel (France), Esquilleu Cave (Spain), Peyrards (France), La Combette (France), La Quina (France), St. Césaire (France), Oscurusciuto (Italy) (Roebroeks and Villa 2011: 5210). They point out that while stone-lined or stone-delimited fireplaces do not occur in the Middle Palaeolithic as commonly as during later parts of the Upper Palaeolithic, they are nonetheless present (Roebroeks and Villa 2011: 5210). The authors further mention nine Middle Palaeolithic sites of mixed characteristics (i.e. open-air, cave sites) with such evidence in their review also confined below 50 degrees north: Vilas Ruivas (Portugal), Les Canalettes (France), La Combette (France), Bolomor layer XIII (Spain), Port Pignot (France), Abri du Rozel (France), Pech de l'Aze II (France) and Grotte du Bison (France) (Roebroeks and Villa 2011: 5210). Fireplaces at Roca dels Bous, Spain are also mentioned.

Roebroeks and Villa (2011: 5211) argue on the basis of their dataset (see table 2) that there is an absence of fire use prior to MIS 11–9, and from that time onward there is a gradual increase in the frequency of hominin fire use in Europe (see fig 4). They report on a threefold increase in number of sites with good evidence of fire per 10 ky increment from MIS 5 followed by a steady increase during MIS 4 and MIS 3 (Roebroeks and Villa 2011: 5210, see fig 4).



MI Stages	MIS duration in ky	Number of sites with good evidence of fire	Number of sites with evidence of fire per 10 ky
>MIS 11	—	0	0
MIS 11–9	124	6	0.48
MIS 8	57	3	0.53
MIS 7	52	10	1.92
MIS 6	61	9	1.47
MIS 5	59	31	5.25
MIS 4	14	14	10.0
MIS 3 (up to 35 ka)	22	46	20.91

Table 2. Sites with good evidence of fire per MIS stage and per 10 ky in Europe from the second half of the Middle Pleistocene. Data based on dataset (from Roebroeks and Villa 2011).

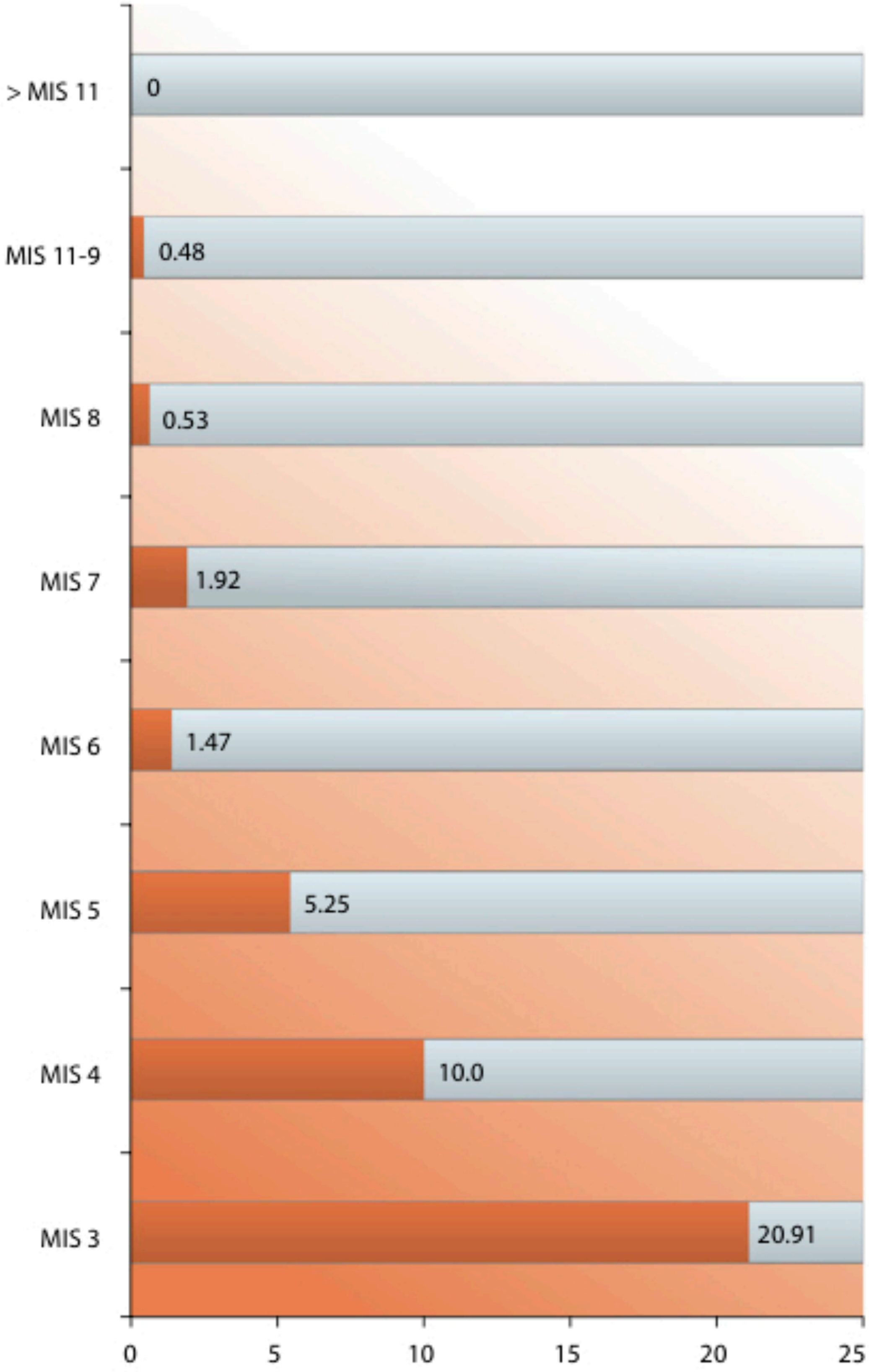


Figure 4. Number of sites with good evidence of fire per 10 ky in Europe from the second half of the Middle Pleistocene (from Roebroeks and Villa 2011).

On the basis of these data, Roebroeks and Villa (2011) argue that Neandertals within Europe used fire on a systematic basis in a wide range of settings both in interglacial as well as glacial conditions (including MIS 4-3), in caves, rock shelters and open-air sites over 250,000 years (at least from MIS 7 and onwards) for a variety of purposes, including pyrotechnology (see Mazza et al. 2006) and cooking (see Henry et al. 2011).

Finally, Roebroeks and Villa (2011: 5211) conclude on the basis of their results that "Middle Paleolithic Neandertals did not have to wait for lightning strikes, meteorite falls, volcanoes, or spontaneous combustion: they had the ability to make, conserve, and transport fires during successive occupations or at different sites, like ethnographically documented recent hunter-gatherers, a pattern comparable to that documented in the Upper Paleolithic".

4.4. Evaluation

4.4.1. Testing the strength of negative evidence of fire use from the Early Pleistocene and first half of Middle Pleistocene Europe

Roebroeks' and Villa's (2011) systematic review of eleven Lower Palaeolithic sites in Europe reveals a surprisingly negative pattern of habitual fire use. What is perhaps even more surprising is that fire does not seem to have been utilized at all at the 19 sampled Lower Palaeolithic sites prior to 400,000 years ago, despite displaying mixed settings (i.e. rock shelters, open-air and cave sites), and despite a rather extensive time depth (i.e. some 800 kyr from the earliest hominin presence in Europe at Sima del Elefante 1.2 Ma, to the earliest traces of fire at Beeches Pit and Schöningen at 400 ka). It is especially strange that there appears to be an absence of archaeological evidence for hominin fire utilization at rich and well preserved archaeological sites with long habitation sequences in temperate climatic conditions.

That being said, such valid representations of hominin behaviour (or lack thereof in the case of fire use) over longer periods of time can only be securely inferred from three sites in closed settings: Gran Dolina, Caune de l'Arago and Visogliano. However, the other three cave sites (i.e. Sima del Elefante, Treugol'naya and Kozarnika) and the five open-air sites discussed in their review have all produced evidence of hominin presence and an absence of evidence of fire. In both these cases, the settings are either completely different (i.e. open-air verses cave/rock shelter), or the abundance and quality of the evidence associated with hominin presence is altogether insufficient to reveal any duration of hominin habitation. It is especially difficult to evaluate the strength of the absence of evidence of fire at the sampled Lower Palaeolithic open-air sites where, as argued by the authors, lightweight traces of fire such as charcoal and ash could easily have been erased by external forces such as water and wind.

Similarly, there are also questions with regards to the validity of the negative evidence of fire at the two eastern European cave sites Treugol'naya and Kozarnika. Here, Roebroeks and Villa (2011) mention a complex history of hominin and carnivore habitation in the oldest / lowest levels at both sites, which begs the question of severe post depositional disturbance. Treugol'naya in particular raises the possibility of traces of fire being potentially erased/destroyed since the accumulation of both the lithics and the faunal remains exhibit evidence of stream transport. At Kozarinka, data on site formation and taphonomy seem to have been insufficiently reported and/or investigated, and thus the taphonomic influences are more difficult to evaluate. As mentioned above, the lowest levels do however indicate a complex habitation history that could potentially have been shaped by taphonomic processes.

On the other hand, if fire was indeed being used at these sites, indirect fire proxies such as heated flints and/or charred bone would have been most likely preserved at least to some extent at some locations given these hominins would have engaged in fire practises involving such proxies, and yet this is not the case. In the case of Boxgrove, which exhibits well-preserved *in situ* archaeology, more than a few pieces of charcoal would indeed have been represented if fire utilization had been an integral part of these hominins' behaviour. Unless, wind and/or water transportation have played a role in the limited visibility of charcoal proxies here or, alternatively, as pointed out by Roebroeks (2012 personal comm.), Boxgrove was only an 'extraction point' for natural resources were hominins were present a brief period of time only in which fire was not a necessity to utilize.

It is precisely the insufficiency of the evidence in revealing any detailed information on frequency of hominin habitation at the localities included in Roebroeks and Villa's (2011) review that have contributed to the uncertainties of the negative signal of fire use prior to the second half of the Middle Pleistocene. To give an example, Sima del Elefante, Treugol'naya and Kozarnika all exhibit inadequate evidence to make any inferences on the duration of hominin presence. Hence, the paucity of the evidence at these sites has resulted in a deficiency of resolution on tempo and mode of hominin habitation. It is therefore extremely difficult to assess the strength of the evidence of hominin behaviour and the negative evidence of fire utilization at these sites. As mentioned by Roebroeks and Villa (2011: 5209), these locations could just have been either briefly visited without the need of using fire, or alternatively, when climatic conditions allowed and in which fire use was not a necessity. On the basis of all these uncertainties, the majority of the Lower Palaeolithic sample reviewed in text (8 out of 11) must therefore be interpreted with extreme caution as being potentially non-valid representations of negative fire utilization.

Conversely, the Lower Palaeolithic cave samples Gran Dolina, Caune de l'Arago and rock shelter Visogliano display long archaeological sequences with abundant and well preserved direct evidence of hominin occupation in multiple levels and in various climatic conditions where taphonomic analysis has indicated limited to no post depositional disturbance. In these three cases, the absence of evidence of hominins using fire must be considered as exceptionally strong and genuinely puzzling indeed. Hominins do not only seem to have made temporary dispersals into Europe when the climate allowed, but also appear to have inhabited particular localities within southern Europe (e.g. these three examples) in temperate climatic conditions for hundreds of thousands of years *without* utilizing fire.

Despite the fact that all three localities are situated in southern parts of Europe (i.e. below 45 degrees north) where cold snaps would have been much less intense than further north, they would nonetheless have reached temperatures below zero degrees at times, particularly during the night. During such conditions, the warmth of fire would have been beneficial if not crucial for survival, even at these latitudes. These hominins would have certainly been able to seek some shelter during harsh weather conditions given the sites covered settings. Even so, the absence of fire for warmth during cold episodes must have had major implications on both mortality rates and physical adaptations of these early European hominin groups.

On the contrary, how can it be proven with certainty that these occupations were in fact successful habitations during ’colder’ or more temperate conditions rather than failed attempts? Do these sites allow the kind of resolution needed to make inferences on mode and tempo of occupation during ’colder’ conditions verses more temperate? Or to put it another way, is there on-site evidence for hominin occupation during “colder” periods at these sites?

Indeed, cold is the question here. What is considered as being cold? And what is the lower limit for tolerable inhabitable climatic conditions *without* fire? Rodriguez et al. (2011: 1406) report on the basis of palynological data from the hominin bearing levels of TD6 at Gran Dolina that “a moderate increase in the presence of open dry taxa occurs in several samples from TD6-3 to TD6-1, although this should not be interpreted as indicative of cold steppes but of steppe habitats in a mosaic environment. The high abundance of *Celtis* seeds at TD6-2 is remarkable proof of Mediterranean conditions. A cold steppe would be incompatible with the abundance of Mediterranean species and the significant presence of mesic taxa in these samples”. A similar view on the character of climate conditions in level TD6 at Gran Dolina has been expressed by Anton Garcia (1998 in Falgueres et al. 1994): “The palynological record, with *Pinus*, *Quercus* and *Cupressaceae*, associated with Mediterranean taxa, such as *Olea*, *Ceratonia*, *Celtis* and *Pistacia*, suggest temperate and wet climatic conditions for the hominid-bearing level”.

Hence, according to the palaeoecology from the hominin bearing levels of TD6 at Gran Dolina, it appears as though this part of the cave’s life history was inhabited by hominins (i.e. *Homo antecessor*) during a mosaic Mediterranean condition, which suggests that we are not dealing with freezing cold temperatures reaching far below zero. According to current averages, low temperatures for winter months (November through March in the Atapuerca region) range from 0-3 °C, with a precipitation rate for the same period ranging between 26-61mm (www.ecmwf.int accessed 25th April 2012). The high altitude of the Atapuerca Mountains at 965 meters above sea level is seen as contributing to cooler winters and a generally dry climate (Rodriguez et al. 2011). Interestingly, according to the Köppen climate classification (see Peel et al. 2007), present climatic conditions of northern Spain have been described as having a mixture of dry - subtropical summer climate and mild to cool and relatively wet winter months, a climatic scenario similar to what palynological data from the hominin bearing depositional sequence of TD6 have indicated some 800,000 years ago, which in turn hypothetically would mean that hominin groups inhabiting Gran Dolina level TD6 could have had to endure average low temperatures of 0-3 °C *without* fire.

Moreover, Antoñanzas and Bescós (2002) work on the distribution of micromammals at Gran Dolina has yielded data on environmental conditions for the entire depositional sequence (i.e. 11 levels) of Gran Dolina. They report on microfuana indicating continental, dry and cold climatic conditions for the beginning of the sequence in levels TD3 to lower TD5, while micro fauna from the upper TD5 and subsequent TD6 are in agreement with the palynological data mentioned above for TD6, suggestive of an interglacial period comprising fluctuations in degree of humidity (Antoñanzas and Bescós 2002: 311, see fig 2). For the lower part of TD8, micro faunal data in the form of *Microtus aff. Ratticepoides* suggests a relatively cold period, while the upper levels of TD8b, TD10, TD11 have yielded micro fauna indicating similar interglacial conditions as seen in upper TD5 and TD6 with fluctuating moisture levels (Antoñanzas and Bescós 2002: 311, see fig 2).

According to these data, direct and abundant evidence of hominin occupation at Gran Dolina TD6 (85 fragmentary human remains of *Homo antecessor*, 268 stone tools of Mode 1 industry and over 4000 large mammal fragments) at 780,000 years ago appears to coincide with an interglacial humid period, whereas the earliest evidence of human presence in levels TD5 and TD4 dated to around 1 mya is not only very sparse and lack human remains, but also appear to correlate to a cooler climate. Level TD4 in particular has only yielded four stone artifacts and small amounts of flake debris (Carbonell 2011 personal comm.). A reversed scenario can then again be seen in younger levels TD10 and TD11, which correlate to similar humid interglacial climates as seen in TD6, and date to around 400-300 ka where higher frequencies of stone tools and flake debris have been recovered (Antonio 2011 personal comm.). Does this imply that hominins only preferred long-term habitation at Atapuerca and the Gran Dolina cave during humid interglacial periods, as these depositional sequences have yielded the only human remains, higher frequencies of stone tools, flake debris and cut mark inflicted mammal remains? Equally, do levels correlated to cooler climates with sparse evidence of human presence such as level TD4 (only 4 tools and little flake debris) only reflect short-term visits? This is a fascinating issue, particularly given the apparent lack of controlled and habitual use of fire by hominin groups visiting and inhabiting Gran Dolina. On the other hand, resolution on climatic data from Gran Dolina is coarse grained and in need of further fine tuning before accepting such a pattern with certainty. Rodriguez et al. (2011 in Mosquera et al. 2012) also argues that there is an overall lack of correlation between climatic changes, faunal turnovers and cultural/hominin changes at Gran Dolina (a scenario applicable to all Palaeolithic sites at Atapuerca).

Next, what about the other rich cave site Caune de l'Arago? Here, there is no fire prior to 350 ka despite evidence of human presence for hundreds of thousands of years; why is that? One could argue that the presence of fire proxies indicates that the activities carried out within the cave changed around 350 ka, and that earlier hominins used fire, but simply did not need it during previous short stops at the cave. Confirming such a hypothetical link could prove difficult, one possible option would be to compare densities of tools and flakes together with frequencies of cut mark inflicted faunal remains and species represented with cut marks (to assess specific hunting preferences), not to mention tool typologies from archaeological layers dating to before and after 350 ka to search for differences. However, such a detailed study is outside the scope of this thesis, unfortunately.

Nevertheless, what can be said on the basis of the Grégoire et al. (2006) study on hominin flint exploitation at Caune de l'Arago in levels L to D 550,000 to 420,000 years ago, is that it appears to be difficult to determine an *overall* pattern of differences in terms of character of occupation (short verses long term) in relation to climate purely on the basis of tool and flaking debris densities (see table 3). Having said that, the oldest level in this sequence (Level L, dated to 550 ka, and correlated by fauna to a cold climate) demonstrates significantly lower frequencies of tools and flakes than the above laying level J, correlated to a warm and humid climate (see table 3). Hence, here one could argue for a potential case of hominins being 'visitors' rather than long-term occupants. On the other hand, subsequent levels G and F correlate to cool and cold climatic conditions, respectively, and have yielded frequencies of tools and flakes that exceed level J, particular level G. Here, almost a threefold increase in the production of tools in comparison to level J appears to have taken place despite being correlated to a cool climate. Interestingly, level G has also yielded human remains, i.e. *Homo heidelbergensis* (see fig 3). In contrast to this, Level E has demonstrated a significant drop in tool production while also being correlated to a cold climate (see table 3).

Level	**Estimated age**	**Climate**	**Deposits**	**Tools**	**Flakes**	**Fauna**	**Landscape**
L	550,000 years	Cold	Sandy	23	246	Reindeer dominant (80%)	Open steppe
J	500,000 years	Warm and humid	Clayey	117	482	Red deer, fellow deer	Forest
G	450,000 years	Cool	Gravel loamy sand matrix	387	1102	Horse, Bovids, Red deer, Rhinoceros	Open plain
F	440,000 years	Cold with strong winds	Stratified sands	161	487	Mouflon dominant	Open plain
E	430,000 years	Cold	Coarse sands	88	133	Mouflon, Horse	Open plain
D	420,000 years	Cold	Coarse sands	274	535	Mouflon	Open plain

Table 3. Main characteristics of occupation levels L to D of the Caune de l'Arago cave (after Grégoire et al. 2006).

That being said, the major issue in this context appears to be the question of what 'cold' actually means during many of these occupations. Obviously hominins occupied Caune de l'Arago during inferred 'cold' conditions *without* fire and produced similar quantities of stone tools as during warmer conditions (on occasion even more, see levels L to D), which from that aspect does not seem to lend support to the idea of 'short stops' during 'cold' conditions. On the other hand, examining the entire European archaeological record from the Late Early Pleistocene and onward, one could argue that prior to the middle portion of the Middle Pleistocene, virtually all sites in Europe date to temperate to full interglacial periods, even Happisburgh 3 (contra Parfitt et al. 2010). In fact, until minimally 400 ka, the record in Eurasia is characterized by discontinuity of hominin presence, and Europe seems to have been depopulated between 800-500 ka (Mosquera et al. 2012). It is only from the middle part of the Middle Pleistocene that we see occupation outside of temperate periods (Cohen et al.

2011 in press). This pattern from the western part of Eurasia is also mirrored by Dennell's recent (Quaternary International 2012 in press) review of the Nihewan Basin and of China north of the Qinling Mountains. There, until the later part of the Middle Pleistocene, human occupation appears to have been restricted to warmer and humid periods with a dominance of summer monsoon. Sites testifying to *occupation* under cooler and drier conditions date, as in Europe, to later parts of the Middle Pleistocene (Roebroeks 2012 personal comm.).

Perhaps it is not entirely unrealistic to draw parallels between discontinuities of the early Pleistocene and early middle Pleistocene fossil and archaeological records of Western Eurasia as a whole and the absence of fire use in these records (see MacDonald et al. 2011; Dennell 2012). In other words, with an absence of a constant source of warmth (fire) in these early hominin groups, dispersals into more temperate zones (e.g. Western Eurasia and Europe in particular) would always have been a risky business, with a high degree of sporadic and failed attempts at a more widespread colonisation of Western Eurasia during the Early Pleistocene and Early Middle Pleistocene period as demonstrated by the discontinuous fossil and archaeological records (see Villa and Bon 2002).

It is even tempting to take it one step further and speculate as to whether a more widespread permanent occupation of the Eurasian landmass owes its delay until the second half of the Middle Pleistocene Period to a lack of controlled and habitual fire utilization among early hominin groups. Yet, Gran Dolina, Caune de l'Arago and Visogliano provide compelling cases and indicate that more long-term habitation across climatic fluctuations including inferred 'cooler' conditions occurred *without* fire. Perhaps, clothing allowed the initial expansion of Europe, while controlled and habitual fire increased its permanency.

Furthermore, the only traces of fire reported from Europe in this review prior to 400 ka were minute pieces of charcoal from the cave sites Sima del Elefante and Gran Dolina at Atapuerca, as well as the open-air site of Boxgrove. As mentioned by Roebroeks and Villa (2011), the original excavators at Sima and Gran Dolina have interpreted these charcoal pieces as the results of natural combustions rather than being the results of hominin agents. Interestingly, these pieces of charcoal have been recovered from layers with direct evidence of hominin presence at both sites. At Gran Dolina, small pieces of charcoal were found in the same level as six individuals of *Homo antecessor* in layer TD6. However, as discussed above, these fire proxies are not in a primary context having come from the exterior of the cave. It is therefore very difficult to infer that these charcoal pieces are in fact the result of hominin activity.

Nevertheless, there are several issues that hamper gaining a clear understanding of the validity and geographical extent of the negative signal of fire use in Lower Palaeolithic Europe. First, several sites in the Roebroeks and Villa (2011) review exhibit uncertainties as to representing ‘true’ absence of fire use, as many are either open-air settings where traces could potentially have been erased or destroyed by natural processes, or they lack investigation on the role of taphonomy. Second, only three sites (i.e. Gran Dolina, Caune de l’Arago, Visogliano) out of the eleven discussed in their review (19 in total for the Lower Palaeolithic) can be considered as being strong uncontested representations of an absence of hominin fire use during long periods of time during the Lower Palaeolithic. Third, all of these strong observations seem to be geographically confined to below 45 degrees north in southern Europe, which, in light of the ambiguity of the remaining sample, makes the validity of such negative patterning of fire use on a larger geographical scale extremely difficult to envisage. It is even more difficult to foresee the regional gravity of such a pattern, since there is no indication of the total number of hominin observation points and their individual characteristics during the Lower Palaeolithic in Europe in Roebroeks and Villa' (2011) review. If many sites exhibit severe disturbance, ambiguous evidence or have been insufficiently published as Roebroeks and Villa (2011) have claimed, it would be interesting to know how many Lower Palaeolithic sites exhibit such features in order to evaluate the strength of the characteristics of the sites sampled.

4.4.2. Testing the strength of evidence for habitual fire use from the second half of Middle Pleistocene Europe

On the basis of selected data in their study, Roebroeks and Villa (2011) argue that fire use became a habitual practice from the second half of the Middle Pleistocene and onwards (MIS 11-9), particularly from MIS 5 (approx. 130 ka) where the frequency of positive indications of fire use sees a threefold increase, followed by a steady increase over time (see table 2 and fig 4). Indeed, there is an increase in the frequency of fire use overall from the initial discoveries between MIS 11-9 and onward in time. However, according to Sandgathe et al. (2011), this is an acceptable pattern since taphonomy would most likely have influenced the frequency of observable fire residues further back in time. In other words, instead of indicating actual reflections of frequencies of Neandertal fire use throughout time as suggested by Roebroeks and Villa (2011), it might just express a biased pattern created by taphonomy.

Let us consider for a moment that taphonomy did play a role in this patterning (a likely scenario, but one in need of thorough investigation): is it enough to say taphonomy alone is responsible for the observable pattern? This is a tricky and (hence) fascinating issue. In an interesting paper, Surovell et al. (2009: 1718) showed that in contrast to previous assumptions (Surovell and Brantingham 2007), "if a site survives its first 10,000 years of existence, its annual probability of destruction is reduced to approximately 0.01%, or a 1 in 10, 000 chance". In other words, the rate of site loss does not remain constant through time, but instead declines with site age (see fig 5, Surovell et al. 2009). Taphonomy (in the sense of destruction of evidence) is therefore not a function of time; it depends on post-depositional modification processes, many of which affect the site before it is buried (Surovell et al. 2009: 1718.). Gran Dolina, Caune de l'Arago and Visogliano all have thousands of bones, none of which has shown evidence of burning. After burial, bones can get broken by sedimentary compression, but they do not disappear. That being said, charred bones are generally more fragile and therefore also more susceptible to post-depositional processes such as trampling which in turn could result in small pieces being overlooked in screening and sorting processes (Roebroeks 2012 personal comm., see also Lyman 1994.). Ashes can be diagenetically modified, yet micromorphologists are quite capable of identifying these altered ashes (see Weiner 2010). No ash-derived siliceous minerals have been identified at Gran Dolina and Caune de l'Arago, although sedimentological studies have been done at both sites.

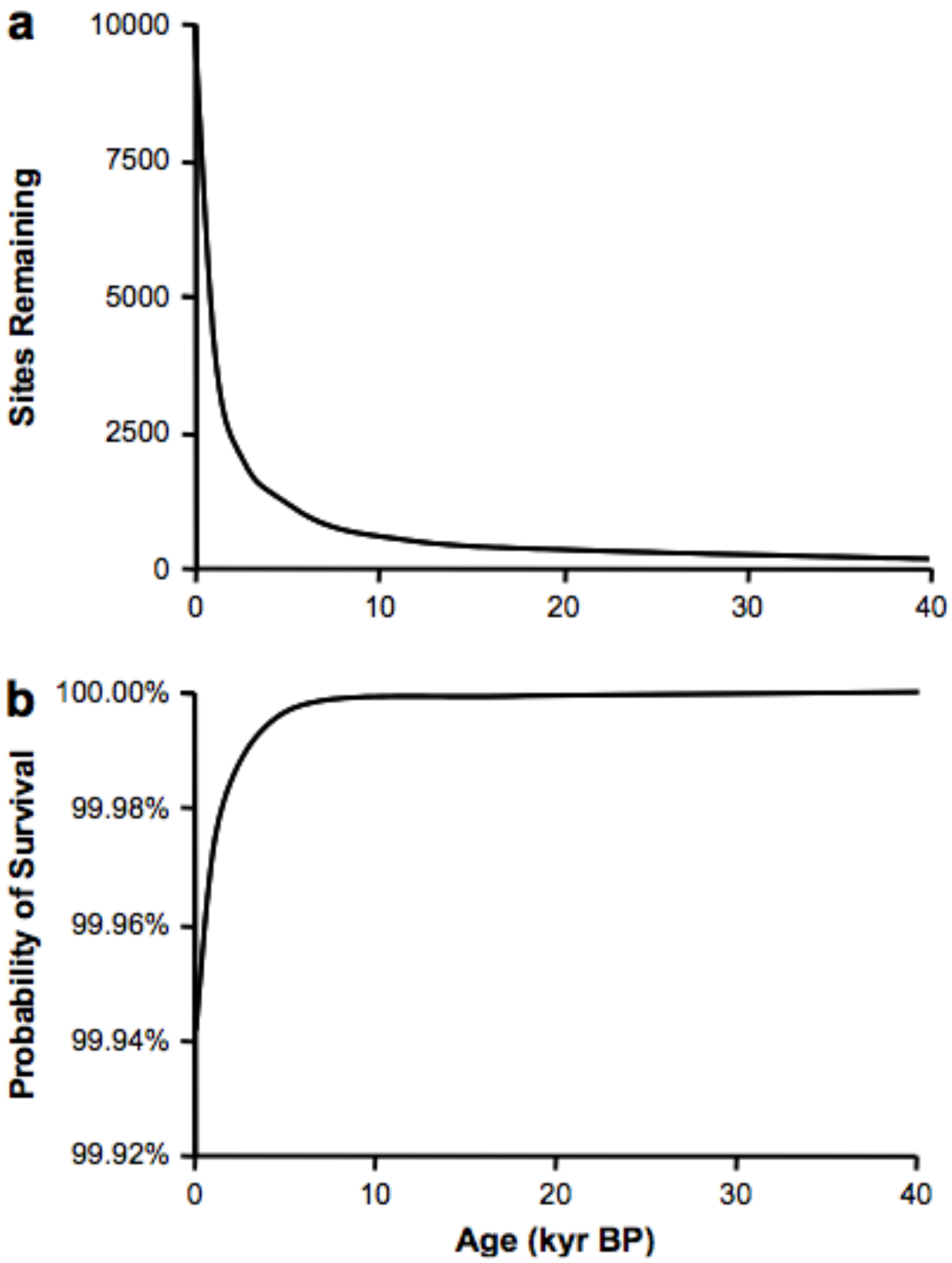


Figure 5. Properties of the empirically derived model of taphonomic bias. a) The predicted loss of archaeological sites over time assuming 10,000 sites at time zero. b) The annual propability of survival (1- λ) as a function of site age (from Surovell et al. 2009).

Subsequently, following the Suvorell et al. (2009) model, taphonomy should *not* be considered as an agent being *exclusively* responsible for the observable pattern of a gradual increase in fire use over time during the second half of Middle Pleistocene Europe. That is not to say that taphonomy did not play *a* role in the pattern. It could have been influential in the visibility of fire traces at particular localities, especially with regard to charred organic material. On the other hand, if fire was indeed being used at particular locations, then evidence of heat-altered, more durable material less affected by taphonomic processes such as stone tools and flaking debris would have been recovered. Having said that, some sites may just have been briefly visited without the occupants using bones as fuel, or conducting any stone knapping activities in proximity to fires, thereby producing heated flint flakes. In such cases, wooden charcoal and ashes would have been the only fire proxies left behind, both having a survival rate in the archaeological record that would have been highly dependent on the mode and tempo of the burial of the site, as well as the site's individual setting and depositional climate (see Surovell et al. 2009; Weiner 2010). Hence, there is a high probability that such lightweight fire proxies could have been removed/relocated by water or wind transport prior to burial, or reworked by other taphonomic processes during earlier stages of the site's life history (see Surovell et al. 2009; Weiner 2010). It is therefore crucial to understand site formation and the influence of taphonomic processes in a given depositional environment to evaluate the probability of taphonomic influence on frequencies of observable more lightweight charred material. In essence, while taphonomic processes cannot be blamed for creating the pattern of fire use envisaged by Roebroeks and Villa (2011), it can nonetheless be responsible for the presence or absence of such 'lightweight' proxies at particular localities. It is therefore very important that sites included in such an analysis have been taphonomically investigated, which for many sites in Roebroeks and Villa (2011) is not always clear.

Moreover, Roebroeks and Villa (2011: 5209) acknowledge the ambiguity surrounding fire proxies such as charcoal, charred bone material, and heated flints, and the issue of traces of fire being potential products of natural fires rather than having anthropogenic affinities. In their view, the context of possible fire indicators is of absolute importance in evaluating anthropogenic involvement (Roebroeks and Villa 2011: 5209). They argue that "If burnt bones, heated artifacts, and charcoal occur in caves or enclosed sites where the deposits are demonstrably in situ and are not reworked by slope wash or debris flow entering the cave, then they can be considered good indicators of anthropogenic fires" (Roebroeks and Villa 2011: 5209). Following this line of reasoning, one could argue all open-air sites associated with such fire proxies to be highly suspicious, including the ones mentioned in their review. Equally, caves and enclosed settings with similar fire proxies and influential taphonomic histories and complex site formation could be considered as unconvincing. How many sites in Roebroeks and Villa (2011) review do in fact coincide with such a description and can thus be considered to be strong candidates of anthropogenic fire?

Given the large dataset included in the Roebroeks and Villa (2011) review, individual geological histories (site formation and taphonomy) are not discussed for each of the individual sites sampled. What the authors have done instead is to divide the database into three categories where each character of fire evidence is given a confidence number from 1-3 depending on their validity as anthropogenic. Sites given a 1 have displayed what the authors call *possible* evidence of fire use, but where evidence has been either insufficiently described or were missing supporting evidence. Sites given a 2 have demonstrated what the authors call *good* evidence of anthropogenic fire, which according to them are hearths and stone-lined or stone-delimited fireplaces. Finally, sites attributed a number 3 yielded what the authors call *clear* evidence of anthropogenic fire, which to them are sites with a combination of attributes (e.g. combustion structures and multiple levels of fire), or taphonomic and micromorphological analyses, and where structured or clearly delineated fireplaces may or may not have been preserved (Roebroeks and Villa 2011).

According to their extensive dataset of sites with evidence of fire in Europe from 400 ka onward (MIS 11-3), 13 open-air sites out of 45 sites in total (29 %) exhibit *possible* evidence of fire, which is almost a third of the sites included (see table 4 below). For closed-system settings (i.e. rock shelters and caves) from MIS 9-3 this number is 14.5 % (11 out of 76, see table 5 below). Such a high number of sites exhibiting uncertainties as to whether or not anthropogenic fire was utilized is somewhat alarming. But what is the main issue at stake at these sites? Is it a lack of supporting evidence, hence is the evidence presented very ambiguously as it stands; or is it a low quality level of detailed reporting from many sites? Here, it would have been interesting to see what variable applies to which site and which settings (caves, rock shelter, open-air), and also what sites have undergone site formation and taphonomic analysis, and in such cases, what those results have indicated. The latter is important, as many sites with a lack of supporting evidence might have been affected by taphonomy, or have had long exposure times to various environmental conditions (e.g. wind, rain, ice) prior to burial that could potentially remove, obscure or displace lightweight fire proxies. In the case of insufficient reporting and publishing, this is a major issue in Palaeolithic research, particularly for the European record where many sites were excavated and published decades ago without (in many cases) a standardized reporting framework and less rigorous demands on the level of detailed reporting than today. In such cases, reinvestigation of these sites might provide more clarity into the matter, especially with the redefined methodology of the 21th century (for further discussion see future outlook chapter).

Next, according to tables 4 and 5 in Roebroeks and Villa (2011), it appears as though there is a general increase (as pointed out by the authors in number of sites) in both open-air and closed settings having *good* and *clear* evidence of fire beginning at MIS 5 (approximately 130-71 ka), with the trend continuing during MIS 3 (approximately 60-27 ka). Interestingly, both MIS stages also comprise several prolonged periods of warmer climatic conditions. MIS 5 in Europe is generally tied to warm climatic conditions with a few cold snaps, while MIS 3 experienced several abrupt climatic warming phases know as Dansgaard-Oeschger (DO) events (Van Meerbeeck 2009: 33). This image appears to mirror (as mentioned previously) the hominin preference during the first half of Middle Pleistocene towards inhabiting Europe during warmer climatic conditions, and might indicate periods when Europe saw more long-term hominin occupation. Interestingly, the number of sites in closed settings also seems to increase during these periods (see table 5), which might lend support to the idea of more permanent occupations of Europe during MIS 5 and MIS 3. This might also explain why there is an increase of sites with evidence of fire, and particularly why there is an increase in sites with *good* and *clear* evidence, as more long-term occupation would yield more pronounced traces of fire use. The idea of more permanent occupation and controlled / habitual fire use from MIS 5 also seem to fit data from the Lower Pleniglacial of MIS 4, which despite being correlated to a very cold climate with mean annual temperatures reaching well below those of today (see van Andel and Tzedakis 1996; Lowe and Walker 1997: 319), have yielded more sites with *good* evidence of fire use per 10 ky increment than MIS 5 (MIS 4 only spans a duration of 14 ky, while MIS 5 covers 59 ky; see table 3). This trend also seems to continue through MIS 3, where the number of sites with *good* evidence of fire doubles in comparison to MIS 4 (see fig 4 above). From this data, it appears as though habitual use of fire might have been able to foster more permanent occupations during cold conditions as demonstrated in MIS 4, since earlier cold stages like MIS 6 had significantly lower frequencies of sites with good evidence of fire compared to MIS 4 (see table 3). Similarly MIS 6 had fewer sites with *good* evidence of fire than MIS 5, despite having a comparable duration (see table 3). While MIS 5 spans 59 ky and has yielded 31 sites with *good* evidence of fire, MIS 6 has only yielded nine over a period of 61 ky (see table 3).

Having said that, the occupation character of the various sites in this data set needs to be examined to see if there is a pattern of more long term occupations from MIS 5 onward than prior to this period. Similarly, would it be interesting to see whether the type of occupation (i.e. short term verses long term) changes from MIS stages associated with more temperate and warmer conditions to MIS stages correlated to cold conditions. Likewise, if it would be possible to spot a *turning point* from *short stops* to more prolonged stays, and whether this coincides with an increase in fire use.

According to the Roebroeks and Villa (2011) dataset, the majority of sites - both open-air and closed settings combined with *good* and *clear* evidence of fire - come from MIS 3 (approximately from 60-27 ka, see table 3), which could point to a time when fire became more routinely used (although MIS 5 has also demonstrated high numbers in comparison to other MIS stages). That said, there is one interesting early discovery from central Italy that lend support to the idea that fire was habitually used and mastered in this part of the old world already some 200,000 years ago. At the open-air site of Campitello Quarry, two flint flakes covered in birch bark pitch have been recovered that testify to advanced pyrotechnological abilities already prior to MIS 6 (and during colder conditions as interpreted from associated fauna; see fig 6. Mazza et al. 2006). Similarly, two more recent sites in Germany – Inden-Altdorf and Königsaue, both dated to MIS 5 - have also yielded evidence of birch-bark production. On the basis of such evidence, it seems as though at least some groups were proficient fire utilizers from MIS 7 onward.

However, in order to examine when fire transitioned from being used only sporadically to becoming more habitual, it is crucial to quantify the total number of sites with *good* evidence of fire relative to the total number of sites for each MIS stage. Similarly, to test the hypothesis of a possible link between lower frequencies of sites with *good* evidence of fire and MIS stages correlated with colder conditions, and higher frequencies of sites with *good* evidence of fire and more long-term occupation during MIS stages correlated to warmer conditions from MIS 5 an onward, the total number of sites for each MIS stage and their individual characteristics are needed together with better resolution of climatic data and taphonomic history. Prior to that, it is very difficult to evaluate fire's role in the colonization of Europe.

MIS stages	Number of sites	Good evidence of fire	Clear evidence of fire	Possible evidence of fire
11-9	4	3	1	0
9	2	0	1	1
8	2	1	0	1
7	5	2	2	1
6	6	2	1	3
5	14	5	5	4
4	2	1	1	0
3	10	4	3	3

Table 4. Frequencies of open-air localities and their individual characteristics of fire evidence in Europe from MIS 11-3. Several sites with the earliest traces of fire in Europe lack precise dating and are therefore indicated as MIS 11-9 (after Roebroeks and Villa 2011 dataset S1).

MIS stages	Number of sites	Caves	Rock shelters	Good evidence of fire	Clear evidence of fire	Possible evidence of fire
9-8	3	2	1	1	1	0
7	7	4	3	3	3	1
6	1	1	0	0	1	0
5	26	14	12	10	14	2
4-3	40	18	22	13 (possibly 14)	19	8 (possibly 7)

Table 5. Frequencies of sites in closed settings, and their individual characteristics of fire evidence in Europe from MIS 9-3 (after Roebroeks and Villa 2011 dataset S1).

Figure 6. Flint flake from Campitello Quarry covered in birch-tar adheisive from some 200,000 years ago, testifying to genuine pyrotechnological skill. Experiments have shown that hominins here utilized fire to produce pitch for the hafting of stone tools (from Roebroeks and Villa 2011, photograph by P. P. A. Mazza, Dipartimento di Scienze della Terra, Università di Firenze, Florence, Italy).

4.5. Conclusion

4.5.1. Evaluating the strength of the short chronology

The short chronology of habitual fire use proposed by Roebroeks and Villa (2011) does challenge established ideas of a long chronology of hominins using fire. In that regard, this review encourages a rethinking of fire's role in human evolution, especially with regards to dispersals into more temperate zones such as Western Eurasia and Europe, in particular. On the positive side, Roebroeks and Villa (2011) have selected well preserved, rich and, in some cases, long inhabited sites, which would most likely have indicated evidence of fire use if such behavior had indeed been applied. Three Lower Palaeolithic sites (Gran Dolina, Caune de l'Arago and Visogliano) out of 19 sampled in total stand out as exceptionally strong indications that, at least at these localities, hominin groups did not seem to have utilized fire despite occupations in inferred ’cold’ and more temperate conditions.

On the negative side, the short chronology also exhibits several issues. The negative pattern of fire use for the Lower Palaeolithic is based on too few uncontested observations to make it come across as a strong pattern, while the habitual fire use hypothesis from MIS 11-9 has failed to quantify the total number of occupation sites during each MIS stage relative to the number of sites with evidence of fire. The latter has resulted in ambiguity to what the current pattern for the gradual increase of fire use from MIS 11-9 in Europe actually represents. Some authors have pointed to taphonomy as being a stark force in shaping the current pattern of a gradual increase in fire use from 400 ka in Europe. However, as discussed in this chapter, taphonomy cannot be held solely responsible for the current pattern, as taphonomy (in the sense of destruction of evidence) is not a function regulated by time, but depends on post-depositional modification processes that on many occasions take place prior to burial of archaeological material, including fire proxies. This is not to say that taphonomy did not play a role in the pattern of a gradual increase in the number of sites with evidence of fire from the second half of the Middle Pleistocene, but its level of contribution needs to be evaluated case by case, as taphonomy is ubiquitous to all archaeological sites.

On the basis of these premises, it is therefore difficult to evaluate the strength of the short chronology and pinpoint with confidence a time where fire use transitioned from being only sporadically used to becoming more habitual, especially since the absence of evidence does not necessarily equate to evidence of absence.

5. A shorter chronology of habitual fire use

5.1. Introduction

Sandgathe et al. (2011) support the hypothesis of fire not being a prerequisite technology for dispersals into higher latitudes and more temperate zones from the Early Pleistocene onwards (as suggested by Roebroeks and Villa 2011). However, they go a step further and contend for an even shorter chronology of habitual fire use by questioning the nature, quality, and intermittent pattern of many of the claimed evidences for habitual fire use in the second half of the Middle Pleistocene in Europe.
They argue that current archaeological evidence much better supports a significantly later appearance of controlled and habitual fire use sometime at the end of the Late Pleistocene, and that prior to this fire utilization had always been sporadic and opportunistic (Sandgathe et al. 2011: 219).

Sandgathe et al. (2011: 5209) stress that although there is an increasing number of sites during the Mousterian period with evidence of fire use, many sites demonstrate an absence of fire use even during prolonged occupations of colder conditions. While the authors acknowledge factors such as insufficient reporting, excavator bias and post-depositional processes as indeed being influential on the patchiness of the Middle Palaeolithic record, they argue that these factors are not exclusively responsible (Sandgathe et al. 2011: 220).

Their own research at two locations in Western Europe has demonstrated that as late as mid-MIS 3, Neandertal groups used fire very infrequently, especially during colder conditions. Here, well-preserved hearths are only present during warmer more temperate conditions, while positive evidence of fire is almost non-existent during cold snaps (e.g. MIS 4 and during particular sub-stages of MIS 3) despite presence of lithics and butchered faunal remains (Sandgathe et al. 2011a). This has led Sandgathe et al. (2011a) to not only question the role of fire during the Middle Palaeolithic, but also Neandertal's abilities in fire production.

They argue that: “if Neandertals had the ability to make fire at will, then evidence for it should occur with much greater frequency in Middle Palaeolithic sites and occupations, and especially those associated with cold stages”

(Sandgathe et al. 2011a). How strong are such claims? And what is the archaeological evidence supporting such conclusions?

5.2. Methodology and Dataset

Sandgathe et al.'s (2011) shorter chronology of habitual fire use is based on their extrapolation of two case studies at two well-stratified Mousterian caves in south-western France: Pech de l'Aze IV and Roc de Marsal (Dordogne). These caves have been previously excavated by both professional (Pech de l'Aze IV by Mortureux in 1953, and Bordes from 1970-1975, see Sandgathe et al. 2011) and amateur archaeologists (Lafille from 1953-1967 at Roc de Marsal, see Sandgathe et al. 2011).

One goal of Sandgathe et al.'s (2011) research has been to re-excavate these two cave sites with modern methods and techniques to get a better understanding of Neandertal fire use at these particular locations. Another focus has been to study the character of the supposedly intentionally buried Neandertal infant skeleton at Roc de Marsal. The re-excavation of these caves took place between 2000-2004 and 2004-2009, respectively. The excavations at Pech de l'Aze IV focused on the western section of the site (close to the original and now collapsed entrance of the cave, see fig 7a and 7b), which is a smaller area in comparison to Bordes' extensive excavation (1970-1975 see fig 7a). Similarly, at Roc de Marsal, the area of re-excavation was smaller than the original excavation (see fig 8 and 9). Together with the original excavations, the bulk of both caves sediments have now been excavated (see fig 7, 8 and 9).

Layer 7 at Pech de l'Aze IV was omitted from in-text analysis in the Sandgathe et al. (2011) report due to evidence of sedimentation formation complexities, such as heavily rolled artefacts and limited preservation of faunal remains that most likely represent a solifluction lobe.

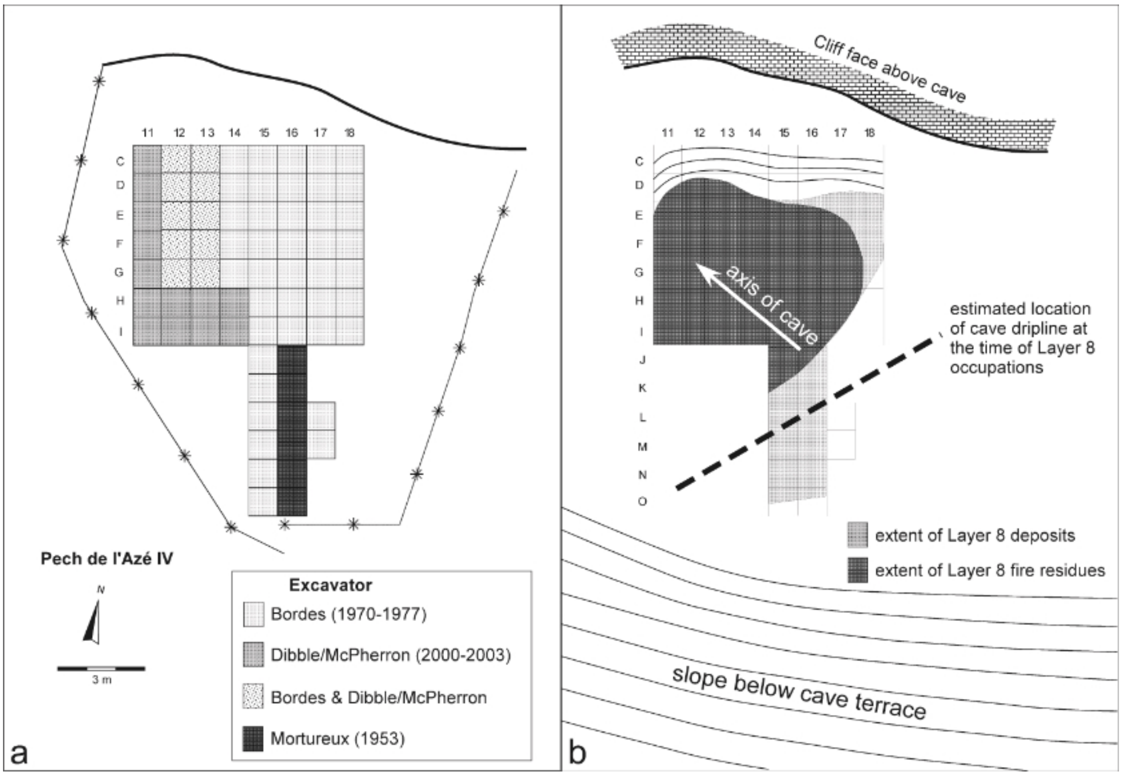


Figure 7.a) Excavated units at Pech de l'Aze IV by the original excavators and Sandgathe et al. (2011) here indicated as Dibble and McPherron; b) position of the cave site in relation to cliff behind and the vertical slope of the valley in front of the terrace. Surface distribution of heated flints and fire residues of layer 8 is also indicated (from Sandgathe et al. 2011).

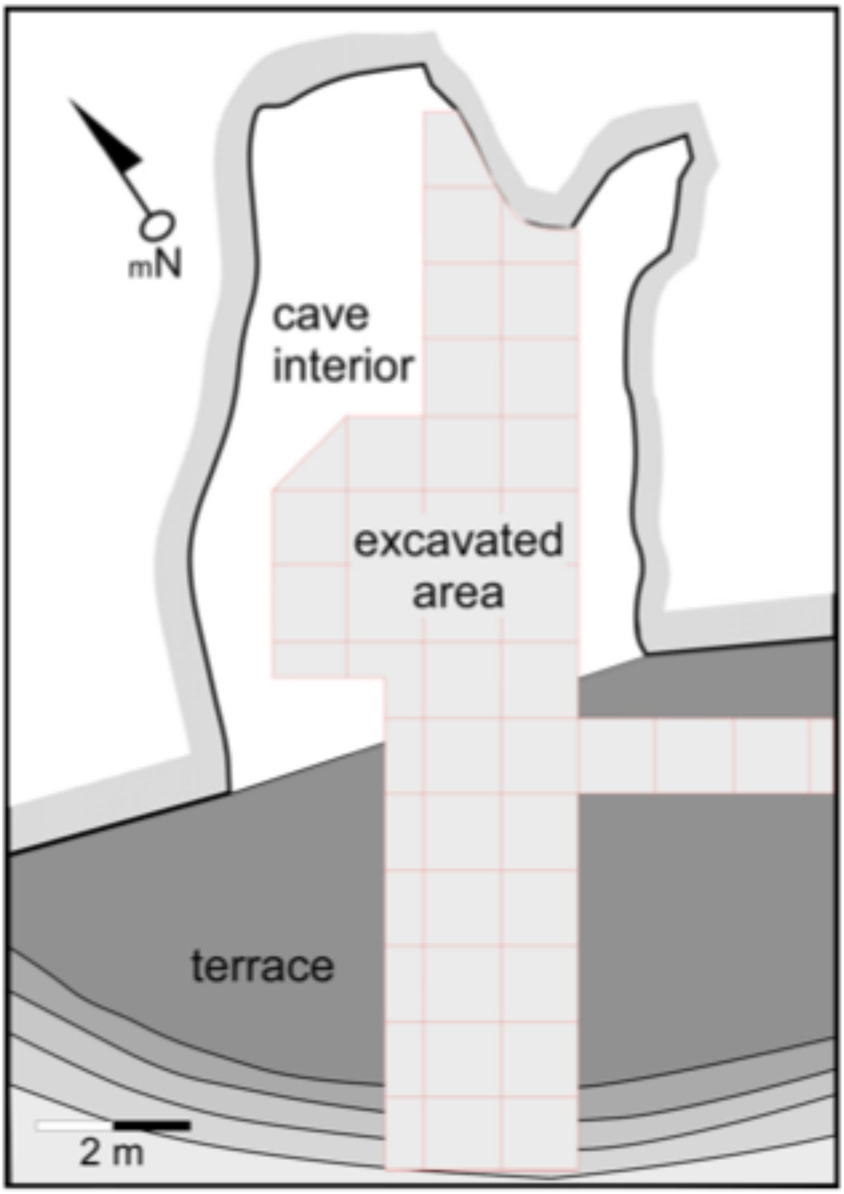


Figure 8. Map of Roc de Marsal indicating excavated units (both the original by Lafille and re-excavated units by Sandgathe et al. 2011) and the total area of excavation (from Sandgathe et al. 2011).

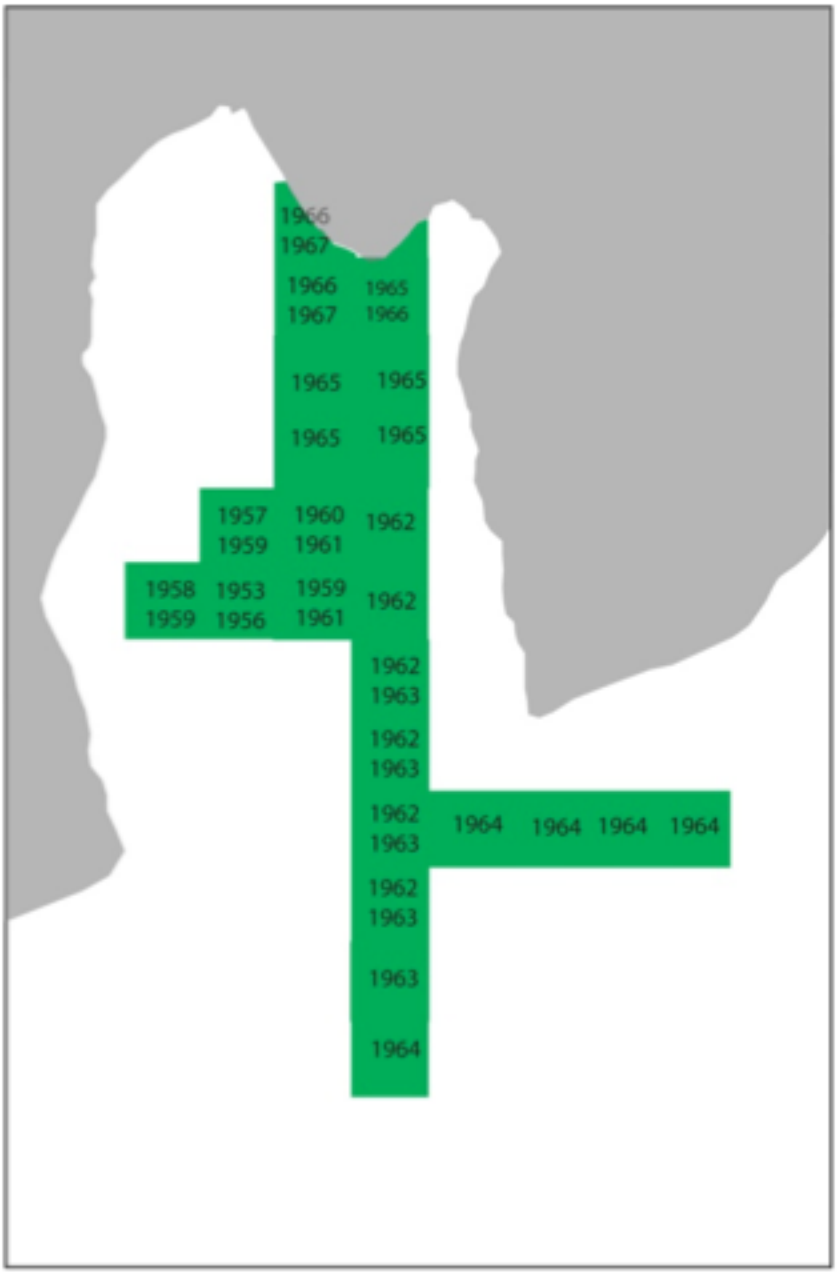


Figure 9. Area excavated by Lafille at Roc de Marsal between 1953-1967 (from Sandgathe et al. 2007).

5.3. Results

5.3.1. Primary evidence of Neandertal fire use and climate at Pech de l'Aze IV

Sandgathe et al. (2011) only report on direct evidence fire (i.e. hearths) in the lowest and earliest occupation layer at Pech de l'Aze IV, layer 8. This layer has also yielded the most abundant evidence of fire associated with human activity altogether at Pech de l'Aze IV (Sandgathe et al. 2011). Layer 8 has been correlated to MIS 5c (approximately 100 kya), a warm and humid climate regime (Sandgathe et al. 2011: 220, 221). Here, clearly delineated, superimposed charcoal and ash units resembling hearth lenses have been observed in close proximity to burned bone and heated lithics (Sandgathe et al. 2011: 220, 221). In cross section, these hearth lenses appear to have been blended together (see fig 10), a phenomenon that has led the authors to conclude that fires were being utilized with intense temporal frequency (Sandgathe et al. 2011: 220-221). Most of the lenses also show excellent preservation, which indicate that post depositional disturbance would have had to be minimal (Sandgathe et al. 2011: 221). The authors conclude the smudged appearance of the individual combustion lenses to most likely having been caused by trampling episodes and hearth raking events, as there is clear evidence of such features in this layer (Sandgathe et al. 2011: 221).

Figure 10. Cross-section of charcoal and ash lenses interpreted as hearths in layer 8 at Pech de l'Aze IV. Scale bar indicating 10 cm (from Sandgathe et al. 2011).

Subsequent layers (7-3), covering a total of three meters of sedimentation and spanning a time range of 50 kyr (MIS 5c – MIS 3), have yielded a negative signal of primary evidence of fire (i.e. hearths, charcoal and ashes), apart from very small pieces of charcoal (< 0.5 cm) at the top of the sequence in layer 3, and despite other evidence of Neandertal occupation (e.g. tools, flaking debris and cut-mark inflicted faunal remains). Fire residues that have been reported from these layers are small amounts of secondary fire residues, such as heated lithics and charred bone (Sandgathe et al. 2011: 221, fig 11). These layers are correlated both by faunal remains and Thermoluminescence (TL) dating to colder conditions, in particular layers 5-3, which demonstrate climatic deterioration by means of a change in faunal representation from species associated with more temperate conditions to high frequencies of reindeer (Sandgathe et al. 2011: 221). Layer 6 exhibits a striking mismatch between fauna-based correlations and TL dating, according to the authors, which has led to uncertainty with regards to climatic and accurate MIS stage correlation (Sandgathe et al. 2011: 221). While the faunal evidence is indicative of more temperate and wooded conditions (e.g. roe deer, red deer, wild pig), and thus most likely dates to MIS 5e (Sandgathe et al. 2011: 22), seven TL dates from sublevel 6a by Richter et al. (2010, cited in Sandgathe et al. 2011: 221) have given average dates of 70.9 ± 3.5 kya, which most likely correlate to MIS 4, a significantly colder period (Lehman et al. 2002; Winograd et al. 1997 cited in Sandgathe *et al*. 2011: 221).

5.3.2. Secondary evidence of fire at Pech de l'Aze IV

Sandgathe et al. (2011: 227) write on the highest frequencies of secondary traces of fire, also from layer 8, where the only evidence of hearths was found, and which has been correlated to warmer conditions (according to the authors, most likely MIS 5c). Here, over 20% of the lithics recovered were heated, and 27.5% of the bones charred (see fig 11). In subsequent layers (7-3), the situation is the complete reverse, where the percentages of both heated flint and charred bone are significantly lower (see fig 11), and, for the most part, the layers are correlated to colder conditions (Sandgathe et al. 2011: 227, see fig. 12). According to Sandgathe et al. (2011: 27), most of the younger layers display a drop in frequencies of heated flint and charred bone to below 1%, apart from a small rise at the very top of the sequence (see fig 11). For instance, layer 3b, which is correlated to a cold period (see fig 12), only displays 0.6 % burned lithics of 1,798 in total (Sandgathe et al. 2011: 227, see fig 11).

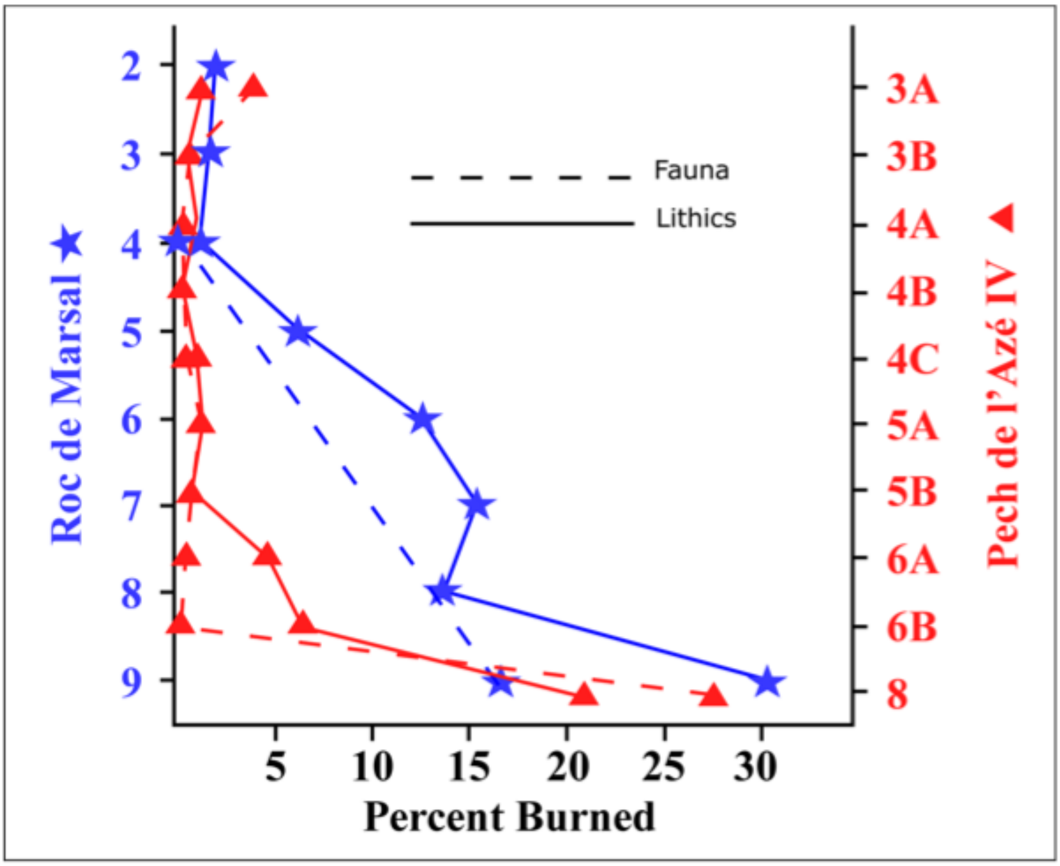


Figure 11. Percentage of heated lithics and charred bone at Pech de l'Aze IV and Roc de Marsal. Both counts are based on items greater than 2.5cm in length, only proximal and complete pieces of lithics are included in the diagram (from Sandgathe et al. 2011).

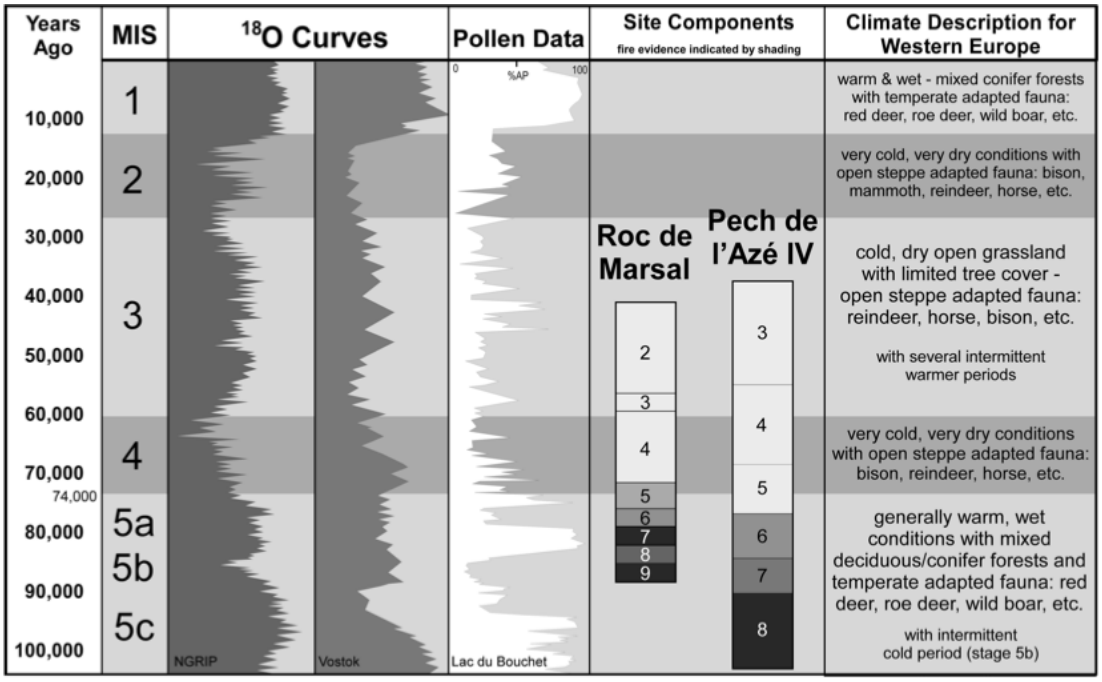


Figure 12. MIS stage correlations of the various layers at Pech de l'Aze IV and Roc Marsal by means of chronometric dates and faunal data. Shading of the various layers is indicative of frequencies of burning within respective layers. Darker shading indicates higher frequencies of burning while lighter shades indicate lower frequencies of burning (from Sandgathe et al. 2011).

5.3.3. Primary evidence of Neandertal fire use and climate at Roc de Marsal

At Roc de Marsal, some 20 km north west of Pech de l'Aze IV, Sandgathe et al. (2011) also report on direct evidence of fire only in the earliest levels. Here, evidence of the initial human occupation has been dated to sometime between 85-75 kya, and took place during temperate and forested conditions, most likely MIS 5a (Sandgathe et al. 2011: 222). Layers 9-6 display evidence of faunal elements usually associated with more temperate climatic conditions, and clear traces of fire (i.e. *in situ* hearths) have been observed in layers 9 and 7 (Sandgathe et al. 2011: 222). In this context, several combustion features are reported as distinct isolated hearths, many of which possess intact charcoal-ash units and considerable quantities of charred/calcined bone (Sandgathe et al. 2011: 222). In cross-section, these combustion features represent a similar "piled" pattern of hearth lenses, as demonstrated in layer 8 at Pech de l'Aze IV (Sandgathe et al. 2011: 222, see fig 13).

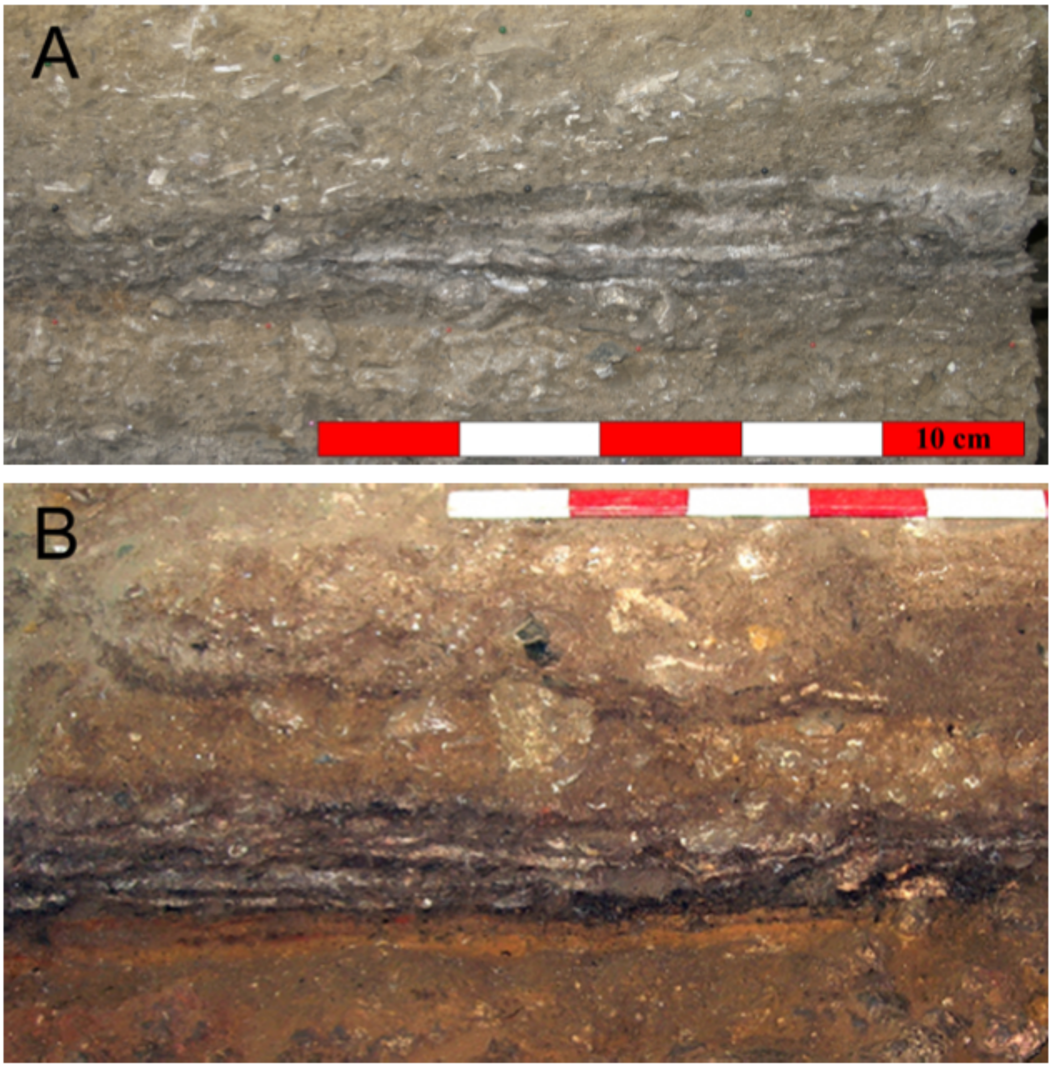


Figure 13. a) Stratigraphic cross-section view of ‘piled’ charcoal/ash lenses interpreted as hearths in layer 7 at Roc de Marsal; b) stratigraphic cross-section view of ‘piled’ charcoal/ash lenses interpreted as hearths in layer 9 at Roc de Marsal. Scale bar for both photographs indicates 10cm (from Sandgathe et al. (2011).

According to Sandgathe et al. (2011), however, not all earlier levels at Roc de Marsal display evidence of hearth features. While layers 5, 7 and 9 display an abundance of such features - particularly layer 7 and 9, which have yielded many combustion features occurring as isolated hearths, several of which contain ashes and charcoal and high frequencies of charred/calcined bone - layers 6 and 8 display an absence or scarcity of direct and intensive evidence of fire (Sandgathe et al. 2011: 222). Similarly, younger layers 4 and 2 - correlated by fauna and TL dating to MIS 4 and mid-MIS 3 respectively (approximately 74-44 kya) - also indicate an absence of direct evidence of fire while being associated with much colder, drier and more open environments than levels 9-7 (Sandgathe et al. 2011: 223, see fig 12). Overall, the physical characteristics of the hearths, as well as the fire residues, exhibit variability at Roc de Marsal. Diameter measurements seems to range from 50-100 cm, while fire residues seem to vary from thick (1-2 cm lenses of ash) to an absence of ash, and a primary composition of only small (< 2 cm) fragmented pieces of charred bone (Sandgathe et al. 2011: 223). Sandgathe et al. (2011: 223) claim such variability indicates differences in duration and frequency of burning events. Differences in combustion material accumulation within the hearth structures are also noted by the authors, where calcined bones are positioned at the centre of the hearth in certain cases, while positioned at the margins in others (Sandgathe et al. 2011: 223).

5.3.4. Secondary evidence of fire at Roc de Marsal

Roc de Marsal has yielded a sample of 23,000 lithics in total, and layer 9, which is also associated with warm-temperate climatic conditions and hearths, has demonstrated the highest frequencies of secondary evidence of fire (Sandgathe et al. 2011: 227). Here, approximately 30% of the lithic objects have been heated together with 17.2% charred bone fragments (see fig 11). A comparable peak in frequency of heated lithics and bone, although smaller, has been observed in layer 7 - also associated with warm climatic conditions (see fig 12) and hearths - where over 15% of the lithics seem to have been heated, and 9% of the bone is charred (Sandgathe et al. 2011: 227, see fig 11). On the contrary, levels that are associated with more recent occupations and colder climates at Roc de Marsal (i.e. layers 2-4, see fig 12) display a significant drop in the frequency of heated lithics, down to 1-2% (Sandgathe et al. 2011: 227, see fig 11). For example, layer 4, which is associated with a very cold period, only displays 1.3% heat-affected lithics out of 1,833 total specimens (Sandgathe et al. 2011: 227, see fig 11 and 12).

5.3.5. Comparison of Pech de l'Aze IV and Roc de Marsal

Overall, both Pech de l'Aze IV and Roc de Marsal sites exhibit similar chronological time spans of human occupation, from mid- to late MIS 5 through mid- to late MIS 3 (Sandgathe et al. 2011: 223).

Neandertal occupation at both sites also follows the same climatic pattern of an initial occupation during more temperate conditions followed by a significant climatic deterioration in younger occupation layers (Sandgathe et al. 2011: 223). There is a pattern at both sites of clear hearth features during the warmer early occupations, while more recent occupations display an absence of such features despite cooler conditions (Sandgathe et al. 2011: 223). Both sites also demonstrate a correlation between higher percentages of secondary fire residues, such as heated lithics and bone, and more direct organic fire residues, such as charcoal and ashes, during warmer conditions as opposed to colder (Sandgathe et al. 2011: 227). Upper Mousterian layers at both sites (5-4 at Pech de l'Aze IV, and 4-2 at Roc de Marsal) are associated with MIS 4 and 3. These layers associated with colder climates include no concentrations of charcoal or ash; only small numbers of charred bones and heated lithics are dispersed throughout the deposits (Sandgathe et al. 2011: 223). Likewise, in these younger levels where direct evidence of fire disappears, the frequency of burned lithics and faunal remains also decreases to very low levels at both sites (Sandgathe et al. 2011). Only one exception to this pattern has been reported from layers 6 and 8 at Roc de Marsal, where high frequencies of secondary fire residues have been observed despite an absence of direct evidence of combustion features. These exceptions are explained by Sandgathe et al. (2011: 227) as the results of either interstratigraphic travel of the lithics, or the spread of fire/heat through the sediments. The latter was observed in layers 7 and 8, where fires in layer 7 modified some of the lithics in layer 8 (Sandgathe et al. 2011: 227).

5.3.6. Explaining the pattern of infrequent fire use at Pech de l'Aze IV and Roc de Marsal

Several plausible explanations for the infrequent pattern of fire use at these two localities were discussed by Sandgathe et al. (2011) in their report. Taphonomic agency, excavator bias, differences in activities carried out at different times and seasonal frequency variation in occupation were discussed as possible agents creating these patterns. The first premise - taphonomy- was ruled out as a likely factor since both sites exhibit exceptionally well preserved fire residues (Sandgathe et al. 2011: 223). Likewise, the absence of edge damage on the edges of the lithics has 'according to the authors' excluded the influence of any considerable post-depositional disturbance in the younger layers of either site that could explain the absence of fire (Sandgathe et al. 2011: 223). The excavations at both sites have also failed to indicate any evidence of ashes being removed and discarded elsewhere, as seen at Kebara cave, Israel (see Meignen et al. 2007 in Sandgathe et al. 2011: 224). For instance, trenching outside the entrances of both caves have failed to yield any evidence of ash dumps (see fig 7 and fig 8). Sandgathe et al. (2011:224) declare that, to their knowledge, there are no natural (i.e. post depositional disturbance) or cultural (human/faunal agents) transformation processes identified in the sediments that would have been influential enough to erase any possible traces of fires in the younger layers of both Pech de l'Aze IV and Roc de Marsal. Similarly, the authors argue that significant decline in frequency of fire proxies such as heated lithics throughout the sequences is not the result of varying sampling size since the dataset from both sites are based on high numbers (Sandgathe et al. 2011: 227). Sandgathe et al. (2011) also use indirect evidence to test the strength of the notion of infrequent use of fire at these sites. They argue that since flint artifacts and bones are commonplace components of the various deposits of both Pech de l'Aze IV and Roc de Marsal (as they are amongst many other French Palaeolithic caves), any fire placed on these sediments in close proximity to the flint or the bones would have altered the surface of these items (Sandgathe et al. 2011: 225). In other words, if fires had indeed been used in these younger layers, but had been erased or destroyed by external factors, then evidence of heating would have been possible to determine indirectly from the lithics and bone, and yet this is not the case (Sandgathe et al. 2011: 225). In a similar fashion, they elaborate on possible fire residues being overlooked in their excavations of these two caves. However, such possibilities are alluded to as minimal, since both of the caves (Roc de Marsal in particular) have been almost entirely excavated in a systematic manner with a high level of precision (Sandgathe et al. 2011: 228, see fig 8 and 9).

In the case of Pech de l'Aze IV, where a large part of the cave has been previously excavated by Bordes (1975, see fig 7), his results of a high frequencies of fire in the lower layers coincides well with Sandgathe et al.'s (2011) data from other parts of the cave. Hence, Sandgathe et al. (2011: 228) claim that if fire had indeed been used in other yet unexcavated parts of the cave, which are minimal, then these traces would most likely have intermingled with the excavated parts and likely identified.

5.4. Evaluation

5.4.1. Testing the strength of infrequencies in Neandertal fire use in relation to climate at Pech de l'Aze and Roc de Marsal

The study by Sandgathe et al. (2011) at these two southwestern French caves has indeed yielded a surprising pattern of Neandertal fire use. Two major points can be observed contradicting common ideas of human adaptations and evolution of fire practices at these two localities. First, the data appear to indicate less fire use during cold conditions, and more frequent use during warmer conditions, a scenario that is completely the opposite of what one would expect. Then again, such a pattern indeed supports ideas of fire's role in human adaptations and demographical expansion as perhaps less instrumental than previously thought. Second, there appears to be a gradual decrease over time in both frequency of fire use and investment of fire practice. In other words, hearths, charcoal and ashes only appear in the oldest layers at both sites, while younger layers only exhibit secondary evidence (i.e. heated lithics and charred bone) in low frequencies. Such a scenario is certainly in contradiction to commonly held ideas of an increase in both fire use and direct evidence of fire, i.e. hearths over time, especially with the emergence of home bases (see Rolland 2004). According to Sandgathe et al.'s (2011) findings, hearths and high frequencies of secondary fire evidence only occur during warm conditions, while cold conditions coincide with an absence of hearths altogether, yet low frequencies of secondary fire residues are interspersed throughout. Sandgathe et al. (2011) have attributed these differences to Neandertals' limited ability to make fire at will, and their reliance on the collection of natural fires, which would have occurred more often during temperate conditions. Although this is an interesting argument, particularly since there is no current direct archaeological evidence exclusively demonstrating Neandertals abilities to produce fire, there might also be other explanations. Differences in site function is one possibility, meaning Neandertals might have utilized these localities in varying ways during warm and cold conditions. For example, more intense fire use during warmer conditions might just reflect Neandertals' adaptability to more permanent occupations of these locations. Such an adaptation would perhaps have been catalyzed by the emergence of a new food niche in non-lean meat resources such as plant foods during warmer conditions (for an example of Neandertal use of plant food (see Henry et al. 2010). By adding a complementary food resource to their subsistence like plant-derived food resources, these Neandertals would no longer have had to be solely dependent on the mobility patterns of their prey, which could at times move over large geographical areas. The presence of hearths and more intense fire use during such conditions might reflect an increased reliance on cooking of large volumes of plant foods, which on many occasions had to be processed before eaten to release their toxins. Conversely, if during colder conditions edible plant species dwindled, then these Neandertals would have had to alter their subsistence strategy to become solely reliant on animal proteins for survival. As a consequence, they would also have had to alter their mobility pattern accordingly, which could mean only brief visitation episodes of caves. Such a high mobility lifestyle during colder conditions could *possibly* explain the low frequencies of fire use and the absence of hearths at Pech de l'Aze IV and Roc de Marsal.

An alternative option explaining the pattern infrequency of fire use in relation to climate at these two caves might be that the sedimentary context differed between temperate and 'cold' settings, with more reworking of "invisible hearths" in colder than in temperate settings (Roebroeks 2012 personal comm.). In other words, sedimentation rates may have been slower during cold periods than warm periods, allowing heaths to remain exposed for longer and thus subject to more taphonomic or anthropogenic disturbance.

Not all the data from these caves conclusively prove the presence of hearths and more frequent fire use during warmer conditions, however. For instance, layer 5 at Roc de Marsal exhibits presence of clear hearth features and high percentages of secondary fire residues (6–7 %, see fig 11) despite having faunal correlations indicative of colder conditions (e.g. an abundance of reindeer). Conversely, layers 8 and 6 at Roc de Marsal have little to no evidence of hearths despite being associated with fauna indicative of warmer conditions, most likely corresponding to MIS 5a (Sandgathe et al. 2008, see fig 12).

The data from Pech de l'Aze IV also exhibit some issues with regard to information on MIS stage correlations and secondary fire residues. For instance, layer 7, which was omitted from analysis, lacks information on both its precise MIS stage correlation (apart from MIS 5), as well as the fire residues themselves. This would not have been an issue if the layer was altogether omitted from the report – and not just from their in-text analysis – but since this layer has demonstrated the second highest representation of fire residues of the entire site (see figure 12), it would be of interest to know what those fire residues are, and in what frequencies secondary fire residues occur, if at all. Indeed, layer 7 is correlated to MIS 5, which is generally a warm stage (see figure 12). However, since no data on fauna or TL dating have been reported from this layer, it is difficult to completely exclude it from being associated with the cold intermittent MIS stage 5b, especially in light of the physical character of this layer as a solifluction lobe, which often occurs during periglacial conditions and/or in areas with colder climatic conditions (see Lowe and Walker 1997).

A similar dilemma of unsecure MIS correlations can be observed in layer 6, in which there appears to be a mismatch between faunal correlation and TL dating. Though faunal representations have indicated more temperate conditions, TL dating has indicated MIS correlation associated with colder conditions. Here, it would be of interest to know the abundance of such faunal remains and the overall thickness of layer 6, since horizontal migration of faunal remains might have taken place from either layer 7 or 5, as seen in the case of heated lithics at Roc de Marsal layers 7 and 8.

Overall, Sandgathe et al. (2011) claims that fine resolution correlation of layers at both Pech de l'Aze IV and Roc de Marsal to MIS substages (such as MIS 5) are highly doubtful, and are in many cases in need of more supporting evidence. Similarly, the Sandgathe et al. (2011) refutal of taphonomy as being an influential agent on the visibility of fire proxies on the basis of an absence of edge damage on lithics is problematic, as lithics have to move far (that is, well beyond the level of a large cave) and in high-energy settings before edge damage can be observed on the edges of lithics (Roebroeks 2012 personal comm.).

However, the main issue at stake is not so much the data itself, but the interpretation of the data as representing opportunistic fire use rather than habitual. Clearly, there are infrequencies of fire proxies and hearths that, for the most part, correlate to climate; but as demonstrated above, this is not always the case. Unmistakably, there is an absence of hearths and lower frequencies of secondary fire residues during colder conditions, with representation within the assemblages sometimes reaching below 1% at both sites, depending on the layer in question (see fig 11). Nonetheless, the mere presence of such proxies indicates that fire had indeed been utilized routinely throughout the sequences at both Pech de l'Aze IV and Roc de Marsal, albeit infrequently. As mentioned above, the pattern of infrequent fire use in relation to climate does not have to reflect these Neandertals' reliance on fire collecting (i.e. the frequency of natural fires would probably have been more abundant during more temperate conditions), but might instead be explained by differences in site use and mobility patterning in relation to climate, or by the reworking of 'invisible hearths' in sediments associated with colder conditions.

5.5. Conclusion

The shorter chronology of habitual fire use proposed by Sandgathe et al. (2011) indeed questions hypothesizes of fire being an integral part of human behavior for hundreds of thousands of years, as envisaged by both the long and the short chronology. It also challenges long-lived assumptions of Middle Palaeolithic Neandertals having been habitual fire practitioners for millennia.

On the positive side, Sandgathe et al. (2011) are careful in assigning terms like routine and habitual use of fire to data that are infrequent, often ambiguous and that display gaps in chronology, as demonstrated by the data of fire use during the Middle Palaeolithic. They also acknowledge factors such as insufficient reporting, misinterpretation of evidence, and taphonomy as having strong influences on the intermittent pattern of fire use during the Middle Palaeolithic.

However, Sandgathe et al.'s (2011) hypothesis of a much later origination of habitual fire use than what has been suggested by Roebroeks and Villa's (2011) short chronology is primarily based on extrapolation of data from only two Middle Palaeolithic cave sites in southwestern France. Although the research conducted by Sandgathe et al. (2011) at these two caves has provided high-resolution data and snapshots into Neandertal behavior over 50,000 years, the main challenge has become how to interpret this data, and determining in what way it can be used to construct a pattern of Neandertal behavior on a larger regional scale. It is especially difficult to envisage Neandertals from as late as mid-MIS 3 (50 kya) lacking the skills to produce fire when evidence of complex Neandertal fire production at Campitello Quarry, Italy, is already demonstrable some 200,000 years ago (see Mazza et al. 2006).

That said such ample fire production akin to what has been documented for the Neolithic and Mesolithic is only demonstrated this early in time (approximately 200 ka) at this *one* location in Europe, and by a very small sample (only two flakes are covered in birch tar adhesive). It is also worth stressing that no fire production tools have been recovered from any Middle Palaeolithic context yet, which supports Sandgathe et al.'s (2011) suspicions on Neandertals' fire production abilities. On the other hand, as pointed out by Roebroeks and Villa (2011:b), very few fire production tools have been recovered from Upper Palaeolithic contexts, and yet, few would question Upper Palaeolithic hunter and gatherers' capabilities in fire production. By and large, the infrequent pattern of fire utilization during the Middle Palaeolithic can be compared to the Upper Palaeolithic record, where many sites lack evidence of fire utilization in their stratigraphic sequences (Roebroeks and Villa (2011:b). Bon's 2006 overview (cited in Roebroeks and Villa 2011:b) on Aurignacian cultures in the context of Middle to Upper transitional industries, for example, reports less than ten sites out of 89 sampled from southern France and northern Spain (both rock shelters and open-air sites) having evidence of hearths. Instead, numerous sites only contain charcoal and ashes, and what Sandgathe et al. (2011) defines as secondary lines of evidence like heated flint and charred bones scattered throughout the layers (Roebroeks and Villa 2011:b).

An additional problem with the shorter chronology and the idea of Neandertals as opportunistic fire users rather than habitual fire practitioners is the evidence of repetitive fire use at La Cotte de Saint Brelade on Jersey (UK), during both cold and more temperate conditions from MIS 7-4. However, this site also suffers from some uncertainties and lack of detailed reporting.

Finally, the shorter chronology of habitual fire use is based primarily on Neandertal behavior from Pech de l'Aze IV and Roc de Marsal, at which fire frequencies of evidence suggestive of burning clearly show Neandertals using fire in all climatic conditions over 50,000 years. As discussed in the previous section, the low percentages of burned flints and charred bone encountered during cold MIS stages could possibly be explained by an increase in mobility that resulted in only brief visits to these caves, or alternatively, by reworking of 'invisible hearths' in sediments associated with colder conditions.

Ultimately, it is difficult to evaluate the strength of the shorter chronology for habitual fire use, especially since Sandgathe et al. (2011) uses negative evidence as a fundamental framework for their hypothesis in from a very small sample geographically confined to southwestern France. The interpretation of the data on Neandertal fire practices at these two Middle Palaeolithic cave sites can be interpreted in various ways. As often as it is the case in Palaeolithic research, the resolution of the mode and tempo of habitation, as well as precise MIS correlations in relation to climate, seems to be an issue here even though these caves have, for the most part, allowed for a high-resolution study. However, to envisage Neandertal behavior and fire practices on a more regional scale and over hundreds of thousands of years on the basis of negative observations from only two sites in southern Europe is very risky, especially in light of evidence of Neandertal fire mastery (i.e. production of artificial glues for hafting) at previously mentioned Campitello Quarry in Italy (MIS 7), and later at Inden-Altdorf (MIS 5) and Königsaue (MIS 5), both in Germany.

6. Limitations of the Short and Shorter Chronologies

By and large, both short chronologies of habitual fire use have demonstrable strengths and weaknesses. A vital ingredient, and unfortunately also a major problem, in the construction of chronologies for the Palaeolithic is precise dating and fine resolution correlation between archaeology and climatic data. A dilemma that unfortunately also applies to the shorter chronologies of habitual fire use, where dating of many sites with or without evidence of fire is still problematic, particularly for the Middle to Upper Palaeolithic transition period (40-30 ka, see Jöris and Street 2008; Higham 2011). Add to this the fact that many sites also lack contextual data on climate, which makes fluctuations in fire use and various types of fire practise in relation to different climatic conditions difficult to infer. Furthermore, even in cases where climatic data derived from palaeoecology and/or micro/macro faunal studies is preserved, it is often very sparse, or the results do not always correlate well with absolute dating methods like TL dating, as demonstrated from Pech de l'Aze IV. Overall, the higher resolution climatic correlation of sites included in both shorter chronologies appears to be a major issue (as is generally the case for Palaeolithic research), as do claims of fine tuned correlation of archaeological material to MIS sub-stages for the shorter chronology, which in many cases are in need of much more supporting evidence.

Moreover, the lack of taphonomic control at many sites is another issue that has contributed to uncertainties about the strength of the short chronologies, where only a handful of sites appear to have been taphonomically investigated. On top of that, many sites appear to have been either insufficiently published or reported on, or were excavated decades ago with other agendas and/or often crude methodologies that might have destroyed or overlooked possible evidence of fire.

Although there is another more fundamental issue that both chronologies share, and which questions their validity as strong representations of hominin fire practise history: the use of negative evidence. Most archaeologists would agree that creating patterns on the basis of negative evidence as being hazardous, especially since absence of evidence is not evidence of absence.

There is also a niggling uncertainty surrounding negative evidence, in which patterns can easily be falsified and/or destroyed by one single positive discovery.

For that reason, many are convinced that archaeologists should only be concerned with what can be observed in the archaeological record, not merely with what is possible. In fact, it has been argued that negative evidence is irrelevant to archaeological research, since it does not generate any concrete or valuable archaeological information, and therefore ought to be omitted from archaeological analysis – a statement difficult to refute, since physically preserved data provide an opportunity for physical analysis, while negative evidence does not (Weiner 2010). Based on these premises, it is very difficult to know how strong these negative patterns are in the construction of the short chronologies of habitual fire use. To what extent shall sites with negative signals of fire be incorporated into the construction of such patterns? How can the strength of the archaeological signal of negative evidence they put out be evaluated? How many of the sites included in the short chronologies are reliable enough to distil a signal from? How strong is the influence of taphonomy? And finally, how shall these negative patterns be interpreted and what do they mean?

Such investigations of negative evidence propose many hindrances, both practical and economical, and are challenging to take on. However, clarification of such uncertainties is a necessity in order to be able to properly assess the strength of patterns built on negative evidence. After all, the emergence of the genus *Homo* is also based on negative evidence, as are all evolutionary developments; hence, the absence of evidence is also a pattern that has been observed and that begs an explanation, preferably a testable/falsifiable one.

In any case, the use of negative evidence in the construction of the short chronologies of habitual fire use does not work very well when taking into consideration repetitive evidence of fire at the gates of Europe, almost 400,000 years earlier. The evidence of fire at Gesher Benot Ya‘aqov, Israel, 780,000 years ago destroys the negative pattern of controlled and habitual fire use for the first half of the Middle Pleistocene in Western Eurasia, and questions the strength of the short chronologies.

7. The outlier: Gesher Benot Ya'aqov

7.1. Introduction

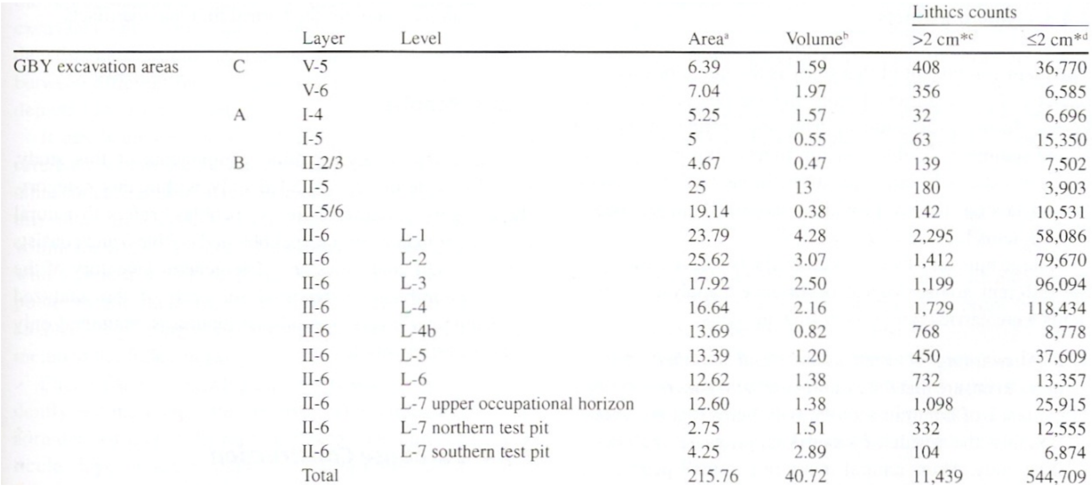
The early Middle Pleistocene Acheulian open-air site of Gesher Benot Ya'aqov (GBY), situated on the shores of former palaeolake Hula on the southern margin of the Hula basin in the Upper Jordan Valley in northern Israel, provides the earliest evidence of controlled and habitual use of fire according to the original excavators (Goren-Inbar et al. 2004; Alperson-Afil et al. 2007; Alperson-Afil and Goren-Inbar 2010). While earlier evidence of fire use in Africa has only been able to demonstrate the presence of burning of archaeological material without yielding data on the specific character of the inferred fire use, the excellent preservation and repetitive evidence of fire in all 14 archaeological levels at GBY have, according to the excavators, allowed for a rare insight into early hominin fire practise over numerous millennia (Alperson-Afil et al. 2007). The original excavators claim on the basis of the continuity of the evidence of fire at GBY that the these hominins were proficient fire makers rather than collectors of natural conflagrations, and that the knowledge of making fire at will was passed on from generation to generation by the hominins inhabiting the site (Alperson-Afil and Goren-Inbar 2010). In their view, the continuity of fire use over 50,000 years from 780 ka at GBY proves that control and habitual use of fire played a key role in the migration of *Homo erectus/ergaster* from Africa into a temperate Western Eurasia (Alperson-Afil and Goren-Inbar 2010).

In this chapter, I will review the evidence of fire at GBY, along with the excavator's interpretation of this evidence as anthropogenic in origin. This will be followed by a critical examination and evaluation of the evidence as secure representations of controlled/habitual fire use.

7.2. Background

GBY was initially discovered in the 1930s, but archaeological investigations of the Middle Pleistocene deposits were not conducted until the late 1980s. Between 1989 and 1999, Prof. Naama Goren-Inbar and her team of archaeologists excavated a 34-meter deep, tectonically tilted sequence of Middle Pleistocene deposits in 0.5m x 0.5m spits in 5 cm levels comprised of cyclic beds of organic-rich calcareous mud, coquina, and conglomerate deposited along the margin of palaeolake Hula (Alperson-Afil and Goren-Inbar 2010). The duration of the entire depositional sequence has been estimated to approximately 100 kyr by magnetostratigraphy, and is estimated to have been deposited between MIS 18-20 (Alperson-Afil and Goren-Inbar 2010: 13). The lower part of the sequence has been correlated to the Matuyama/Brunhes chronological boundary at 0.78 Ma (Alperson-Afil et al. 2007: 1). It is comprised of 14 archaeological levels spanning a duration of approximately 50 kyr (Goren-Inbar et al. 2004). The sequence has for the most part yielded high frequencies of lithics, of which micro flints (< 2cm) are the most common (more than 500,000, see table 6). Various paleontological and archaeobotanical remains have also been recovered (Goren-Inbar et al. 2004). The archaeology of GBY has been attributed to the Acheulian industrial complex, comprising numerous Acheulian hand-axes, cleavers, cores and core tools, flakes and flake tools, many of which are made from local basalt (Alperson-Afil et al. 2009; Alperson-Afil and Goren-Inbar 2010). The faunal remains consists of medium to large-sized mammals (e.g. bear, elephant, hippopotamus, rhinoceros, gazelle, horse, bovids), and micro-vertebrates including mammals, reptiles and amphibians (Alperson-Afil and Goren-Inbar 2010; Goren-Inbar et al. 2012). The depositional environment of the archaeological sequence at GBY is predominantly lake beach with sedimentary matrices comprising a mixture of clay, silt, sand and gravel/coquina (Alperson-Afil and Goren-Inbar 2010, see fig 14). The excavators have reported very little redeposition of the lithic material, and claim the archaeological material to be in primary context (Alperson-Afil and Goren-Inbar 2010; Goren-Inbar et al. 2012). No hominin remains have been recovered from the site, but as previously mentioned, the excavators believe the site to have been inhabited by *Homo erectus/ergaster* or archaic *Homo sapiens* (Goren-Inbar et al. 2004; Alperson-Afil and Goren-Inbar 2010).

Table 6. Archaeological layers from GBY indicated from the lowermost/oldest (V-5) to the youngest (II-6) at the top of the sequence. Area in m^2, Volume in m3 (from Alperson-Afil and Goren-Inbar 2010).



						Lithics counts	
		Layer	Level	Area[a]	Volume[b]	>2 cm*[c]	≤2 cm*[d]
GBY excavation areas	C	V-5		6.39	1.59	408	36,770
		V-6		7.04	1.97	356	6,585
	A	I-4		5.25	1.57	32	6,696
		I-5		5	0.55	63	15,350
	B	II-2/3		4.67	0.47	139	7,502
		II-5		25	13	180	3,903
		II-5/6		19.14	0.38	142	10,531
		II-6	L-1	23.79	4.28	2,295	58,086
		II-6	L-2	25.62	3.07	1,412	79,670
		II-6	L-3	17.92	2.50	1,199	96,094
		II-6	L-4	16.64	2.16	1,729	118,434
		II-6	L-4b	13.69	0.82	768	8,778
		II-6	L-5	13.39	1.20	450	37,609
		II-6	L-6	12.62	1.38	732	13,357
		II-6	L-7 upper occupational horizon	12.60	1.38	1,098	25,915
		II-6	L-7 northern test pit	2.75	1.51	332	12,555
		II-6	L-7 southern test pit	4.25	2.89	104	6,874
		Total		215.76	40.72	11,439	544,709

7.3. Methodology

The primary goal of the research conducted by Alperson-Afil and Goren-Inbar (2010) on the fire evidence at GBY was to identify anthropogenic verses natural fires. In order to do so, they examined differences in spatial distribution and frequencies of overlap between burned and unburned micro flints in the various archaeological levels by means of GIS mapping (Alperson-Afil and Goren-Inbar 2010). 'Phantom hearths', or remnants of ancient hearths, were defined by identifying particular spatial distributions of heated micro flints within deposits, where a detected distribution of heated micro flints would surpass the expected levels (Alperson-Afil and Goren-Inbar 2010: 30). The expected level was inferred by the application of a chi square test on the excavated levels in order to statistically identify an expected homogeneous spatial distribution of both burned and unburned micro flints. In cases where small but non-random clusters of burned micro flints could be detected, these were interpreted as 'phantom hearths', and thus, anthropogenic in origin (Alperson-Afil and Goren-Inbar 2010: 30). In cases where burned and unburned micro flints would spatially overlap, possibilities of natural fires were considered (Alperson-Afil and Goren-Inbar 2010). In order to ensure that the spatial patterns represent hominin activity, the authors only included items that irrefutably can be related to hominin activities, *i.e.* to stone knapping activities. Natural items (e.g. small pebbles) were excluded from analysis altogether. Micro flints with clear diagnostic features (e.g. bulb of percussion, striking platform, and a ventral surface) were included in the study sample and defined as ‘micro artifacts’ (Alperson-Afil and Goren-Inbar 2010).

7.4. Results

7.4.1. Archaeological evidence of fire at GBY

GBY has yielded heated lithics, charred wood, and pieces of charcoal in various frequencies throughout the stratigraphic sequence, most of which can be correlated to MIS 19 (Alperson-Afil and Goren-Inbar 2010). Small pieces of flint (< 2 cm) interpreted as micro artefacts make up the majority of the heated material, but heated macro artefacts have also been reported (Alperson-Afil and Goren-Inbar 2010). Both the heated micro and macro artefacts are reported to occur in small frequencies throughout the sequence. For heated micro flints, these frequencies range between 0.76-5.8%, while 0.3-6.06% of the macro artefacts are reported as having been have burned (see table 7). Many of the heated micro flints have demonstrated potlid fractures, and TL analysis has confirmed former exposure of the flint to temperatures between 300-500°C, which is indicative of temperatures commonly reached in concentrated campfires (Alperson-Afil and Goren-Inbar 2010). An abundance of faunal remains has also been reported as being potentially charred, although less than 1% (14 out of 1568) has been securely identified as charred (Alperson-Afil and Goren-Inbar 2010). The authors report that a large portion of the bones has been highly affected by anaerobic waterlogged sediment, which has prevented the use of conventional identification methods for identifying burning or heating (Alperson-Afil and Goren-Inbar 2010:16). Carbonized wood pieces have also been described to occur in low frequencies by less than 2% (Goren-Inbar et al. 2004).

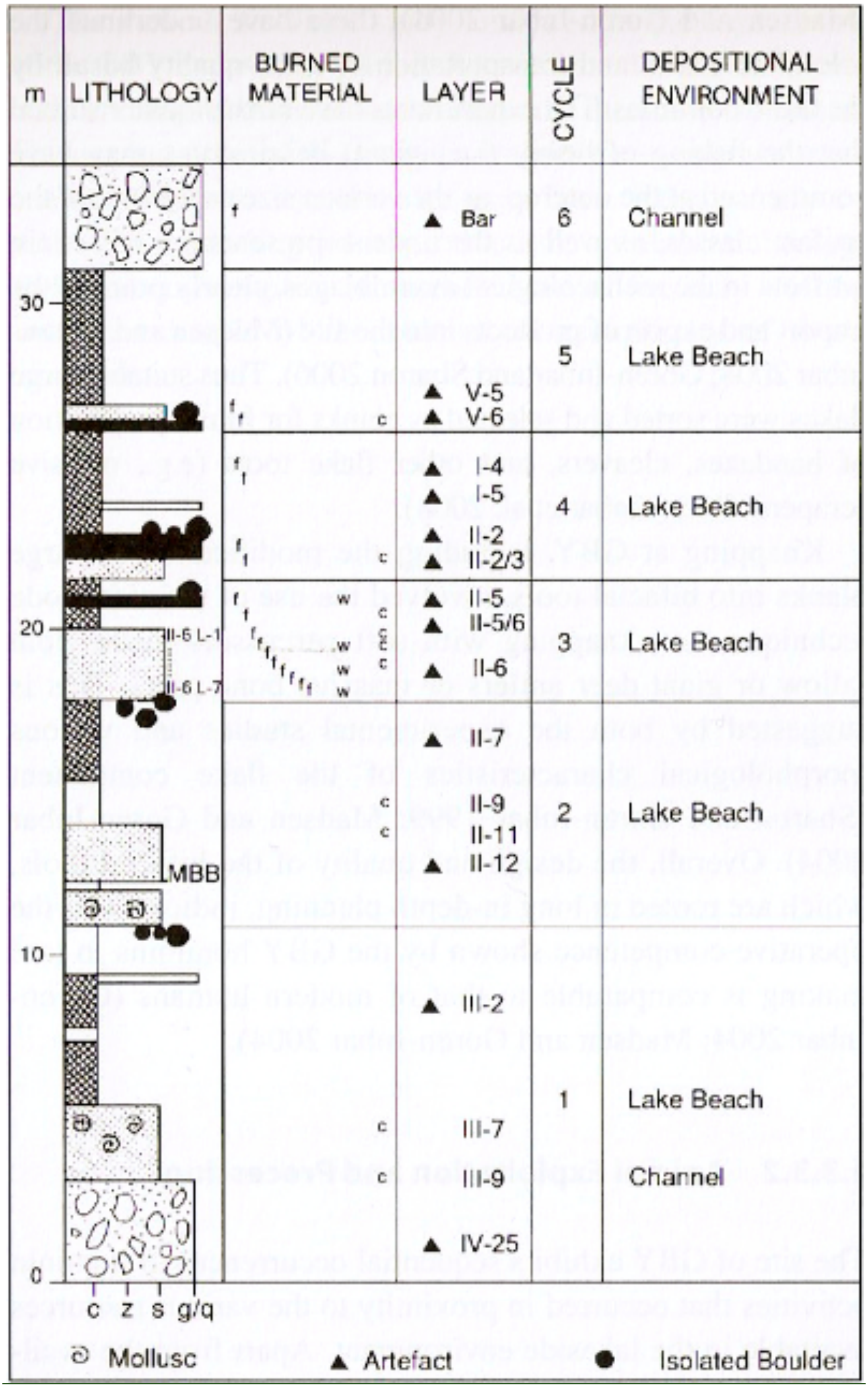


Figure. 14. Composite section of the GBY stratigraphical sequence. Burned material are indicated as follows: burned wood = w, charcoal = c, heated

flints = f. Texture of the sedimentary matrixes are indicated as; c = clay, z = silt, s = sand, g/q = gravel/coquina (from Alperson-Afil and Goren-Inbar 2010).

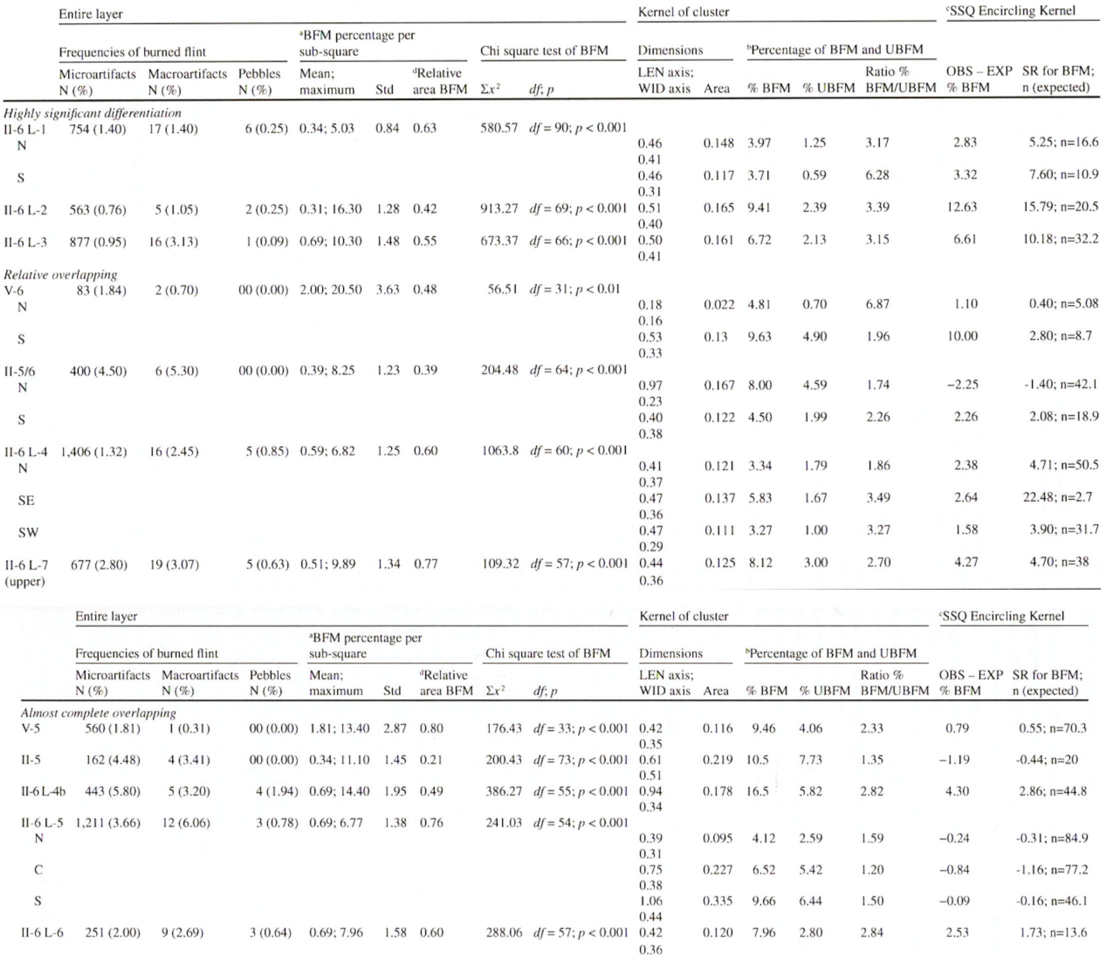
7.4.2. Alperson-Afil and Goren-Inbar's hypothesis of controlled and habitual fire use at GBY

While archaeological evidence from all occupational levels of GBY has demonstrated exposure to heating, the challenge has become to tie this heating to fires with anthropogenic origins. This has been a particular concern to the excavators of GBY due to the site's open air setting in which natural fires could easily have burned accumulations of wood and plant remains, thereby thermally altering flints in direct proximity to the conflagrations (Alperson-Afil and Goren-Inbar 2010: 24). In order to distinguish between anthropogenic and natural burning episodes, the authors have extrapolated spatial distribution patterns of heat altered flint residues at well-documented younger Magdalenian open-air localities - where knapping near hearths was regularly practised, which in turn yielded dense accumulations of heated flint flakes near the hearth - onto the spatial distribution of heated micro flints at GBY to search for a matching pattern (see Leesch et al. 2007, 2010). Hence, it was assumed that anthropogenic fire in the form of hearths would only thermally alter flint flakes selectively, and not across the majority of the occupational surfaces (Alperson-Afil and Goren-Inbar 2010: 24). An anthropogenic agency would instead yield relatively small but non-random frequencies of heated flakes, spatially clustered across the surfaces (Alperson-Afil and Goren-Inbar 2010: 24). It was also assumed that in cases where burned and unburned micro flints show distinct spatial separation (as opposed to identical distribution across the surface), they could be confidently interpreted as remnants of anthropogenic fires (Alperson-Afil and Goren-Inbar 2010: 24).

According to the excavators' interpretation, spatial distribution of heated micro flints from GBY strongly coincide with such a pattern, since applied chi square testing has demonstrated a presence of high-density accumulations, i.e. clusters of micro flints at various locations throughout the sampled levels where heated micro flints surpass the expected level and always exceed the frequency of unburned ones (Alperson-Afil and Goren-Inbar 2010). The authors' claim these clusters to be good representations of remnants of ancient hearths, now invisible, where lightweight fire proxies such as charcoal and ashes would have been blown away by wind prior to burial, or erased by the waterlogged depositional environment after burial (Alperson-Afil and Goren-Inbar 2010: 24).

Moreover, Alperson-Afil and Goren-Inbar (2010) claim on the basis of GIS spatial distribution mapping of burned and unburned micro flints that three levels (II-6 L-1-3) exhibit 'unambiguous' representations of anthropogenic fires, as these levels exhibit what the authors call "highly significant spatial differentiation" of burned and unburned micro flints (see table 7 and fig 15). The remaining nine levels sampled in their (2010) review (i.e. V-6, V-5, II- 5/6, II-6 L-4, II-6 L-7, II-5, II-6, L-4b, II-6 L-5, II-6 L-6) have all been reported to exhibit varying degrees of overlapping of burned and unburned micro flints (see table 7). Such 'partial' overlapping has been explained by the authors as mirroring various types of 'hearth related patterns', i.e. flint knapping and discard activities that in some cases would have been carried out in close vicinity to a hearth and in others away from hearth areas, as demonstrated at later Magdalenian sites in Western Europe and by more contemporary ethnographic sources (Alperson-Afil and Goren-Inbar 2010: 96). The authors hypothesize that in levels exhibiting varying degrees of overlap (which is 9 out of 12, according to table 7), flintknapping or discard activities would have been performed within close proximity to hearths, whereas in levels described as having *'highly significant spatial distribution'* (3 out of 12, II-6 L1-3, according to table 7), flintknapping and discard activities would have taken place away from hearth areas, hence producing distinctly separated clusters of burned and unburned micro flints (Alperson-Afil and Goren-Inbar 2010: 96, see fig 15).

Table 7. Data from the sampled GBY levels indicating spatial distribution and degree of overlap between burned and unburned micro flints. Dimensions are expressed in m (LEN and WID axis) and m² (area) (from Alperson-Afil and Goren-Inbar 2010).



	Entire layer								Kernel of cluster					[c]SSQ Encircling Kernel	
	Frequencies of burned flint			[a]BFM percentage per sub-square			Chi square test of BFM		Dimensions		[b]Percentage of BFM and UBFM				
	Microartifacts N (%)	Macroartifacts N (%)	Pebbles N (%)	Mean; maximum	Std	[d]Relative area BFM	Σx²	df; p	LEN axis; WID axis	Area	% BFM	% UBFM	Ratio % BFM/UBFM	OBS – EXP % BFM	SR for BFM; n (expected)
Highly significant differentiation															
II-6 L-1	754 (1.40)	17 (1.40)	6 (0.25)	0.34; 5.03	0.84	0.63	580.57	$df = 90; p < 0.001$							
N									0.46 0.41	0.148	3.97	1.25	3.17	2.83	5.25; n=16.6
S									0.46 0.31	0.117	3.71	0.59	6.28	3.32	7.60; n=10.9
II-6 L-2	563 (0.76)	5 (1.05)	2 (0.25)	0.31; 16.30	1.28	0.42	913.27	$df = 69; p < 0.001$	0.51 0.40	0.165	9.41	2.39	3.39	12.63	15.79; n=20.5
II-6 L-3	877 (0.95)	16 (3.13)	1 (0.09)	0.69; 10.30	1.48	0.55	673.37	$df = 66; p < 0.001$	0.50 0.41	0.161	6.72	2.13	3.15	6.61	10.18; n=32.2
Relative overlapping															
V-6	83 (1.84)	2 (0.70)	00 (0.00)	2.00; 20.50	3.63	0.48	56.51	$df = 31; p < 0.01$							
N									0.18 0.16	0.022	4.81	0.70	6.87	1.10	0.40; n=5.08
S									0.53 0.33	0.13	9.63	4.90	1.96	10.00	2.80; n=8.7
II-5/6	400 (4.50)	6 (5.30)	00 (0.00)	0.39; 8.25	1.23	0.39	204.48	$df = 64; p < 0.001$							
N									0.97 0.23	0.167	8.00	4.59	1.74	−2.25	-1.40; n=42.1
S									0.40 0.38	0.122	4.50	1.99	2.26	2.26	2.08; n=18.9
II-6 L-4	1,406 (1.32)	16 (2.45)	5 (0.85)	0.59; 6.82	1.25	0.60	1063.8	$df = 60; p < 0.001$							
N									0.41 0.37	0.121	3.34	1.79	1.86	2.38	4.71; n=50.5
SE									0.47 0.36	0.137	5.83	1.67	3.49	2.64	22.48; n=2.7
SW									0.47 0.29	0.111	3.27	1.00	3.27	1.58	3.90; n=31.7
II-6 L-7 (upper)	677 (2.80)	19 (3.07)	5 (0.63)	0.51; 9.89	1.34	0.77	109.32	$df = 57; p < 0.001$	0.44 0.36	0.125	8.12	3.00	2.70	4.27	4.70; n=38
Almost complete overlapping															
V-5	560 (1.81)	1 (0.31)	00 (0.00)	1.81; 13.40	2.87	0.80	176.43	$df = 33; p < 0.001$	0.42 0.35	0.116	9.46	4.06	2.33	0.79	0.55; n=70.3
II-5	162 (4.48)	4 (3.41)	00 (0.00)	0.34; 11.10	1.45	0.21	200.43	$df = 73; p < 0.001$	0.61 0.51	0.219	10.5	7.73	1.35	−1.19	-0.44; n=20
II-6 L-4b	443 (5.80)	5 (3.20)	4 (1.94)	0.69; 14.40	1.95	0.49	386.27	$df = 55; p < 0.001$	0.94 0.34	0.178	16.5	5.82	2.82	4.30	2.86; n=44.8
II-6 L-5	1,211 (3.66)	12 (6.06)	3 (0.78)	0.69; 6.77	1.38	0.76	241.03	$df = 54; p < 0.001$							
N									0.39 0.31	0.095	4.12	2.59	1.59	−0.24	-0.31; n=84.9
C									0.75 0.38	0.227	6.52	5.42	1.20	−0.84	-1.16; n=77.2
S									1.06 0.44	0.335	9.66	6.44	1.50	−0.09	-0.16; n=46.1
II-6 L-6	251 (2.00)	9 (2.69)	3 (0.64)	0.69; 7.96	1.58	0.60	288.06	$df = 57; p < 0.001$	0.42 0.36	0.120	7.96	2.80	2.84	2.53	1.73; n=13.6

BFM = burned micro flints; UBFM = unburned micro flints; SSQ = sub-square; N = north; C = center; S = south; E = East; W =west; LEN = length; WID = width; OBS = observed; EXP = expected; SR = standardized residuals (from Alperson-Afil and Goren-Inbar 2010).

a) Statistics for percentages of burned micro flints per excavated unit/sub square (i.e. 0.5 m²)

b) Percentages relative to the total number of burned and unburned micro flints within high density kernel of the cluster

c) Sub-square occupying or encircles the majority of the high-density kernel of the cluster

d) The ratio between numbers of excavated units with micro flints relative to the total number of excavated units of the layer (from Alperson-Afil and Goren-Inbar 2010).

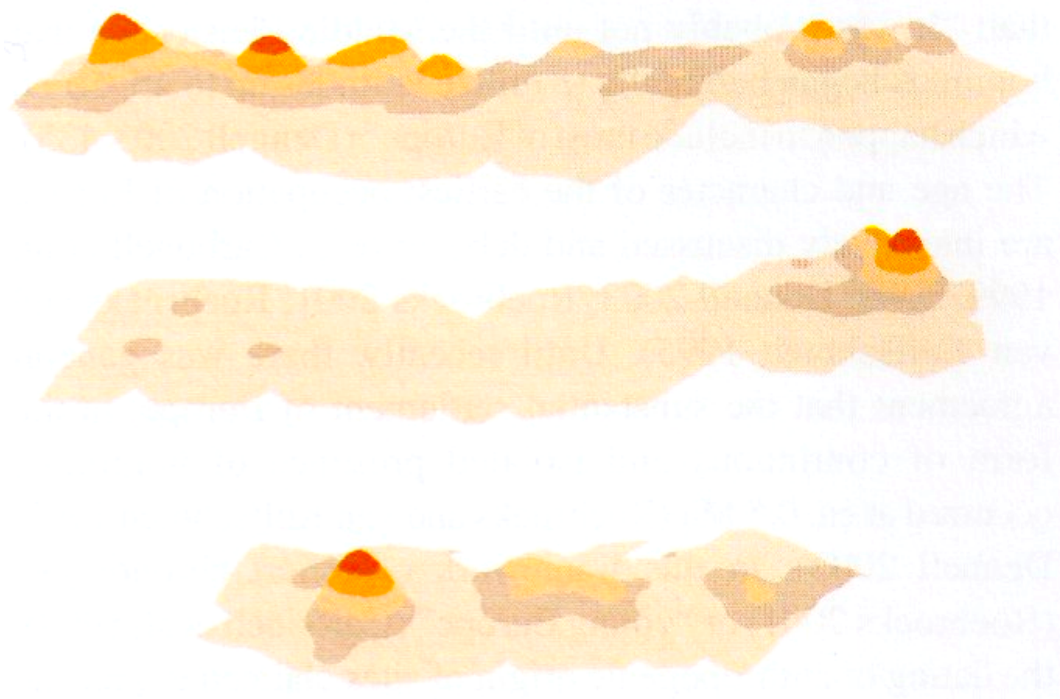


Figure 15. The sequential occurrence of localized clusters of heated micro flints (according to chi square tests and GIS mapping) interpreted as 'phantom hearths' in layer II- 6, level by level from top to bottom II-6 L1– L3 (from Alperson-Afil and Goren-Inbar 2010).

Heated micro flints that have been located outside these inferred 'phantom hearth' features (i.e. clusters) have been interpreted by the excavators as either the result of trampling and/or raking activities, or as a result of taphonomic processes (Alperson-Afil and Goren-Inbar 2010: 96). Alternatively, they have suggested that burned 'background' material may represent remnants of other hearths used with less intensity, which in turn yielded a lower density of burned material; or potentially margins of hearths, of which full radius probably occurs outside the excavated area (Alperson-Afil and Goren-Inbar 2010: 96).

Furthermore, Alperson-Afil and Goren-Inbar (2007, 2010, 2012) argue the selective burning of the micro flints, ranging from 0.76-5.8 % across the sequence (see table 7), to be in favour of anthropogenic origin rather than natural, as surface wild fires would have yielded higher frequencies of heat altered micro flints than what the GBY levels display. They have also excluded other natural explanations, such as volcanic activity, underground fires, and peat fires, to be responsible for the burnings (Alperson-Afil and Goren-Inbar 2010: 10).

Volcanic activity has been excluded as the cause for the burning since the area of GBY has failed to locate any data on such activity, while underground fires and peat fires have been rejected on the basis of their inabilities to sustain burning and produce high enough temperatures to physically damage flint in the moisture rich sediments and thin stratums of peat at GBY (Alperson-Afil et al. 2007: 10).

The excavators have also ruled out taphonomic influences as being responsible for the spatial distribution of burned and unburned flints, and for the production of clusters inferred to as 'phantom hearths' on the basis of Morton's 1995 model (cited in Alperson-Afil and Goren-Inbar 2010) on a correlation between artefact weight and transport mode. His model argues that if taphonomy would have played an prominent role in the spatial distribution of the archaeological material at GBY, then a more linear distribution would be have been expected along the presumed shore line rather than the present case of a non-linear distribution with localized clusters (Alperson-Afil and Goren-Inbar 2010). The authors' further claim on the basis of Feibel's 2001 work (cited in Goren-Inbar et al. 2012: 237) on the deposition of the archaeology at GBY that a 'rapid sealing' of the archaeological material took place at the lake margin, which in turn limited the exposure time available for environmental conditions to sort and alter the spatial distribution of the archaeological material. Feibel (2001: 137,139 cited in Goren-Inbar et al. 2012: 237) has, for instance, argued that level V-5 was subjected to a rise in lake level accompanied by a storm event that in turn buried the archaeological level quickly in a transgression. Feibel (2001: 137, 139 cited in Goren-Inbar et al. 2012: 237) claims such 'rapid sealing' of the archaeological material to be mirrored by the unbroken and unabraded characters of the bulk of the molluscan material from level V-5. Hence, the inferred 'rapid burial' hypothesis of the archaeological material proposed by Feibel (2001) together with Morton's (1995) distribution model has led Alperson-Afil and Goren-Inbar (2010) to conclude the mechanism behind the spatial distribution and clustering of micro flints at GBY to be of anthropogenic origin and *in situ*.

While Alperson-Afil and Goren-Inbar (2010) claim clusters of heated micro flints to represent remnants of now invisible ancient hearths, the repetitiveness of these inferred clusters throughout the sequence (14 levels in total, 12 reported on in 2010) to provide exceptionally strong evidence of controlled and habitual use of fire by hominins already by 780 kya.

7.5. Evaluation

7.5.1. Testing the strength of the evidence of anthropogenic fires at GBY

The site of GBY provides a compelling case of early hominin fire practise. Not only have the unique preservation of the site and its crucial geographical position within the Levantine corridor - widely seen as a central route for hominin dispersal out of Africa and into Eurasia - offered a rare window of insight into hominin behaviour associated with early dispersals out of Africa, but it is also the only example prior to 400 ka in Western Eurasia that expresses possible evidence of hominin habitual use of fire. It is therefore of absolute importance that both the archaeological evidence of GBY and the interpretation of hominin adaptations based on the evidence is critically examined; and yet, this has rarely been the case with GBY. Instead, the scientific community at large seems to accept the original excavators hypothesis without having further examined some of the issues associated with their claims. This is certainly strange given the peculiarity of GBY as an isolated case in an otherwise negative pattern of habitual fire use in Western Eurasia during the first half of the Middle Pleistocene. Therefore, before jumping to conclusions on such an early date of habitual use of fire (780 kya), it seems appropriate to test the strength of the evidence at GBY. The key question arises as to whether the evidence of fire at GBY in fact represents anthropogenic activity, natural combustions, or perhaps both; and if the latter, how one would go about differentiating between the two?

7.5.2. On spatial distribution patterns and ‘invisible’ hearths

While the excavators stress that all archaeological levels at GBY exhibit traces of anthropogenic fires, three levels in particular have been argued to display clear traces of ‘invisible hearths’. This was argued on the basis of high-density isolated clusters of burned micro flints and ‘highly significant differentiation’ of burned and unburned micro flints. These three levels are, as previously discussed, levels II-6 L-1-3. Indeed, according to Alperson-Afil and Goren-Inbar’s (2012) chi square test (see fig 15), there appear to be distinct isolated clusters with a high density of heated micro flints in these levels.

However, according to ratios of burned and unburned micro flints per excavated unit within each level, there exists clear overlapping of burned as well as unburned material; and burned micro flints appear to be spread out almost across the entire excavated surfaces. This certainly contradicts the excavators' interpretation of ‘highly significant differentiation’ of burned and unburned micro flints in these levels. To illustrate more in detail, Figure 16 from level II-6 L-1 demonstrates distinct clusters of burned micro flints inferred as ‘invisible hearths’, that is, isolated from unburned ones even though Figure 17 display both clear overlapping as well as distribution of burned micro flints almost across the entire excavated area.

Figure 16. Spatial distribution of distinct clusters of burned micro flints interpreted as ‘phantom hearths’ from chi square tests and GIS mapping in level II-6 L-1 (from Alperson-Afil and Goren-Inbar 2010).

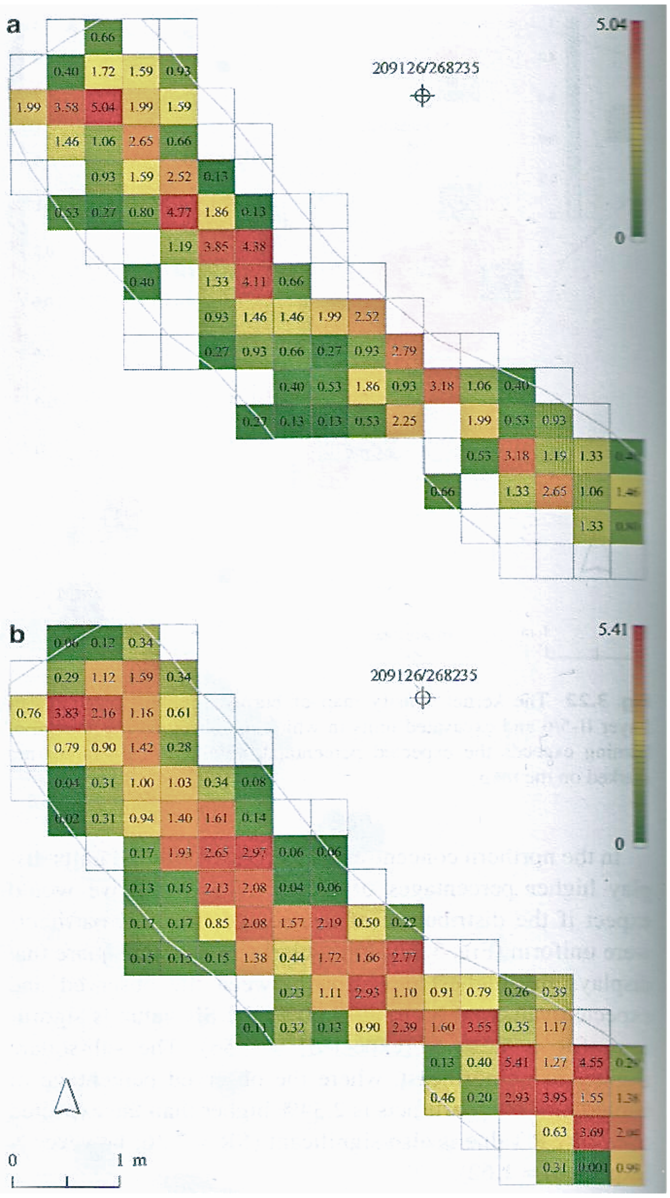
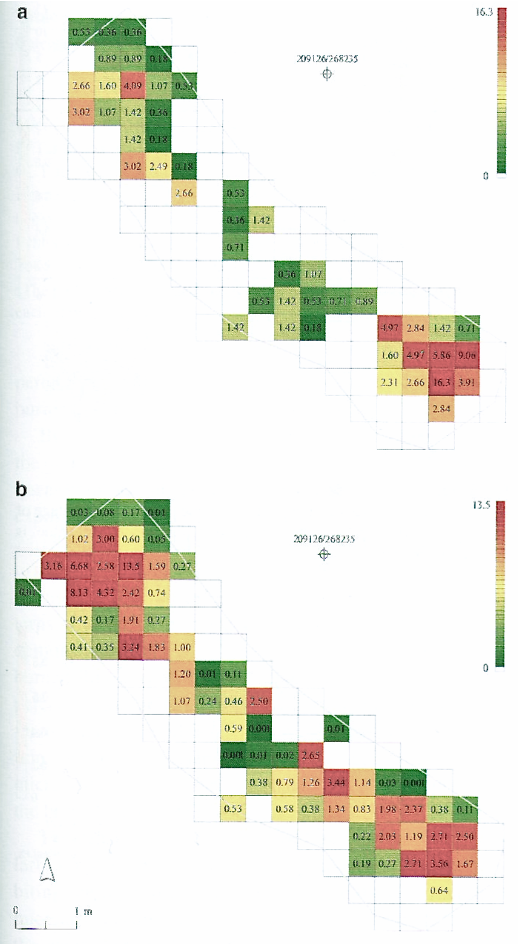


Figure 17. Percentages of micro flints per excavated unit in level II-6 L-1; a) burned micro flints (N=754); b) unburned micro flints (N=53,081) (from Alperson-Afil and Goren-Inbar 2010).

A similar situation can be observed in level II-6 L-2, where Figure 18 demonstrates a single distinct cluster of burned micro flints despite indications of clear overlapping of burned and unburned micro flints across the majority of the excavated surface (see fig 19). Even within the supposed 'high-density' cluster of burned micro flints (see fig 20), high frequencies of unburned micro flints have been reported (see fig 19). Likewise, within the cluster of unburned micro flints (see fig 20), burned micro flints sometimes even exceed frequencies of unburned micro flints (see percentages in fig 19).

Figure 18. Chi square test and GIS mapping displaying one distinct cluster of burned micro flints interpreted as a 'phantom hearth' in level II-6 L-2 (from Alperson-Afil and Goren-Inbar 2010).



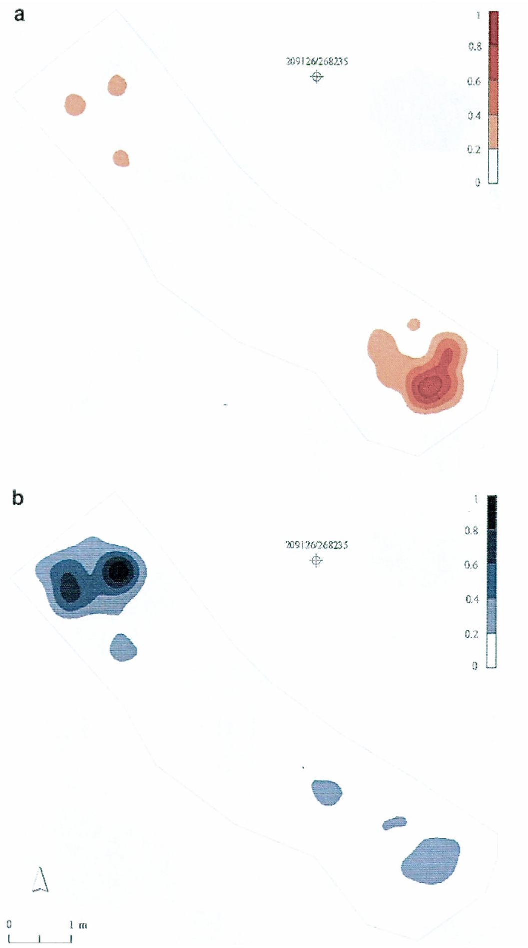


Figure 19 left. Percentages of micro flints per excavated unit in level II-6 L-2; a) burned micro flints (N=563); b) unburned micro flints (N=73,064) (from Alperson-Afil and Goren-Inbar 2010).

Figure 20 right. Kernel density maps of micro flints in level II-6 L-2; a) burned micro flints (N=563); b) unburned micro flints (N=73,064) (from Alperson-Afil and Goren-Inbar 2010).

Level II-6 L-3 demonstrates a comparable contradictory condition. Figure 21 illustrates a single isolated cluster of burned micro flints without any overlap. However, according to Figure 22, burned and unburned micro flints overlap significantly.

Figure 21. Chi square test and GIS mapping illustrating one distinct cluster of burned micro flints interpreted as an 'phantom hearth' in level II-6 L-3 (from Alperson-Afil and Goren-Inbar 2010).

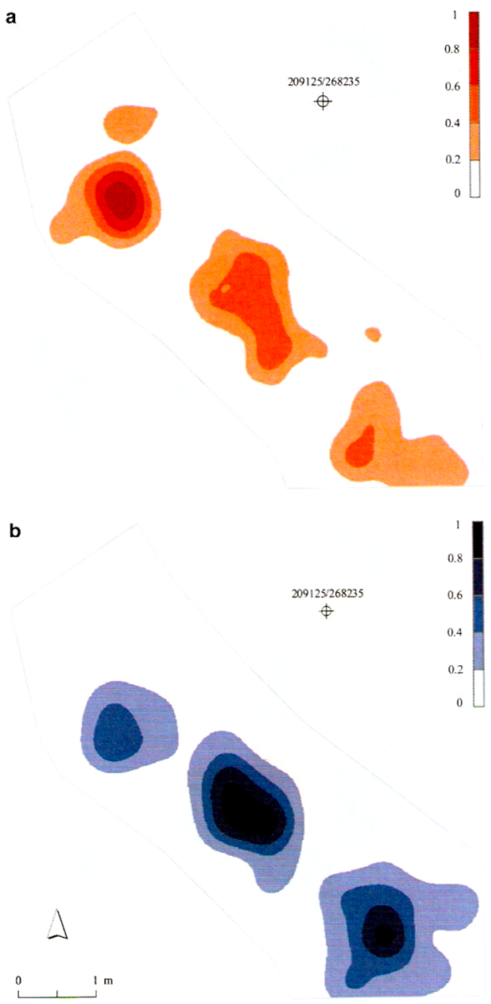


Figure 22. Kernel density maps of micro flints in level II-6 L-3; a) burned micro flints (N=877); b) unburned micro flints (N=91,050) (from Alperson-Afil and Goren-Inbar 2010).

Overall, the intermingled distribution pattern of both burned and unburned micro flints, coupled with the widespread spatial distribution of burned micro flints, contradicts the interpretation of distinct spatially separated clusters of burned micro flints within these levels. When combined, all levels then appear to exhibit overlap of both burned and burned micro flints in various degrees, as well as evidence of burning across the majority of the excavated surfaces. Some areas do, however, exhibit higher frequencies of burned micro flints than unburned ones, which the authors have interpreted as remnants of ancient 'invisible' hearths.

Indeed, there appear to be clusters in each of the levels, as demonstrated by the chi square test figures and distribution maps above. However, where the original excavators claim percentages of burned micro flints to always exceed unburned ones in clusters described as ‘invisible hearths’, their numbers are only relative to the individual total percentage number of excavated micro flints of the entire excavated surface. In direct comparison, unburned micro flints always outnumber burned ones, even within clusters that are expressed as having higher percentage frequencies of burned micro flints. To give an example, in level II-6 L-2 there is a cluster indicating high-densities of burned micro flints (see fig 20a). This cluster covers several sub squares indicating various frequencies of burned micro flints whereof the highest frequency is 16.3 % for burned micro flints (see fig 19a). In the same sub square, proportions of unburned micro flints only amount to 3.56%, which, in direct comparison, appears significantly lower (see fig 19b). However, given that only 563 burned micro flints have been recovered from the entire level, 16.3% in this sub-square only amount to 92 heated micro flints, which is significantly lower than the 2600 unburned micro artifacts that 3.56% out of 73,064 in total amounts to (see caption below fig 19).

Consequently, it appears difficult to envisage ‘invisible hearths’ where the majority of the cluster is made up by unburned micro flints, in this case by thousands. Moreover, even though much later Magdalenian open-air sites have reported on frequencies of unburned flint flakes within or in close proximity to hearths (see Leesch et al. 2007; 2010), such amounts are not as considerable as the numbers presented for unburned micro flints at GBY. It is of course theoretically possible that a knapping place could have been established on top of an abandoned hearth, but of the numerous Upper Palaeolithic (UP) hearth features analyzed by Leesch, no such phenomenon has ever been observed. Not even at Monruz and Champréveyres, despite the fact that both sites are situated on a lake margin, i.e. Lake Neuchâtel (Leesch 2012, personal comm.). In fact Leesch (2012 personal comm.) stresses that such high frequencies of unburned material within or in close proximity to hearths are very strange indeed. This, however, is a frequent dilemma at GBY, where on average incredibly high amounts of micro flints are reported from each level, in some cases more than 5000 micro flints per m² (see table 6). Such large amounts of lithics in such small areas are puzzling, indeed, and evoke all kinds of questions regarding the site formation of GBY. In spite of this, the authors declare the lithic assemblages to be primary context. They argue on the basis of Feibel's (2001) work that the lake margin environment at GBY has allowed for a 'rapid burial' of the archaeology and that post depositional processes had very limited if any influence on the spatial distribution of the lithic material (Alperson-Afil and Goren-Inbar 2010). However, given the deep time element within Palaeolithic archaeology, a 'rapid burial' could mean anywhere from 1 day to 100 years and more. A lot can happen to a site on a lake margin prior to a 'rapid burial'. Therefore, much more information on GBY's site formation is needed to clarify such claims, for example, on how the micro flints were deposited in each level, and what the characteristics are of the sedimentary matrices the finds were recovered from (i.e. coarse or fine grained, etc.).

7.5.3. Anthropogenic verses natural fires at GBY

All levels in total appear to exhibit an overlap of burned and unburned micro flints in varying degrees, which could potentially have been caused by natural combustions following Alperson-Afil and Goren-Inbar's (2010) argument. However, as previously mentioned, the authors have rejected the idea of natural burning even with spatial overlap of burned and unburned micro flints. Instead, they stress that spatial overlap of burned and unburned micro flints might reflect spatial activities in which flintknapping occurred in various proximities to hearths areas, as demonstrated by later Magdalenian site examples (see Leesch et al.

2007; 2010). A very efficient way of testing such hypotheses, as well as the influence of taphonomic disturbance on spatial distribution of stone artifacts, are refitting studies. Such studies were indeed conducted at both Magdalenian site examples used by Alperson-Afil and Goren-Inbar (2010) for comparison, and in both these cases, such attempts were successful in substantiating *in situ* archaeology and hearths, as well as yielding information on the architecture and spatial distribution of hearth features (see Leesch et al. 2010). However, no information on such refitting attempts has been reported from GBY apart from a brief passage on lithic assemblages of unspecified character (i.e. it is unspecified whether these refitting attempts were done on both micro or macro artefacts, or just one or the other) from levels V-6 and V-5, both of which exhibit considerable overlapping (see table 7). In these levels, refitting attempts of the lithic material appear to have failed to yield any positive results, which is puzzling given the flint knapping hypothesis referred to above, and the idea of GBY's lithic assemblages being in primary context. The authors explain the refitting failure as a probable outcome of the small excavated surface and volume from both levels (see table 6), and argue that these results are based on inconclusive data only and might not account for the whole archaeological sequence at GBY (Alperson-Afil and Goren-Inbar 2012: 240). They argue that similar refitting attempts need to be applied to the rest of the levels containing evidence of heated lithic material before jumping to any conclusions on taphonomic explanations for missing refits (Alperson-Afil and Goren-Inbar 2012: 240).

However, such difficulties in succeeding with refit attempts within levels V-6 and V-5 might not come as a complete surprise given the character of some of the burned micro flints within these layers. Even though the authors have interpreted these burned micro flints as artifacts some of those illustrated by Alperson-Afil and Goren-Inbar (2010) exhibit morphological characteristics suggestive of having been produced via natural processes (e.g. frost fracturing). Here, "artifacts" J, K, L in level V-6 are especially suspicious, while C in level V-5 could be a small, heavily burnt piece of flint detached from a larger burned artifact, as it exhibits severe rounding and does not bear clear diagnostic features of a man-made artefact (e.g. a bulb of percussion, striking platform, and/or a ventral surface; see fig 23). On the basis of what can be visually observed from the photograph (which is the only photograph published of the burned micro flints at GBY, to my knowledge), most pieces of lithic material could have been naturally produced with characteristic rounded edges, as opposed to clear affinities to human fabrication - especially artefact J from level V-6, which displays the morphological characteristics of a pebble (see fig 23). This is certainly surprising, and begs the question of how representative this small sample is for the entire assemblage of “micro artefacts” at GBY. Are these the best examples of humanly produced and modified micro flints the excavators have to offer from GBY? This, in turn, leads one to wonder how the evidence of fire at GBY could be considered anthropogenic in nature should a large portion of the burned micro flint assemblage turn out to be merely heat-affected geofacts.

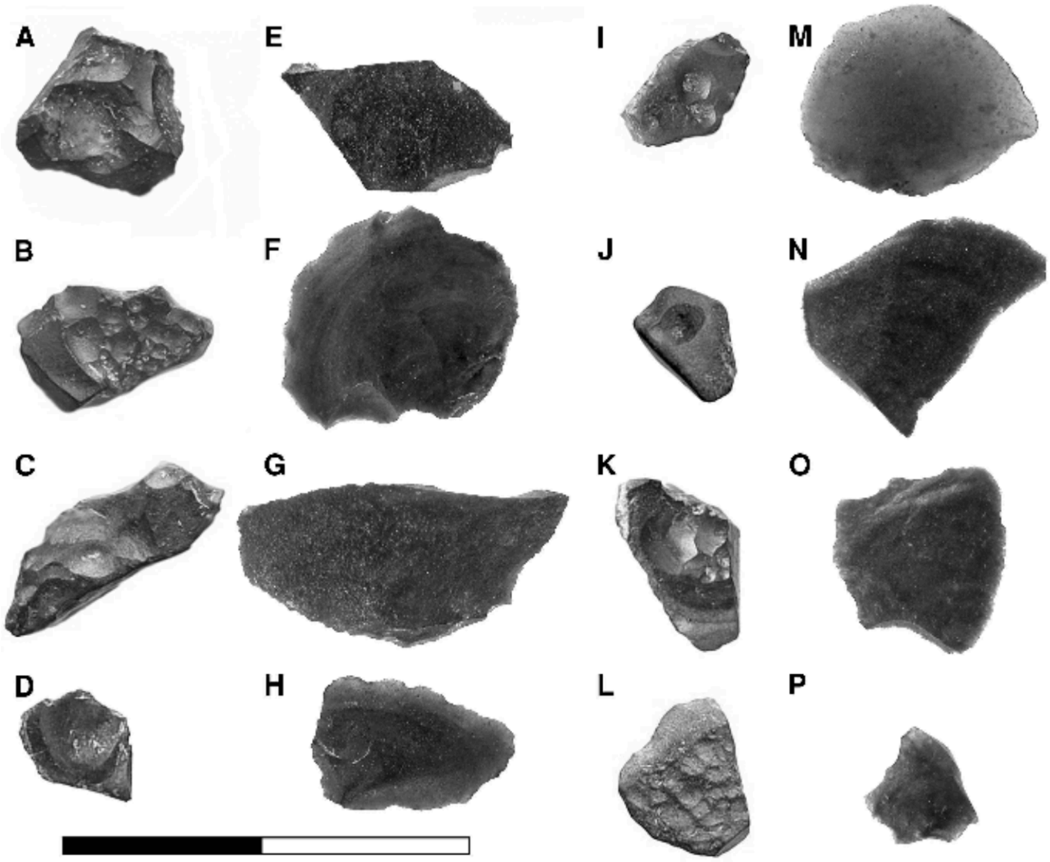


Figure 23. Micro flints (interpreted as man-made micro artifacts) from Area C at GBY. A-D: level V-5 = burned micro artifacts; E-H: level V-5 = unburned micro artifacts; I-L: level V-6 = burned micro artifacts; M-P: level V-6 =unburned micro artifacts. Scale bar is 2cm (from Alperson-Afil and Goren-Inbar 2010).

One way of testing this could be to sample perimeter sediments outside of the occupational area. Should heated natural pieces of flint turn up here, then one could ask: are the naturally heated micro flints in the occupational floors of GBY really primary context? However, it is unclear whether or not Alperson-Afil and Goren-Inbar (2010) have done such sampling.

An additional problem with the dismissal by the authors of natural fires at GBY can be observed in Alperson-Afil and Goren-Inbar (2010), Figure 14. Here, levels II-9, II-11, III-7 and III-9 exhibit presence of charcoal residues despite having an absence of hominin proxies (e.g. burned flint, burned wood). These separate charcoal indications occur in between levels of supposed hominin habitation. This is interesting from the point of view that although there is an absence of hominin presence in these layers, there are still proxies of fire (i.e. charcoal), which in turn suggests the presence of natural fires having been ignited on the same stretch of beach without a hominin presence. Unless these pieces of charcoal have been subjected to horizontal interstratigraphic migration, a phenomenon not discussed by the authors, natural fires appear to be the most likely agent. This could imply the possibility of mixed origins of the fires at GBY, i.e. both natural and anthropogenic. This is certainly a possibility when one compares the levels with charcoal and no apparent human presence to levels with inferred humanly modified micro flints. However, for levels with heated micro flints, it seems more plausible to be either anthropogenic or natural, not both, as mixed origins of fires would most likely have yielded a more pronounced differentiation between the characteristics of evidence than the uniformity demonstrated in these levels. Although, how to distinguish between natural and anthropogenic fires with certainty is a universal problem within the domain of Palaeolithic fire that, unfortunately, based on current data, also applies to GBY.

One of the key issues with GBY is that it is a unique site in many respects, and therefore extremely difficult to evaluate. Unfortunately, there are no contemporary sites with similar ecological and morphological signals and a comparable continuity of burning throughout the sequence, leading to uncertainty as to what the burning actually represents. As an alternative, Alperson-Afil and Goren-Inbar (2010) used intra-site spatial structuring of hearth features and activities carried out around hearth features during the Magdalenian period to infer evidence of anthropogenic fire at GBY. However, to draw behavioural comparisons across some 760,000 years of human evolution from completely different latitudes, depositional environments, and ecological settings may be considered an unsound analogy.

On the other hand, there are striking similarities between the frequencies of burned flint at GBY and much younger Upper Palaeolithic open-air localities at which hearth features have been demonstrated (again see Leesch et al. 2007, 2010). In fact, the low percentages of heated micro flints at GBY that range from 0.76-5.8 % are strikingly similar to the percentages of heated flint chips (3-10 mm in maximal dimension) at the Magdalenian sites used for comparison in Monruz and Champréveyres, where percentages ranges from 4–4.55%, respectively (Leesch 2007 in Plumettaz 2007: 209; Leesch 1997: 43,44). Actually, low percentages of heated micro flints seldom reach above 5% in Magdalenian flint assemblages, and are a widespread characteristic of Late Upper Palaeolithic sites (see Löhr 1979: 26-34; Kind 1987:71-72; Leesch 1997: 41). It is not until much later in time at Azilian and Mesolithic sites in Europe that flint assemblages display more than 10% heating of flint residues, and on several occasions up to 40% (Leesch et al. 2010: 63). Such differences in frequencies of heat altered flint residues have been interpreted by Leesch et al. (2010) as mirroring the mode and function of hearths. In the case of the low frequencies of heat altered flint chips from Late Upper Palaeolithic open-air sites in Europe, Leesch et al. (2010, 2012) have attributed this to a culture specific feature, as hearths from this period are almost exclusively represented as stone covered hearth features (Leesch 2010: 66). These 'stone covered hearths' in turn, explain the presence of low frequencies of heated flint chips at these locations where knapping debris falling into the hearth would have been heavily reduced by the stone covering around the fire. Hence, knapping activities at the periphery of these hearths would only have resulted in small numbers of chips being heated (Leesch et al. 2010: 64, see fig 24 for a reconstruction of a stone-covered hearth). Conversely, the high frequencies of heat altered flint chips at later Azilian and Mesolithic assemblages could then, according to Leesch et al. (2010), be explained by the use of larger open fires around which knapping activities resulted in higher frequencies of flaking debris falling into the fire and becoming heat altered.

In the case of the two Magdalenian comparison sites of Monruz and Champréveyres, large amounts of stones, i.e. cobbles and stone-slabs, were also found scattered across the entire occupational surfaces, approximately 2000 kg at Monruz, and half that amount at Champréveyres (Leesch et al. 2010: 58). The majority of these were brought onto the sites for procurement of slabs used in the construction of stone covered hearths, as has been substantiated by refitting at both sites (Leesch et al. 2010: 58, see fig 25 for an example on refitting of stone slabs used in stone-covered hearths at Monruz). All this has interesting implications for the inferred hearth features of GBY where the similarly low frequencies of heated micro flints could imply the use of stone covered hearths. However, GBY seems to lack not only refitting (although this has only been attempted at two levels yet, V-5 and V-6, see above), but also comparable amounts of stone slabs and cobbles like those scattered across the occupational surfaces at Champréveyres and Monruz. Following this line of reasoning, one could question whether the low frequencies of heated micro flints alone are enough evidence to except a hypothesis of anthropogenic fire since taphonomic processes could be held responsible for producing the spatial distribution of the heated micro flints and the clusters inferred as 'invisible hearths'. The origin of the fires could thus be hypothetically explained as natural, in which natural combustion could have taken place at one or several locations, heating portions of flint debris that in turn could have been spatially distributed by natural causes, thus yielding clusters at various locations throughout the sequence. Having said that, such hypothetical claims needs to be tested. Therefore, it is crucial to clarify site formation and the role of taphonomy at GBY, which at present could be difficult considering the destruction of major parts of the site in 1999 (see Sharon et al. 2002). The other key for solving the origins of the fires at GBY is refitting, where success in even just one level would lend more conclusive support to the argument for anthropogenic fires. Prior to more thorough investigation, the claims of controlled and habitual use of fire at GBY must be viewed with severe caution.

Figure 24. Recontruction of a stone-covered hearth Late Upper Palaeolithic Magdalenian style in Europe, around which frequencies of heat altered flint chips occur below 5 % (from Leesch et al. 2010: 60).

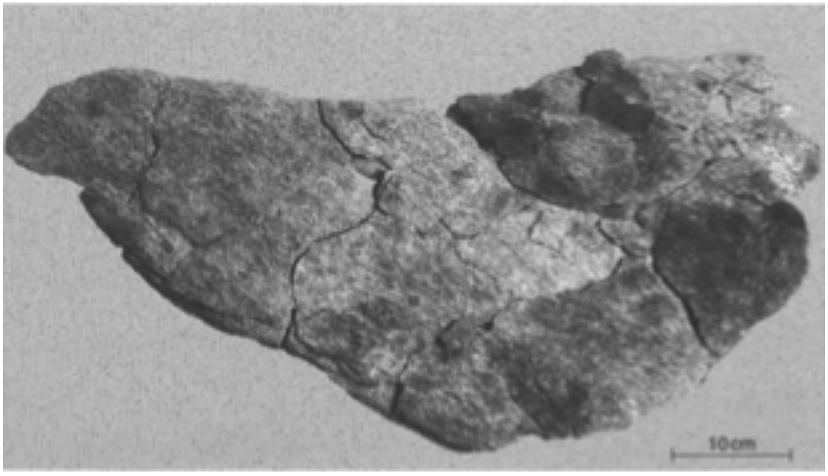


Figure 25. Refitting of stone-slab used in the construction of stone-covered hearths at the Magdalenian site of Monruz, Switzerland. Scale bar indicating 10 cm (from Leesch et al. 2010: 60).

7.6. Conclusion

The repetitive evidence of burning throughout the sequence of GBY is striking. The fundamental problem then becomes how to securely link these fire proxies to specific types of fire producing agents. As previously discussed, Alperson-Afil and Goren-Inbar (2010) spatial exercise is misleading in its use of percentages, and the inferred ‘clear’ separation of heated and non-heated lithics. There are also problems with their interpretation of heated “artefacts”. Moreover, there is burnt material (charcoal) where there is no info/data indicating human presence.

This all calls for additional data (including data on site formation processes, sedimentary processes, refitting, and artefact-non-artefact issues) to evaluate the claim of controlled and habitual use of fire at GBY, because extraordinary claims call for extraordinary evidence. As it stands now, the evidence at GBY can be explained in terms of natural fires.

8. Final Discussion

In sum, archaeological evidence from Western Eurasia clearly suggests that controlled and habitual fire utilization was not a behaviour practised by hominins that left the tropical zone to colonize temperate latitudes as envisaged by advocates of the long chronologies. Yet, such patterning is based on negative evidence that only requires a single positive observation to be debunked. GBY has willingly been accepted as such a destroyer of the present negative pattern. However, as demonstrated by this research, current evidence from GBY is riddled with too many uncertainties and ambiguities that could very well be the result of palimpsests of natural fires commingled with hominin habitations. In that regard, present studies of the evidence at GBY fail to reject the current null hypothesis of a negative signal of fire use in Western Eurasia prior to 400 ka.

On the other hand, hypothetically speaking, even when accepting GBY as an outlier, it does not necessarily change the negative pattern of controlled and habitual fire use prior to the second half of the Middle Pleistocene. One could argue a single outlier to be too weak to completely destroy an otherwise negative pattern of controlled and habitual fire use. Perhaps it is possible to envisage, just for argument's sake, that some groups developed habitual fire practices and transmitted the skills to do so from generation to generation, but that these practices disappeared when these groups vanished. Thus, habitual use as a skill only transmitted from generation to generation over large amounts of time and (social) space later, after undoubtedly many earlier inventions of such practices in many areas and at many points in time. However, it might have taken a lot of time before fire became an integral part of the human niche. While there is a possibility that GBY *may* indicate the use of fire over many generations (which is doubtful, as demonstrated), it does not mean that habitual use of fire was an integral part of hominin behaviour by this time, as envisaged by the advocates of the long chronologies.

That said there is a more fundamental problem here with regards to the construction of chronologies based on evidence of inferred behaviour. When is there enough evidence to turn “sporadic” fire use into “habitual”? Where do we draw the line?

The apparent negative pattern of controlled and habitual fire use in Western Eurasia prior to the second half of the Middle Pleistocene does not discount the notion that earlier hominins in Africa or Asia might have used fire occasionally from natural sources, especially in ‘frequent fire areas’, such as the African savannah and South East Asia (see fig 26). At the other extreme of the *Homo erectus* range, Trinil, Java in particular provides a good archaeological demonstration on frequent volcanic activity yielding tropical forest fires, as demonstrated by charred plant remains in *Homo erectus* bearing deposits (see Carthaus 1911; Schuster 1911). However, as pointed out by Roebroeks and Villa (2011) and Gowlett (2010), amongst others, natural fires of various characters would only have been accessible to manipulate occasionally, which means that traces of such ‘opportunistic’ activities might have failed to manifest themselves archaeologically. That being said, the recent article by Berna et al. (2012 in press) claims microscopic evidence from Wonderwerk cave in South Africa to demonstrate *in situ* hearths, thus controlled use fire, at approximately 1.0 Ma already. However, in this case, there are clear issues with the authors' interpretation of *in situ* hearths, since the sediments beneath the concentrated charred material (plant remains and small pieces of bone) do not appear to have been oxidized, as would have been the case if the fire proxies had indeed been in a primary context. This means that there must have been some transport of the heated material within or from outside Wonderwerk cave (Roebroeks 2012 personal comm.)

Nevertheless, if controlled use of fire was indeed routinely used from the Early Pleistocene onward, then this would have left archaeological signals at least at some of the early occupation localities within Western Eurasia, not to mention at long and well preserved Middle Pleistocene cave sites such as Gran Dolina and Caune del Arago. Yet, this is not the case. What we are perhaps looking at in these early colonisations of Western Eurasia and Europe in particular is a mixture of seasonal habitation, short stops, many accumulated short stops, and failed colonization attempts as a result of a lack of fire domestication. Unfortunately, many of these early sites only provide sparse evidence of human presence that only allows for low-resolution data on mode and tempo, which in turn have resulted in difficulties in inferring the duration of an occupation. One hint might be that a more widespread occupation of Europe in a wider range of climatic conditions including glacial occupation did not appear to have taken place prior to 500 ka (see Roebroeks and Kolfschoten 1994), which is shortly before (in Palaeolithic terms) the earliest evidence of fire presents itself. This would imply that more permanent habitation of higher latitudes (above 50 degrees north) owe its delay to the second half of the Middle Pleistocene due to a lack of fire domestication and fire production.

While this appears to be a possible explanation, there are, however, indications of human presence at higher latitudes (above 50 degrees north) during the Early and first half of the Middle Pleistocene *without* any evidence of fire at, for example, Happisburgh and Pakefield in the UK. However, here, resolution on the duration of habitation is missing, which means that these locations could have been only briefly visited when conditions allowed, i.e. warmer conditions - a scenario that has also been confirmed by palaeobotanical and faunal remains from archaeological bearing deposits at both sites (see Parfitt et al. 2005, 2010).

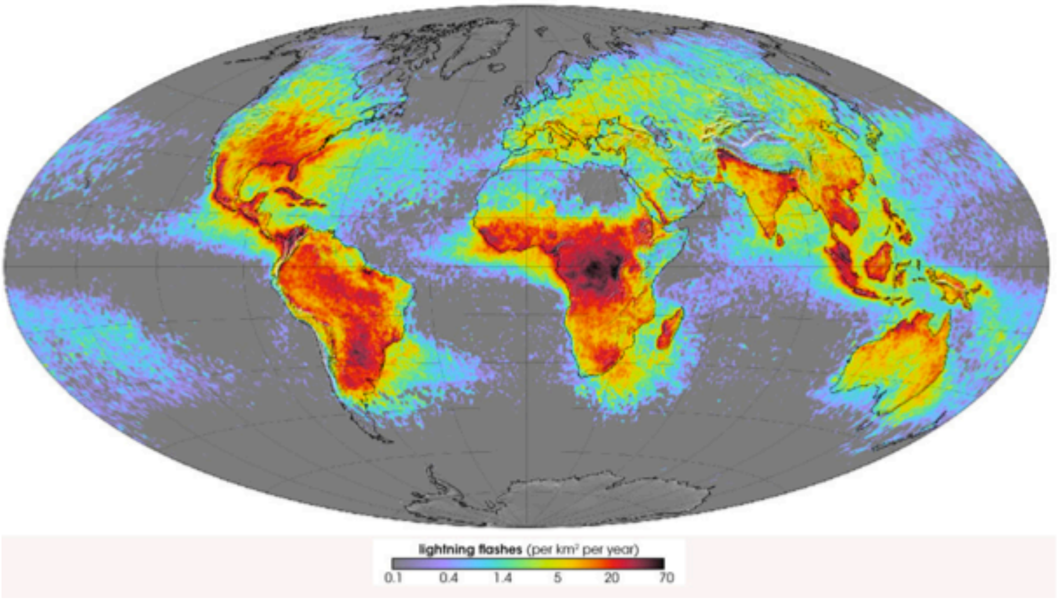


Figure 26. Frequencies of annual lightning flashes across the globe per km². Data collected by NASA satellities between 1995 and 2002 (NASA image from Sandgathe et al. 2011).

Having said that, difficulties in establishing chronological frameworks for various types of fire practices is not only hampered by the ambiguities that patterns of negative evidence propose, but also by the ambiguity of fire proxies that even with positive indications (i.e. identified as burned), as seen at GBY, display uncertainties to their origins. Such undefined criteria for hominin fire utilization have resulted in contradictory results. To illustrate, Sandgathe et al. (2011) consider heat altered flint residues below 1% at Pech de l'Aze IV and Roc de Marsal an indicator of absence or extreme scarcity of fire use, while similar low frequencies of identical fire proxies (all the problems of their identification at GBY not taken into consideration for argument's sake) are interpreted as controlled and habitual use of fire by Alperson-Afil and Goren Inbar (2010) at GBY. Likewise, where Roebroeks and Villa (2011) consider evidence from 400 ka and onwards to represent controlled and habitual fire use, Sandgathe et al. (2011) interpret this evidence as sporadic only and not habitual. It is exactly such issues of interpretation and absence of a framework on specific proxies for inferred fire use (e.g. controlled and habitual use) that have produced a blurred chronological understanding of hominin fire utilization.

9. Final Conclusion

The goal of this thesis was to test the strength of the models that are challenging the long chronology of controlled and habitual fire use. This research has clearly pointed out ambiguities in the interpretation of positive as well as negative evidence of hominin fire utilization. Not only are the short chronologies built on negative evidence, which means that they could easily be falsified since absence of evidence is not necessarily evidence of absence, but there are also problems with regards to the authors' interpretation of the fire proxies upon which they reach different conclusions on inferred fire use (opportunistic, controlled, habitual, etc.) based on the same evidence. This is particularly the case with regards to circumstantial fire proxies (e.g. heated sediments, lithics and fauna) in open settings that could have easily been the product of natural fires. However, correct identification on the origins of circumstantial fire proxies is not just a problem in the short chronologies, but is even more of an issue for the long chronologies in which most of the archaeological evidence of fire is circumstantial and sparse. The ambiguities of the evidence used in the various chronologies by and large stem from a lack of clearly defined frameworks for fire proxies and the inferred fire use they may represent. On such terms, it is therefore very difficult to a) securely determine presence of anthropogenic fire, and b) assess the strength of the various fire chronologies. In light of such ambiguities, how can anyone expect a reliable fire chronology to be developed? More importantly, how can we get there?

10. Future Outlook – Turning Heat into Light

As demonstrated in this research, there are several issues that have led to the creation of the various fire chronologies; 1) the use of negative evidence, 2) the ambiguity of circumstantial fire proxies, 3) undefined framework and criteria for identifying fire proxies produced by hominin agency as opposed to natural causes, and 4) a lack of a framework for identifying different types of fire practices (i.e. opportunistic, controlled, habitual). While many of these issues are indeed difficult to solve and/or clarify, they are nonetheless necessary hurdles to overcome if secure fire chronologies are to be developed.

In this chapter, I aspire to turn some of the current heat into light by providing a dynamic and practical approach to clarifying some of the ambiguities and discrepancies that have yielded this blurred understanding of fire use during the Palaeolithic. In addition to this, I seek to provide avenues for future research on issues within the Palaeolithic domain that are yet to be solved that hamper the development of clear and secure fire chronologies (i.e. controlled and habitual).

10.1. Suggestions on how to test the strength of negative evidence of fire

It is a common fact that archaeological methods have certain limitations in reconstructing past human activities, even more so within the domain of Palaeolithic fire research, where perishable organic material like charcoal and ash could easily have been redeposited far away from its original location by the actions of water, wind or ice, or been destroyed by degradation and destructive post-depositional processes (see Weiner 2010). It is also likely that past and current archaeological methods could have destroyed evidence, or, even more likely, overlooked evidence of fire, particularly small microscopic particles of charred plant and bone material, as such evidence would be difficult to detect with the naked eye. Combined, these factors could have contributed to what appears to be an absence of fire evidence or negative evidence at a site.

However, by means of the application of accurate methods, microscopic evidence of fire might possibly be detected and recovered if possible to differentiate between natural and anthropogenic. Unfortunately, as of now, investigations of fire have for the most part only been launched at sites with clearly visible traces (e.g. heated lithics, charred bone, combustion features, stone-lined hearth features, etc.). This has resulted in seemingly invisible evidence of fire potentially being missed at sites that lack such clear visible traces.

In order to test the strength of a negative signal of fire at a site via ‘undetectable evidence’ (i.e. microscopic evidence), a multidisciplinary approach is suggested, which warrants development of standardized technological packages comprising geological site formation analyses, and a variety of efficient fire detecting methods like micromorphological thin section analysis (see Weiner 2010: Berna et al. 2012 in press), archaeomagnetism (see Herries 2009), and chemical analyses (where elevated phosphorous or trace elements levels in layers with burning). Such a ‘standardized package’ would have to be *routinely* implemented at archaeological investigations of Palaeolithic deposits, particularly at sites that appear to be fire sterile. With such a new approach, it might also be wise to re-visit Palaeolithic sites with a current status of absence of fire to test the strength of the negative signal, especially Palaeolithic sites excavated during the early and mid-20th century (which are numerous within Europe), where crude and limited methodologies could have easily overlooked microscopic traces of fire.

10.2. Suggestions on how to develop clear frameworks for anthropogenic fire and the various fire practices

Other issues hampering the development of secure fire chronologies are undefined criteria for anthropogenic fire and missing frameworks for identifying various types of fire use (i.e. opportunistic, controlled, habitual). In these cases, a clear set of criteria for anthropogenic fires needs to be developed, which defines fire proxies that clearly distinguish between hominin-derived and natural fire. Though, in order to establish such a framework, we first need to develop a clear understanding of the characteristics of both anthropogenic fires and natural fires, and how these various types of fires affect archaeological material. One way of studying the effects of fire on the environmental could be to examine sites with evidence of burning with a clear negative signal of human presence, for instance, sediments that date from before the emergence of the genus *Homo*. At such locations, it would then be possible to study the characteristics of natural fires (i.e. the physical effects of the fires on organic and inorganic material). Next, sites with evidence of burning and certain hominin presence would be examined in terms of physical effects of fire on the environment. Finally, the results of both these sites would then be compared with each other in order to define proxies for evidence of anthropogenic and natural fire (Roebroeks 2012 personal comm.). Perhaps, a more exciting work (and perchance also more fruitful) would be as previously discussed, to examine sterile layers from sites like GBY and compare the findings from artefact bearing horizons. Here, one could possibly expect to find instances of off-site burning when exploratory trenches or test units are sunk around existing sites.

Another way of differentiating between natural and anthropogenic fires would be to apply sedimentary DNA testing (*seda DNA*) at locations with evidence of burning, but lacking visible hominin proxies (e.g. lithics or skeletal remains). Seda DNA sampling has the ability to detect seemingly invisible traces of hominin presence in mitochondrial DNA from traces of hair, urine, epidermal cells and feces in certain well-preserved Palaeolithic sedimentary contexts, and could aid in identifying physical presence of hominins, thus lending credence to the human or natural origin of fire at a site (for more information on seda DNA's abilities to detect traces of humans and other faunal elements, see Haile 2009; Willerslev 2003).

In this context, it is also important to stress once again that refitting studies of lithic material at sites with burning could help identify primary contexts and *in situ* archaeology with evidence of burning, which in turn would lend support to the argument of anthropogenic fires rather than naturally caused ones. Furthermore, it would be necessary for cases like GBY, where extraordinary claims of controlled and habitual use of fire and fire production could be explained as natural fires, that excavators deliver more detailed information of site formation and taphonomy as well as more and better visuals on the fire proxies themselves.

The issue of a missing framework for identifying various types of fire use (i.e. opportunistic, controlled and habitual) is another tough challenge. One of the major keys to this would be to conduct thorough archaeological and geological field surveys to identify new sites with evidence of hominin presence and burning. Again, this includes checking 'background noise' around the perimeter of sites with negative and/or positive evidence of fire to search for either more traces, or to detect positive traces in a seemingly fire sterile contexts. Unfortunately, in this day in age, we often dig where we must, not always where we would like. However, in order to evaluate opportunistic verses habitual fire use, it is crucial to examine a number of sites with evidence of anthropogenic fires relative to the total number of human habitation localities per MIS stage correlate and geographical area (see Sandgathe et al. 2011b). Such an approach would be able to reveal patterns of when fire use might have altered from being opportunistic to habitual (see Sandgathe et al. 2011b). Then again, this requires a simultaneous launch of the new research approach discussed above to exclude or confirm negative evidence of fire at sites.

Habitual fire use would also have required the knowledge of fire production, as natural conflagrations would have occurred only sporadically, potentially with large hiatuses in between, especially in less fire dense areas like Europe. Therefore, to securely infer habitual fire use, fire production tools need to be sought for in Palaeolithic deposits. As there is no current substantial evidence of how humans prior to Upper Palaeolithic hunter and gatherers made fire (although see Stapert and Johansen 1999 for a suggestion), we do not know which human taxon could make fire at will beyond modern humans, or how they might have done it. As discussed in this thesis, some authors even question late Neandertals' abilities in making fire at will (see Sandgathe et al. 2011). According to ethnographic sources on contemporary hunter and gatherers, there are two basic ways of producing fires: either by wood on wood friction via linear or rotational motions (see Hough 1926, 1928; Weiner 2003), or by stone on stone percussion, usually between flint and pyrite (see Weiner 1997, 2003). Since wooden items are easily perishable materials, it might explain the absence of evidence of such fire making methods in early Palaeolithic contexts. However, fire production tools of stone would have a better chance of surviving the hands of time. This begs the question as to whether the apparent absence of such items in the archaeological record is dependent upon how extensively the tools were being utilized. Such a variable would be particularly pertinent with regards to Neandertals, who are well known for their expedient use of technology (see Dibble 1984, 1987; Roebroeks et al. 1997). This being said, microscopic use-wear traces of fire production on flint and pyrite items might have been overlooked due to weak use-wear traces resulting from short term usage (see 'expedient strike-a-light hypothesis' in Sorensen 2011). In order to test for possible presence of fire production in Palaeolithic assemblages, one might consider conducting use-wear analysis on the lithic artefacts from these deposits to look for said traces (see Stapert and Johansen 1999; Sorensen 2011).

A final avenue for future the research of habitual fire use would be to follow up on Sandgathe et al.'s (2011) results from Roc de Marsal and Pech de l'Aze IV. In this context, it would be interesting to 1) search for a matching pattern of more frequent fire use during warmer climatic conditions as opposed to less frequent during cold snaps on a wider geographical scale in Middle Palaeolithic Western Europe (and/or across the whole Neandertal biogeographic range, for that matter), and 2) test the hypothesis of Neandertal infrequencies of fire use in relation to climate as a result of seasonal alternations of mobility patterns by means of raw material provenance data. Subsequently, such research would test the validity of the hypothetical claims of some late Neandertal groups possibly being seasonal fire exploiters relying on natural conflagration, rather than ubiquitous fire utilizers producing fire at will.

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Abstract

Decades of research on the role and frequency of fire use in human evolution have only yielded a blurred understanding of the chronology of anthropogenic fire practise. This predicament has by and large resulted from an ambiguous archaeological record, issues of preservation of fire residues, as well as undefined frameworks for the scientific study of anthropogenic fire. In fact, besides stirring scholarly debates that in many ways has produced more heat than light, very little actual progress has been made in the last decade with regards to the general understanding of when and where various fire practices (i.e. controlled, opportunistic, and habitual) have emerged. Instead, variable length chronologies have been developed in which various researchers read and interpret the same evidence of fire in a variety of ways.

This thesis sets out to add some clarity to the debate by 1) providing a comparative analysis of the various chronologies, with a focus on testing the strengths and weaknesses of the shorter chronologies against the wider background of fire evidence, i.e. the long chronologies; 2) by examining major challenges hindering any considerable progress in establishing a sound and agreed upon chronological framework for fire use and its subsequent production during the Pleistocene Period; and 3) by providing practical solutions and suggestions on directions for future research.