On the Role of Fire in Neandertal Adaptations in Western Europe: Evidence from Pech de l'Azé IV and Roc de Marsal, France

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ABSTRACT

Though the earliest evidence for the use of fire is a subject of debate, it is clear that by the late Middle Paleolithic, Neandertals in southwest France were able to use fire. The archaeological record of fire use in this place and time is, however, quite patchy. While there are a growing number of sites with impressive evidence for fire use, there are also a much larger number of sites without such evidence. Based primarily on evidence from two recently excavated well-stratified Middle Paleolithic sites, we argue here that taphonomic issues, sampling bias, or site use are not sufficient explanations to account for the relative lack of evidence for fire. Given that modern hunter-gatherers use fire daily and in a wide variety of circumstances, the prolonged periods of Mousterian occupation without fires, even during some of the harshest conditions of the late Pleistocene, raises significant issues regarding the role of fire during these times. In our view, the evidence suggests that Western European Neandertals were not habitual fire users. One explanation advanced here is that at least some Neandertals, even in the late Middle Paleolithic, lacked the technological skill to make fire on demand, and thus relied on access to natural sources of fire.

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> Thus Zeus spoke in rage… and would not bestow the power of inexhaustible fire to the Melian tribe of mortal men who dwell on the earth. However, the noble son of Iapetos deceived him, pilfering the far-seen glow of inexhaustible fire in a hollow wand of fennel. And he stung high-thundering Zeus to the depths of his soul whose dear heart was filled with rage as he glimpsed amongst men the far-seen glow of fire. (Hesiod, Theogony: 561–569)

INTRODUCTION

According to Greek mythology, one of the greatest gifts to humans was presented to them by Prometheus when he brought down fire that he had stolen from Zeus. Today, just as in 8th Century BC Greece, fire is seen as a fundamental aspect of human adaptation, from hunter-gatherers through to the most technologically sophisticated. Understandably, therefore, there is considerable interest among paleoanthropologists in documenting not only when hominins began using fire but also how they used it. There is, however, considerable debate over the evidence for fire, and, not surprisingly perhaps, particularly over the earliest evidence.

Various claims, based on a range of evidence, have been presented to suggest that fire use began prior to 1.5 Ma among early hominins in Africa and Eurasia. Many of these claims have been called into question, however, based mainly on the potential for equally plausible natural origins for such fire residues (e.g., Bellomo 1990, 1994; Binford and Ho 1985; Clark and Harris 1985; Goldberg et al. 2001; James 1989; Karkanas et al. 2007; Weiner et al. 1998). Similar criticisms can be extended to the presence/occurrence of presumably burned bone or flint as well, as for example, at Yuanmou and Zhoukoudian in China at 500+ kya (see above references). There are also examples where residues originally interpreted as the remains of fires are later identified as something else. At Zhoukoudian, for example, black lenses originally assumed to be fire residues (e.g., Jia 1975) have since been identified as finely laminated silts and organic matter unrelated to burning and certainly redeposited, possibly as a peat-like accumulations; the upper ashes in Layer 4 are simply diagenetically altered loessial deposits washed into the cave from above (Binford and Ho 1985; Goldberg et al. 2001; James 1989; Shahack-Grosset al. 1997).

Recently, Roebroeks and Villa (2011) have considered the question of early fire use in Europe. They specifically question the assumption that the colonization of European latitudes would have required fire. To test this they assemble a large database of published sites and, importantly, they consider not only direct evidence of hearths but also indirect evidence of burned bones, heated lithics, and charcoal. Further, given that natural fires in the landscape can leave traces of fire on open-air archaeological sites, Roebroeks and Villa limit their database to cave and shelter sites. The result is that evidence for fire starts to occur in the archaeological record after 400 kya, which is well after the initial occupation of Europe, and is not frequent until MIS 5 and later where it shows a trend of increasing frequency in the archaeological record.

The Roebroeks and Villa (2011) approach, however, does not attempt to quantify what proportion of sites have evidence for the use of fire or even within a site what levels have evidence for fire (Sandgathe et al. 2011a). So while the results provided by them make it clear that there is increasing evidence for fire through the Middle Paleolithic, it seems likely that this pattern is driven by the number of dated Middle Paleolithic contexts, which also increases through time. We therefore suggest that this taphonomic explanation for the pattern should be the null hypothesis. This would help reconcile the authors' observation that the evidence for fire use increases over time with the work of others who have demonstrated an apparent scarcity of fire evidence overall, which appears in only a very small percentage of occupation layers (Cohen-Ofri et al. 2006; Davies and Underdown 2006; Dibble et al. 2009; Gowlett 2006; James 1989; Perlès 1981; Roebroeks and Tuffreau 1999).

Here we present evidence, based on recent excavations by the authors at two Mousterian sites in southwest France, Pech de l'Azé IV and Roc de Marsal, for the persistent scarcity of fire well after its first occurrence in the European Middle Paleolithic record. What these data strongly suggest is that while Neandertals occasionally used fire, there were also major periods of time when fires were either not present at these sites or were present only sporadically, even during periods of relatively cold conditions. As will be argued below, the near absence of fire evidence in some levels at these sites cannot be explained by taphonomic processes, excavation bias, or changes in site function, and furthermore, the length of time these sites were occupied without using fire to any significant degree is totally inconsistent with modern hunter-gatherer use of fire. This evidence challenges the assumption of immediate and widespread use of fire, and at least in the case of western European Neandertals, it seems quite likely that fire use was not an essential aspect of their behavior (Sandgathe et. al 2011a). Because this suggestion would represent a significant difference between their behaviors and those of recent hunter-gatherers and even contemporaneous populations of both moderns and Neandertals living in Africa and the Near East (e.g., Brown et al. 2009; Meignen et al. 2007), it raises questions as to exactly what European Neandertals were doing with fire and/or the level of control that they had over it.

MODERN HUNTER-GATHERER USE OF FIRE AND EVIDENCE FOR USE OF FIRE DURING THE MOUSTERIAN

There is a wide range of applications involving fire among historic hunter-gatherers. Initially these can be divided into two major categories—off-site and on-site applications. "Off-site" applications (i.e., in non-occupied areas) include such things as using fire as a hunting aid—burning off areas of old vegetation to promote the growth of new graze/browse to attract game animals or using grass fires to direct the movement of game animals (Gould 1971). On-site, or

TABLE 1. COMMON HUNTER-GATHERER DOMESTIC USES OF FIRE*.

Grease rendering
Heat-treating flint
Processing hides
Modifying wood for tools
Protection from predators
Clearing sites of refuse
Food preservation (e.g., smoking meat)
Heat/Warmth
Cooking Food

*data from Binford 1978; Fessler 2006; Fisher and Strickland 1989; Galanidou 2000; Gould 1971; Hayden 1981; Mallol et al. 2007; Marlowe 2005; O'Connell 1987; Worthman and Melby 2002.

"domestic" fires, involve a relatively limited range of general activities (Table 1) and morphologies, although there is still a great deal of variation (see Table 1) (e.g., Binford 1967, 1978; Chambaron 1989; Driver and Massey 1957; Fisher and Strickland 1989; Gould 1971; Hayden 1979; Mallol et al. 2007; O'Connell 1987).

There are few data for any of these uses in Mousterian sites. Grease rendering, which usually involves stone boiling, is easily evidenced by the presence of fire-cracked rock in Upper Paleolithic and later contexts (e.g., Manneet al. 2005; Nakazawa et al. 2009), but not earlier. Among recent hunter-gatherers different technologies have been employed to extend the storage life of meat, which includes smoking, drying, salting, and mixing other natural preservatives (e.g., berries with tannic acid) with the meat. These actions all serve to severely restrict normal bacterial processes that will cause rapid decay of the meat. Again, there is currently no good evidence that any of these meat preservation techniques, including ones involving fire, were employed during the European Middle Paleolithic, and claims for such behaviors are rare. The thick ash and charcoal deposits associated with fish remains in the Mousterian layers of Grotte XVI, for example, have been proposed as potential evidence for fish smoking, but there is no direct supporting evidence for this (Karkanas et al. 2002; Rigaud et al. 1995).

Regarding the smoking of hides, although it is certainly possible that Neandertals made use of animal hides to some degree, there is little evidence to indicate extensive, or at least well developed, hide processing in the Western European Mousterian. Ethnographically, the smoking of hides is carried out at the end of an extended process of hide preparation (defleshing, removing the hair, stretching, chewing, etc.) that improves their pliability, preservation, and waterproofing. It is most likely, therefore, that hide smoking would occur only with well-developed hide technology, and many elements of such technology are lacking in Mousterian contexts. Such elements include true end scrapers, which become almost universally associated with processing hides among later hunter-gatherer cultures; ochre, which can be used in tanning (Wadley 1993, 2001); or piercing tools of either stone or bone, which are used in the fashioning of tailored clothing (Gilligan 2007). Thus, if Neandertals did use hide as a raw material for clothing, containers, and/or shelter, their hide-processing technology was likely rudimentary and not developed to the point where smoking would have been employed.

Other fire use activities observed among modern hunter-gatherers are associated with what might typically be viewed as simple campfires or hearths. The term 'hearth' as used here is a spatially limited residue of combusted material of human origin. They can be sub-circular fires, typically less than a meter in diameter, often constructed directly on a flat surface or inside a shallow basin scooped out of the ground surface. They may also be ringed with cobbles to contain the fire and its heat, although this appears to be a rare practice in the Middle Paleolithic. Such hearths are associated with a number of common applications, including modifying raw materials such as wood (Fessler 2006; Gould 1971; Hayden 1981; Mallol et al. 2007; Marlowe 2005; Oakley et al. 1977; O'Connell 1987) or in heat treatment of lithic raw materials to enhance their flaking qualities (Brown et al. 2009; Domanski and Webb 1992). Small hearths also are used to ward off predators (Fessler 2006; Marlowe 2005; Worthman and Melby 2002), to keep irritating (or dangerous) insects at bay (Fessler 2006; Hayden 1981), to fumigate against small rodents (Worthman and Melby 2002), or simply as a means of eliminating site refuse (see Galanidou 2000). These latter uses are unlikely to leave distinct signatures in the archaeological record, however.

It has long been suggested that wood artifacts likely played a significant role during the Lower and Middle Paleolithic (e.g., Hayden 1979), and in spite of their rarity, enough wooden implements have been discovered that their use is reasonably demonstrated (Carbonell and Castro-Curel 1992; Freeman et al. 1981; Howell 1966; Movius 1950; Oakley et al. 1977; Rolland 1999; Thieme 1999; Villa and Lenoir 2006). However, the use of fire to shape or harden such items has not as yet been conclusively demonstrated for any of these finds. The same is true for heat-treating flint to increase its knapping qualities; there has been no reported use of heat-treatment in Western Europe until much later in the Upper Paleolithic, i.e., during the Solutrean (Aubry et al. 2003), although elsewhere this practice may have begun much earlier (Brown et al. 2009).

While some of the above uses of fire do not appear to have been a significant part of Mousterian adaptation, other uses may be more dependent on particular circumstances and needs, and still others may not have been relevant given the overall level of technological development present during the Mousterian. However, two uses of fire—for cooking and for warmth—are (with very rare exceptions) true universals among humans everywhere, and there are many reasons to think that they would have represented major aspects of Neandertal adaptation during Mousterian times.

Among modern hunter-gatherers, the cooking of meat and plants (e.g., tubers) over fire is essentially a daily exercise (Binford 1978, 1996; Chambaron 1989; Gould 1971; Hayden 1981; Mallol et al. 2007; O'Connell 1987). Although there are examples of forager groups who eat some raw meat, all known societies cook at least some, if not the majority, of their meat resources, and the same is true of plant resources (Wrangham 2009: 30).

Various suggestions have been made in the literature on the advantages of cooking food. One general suggestion is that by breaking down fiber and denaturing plant and animal tissues, cooking would facilitate the digestive process and thereby increase, in some cases dramatically, the nutritional yield of those resources (e.g., Hawkes et al. 1999; Sussman 1987; but see especially Wrangham 2009 and Wrangham et al. 1999). It is also the case that cooking would have opened up a much broader range of plant foods (Lee and DeVore 1968; Marlowe 2005; Stahl 1984).

Considering that cooking food is universal among historic foragers, this would seem to be a very likely candidate for Paleolithic fire use. Wrangham, in particular, has argued for the universal presence of cooking prior to the Middle Paleolithic (e.g., Wrangham 2009; Wrangham and Conklin-Brittain 2003, Wrangham et al. 1999). Some of these arguments that relate to the cooking of plant resources may not be so relevant, however; in spite of some evidence for the exploitation of plant foods by Neandertals (e.g., Hardy 2004; Henry et al. 2011), recent studies of bone isotope chemistry indicates that Neandertal dietary protein came predominantly from meat (Bocherens et al. 2005; Richards and Schmitz 2008; Richards et al. 2000).

Unfortunately, it is very difficult to identify positively whether or not cooking took place. Burned bone is relatively common in Middle Paleolithic site deposits, often associated with combustion features, and these could potentially represent the remains of cooked meals, but so far there is no method for distinguishing between bone that may have been subjected to heat intentionally (as from roasting meat) and bone refuse that incidentally made its way into a fire. Bone has also been used as fuel for fires at times (e.g., Théry-Parisot 2002; Théry-Parisot and Costamagno 2005), and this is certainly the case at Pech de l'Azé IV (Dibble et al. 2009). So, while there may be good arguments for the benefits of cooking, there is still a lack of clear demonstration that it was used during the Mousterian.

Likewise, the use of fire for warmth is a modern cultural universal. Fires are used either to warm the interiors of structures, especially at night ("sleeping fires"), or individuals sleep next to open-air hearths. This is the case even among groups who inhabit relatively warm regions, such as equatorial Africa (e.g., Fisher and Strickland 1989; Mallol et al. 2007; Worthman and Melby 2002) and Australia (Gould 1971; Hayden 1981; O'Connell 1987). On the other hand, fire for warmth is seen as even more necessary among groups who occupy higher latitude regions. This would include Pleistocene Europe, where during colder intervals annual temperatures would have been substantially lower than today. Unfortunately, as with so many of these applications of fire, its use to provide warmth would be almost impossible to demonstrate in archaeological sites.

In fact, identifying any *single* use of fire is made all the more difficult given that a single fire can serve more than one function (Galanidou 2000; Mallol et al. 2007). For example, within modern traditional societies, a domestic hearth is typically the central focus of a large part of daily camp activities (cooking, tool production/maintenance, eating, and socializing) and the same fire will also serve as a source of warmth, light, and protection against predators at night. But the point here, and one that requires emphasis, is that virtually all recent populations use it for at least some of these applications and also that among modern hunter-gatherers, it is used daily and at almost every location where people spend any time at all. As such, it represents one of the premier technological advances of humans. Given its fundamental importance to the successful adaptations of modern groups, and given the low level of technology required to use it, most would expect to see evidence of widespread use once it became available.

HOW IMPORTANT WAS FIRE TO WESTERN EUROPEAN NEANDERTALS?

There is no doubt that fire was used during the Mousterian, and even though it is difficult to demonstrate the exact role that it played in their daily lives, its presence clearly indicates that it provided some benefits to those populations. In fact, of all of the uses of fire seen among modern hunter-gatherers, the only one that can be ruled out, at least on the basis of data presently available, is its use for heat-treating flint, though it is also most likely that grease rendering and hide smoking were not practiced as well. While fire may have been used as a source of light, Neandertal cave occupations are almost universally situated at or very near the cave mouth (as is the case with Pech de l'Azé IV and

Roc de Marsal), not in darkened interiors, and even among modern hunter-gatherers providing light appears to be a relatively minor function of fire (e.g., Mallol et al. 2007). Of the other uses, cooking and providing warmth are two that would appear to be the most likely given the adaptive advantage that they confer and the fact that these two uses are fundamental and universal behavioral traits of humans today. So, given the presence of fire in some Mousterian occupations, should we simply assume that these two basic functions played a significant role?

The single biggest problem in making such an assumption is the simple fact that evidence for fire in Mousterian occupations is rather scarce. While there has been evidence presented for potential fire use by hominins well before the Middle Paleolithic (e.g., Gesher Benot Ya'aqov) and arguments have been made that this reflects routine use of fire throughout the Acheulian (Alperson-Afil 2008; 1737–1738), potential evidence for such early use of fire remains scarce and is still best described as intermittent at best, even well into the Middle Paleolithic. This is not a new observation. Perlès (1981) noted some time ago that whereas there is a large number of Middle Paleolithic occupations in higher latitudes or associated with harsher climatic periods, there is generally a very small number with evidence for use of fire. In fact, the general paucity of Paleolithic occupations with fire residues prior to 100 kya led her to conclude that fire was not a requisite technology for hominins to move out of Africa into the cooler latitudes of Eurasia (see also Cohen-Ofri et al. 2006; Davies and Underdown 2006; Gowlett 2006; James 1989; Roebroeks and Tuffreau 1999; Roebroeks and Villa 2011; cf. Alperson-Afil 2008; 1737–1738). Given the ubiquity of fire use among essentially all modern hunter-gatherers—fires are truly an important part of their *daily* behavior, both year round and in every environmental circumstance—then it should be ubiquitous in Mousterian occupations as well if it were a major part of their adaptation to the conditions that they faced at that time.

There are several arguments that could be used to explain this scarcity. For example, it could be due to a lack of adequate reporting. As an illustration, a recent compilation by Steenhuyse (personal communication) found that of 352 Paleolithic sites from southwest France alone that have been excavated since the middle of the 19th century, less than ten percent have been adequately published. Even one of the most prominent prehistorians of the last century, François Bordes, who excavated at Pech de l'Azé I, II, III, and IV, Combe Grenal, Corbiac, Roc de Combe, and other major sites, never adequately published any of them. Clearly, without access to the detailed results of these excavations, it is impossible to arrive at an accurate idea of the prevalence of fires. To some extent, the older literature is likely to be somewhat biased by the fact that for many archaeologists, once the presence of fire during the Mousterian had already been demonstrated, further investigation of its use during Neandertal times was not a major research question. Rather, it was assumed to be the case and so evidence for fire was under-reported or mentioned only in passing. Moreover, the reporting of secondary evidence for fire (such as heated flints and bones) is inconsistent, meaning that when it is not reported it cannot be assumed that it was not present, and, in other cases, the problem is compounded by the fact that non-fire residues were sometimes mistakenly interpreted as fire, as for example at Fontéchevade (Chase et al. 2009; Henri-Martin 1957). For all of these reasons it is very difficult to assess how frequently fire was used by Neandertals and in what contexts.

A second problem that greatly affects our ability to determine the prevalence of fire use is that it is relatively easy for the primary evidence for fires (whether controlled by hominins or not) to be removed or dispersed due to post-depositional processes, especially aeolian and alluvial processes, as well as diagenesis (e.g., Karkanas et al. 2000; Goldberg and Bar-Yosef 1998; Weiner et al. 2007). This is especially true in the absence of structures (e.g., pits, stone barriers) that would provide good indirect evidence of their former presence.

While there is nothing that can be done at this time to correct for under-reporting, attention will now be turned to the data from Roc de Marsal and Pech de l'Azé IV, where it can be shown that fire was rare or absent during many of the occupations there.

TWO CASE STUDIES ON NEANDERTAL USE OF FIRE: PECH DE L'AZÉ IV AND ROC DE MARSAL

Pech l'Azé IV and Roc de Marsal are two Mousterian cave sites in the Dordogne region of Southwest France (Figure 1). While both were originally excavated in previous decades, they have been recently re-excavated by the same multi-disciplinary team using modern approaches and techniques (Dibble et al. 2004, 2009; Goldberg et al. in press; McPherron et al. 2001; Sandgathe et al. 2007; Turq et al. 2008). The span of their occupational histories is very similar, beginning in mid to late MIS 5 and continuing to MIS 3, and both contain rich lithic and faunal assemblages.

PECH DE L'AZÉ IV

The recent excavations at Pech de l'Azé IV, or simply Pech IV (Turq et al. 2008, in press), which took place from 2000–2004, identified several layers of Mousterian occupation, with the lowermost Layer 8 lying directly on bedrock (see Dibble et al. 2009). The lithic component of this assemblage is relatively rich in scrapers (especially single, double, and convergent forms), low in notches/denticulates, and also includes a relatively high Levallois component. This layer has yielded a mean TL date of 99.9±5.4 kya, which places it in MIS 5c (Gibbard and Van Kolfschoten 2005; Winograd et al. 1997). This association of Layer 8 with a warm, humid climatic regime is supported by the fauna, which is dominated by red deer (*Cervus elaphus*) and also has significant quantities of roe deer (*Capreolus capreolus*) and wild pig (*Sus scrofa*), and includes beaver (*Castor fiber*) (Dibble et al. 2009; Laquay 1981).

It is in this layer that evidence for fire is most abundant. It includes clear charcoal and ash units, burned bone,

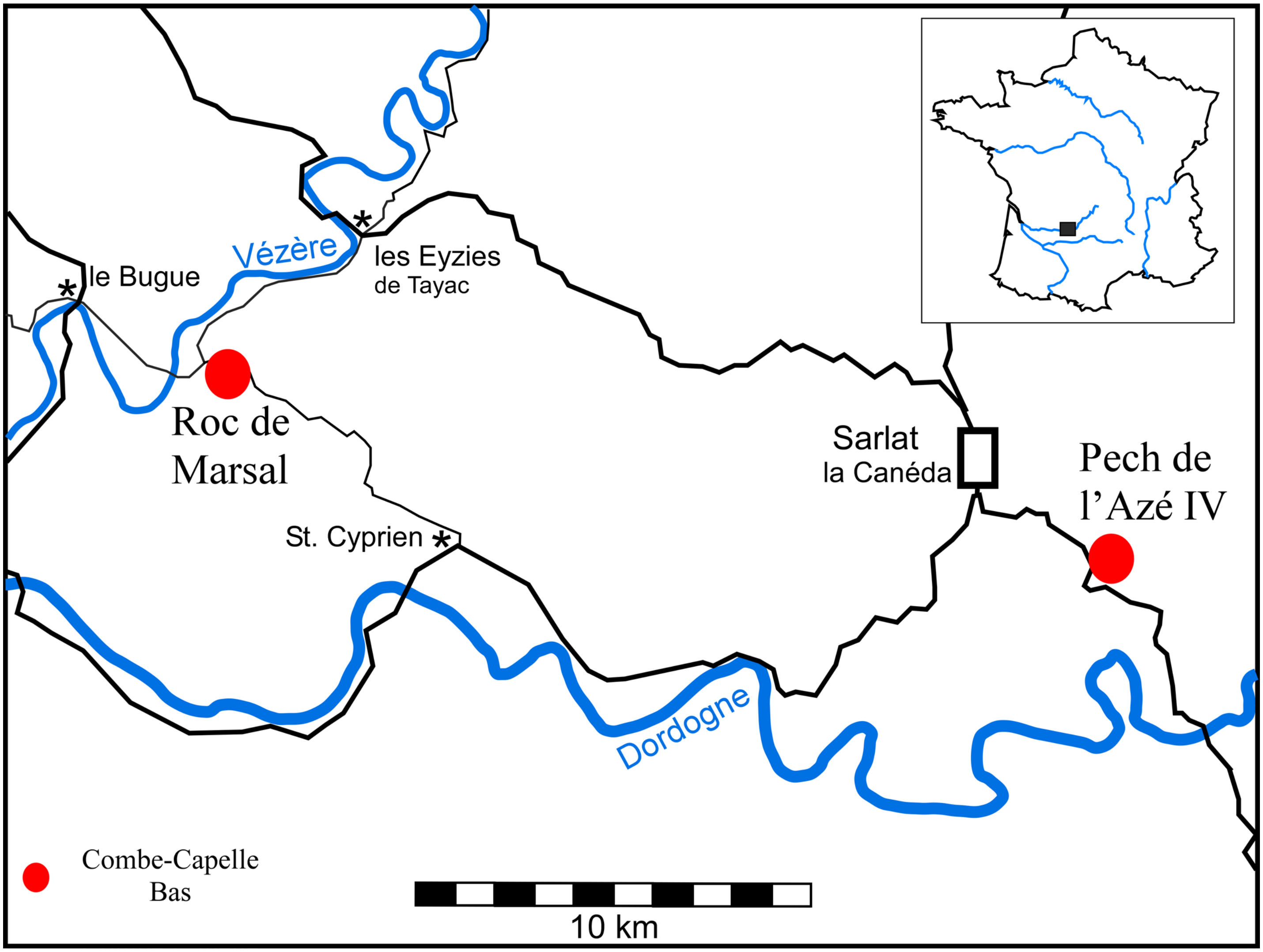

Figure 1. Location of the sites discussed in the text.

burned lithics, and rubefied sediments. In stratigraphic cross-section (Figure 2), some of the ash-charcoal units occur mainly as discrete lenses, many with easily discernible vertical limits. In this regard, these features very much resemble individual hearths, with several different such features superimposed throughout the layer. However, attempts to isolate individual combustion features in plan-view on the excavation surface were not particularly successful. What appear to be individual features in cross-section tend to be intercalated and bleed into each other when exposed horizontally. It appears that these features were constructed across the ground surface with enough frequency during subsequent occupations that individual hearth features blended into each other. However, the fact that many of the individual ash and charcoal lenses survive as intact units suggests there was very minimal non-human post-depositional disturbance, although syn-depositional modifications, such as hearth rake out and trampling, clearly did occur and helped contribute to the 'blurring effect' of individual features. Diagenesis is also quite limited as original calcareous ash crystals and pockets can be observed microscopically in many of the features, although phosphatization of some ashes is discernible (Dibble et al. 2009; Karkanas et al. 2000).

Subsequent to the deposition of Layer 8 there are an additional three meters of deposit with evidence of Neandertal occupation, but little direct evidence of fire. Layer 7 includes heavily rolled lithics and few surviving faunal remains; it likely represents a solifluction lobe and the artifacts are therefore notably edge damaged. For this reason, this assemblage from this layer is excluded from subsequent discussion in this paper. Layer 6, on the other hand, shows little evidence of post-depositional modification. It contains a lithic assemblage that the original excavator, Bordes (1975), called the "Asinipodian," which is characterized by several different techniques of producing very small flakes, such as truncated-faceted pieces, Kombewa cores/flakes, and very small Levallois cores/flakes (Dibble and McPherron 2006, 2007). It is dominated by red deer and roe deer and includes wild pig, beaver, and one example of *Megaloceros* sp. (Laquay 1981), which suggests a correlation with a relatively temperate, wooded environment, most logically MIS 5a. A total of seven TL dates from Layer 6a have yielded an average age of 70.9±3.5 kya (Richter et

Figure 2. Close-up of a section-view of Layer 8 at Pech de l'Azé IV. Individual lenses of charcoal and charcoal-ash units are visible.

al. 2010). This date would put the layer in MIS 4, which in general was a relatively cold period (e.g., Lehman et al. 2002; Winograd et al. 1997), but this is clearly incorrect in the face of the faunal evidence. The high percentage of roe deer and the presence of wild pig and beaver, in particular, exclude the possibility of an association with such an extremely cold climate. Although Bordes (1975) reports some limited traces of fire residues in this layer, our own excavations did not.

Following another coarse layer (5a), Layer 5b represents the beginning of major changes in both fauna and the lithic assemblages. In this layer, reindeer increases, roe deer decreases, and wild pig disappears, all of which indicate the onset of a colder period, probably correlating to the beginning of MIS 4; four TL dates for this layer have yielded an average age of 72.6±4.6 kya (Richter et al. 2010) which is very much in line with the current dating of the onset of MIS 4 (e.g., Dorale et al. 2010; Lehman et al. 2002; Winograd et al. 1997). The lithic assemblages become much more dominated by scrapers, and Levallois technology drops off significantly. These trends continue through Layer 4, in which reindeer becomes the dominant species, and percentages of both red deer and roe deer drop significantly (Laquay 1981). These changes likely indicate the onset of much colder and drier conditions, and potentially correlate with MIS 4. By this time the industry is very rich in scrapers, including many heavily-reduced forms. The final layer, subdivided into 3b and 3a, contains a lithic industry that correlates best with a Mousterian of Acheulian Tradition with some bifaces and backed knives present, along with moderate frequencies of scrapers and denticulates. ESR dates (Turq et al. in press) suggest an age of approximately 47–57 kya and a recent series of AMS dates on bone from this layer suggest a similar ,though slightly younger, age. These dates suggest that Layer 3 is associated with MIS 3.

ROC DE MARSAL

Roc de Marsal is a small, south-facing cave site in a tributary valley of the Vézère River, about 20km west of Pech IV (Sandgathe et al. 2011b; Turq et al. 2008). In the course of our recent excavations (from 2004–2009), 13 stratigraphic layers were recognized. At the base, Layers 13 through 10 represent locally mobilized sediments from *in situ* weathering of the limestone bedrock. Layer 10 contains some limited archaeological materials (n=129 lithics), but these may be mostly or entirely intrusive. Artifact densities in Layers 9 through 2 are very high, with over 23,000 lithic artifacts greater than 2.5cm.

Layers 9 through 5 comprise a single lithostratigraphic unit with darker anthropogenic components (including major concentrations of ash and charcoal) interbedded with lighter sandy sediments. The lithic industries are relatively low in scrapers and relatively high in Levallois and contain some Asinipodian elements. Several TL dates (77.4±4.8 kya, 81.4±5.0 kya, and 86.7±5.2 kya) were obtained for burned sediments from Layer 11. These dates are presumably from the substrate associated with fires from Layer 9 as Layer 11 is sterile and is only separated from Layer 9 by a very thin (and often non-existent) Layer 10. These dates suggest that initial occupation occurred in MIS 5a (Sandgathe et al. 2008), which is currently dated to ≈85 to 75 kya (e.g., Dorale et al. 2010; Lehman et al. 2002; Winograd et al. 1997). The faunal data indicate temperate conditions, with an abundance of forest species, such as roe deer, along with some horse (*Equus* sp.). Reindeer occur to some extent throughout the sequence and increase through time, but only become significant from Layer 5 and up. The dominance of forest adapted species in Layers 9 through 6, along with the presence of wild pig and the inclusion of field vole (*Microtus agrestis*), garden dormouse (*Eliomys quercinus*), and European pine vole (*Microtus subterraneus*) among the rodent species, all suggest a late MIS 5a date (Marquet, in Sandgathe et al. 2008).

The change to increasingly cold conditions reaches its maximum in Layers 4–2, which contain a more scraper-rich set of industries with numerous diagnostic Quina scrapers that are clearly associated with this Bordian industrial variant. These upper layers also are clearly associated with a much colder, drier, and more open environment. This is indicated by a dominance of reindeer and various vole species such as the common vole (*Microtus arvalis*), water vole (*Arvicola terrestris*), narrow-headed vole (*Microtus gregalis*), snow vole (*Chionomys nivalis*), and the similar tundra vole (*Microtus malei*). A series of ESR dates for the lower part of Layer 4 (72 to 80 kya) are a reasonable match with a suggested correlation between this layer and the start of MIS 4 (c. 74 kya), whereas a mean ESR date for Layer 2 (the final Mousterian layer) of 43.6±2.6 kya suggests the final Paleolithic occupations occurred during late mid-MIS 3 (Blackwell et. al., in Sandgathe et. al 2008).

As at Pech IV, evidence for *in situ* hearths is not found throughout the Roc de Marsal sequence, but rather only in the earliest layers. This evidence includes discrete charcoal and ash units, burned/calcined bone, burned lithics, and rubefied sediments. Layer 10 includes several discrete patches of rubefied sediments that were separated from hearths in Layer 9 by a thin layer of un-rubefied sediments. However, these units lack any associated charcoal, ash, or burned bone and may represent sediments heated by fires associated with Layer 9, but which were subsequently removed through diagenetic processes such as phosphatization. In Layers 7 and 9, on the other hand, many combustion features are visible and occur as discrete, easily isolated hearths, many of which contain intact charcoal-ash units and significant quantities of burned/calcined bone. In fact, in both Layers 7 and 9, localized examples of "stacked" hearths are clearly visible in section view, indicating that individual hearths were repeatedly constructed in more or less the same location throughout the duration of each of these stratigraphic components (Figure 3). However, not all of the lower layers exhibit direct and intensive evidence for fire, and in fact, such evidence alternates—Layers 5, 7, and 9 are rich in such features, while Layers 6 and 8 have little or no evidence for them.

The Roc de Marsal hearths range in diameter from approximately 50cm to 100cm. There also appears to be a certain degree of variability in the nature of the residues in the hearths. Some contain thick (1–2cm) lenses of ash (Figure 4a) while others lack the ash component and are composed primarily of small (<2cm) fragments of burned bone. Such differences likely represent variability in the duration and intensity of burning events, possible differences in the kinds of fuel used, and to some extent, diagenesis. Differential degrees of combustion can also be seen within individual features—in some hearths calcined bone occurs in the center of the hearth and decreases as one moves towards the periphery.

As shown in Figure 5, Pech IV and Roc de Marsal overlap considerably in time, and they share similar temporal patterns in the use of fire. Although radiometric dates are still lacking for the entire sequences at both sites, the dates that are available, coupled with faunal and other data, can be used to help correlate the two stratigraphic sequences with general climatic conditions and potentially with specific Marine Isotope Stages. Given the dates currently available, both Pech IV and Roc de Marsal span roughly the same time period, that is, mid to late MIS 5 through mid to late MIS 3, although the former appears to have a slightly longer occupational history, which includes a somewhat older initial occupation and somewhat later final occupations. Regardless of the precise temporal correlation between the two sites, it is clear that both were initially occupied during a temperate period that was followed by a marked deterioration in climate.

POSSIBLE EXPLANATIONS FOR THE VARIABILITY IN FIRE USE AT PECH IV AND ROC DE MARSAL

At both Roc de Marsal and Pech IV unmistakable hearth features occur in their lower layers, and thus clearly indicate that fire was certainly used at this time. In both sites the deposition of these layers occurred during a time of relatively warm conditions. But it is equally clear from both sites that such evidence is much rarer in other occupational layers. At Roc de Marsal, for example, the lower layers seem to alternate between those with clear fire residues and those without. Moreover, at both sites, the upper Mousterian layers (Layers 5 through 4 at Pech IV and Layers 4 through 2 at Roc de Marsal) contain no identifiable fire features such as concentrations of charcoal, or ash, and even the small numbers of burned bones and lithics are dispersed throughout the deposits. At the top of the Pech IV sequence, in Layer 3, direct evidence for fire in the form of very small fragments (<0.5cm) of charcoal increases a little, but such fragments remain exceedingly rare.

There are four possible explanations for the discontinuous evidence for fire at these two sites.

1. The first explanation is that in those layers where fire residues are lacking, various taphonomic agencies removed them—in other words, that fires were originally there, but direct evidence of their presence was simply not preserved.
2. There is also the possibility that fires occurred in all occupations, but not necessarily in the parts of the site that were excavated.
3. Another possibility is that through the sequence of occupations at the two sites, the range of activities carried out at the sites varied, and that some of these activities simply did not require the use of fire.
4. Finally, it could be that the various occupations of these sites took place during different seasons of the year. During winter occupations the need for fire for warmth may have been greater than during summer occupations, for example.

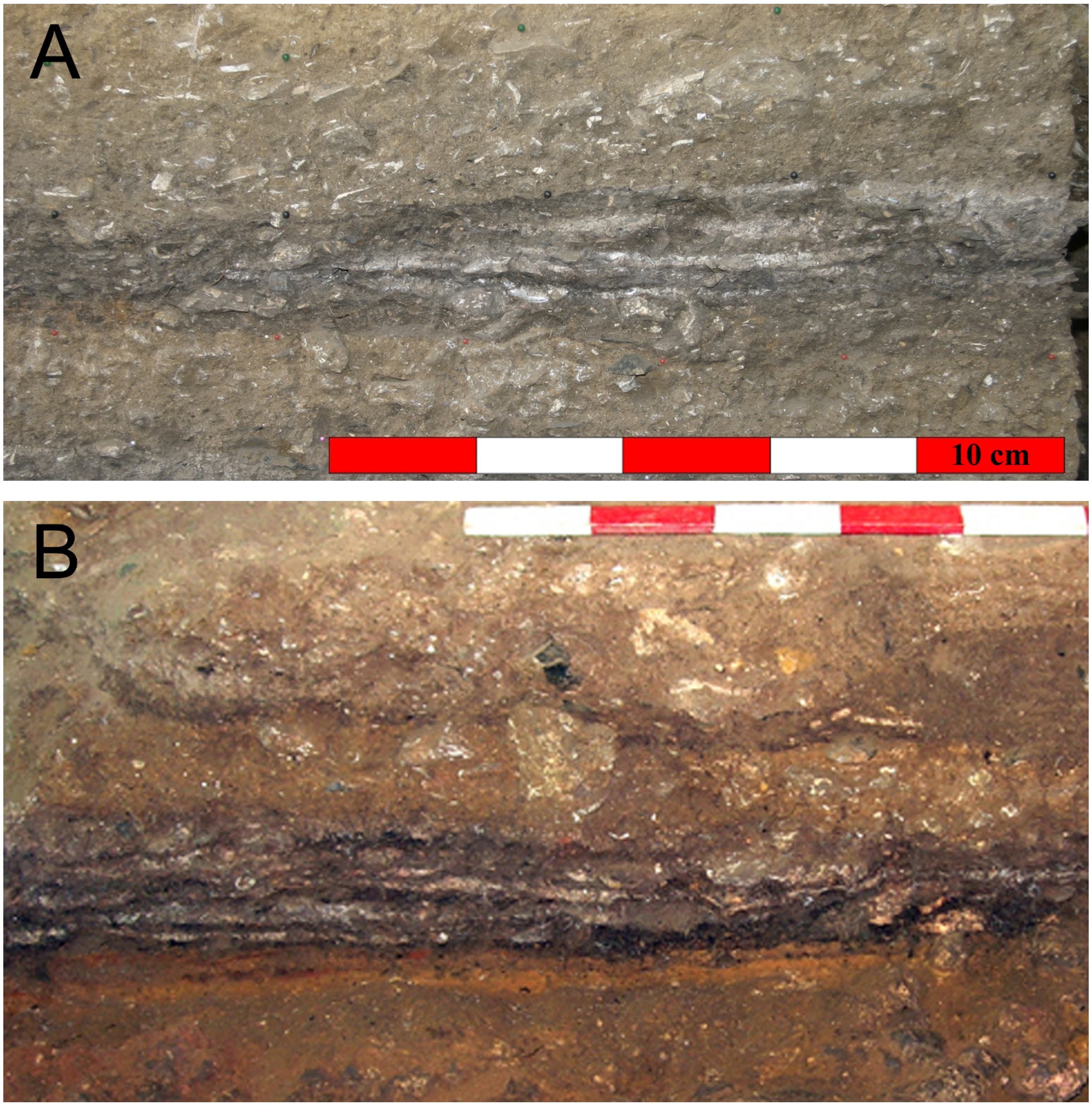

Figure 3. a) stratigraphic cross-sections highlighting multiple, stacked, intact combustion features in Layer 7 at Roc de Marsal; b) stratigraphic cross-sections highlighting multiple, stacked, intact combustion features in Layer 9 at Roc de Marsal.

IS THE SCARCITY OF FIRE RESIDUES DUE TO TAPHONOMIC FACTORS?

With regard to this possible explanation, strong arguments can be made to show that preservation was not a significant factor. First, at both sites, well-preserved fire residues occur both just inside the cave mouth as well as beyond what would have been the driplines at the time of occupation. Therefore, the degree of overhead cover is not a factor. Second, there is no evidence in the form of edge damage on the lithic artifacts, preferred orientations of objects, winnowing of smaller objects, or micromorphological studies of the sediments to indicate significant post-depositional disturbance in the upper layers of either site, and there is no evidence that ashes were removed and dumped elsewhere, as at Kebara (Meignen et al. 2007). To our knowledge, therefore, no site formation processes, either through natural or human agencies, have been identified in the sediments or the archaeological objects that could have removed the fire residues.

Further evidence that the lack of fires in the upper layers is not a result of preservation comes from indirect data that reflects the presence of fire even when more direct evidence of actual fire residues are missing. These data include flint and bone, both of which undergo macroscopic changes when exposed to sufficient heat. Burned flint is readily recognized because of spalling, crazing, luster, and alteration of color (see Sergant et al. 2006), while burned bone can vary from slightly charred (black, brown) to calcined (grey, white, blue). Flints and bones are a ubiquitous component of the sediments at both Pech IV and Roc de Marsal, as they are at most cave and rockshelter sites in southwest France, and any fire placed directly on these sediments would have heated the flints and bones directly under it. In an experiment designed in part to assess the ef-

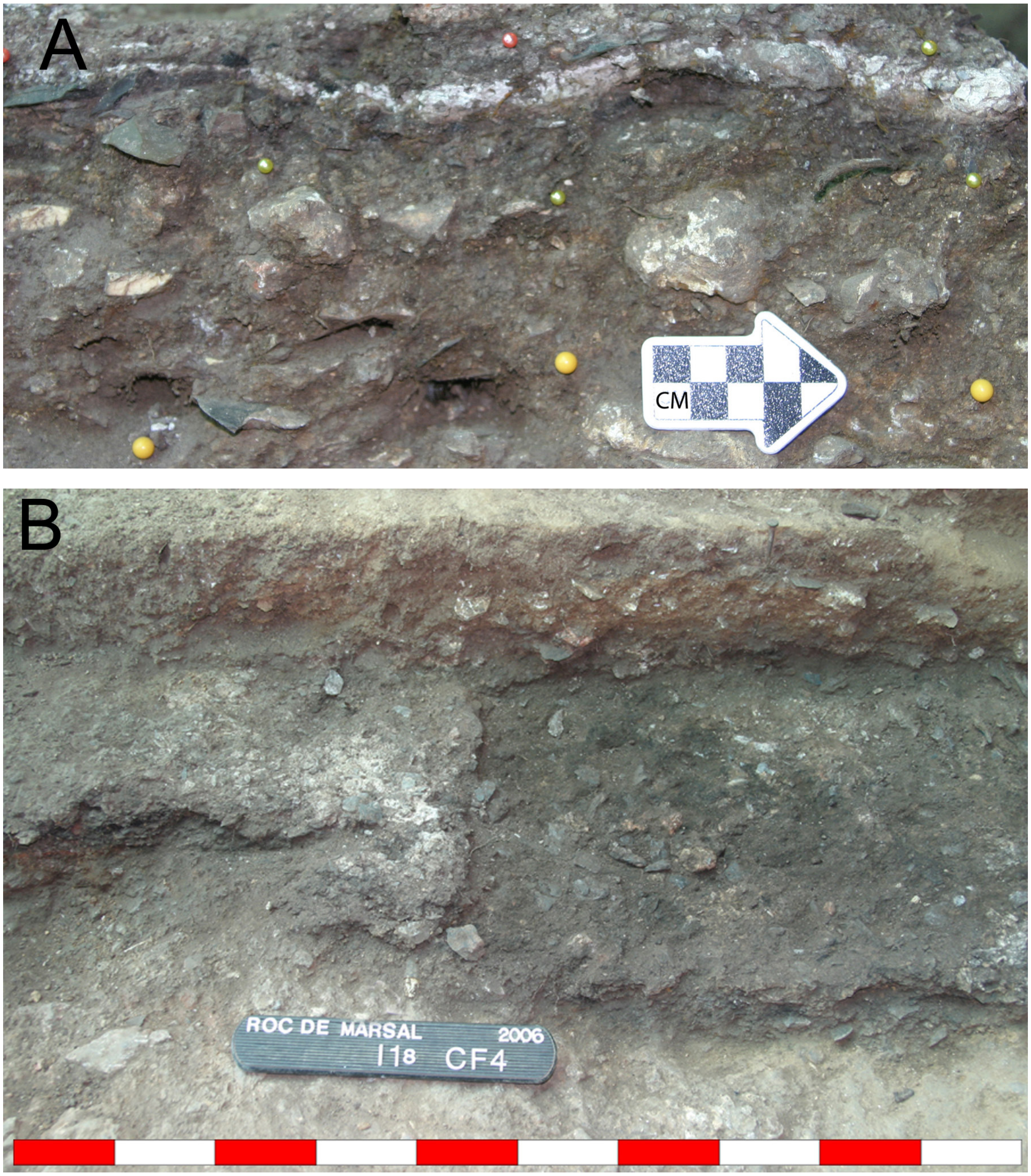

Figure 4. Roc de Marsal. a) cross-section view of thick, undulating lens of ash in Layer 7 (top of photo); b) oblique view of west half of Combustion Feature 4 (the half left by J. Lafille, the original excavator of the site) partially excavated in Layer 9. A portion of the ash component remains on the left, but it has been removed on the right exposing the lower charcoal and burned bone component.

fects of fire on buried bones, Stiner et al. (1995) found that bones within 5cm of the fire surface were visibly altered; plant charring also can occur centimeters beneath the base of a combustion event (Sievers and Wadley 2008). Similarly Werts and Jahren (2007) found that once the water in the sediment was boiled away, soil temperatures rose in less than an hour to over 300ºC at a depth of 2–3cm and to over 200ºC at a depth of 3–4cm. Though there is considerable variability among different flints, color changes can be visible at temperatures starting at 250ºC, luster requires temperatures of approximately 350ºC or more, and crazing can occur starting at 320ºC (Julig et al. 1999: 838 and citations within; Rottländer 1983). Thus any fire activities on the site should leave secondary traces in the bones and flints even if neither were directly in the fires themselves (see Callow et al. 1986 for an example of this approach at La Cotte de St. Brelade).

In Pech IV Layer 8, where direct evidence for fire is most abundant, over 20% of the lithic objects and 27.5% of the bones were burned (Figure 6). This peak coincides directly with the direct evidence of hearths in this layer. In the overlying layers, where direct evidence for fire is lack-

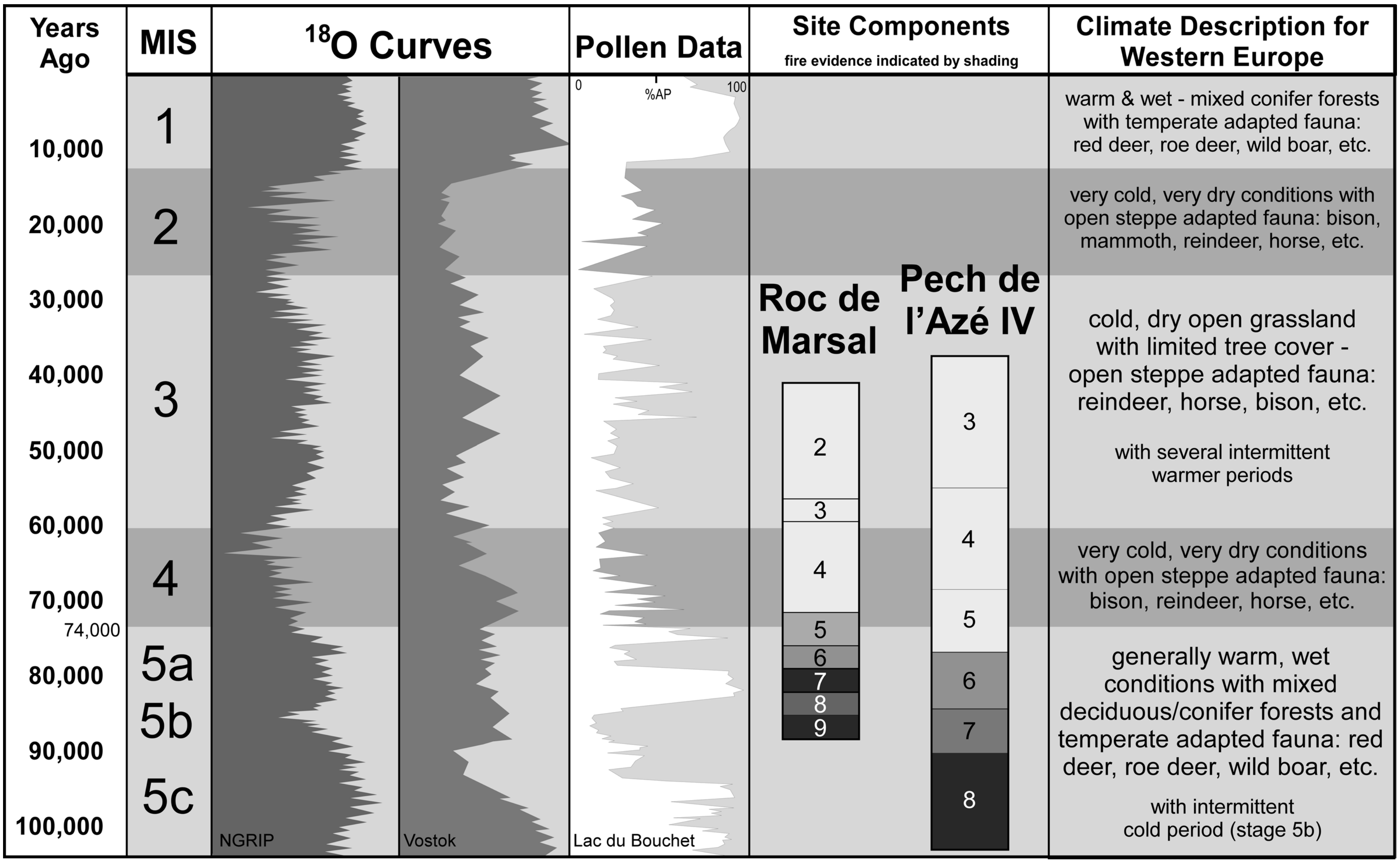

Figure 5. Based on chronometric dates and faunal data from Roc de Marsal and Pech de l'Azé IV. Sequences are positioned here in relation to Marine Isotope Stages and a generalized description of the associated environments. Shading of the various site components indicates the degree to which fire residues are represented (with darker shades indicating more burning and lighter shades less). (^{18}O curves are drawn from NGRIP and Vostok and Pollen curve is drawn from Lac du Bouchet [Reille and Beaulieu 1990]).

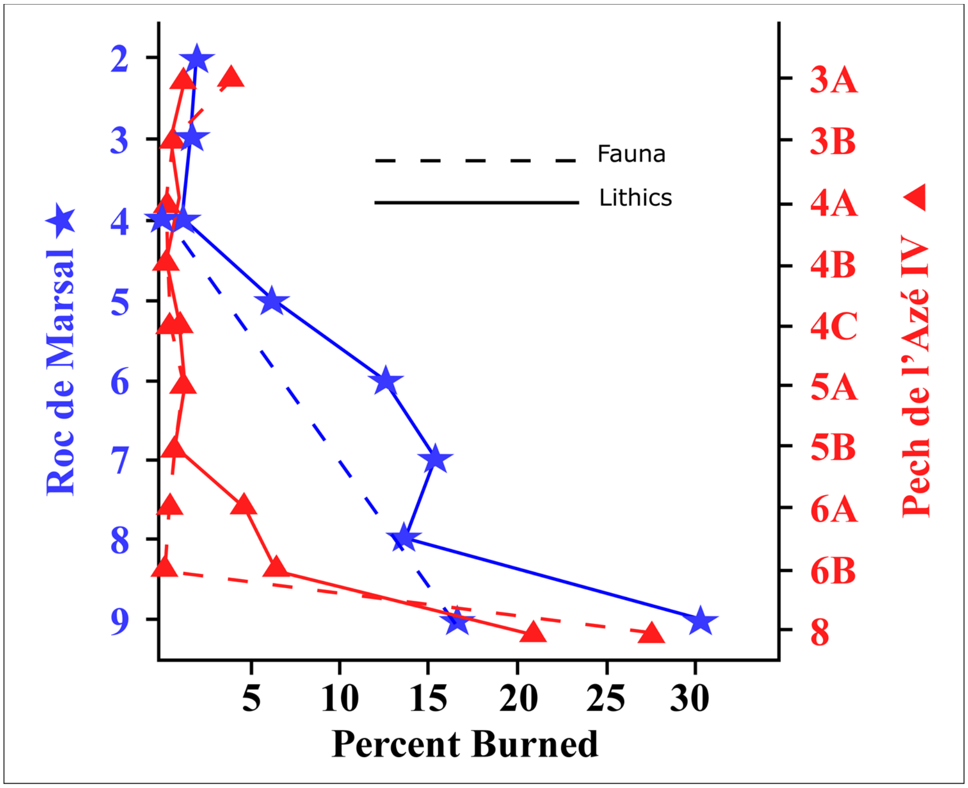

Figure 6. Percentage of burned flint and bone by level from Roc de Marsal and Pech de l'Azé IV. Both counts are based on objects greater than 2.5cm in length and the flint includes only proximal and complete pieces (flakes, tools, and cores).

ing, the percentages of both burned flint and bone begins to drop and falls to less than 1% for the remaining upper layers, except for a slight rise at the very top of the sequence (where, as noted above, charcoal flecks were found during excavation). Likewise, at Roc de Marsal, Layer 9 has nearly 30% burned pieces among the lithic objects accompanied by 17.2% of burned bone fragments (n=1922). There is another, though smaller, spike for Layer 7 where over 15% (see Figure 6) of the lithics are burned. During the occupations of Layers 2–4, however, the amount falls again to 1–2%. The numbers are not a function of varying sample size. The Pech IV dataset is based on over 10,000 lithic pieces and the Roc de Marsal sample contains over 23,000 lithics. Layer 4 of Roc de Marsal, which has only 1.3% burned lithic pieces, has a sample size of 1,833, and Pech IV Layer 3b, which has 0.6% burned lithics, has a sample size of 1,798.

At both sites, the percentage of burned objects, both lithic and fauna, agrees very closely with the frequency of more ephemeral, direct fire residues (charcoal and ash). During the later occupations as direct evidence for hearths disappears completely, the percentages of burned lithics and fauna decrease to very low levels. Notable exceptions are Layers 6 and 8 at Roc de Marsal, where the percentages of heated flints remains high even though there are no direct fire residues; this might represent some vertical movement of lithics or it may represent the movement of heat through the sediments (i.e., the fires of Layer 7 modified some of the underlying lithics of Layer 8; e.g., Sievers and Wadley, 2008).

Finally, there is no evidence that the frequency of burned objects is a function of object density. Figure 7 presents the density (per liter of sediment) for both bones and lithics from each of the two sites, in comparison with the overall burning of both of these artifact classes. While both lithic density and the percentage of burned lithics covary at Roc de Marsal, the bone density and percentage of burned bone at that site, and the density of both bones and lithics in relation to the percentage of them that are burned at Pech IV, show no relationship.

In summary, both Pech IV and Roc de Marsal exhibit excellent preservation, and the correlation is high between the presence or absence of direct evidence for fire (i.e., ash, charcoal or burned bone, rubefied sediments) and the indirect evidence in the form of burned artifacts. This relationship is not surprising given the causal nature of one to the other, but it means that the presence of fire can be detected even though various taphonomic processes may have obliterated the more direct evidence. Therefore, in the near absence of both direct and indirect evidence, the conclusion that fire was either absent or, at best, very rarely used during some occupations of these two sites is much stronger than it would be by relying on the direct evidence alone.

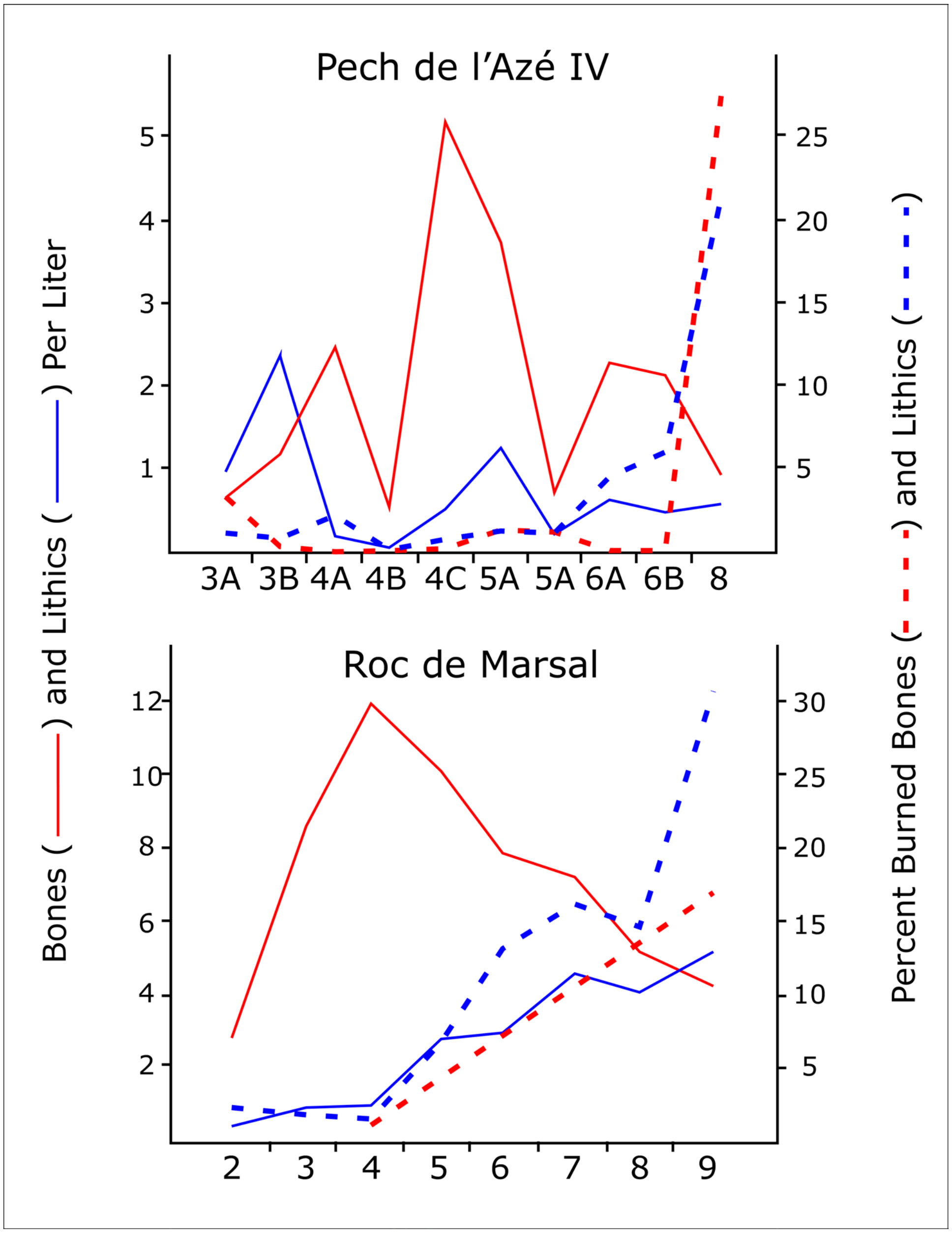

Figure 7. Density of lithic and bone objects greater than 2.5cm in length, per liter of sediment, compared with percent of burned objects from Roc de Marsal and Pech IV.

DID THE EXCAVATIONS MISS THE HEARTHS IN THE UPPER LAYERS?

It is not likely that at either site fires were constructed at other, as yet unexcavated, locations during the later occupations. At Roc de Marsal, the majority of the site has now been excavated (when combining our own excavations with the previous excavations of Lafille) (Figure 8), and the morphology of the cave in relation to the remaining sediments from the upper layers makes it essentially impossible that evidence of fire was missed; there is simply very little left of the deposits associated with the upper layers. Our own excavations extended along the entire length of deposits from well in front of the dripline to the rear of the cave, as well as laterally across the width of the cave. If there had been any other fire residues (including burned flints or bones) these would have been detected. At Pech IV, our own excavations were concentrated on the western section of the site; that is, the side that is closest to the original (and now collapsed) entrance of the cave (Figures 9a and 9b; Turq et al. in press). But observation of the eastern section remaining from the earlier excavation clearly indicates the same level of burning in the basal deposits, and a similar lack of such traces in the upper layers. Analysis of Bordes' (1975) entire lithic collection, which represents a much larger area than our own, and analysis of the faunal material from three of his layers (Bordes' Y and Z, which together correlate to our Layer 8, and Bordes' I2, which most likely correlates to our Layer 4c—see Turq et al in press) shows an identical pat-

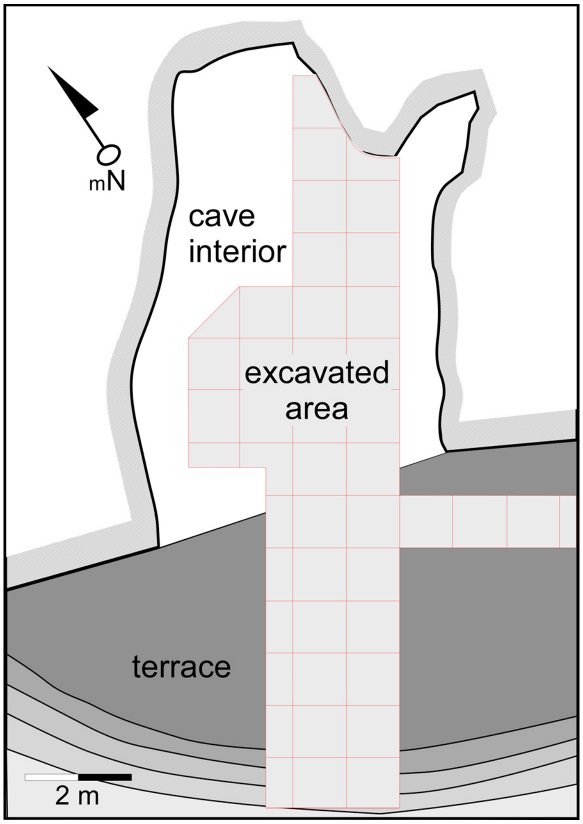

Figure 8. Map of Roc de Marsal indicating the extent of both Lafille's and our excavations. As is clear, because such a large percentage of the site was excavated, it is very unlikely that there are any areas of the site where evidence of fire residues could remain undetected.

tern of decreasing percentages of burned lithics and faunal fragments through the sequence (Figure 10). Between the two excavations, however, it is clear from topographic relief that the central area of the deposits was excavated. The remaining, unexcavated deposits associated with the upper layers (Layers 4 through 1) represent a very small area of the site. Realistically it is highly unlikely that fires could have been constructed in these remaining areas without resulting in residues (even if only burned lithics) bleeding into the adjacent excavated areas.

DID THE ACTIVITIES CARRIED OUT AT THE SITE CHANGE THROUGH TIME?

Another possible explanation for the variability in frequency of fire evidence—either direct or indirect—is that it reflects changes in the way these two sites were being used in their later occupations, and that these later activities did not require the use of fire.

Based on ethnographic data (e.g., Bartram et al. 1991; Binford 1978, 1980; Hayden 1981; Kelly 1995; Marlowe 2010), there is a very limited number of different site types, beyond basic residential or base camps, that may have existed in the western European Mousterian, and certainly some types of sites, mainly variations on special purpose/resource extraction locations, will leave little, if any, signature in the archaeological record (e.g., Bartram et al. 1991; Binford 1980). Additionally, most special purpose locations will only rarely occur at the same location over extended periods of time (centuries or millennia in the case of Roc de Marsal and Pech IV) since changes in the localized distribution of flora and fauna would inevitably vary through time. It is not even certain that the range of site types during the Mousterian is very large, considering that Neandertal lifeways are likely among the more basic of forager adaptations (Binford 1980, but cf. Costamagno et al. 2006). At any rate, with these limitations in mind, our data do not suggest any significant differences in the kinds of behaviors that took place when fires were present *versus* when they were absent.

One of the most archaeologically visible types of special purpose sites are ungulate kill sites where some initial butchering and/or processing has been carried out that results in the deposition of some bones and stone tools. It should be noted that there is nothing about their settings (at the base of low cliffs facing small valleys) that would suggest Roc de Marsal and Pech IV would be suited to this kind of activity (see Stiner 1994: 233). Another alternative is that they were some sort of initial butchering sites associated with a nearby kill site. This scenario has been argued to be the best explanation for the Quina Mousterian layers at Les Pradelles (Costamagno et al. 2006). However, there are problems with this interpretation for either Pech IV or Roc de Marsal, and even for Les Pradelles itself. Logistically, it makes little sense to move prey carcasses from a kill site to a whole new location simply to carry out initial butchering, which takes a relatively short period of time, especially for medium sized game such as reindeer. This is supported by available ethnographic examples like the Kua San (Bartram et al. 1991) and Hadza (Marlowe 2010), which show that modern hunter-gatherers generally take game carcasses directly back to camp from the kill site whole, if they are small enough, or cut into manageable portions, if they are larger. The remaining possibility is that these sites served as base/residential camps.

One way to test for site function is to examine the skeletal compositions of the prey species left at the site. If the functions of the sites were different during occupations with significant evidence for fire and *versus* those without fire, then we would expect to see differences in the general composition of the faunal assemblages. This is not the case, however. As illustrated in Figure 11, an evaluation of the "high survival elements" (i.e., those less prone to density-mediated destruction; see Marean and Cleghorn 2003) from large cervids (red deer and reindeer) show that the overall frequencies of the boney parts of the cranium and mandible plus fore- and hindlimb long bones were consistent over time at Pech IV. Although the data are available for only two layers (4 and 9) from Roc de Marsal, a similar lack of change is apparent, even though the two layers represent the extremes in terms of absence or presence of fire, respectively. In both cases, low utility heads were transported to the cave in much smaller numbers than the nutritionally-rich long bones for butchering and consumption. This is the pattern that would be expected if these sites were used as

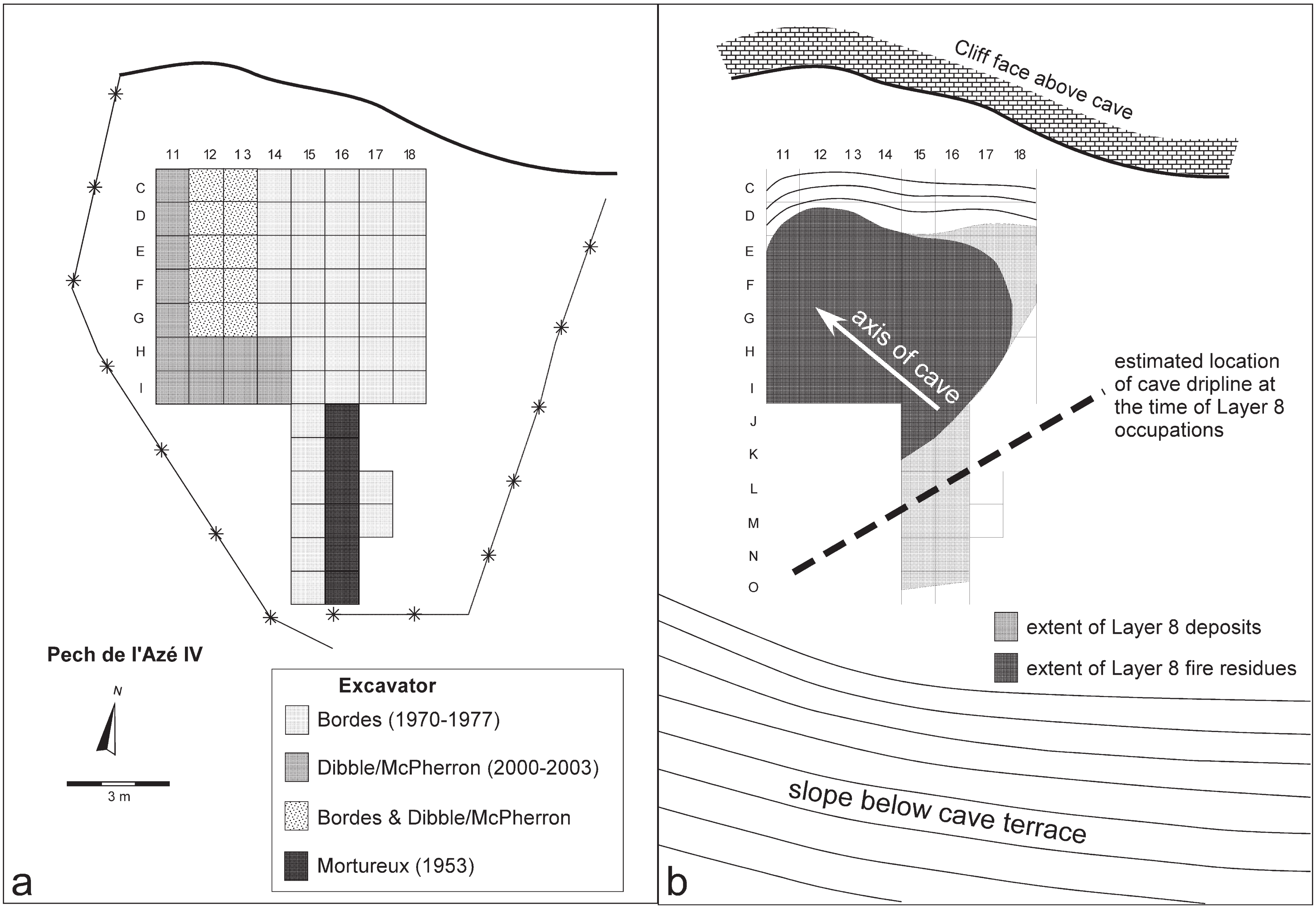

Figure 9. a) Units excavated by Mortureux, F. Bordes, and by us at Pech de l'Azé IV; b) placement of the site relative to the cliff behind and the steep slope of the valley in front of the terrace. Also shown are the extent of all Layer 8 deposits and the extent of burned flints and fire residues within Layer 8.

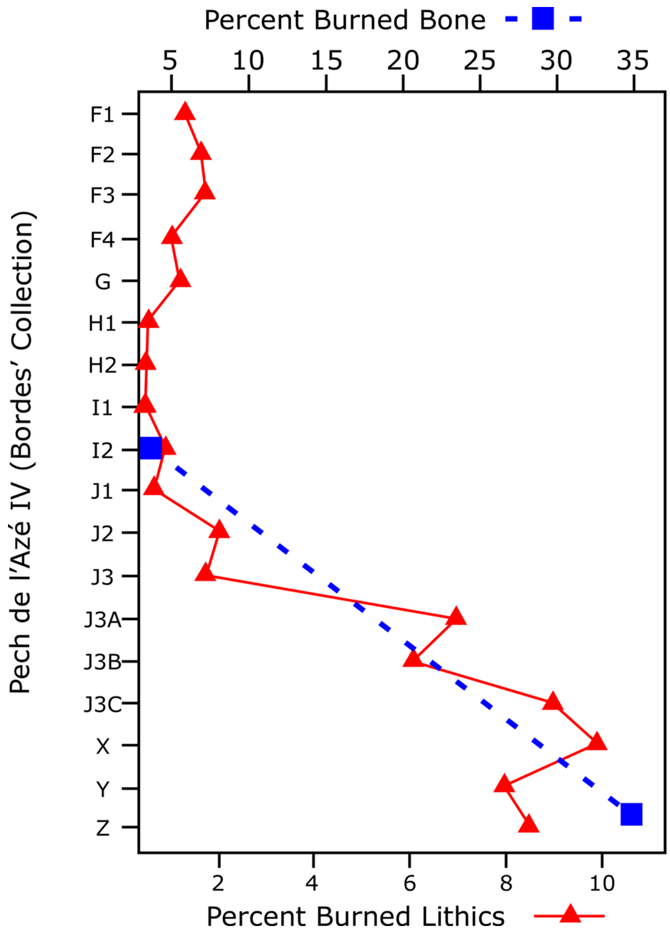

Figure 10. Percentage of burned flints (platform-bearing flakes) in Bordes' assemblages from Pech de l'Azé IV.

base/residential camps.

This interpretation is further supported by the fact that there are significant concentrations of heavily butchered faunal remains, as reflected by proportion of percussion marks on marrow-yielding long bones at both sites through time. For example, at Roc de Marsal, 20.5% of the long bones in Layer 4 show percussion marks, while 13.1% show them in Layer 9; at Pech IV, faunal material show between 19.8% and 38.2% from Layer 4, and 2.4% and 34.8% from Layer 8 (Bordes' excavations and newly excavated material, respectively). Clearly, at both sites, and in layers that both do and do not yield evidence of fire, the hominins were using the caves as a butchering site. Again, this fact makes it difficult to argue that the upper layers of either site were occupied for the purpose of engaging in specialized activities that made the use of fire less necessary or likely.

In terms of the lithic evidence for site function, again there is nothing that suggests major changes in how the site was used during the various occupations. While there is both typological and technological variation in the lithic assemblages, after 50 years of debate there is still no consensus as to exactly what gives rise to it. While site function has been advanced as one possible explanation (Binford 1973; Binford and Binford 1966), other explanations have been offered that are not activity based (Bordes 1961, 1973; Bordes and de Sonneville-Bordes 1970; Dibble and Rolland 1992; Mellars 1965, 1969, 1986, 1988; Rolland and Dibble 1990).

In Figure 12 are displayed the relative proportions of notched tools, scrapers, and other retouched pieces, plotted against the percentages of burned lithics. At Pech IV, in Layer 8, which exhibits the highest degree of burning, the composition of the retouched tools is virtually identical to that of other layers, such as 4a through 5b, which exhibit very little burning. While the exact typological composition among the scrapers changes a bit between these layers, most of this can easily be accounted for by varying degrees of reduction (Dibble 1995; Dibble and Rolland 1992; Dibble et al. 2009), and thus has little to do with function *per se*. It is also clear that none of the occupations of either Roc de Marsal or Pech IV reflect specialized raw material procurement activities, and in all of these layers there is evidence that both core reduction and tool production were taking place. Like most western European Mousterian sites, there is a full range of types represented (Debénath and Dibble 1994), and there is no single type or type class that is clearly associated with fire. Unfortunately, it is also a fact that we are currently unable to link any of these lithic types to specific functions, which means that any argument that ascribes specific activities to these various assemblages would be unfounded.

Together, all of these arguments based on both the lithic and faunal data suggest that the presence or absence of fires is not a reflection of differences in the site use. The most parsimonious explanation in the face of the ethnographic data and what we see at Pech IV and Roc de Marsal is that both sites served generally as base or residential camps, and there is nothing to suggest that this function changed significantly throughout their occupational histories.

IS SEASONALITY A FACTOR IN WHETHER OR NOT FIRE WAS USED?

Unfortunately, there are presently no data concerning seasonality at Roc de Marsal, but those that are available for Pech IV show a mixed pattern (Table 2). There are, for example, occupations year-round in Layer 8, which exhibits the highest frequency of burning, and there is evidence for winter occupation through Layer 5a, by which time evidence for fire is greatly diminished. As yet we cannot exclude the possibility that the other non-fire occupations were limited to summer months, but given the long temporal span of these deposits, it would seem unlikely that occupations took place only during warm months for many tens of millennia. That said, conditions during even the warm months of MIS 4 were still far cooler than today's and, again, modern hunter-gatherers in even substantially warmer environments still rely on fire to warm themselves, especially at night.

DISCUSSION AND IMPLICATIONS

In summary, it is clear at both Roc de Marsal and Pech IV

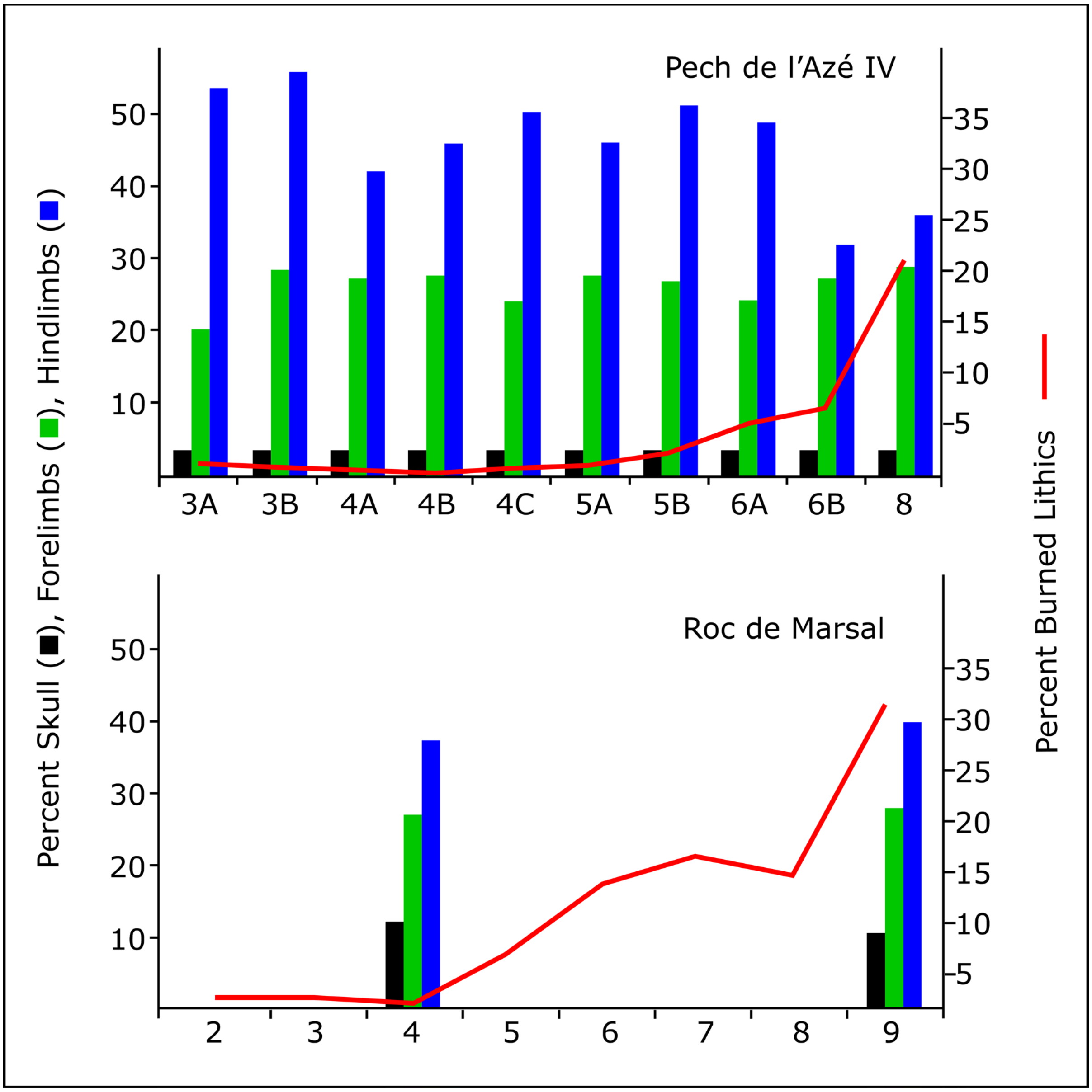

Figure 11. Skeletal element frequency of large cervids (red deer, reindeer) expressed as %NISP for skull, fore- and hindlimb long bones analyzed from Pech de l'Aze IV (top) and Roc de Marsal (bottom), plotted against the percentage of burned lithics found in each level. Teeth and small limb bones (e.g., carpals, tarsals, feet) excluded.

that fire was being used frequently and/or intensely during their earlier occupations, but this use drops to near zero in their upper occupations. These patterns cannot be explained through taphonomy, sampling bias, site function, or seasonality. In spite of the fact that arguments based on negative evidence are fraught with problems, it is difficult in this case not to conclude that the scarcity of evidence for fire in some layers accurately reflects the infrequent use of fire during occupations associated with those layers. For some layers, the very low percentages as well as the simple counts of burned lithics mean that there had to have been some occupations associated with these layers that resulted in no burned lithics. For example, Layer 3b at Pech IV is a relatively thick deposit and must span at least centuries. It includes multiple occupations and yet only 30 lithics were burned (out of a total of 2,851). Use of fire was clearly very infrequent, if not entirely absent, during long periods of time.

What are these results telling us about the role of fire as part of the overall Neandertal adaptation to the conditions present during their occupation of Western Europe? As discussed above, modern hunter-gatherers use fire for a variety of things, and two of the most important are for warmth and cooking. Again, these are activities that take place almost daily. Thus, one of the most interesting patterns to emerge from these Mousterian sites is that the use of fire was greatest during temperate climates, and that its use decreased dramatically during colder conditions. The extreme scarcity or even absence of evidence for fire in occupations associated with colder times is also noted at the site of Combe-Capelle Bas, which was excavated and analyzed using identical techniques. Here too, there was no di-

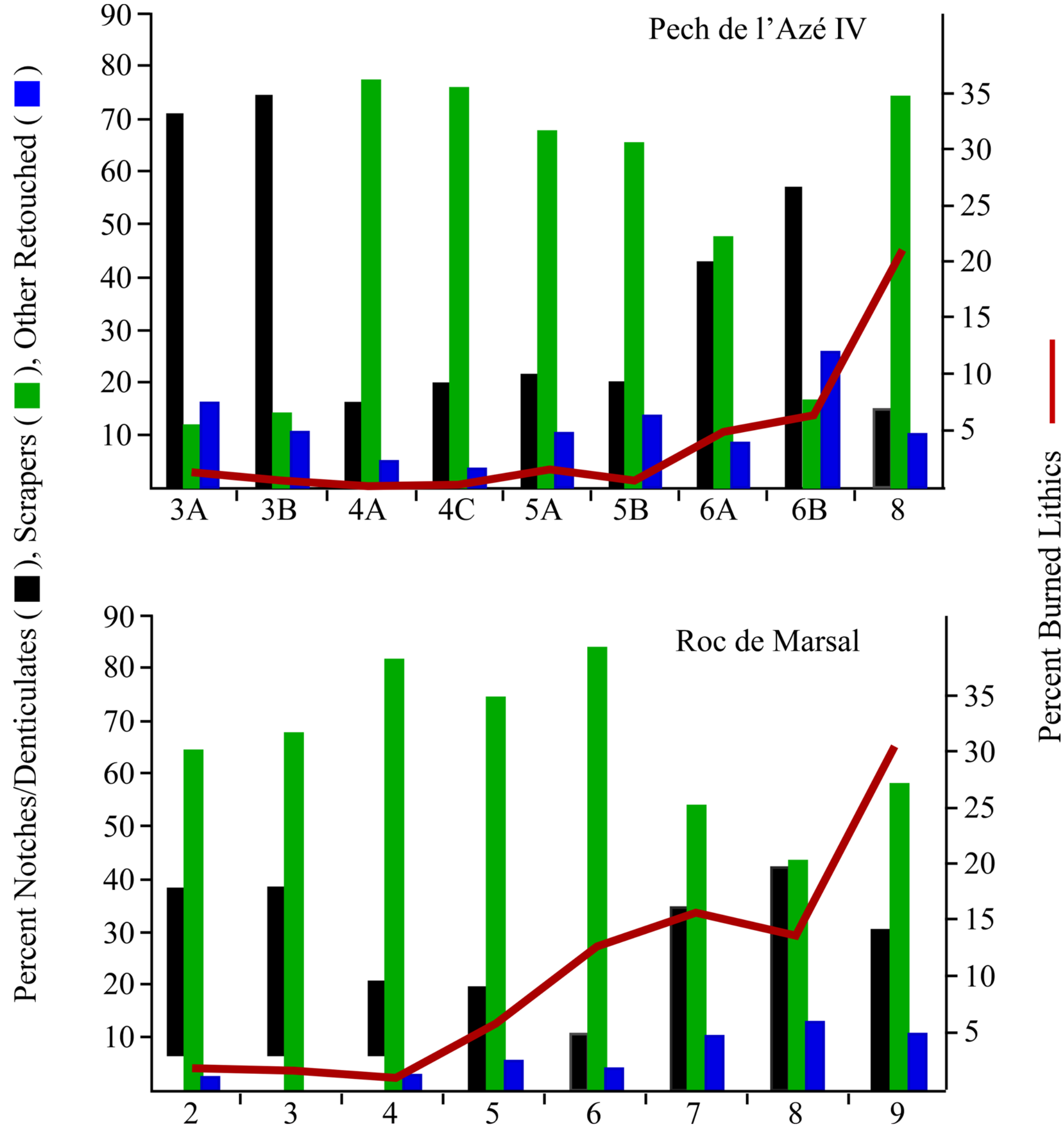

Figure 12. Relative percentages of major classes of retouched tools plotted against the percentage of burned lithics found in each level of Roc de Marsal and Pech IV.

rect evidence of fire residues and the percentage of burned flints remained at <2% for the entire sequence (Dibble and Lenoir 1995). This site has been dated to MIS 3 (Valladas et al. 2003), and is thus contemporary with the non-fire occupations from Pech IV and Roc de Marsal. Similarly, in the Quina Mousterian levels at Jonzac (Jaubert et al. 2008) and La Quina (Bierwirth 1996; McPherron et al. n.d.), neither of which have direct dates but both of which are associated with very high percentages of reindeer, the percentage of heated flints is less than 0.5%. In the overlying levels at these two sites heated flints are never more than 4% of the assemblage and are generally much less.

Thus, the pattern of infrequent fires during colder periods extends beyond Roc de Marsal and Pech IV, and together this strongly argues against the notion that fire was used primarily for warmth. We know that it would be impossible for modern human foragers to inhabit more northerly latitudes without fire, even if they had extremely sophisticated clothing and shelter technology. However, anatomically modern humans were relative newcomers to higher latitudes, and not surprisingly later European Upper Paleolithic occupations exhibit much more fire use when climatic conditions were the most extreme during the last glacial cycle (Théry-Parisot 2002). The Neandertals and their ancestors, on the other hand, had a potential time depth in Europe of at least several hundred thousand years and during several of the climatic oscillations of the Pleistocene. While it is possible that Neandertal populations migrated to some extent in response to major climatic changes and did not always inhabit the most northerly European latitudes during colder periods (e.g., Roebroeks 2006; Steegmann et al. 2002), the presence of occupations in Europe during full glacial conditions indicates that Neandertals were adapted to such conditions. The question is: to what extent was theirs a physiological adaptation *versus* a cultural/technological one? Although there is ongoing discussion about how much of the difference in morphology between Neandertals and their African contemporaries is

TABLE 2. SEASONS OF OCCUPATION AT PECH IV AS INDICATED BY VARIOUS SPECIES.

Layer	Spring	Spring/Summer	Summer	Summer/Fall	Fall	Winter
3A						
3B				horse		
4A	reindeer		reindeer			
4B	reindeer					
4C	reindeer		reindeer			
5A	reindeer					reindeer
5B						
6A		red deer/boar			red deer	red deer
6B	red deer/boar		boar			red deer
8	boar		red deer		red deer	red deer/boar

due to active selective pressures or to random genetic drift, it has long been accepted that Neandertals do exhibit significant cold-adapted features, such as their short, squat, heavy bodies with shorter, stockier limbs (e.g., Holliday 1997; Ruff 1993; Steegmann et al. 2002; Trinkaus 1981).

Cooking is the other daily use of fire among modern hunter-gatherers, and again, the extreme scarcity or even absence of fire during the repeated occupations of these Mousterian sites over significant periods of time suggests that cooking may not have been nearly as ubiquitous as is sometimes believed. This would have significant implications for Neandertal energetics, which is an area where Neandertals differed significantly from anatomically modern humans and it may have behavioral consequences that played a role in the replacement of the former by the latter. It is argued that due to their larger body mass and unique shape, Neandertals would have had a higher basal metabolic rate than anatomically modern humans and therefore a proportionally larger total energy expenditure (e.g., Aiello and Wheeler 2003; Sorenson and Leonard 2001; Steegmann et al. 2002). Conservative estimates suggest a 10% difference between Neandertals and middle Upper Paleolithic humans (Churchill and Rhodes 2009; Froehle and Churchill 2009; MacDonald et al. 2009). This estimate is based on the premise that Neandertals and anatomically modern humans derived the same caloric benefits from the food consumed, and it means that if Neandertals and early anatomically modern humans had the same diet composition, Neandertals would have been obliged to consume more. This in turn may have necessitated more frequent moves (Macdonald et al. 2009). Moreover, given that cooking raises the nutritional and energetic value of food (e.g., Carmody and Wrangham 2009; Wrangham 2009), then an inability to cook their food for extended periods would further increase the amount of food that was needed to be ingested by Neandertals to meet their daily energetic needs. Lower overall energy requirements could have given anatomically modern humans competitive advantages over the Neandertals in terms of reproductive success and demographic expansion (Froehle and Churchill 2009).

It is clear that the evidence from these few sites cannot easily be applied to an entire region, and it is important to emphasize that we are not arguing that the western European Neandertals always ate raw food and never used fire for heat. Clearly, there is no doubt that they did use fire extensively at certain times, as the hearths at Roc de Marsal and Pech IV demonstrate. Just as clearly, however, these sites also show that there were other times when Neandertals did not use fire to a significant degree. This brings us back to the assumption behind the opening quote relating the myth of Prometheus—that once the technology for controlling fire was developed, its use must have immediately become widespread and that its benefits would be enjoyed all of the time. In the case of fire, if one accepts the evidence for controlled use of fire at Gesher Benot Ya'aqov (Alperson-Afil 2008; Goren-Inbar et al. 2004) at approximately 800 kya, it means that thereafter fire would have become an immutable part of the hominin behavioral repertoire. Yet in spite of the fact that Neandertals knew about fire, brought it into their sites, and presumably were able to maintain it over significant periods of time, they did not do so all the time, and especially when climatic conditions were the harshest.

It might be tempting to explain the absence of fire during colder periods as being due to a lack of availability of fuels. It is apparent from long pollen records (e.g., Grande Pile, Les Echets, le Bouchet; [Guiot et al. 1989, 1993; Pons et al. 1992; Reille and De Beaulieu 1990; Woillard 1978]) that wood would have been relatively scarce during colder climatic periods such as MIS 4, when the environment was generally open and dominated by grasses (e.g., Van Andel and Tzedekis 1996: 491). Perhaps, then, the absence of wood as a fuel led to a much decreased frequency and duration of fire use during colder periods. There are, however, two arguments against this explanation. First, even during extreme cold periods there were always some trees around, though likely restricted mainly to river valleys. The second argument is even stronger, however; bone can also be used as fuel, and even though recent experiments have indicated that some wood is needed initially to start bone burning, once started it burns quite well (Théry-Parisot and Costamagno 2005). Clearly, Mousterian sites generally contain large quantities of bone, and at Pech IV, Layer 8, it was definitely used as fuel (Dibble et al. 2009). This situation indicates that availability of wood, while perhaps playing a role in the use of fire, was not a major factor.

A second possible explanation for the absence or scarcity of fires is that European Neandertals did not know how to make fire, even though they knew how to control it by adding fuel, limiting its spread within a site, and transporting it. At first glance, this possibility may seem remote, since the common methods used by recent hunter-gatherers to produce fire, such as fire drills, are relatively simple and fires are easily started—among the Hadza, for example, hunters will construct fires simply to light their cigarettes (Mallol et al. 2007: 2). Yet as simple as it is once one knows how to do it, the production of fire is not something that is an obvious result of rubbing two sticks together or striking two specific kinds of rocks together. Furthermore, just carrying out these behaviors casually or for other intended purposes (e.g., shaping wooden objects or flaking stone) will not, by themselves, result in the production of fire.

However, fires do occur relatively frequently in nature, from lightning strikes, volcanoes, meteorites (Halliday et al. 1984), and spontaneous combustion in organic deposits (e.g., bat guano in caves). Of these, natural fires resulting from lightning strikes are the most common and occur over wide areas, though they occur most frequently in areas and during climatic periods that are warm and humid (Figure 13). Lightning frequency is directly related to temperature and humidity and drops significantly in cold dry climatic conditions (Rakov and Uman 2003). Interestingly, the relationship between climate and lightning frequency matches what the data show is the case during the Mousterian, namely less fire in cold/dry periods and more during warm/humid ones.

A reliance on natural fires by Western European Neandertals resolves many of the contradictions that are apparent in the present review concerning the use of fire by European Neandertals. There is no doubt that harvesting natural fire is simpler than making it, and natural fires would be easy to spot even from considerable distance. Putting aside anecdotes regarding the lighting of cigarettes, even among ethnographic hunter-gatherers who do possess fire making technology, fire curation and transport is a relatively common approach to fire management (e.g., Turnbull 1962). Pruetz and LaDuke (2010) have argued that there are three distinct cognitive stages in the control of fire, beginning with conceptualization (understanding how fires behave and how to predict their movement), then learning how to control fire (how to contain it, keep it going, and put it out), and finally, developing the technology to make it. Quite clearly, it is not at all inconceivable that learning how to control and exploit natural fires is a necessary first step to developing the technology necessary to make it, and there is no reason to assume *a priori* that full pyrotechnology developed simultaneously with the first use of fire by early hominins. As discussed above, the earliest evidence for the use of fire extends far back in prehistory, and since that time it was likely a desired resource that, when available, was used for a variety of things, including cooking and warmth.

The use of fire itself may indeed have started as a gift from the gods, but it took humans to develop the technology to make it at will; the question before us now is when and where did our ancestors develop that technology. Clearly, this is not a statement regarding the intelligence of European Neandertals any more than their lack of ceramic or metal technology indicates that they lacked the cognitive ability of modern humans.

SUMMARY AND CONCLUSIONS

This paper has presented detailed data concerning the variability in the presence, and especially the extreme scarcity or absence, of fire at two Mousterian sites in southwest France. Because direct evidence of fire is subject to a myriad of taphonomic issues that may prevent it from being preserved in the archaeological record, one of our primary goals was to determine if the absence of *in situ* evidence for fire in certain occupation levels at these sites was an artifact of preservation, or whether it accurately reflects the absence of fire itself. By using data such as the frequency of burning on both faunal and lithic objects, it was shown that the scarcity of fire in some layers of either site does not reflect differential preservation, and furthermore, that the scarcity of fire evidence was not due to sampling bias, site function, intensity of occupation, or season of occupation. Instead, the only pattern that was found to be associated with variability in frequency of fire residues was the overall climate, in that occupations during colder times are generally characterized by its rarity or complete absence.

In reviewing the evidence on fire use by modern hunter-gatherers, it became clear that these findings raised an apparent contradiction. Modern hunter-gatherers use fire virtually all of the time, in a wide variety of circumstances, and for a wide range of reasons. European Neandertals did not seem to follow this pattern, even for such basic uses as cooking or for warmth, in spite of the fact that they clearly had at least some control of fire as evidenced by the unquestionable hearths at Roc de Marsal and Pech IV. This contradiction is resolved, however, if we consider the possibility that the Neandertals who lived there simply lacked the ability to make fire, relying instead on the occurrence of natural fires across the landscape. The most common source of natural fires is from lightning strikes, although the frequency of lightning is much higher during warm and humid conditions than it is during periods that are cold and dry. Thus, if Neandertals did lack the technology to create fire at will, then the decrease in natural fires during cold climates is a natural consequence. This interpretation

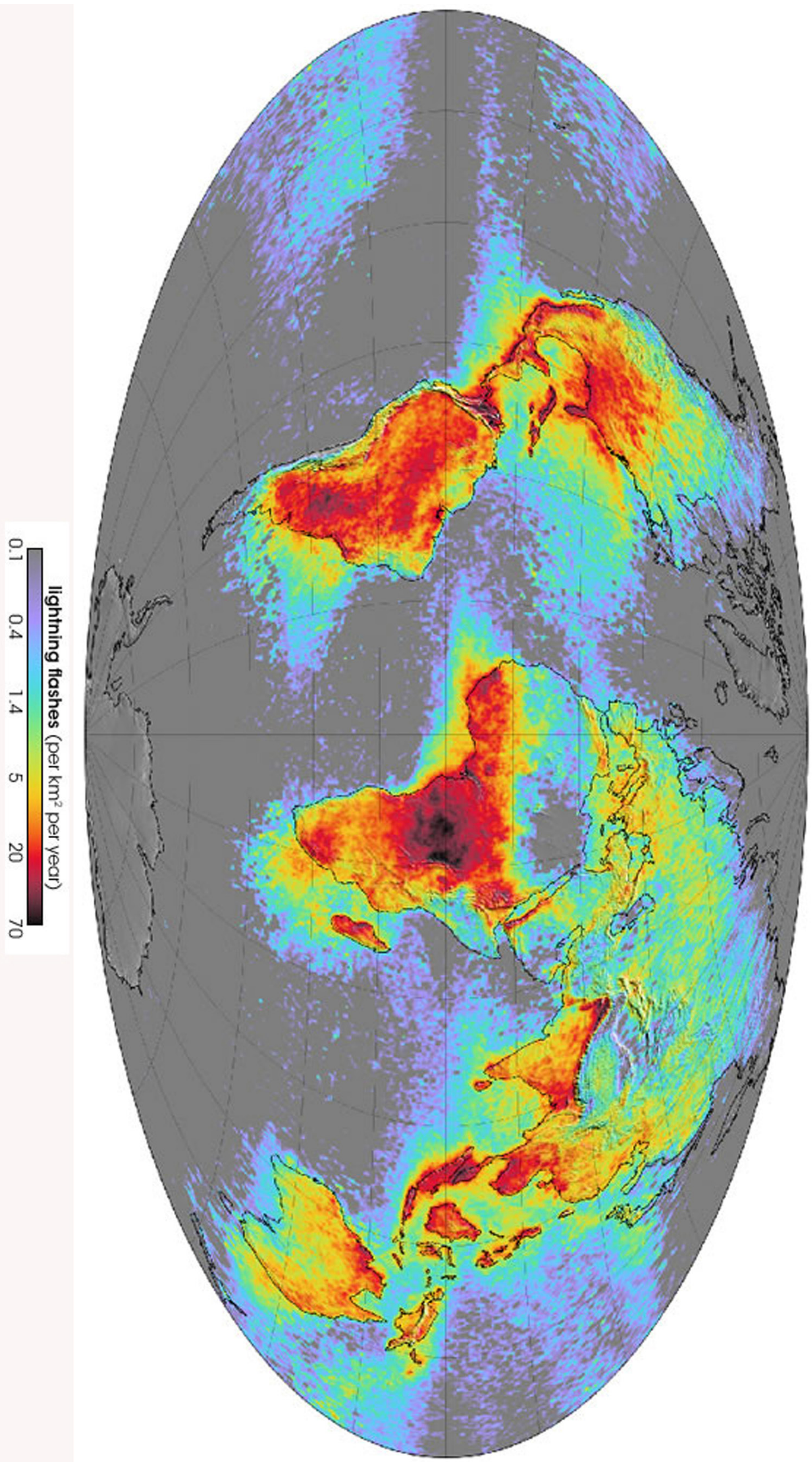

Figure 13. Average yearly counts of lightning flashes per square kilometer. These data were collected by NASA satellites between 1995 and 2002. Image by NASA.

has no implied relation to differences in cognitive abilities between Neandertals and modern humans. In fact, there are examples of very recent hunter-gatherers who lacked the knowledge of how to produce fire (e.g., Hill et. al. 2011: 1288; Stearman 1991: 250) and furthermore, as is true of all innovations, the fact that some populations lack a particular technology, such as the absence of wheeled vehicles in the Americas, does not imply intellectual inferiority.

Admittedly, the data presented here come from very few sites, but the fact is that such high resolution data are generally not available. Many authors simply report—sometimes mistakenly—on the presence of fire residues, and there are few attempts to quantify the occurrence of fire or to use other data, such as burned objects, that may reflect more accurately both presence and absence of fire in the Mousterian. Until we have more data, it is impossible to demonstrate conclusively the ways that Neandertals used fire, or whether they knew how to make it. On the other hand, the data that are available do present unexpected patterns, and therefore offer some directions for future research. If that research shows that fires are indeed rare at many Mousterian sites, then it suggests that fire did not play a significant role in Neandertal adaptions to their local environmental situations, even though it was used occasionally. If we continue to find that fires during the Mousterian are more frequent during temperate conditions and less frequent during colder climates, then that will then support the conclusion that natural fires resulting from lightning strikes were being exploited by Neandertals. On the other hand, future research may show that fires were ubiquitous throughout the period of the Mousterian, and that the patterns presented here for Roc de Marsal and Pech IV reflect some local situation that was particular to those two sites. Clearly, however, such efforts will require archaeologists to begin collecting and reporting more systematically both direct and indirect evidence of fires (see Sergant et al. 2006). Furthermore, evidence from Neandertal sites outside of Western Europe, such as in the Levant (e.g., Meignen et al. 2007), show an intensity of fire use that is much more in keeping with modern hunter-gatherers. Thus, the patterns reported on here quite possibly represent regional variation of culture and behavior, and not a behavioral pattern that is linked specifically to Neandertals in general.

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