On the earliest evidence for habitual use of fire in Europe

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The timing of the human control of fire is a hotly debated issue, with claims for regular fire use by early hominins in Africa at ~1.6 million y ago. These claims are not uncontested, but most archaeologists would agree that the colonization of areas outside Africa, especially of regions such as Europe where temperatures at time dropped below freezing, was indeed tied to the use of fire. Our review of the European evidence suggests that early hominins moved into northern latitudes *without* the habitual use of fire. It was only much later, from ~300,000 to 400,000 y ago onward, that fire became a significant part of the hominin technological repertoire. It is also from the second half of the Middle Pleistocene onward that we can observe spectacular cases of Neandertal pyrotechnological knowledge in the production of hafting materials. The increase in the number of sites with good evidence of fire throughout the Late Pleistocene shows that European Neandertals had fire management not unlike that documented for Upper Paleolithic groups.

human evolution | Paleolithic archeology | fireplaces | hafting adhesives

The emergence of stone tool manufacture and the control of fire are undoubtedly the two most significant events in the technological evolution of early humans. Although stone tool use and manufacture were regular activities from at least 2.6 million y ago (1), the timing of the human control of fire is a controversial issue (2), with some claims for regular fire use by early hominins in Africa at ~1.6 million y ago (3–5). Longer chronologies for the use of fire include Wrangham's recent hypothesis that fire was a central evolutionary force toward larger human brains (6–9): eating cooked foods made early hominin digestion easier, and the energy formerly spent on digestion was freed up, enabling their energy-expensive brains to grow. Using fire to prepare food made early humans move away from the former feed-as-you-go-and-eat-raw-food strategy and toward the sharing of cooked foods around fires, which became attractive locations for increased social interaction between individuals. Wrangham situates these developments around the time of the emergence of *Homo erectus*, approximately two million y ago. Most archeologists would agree that the colonization of areas outside of Africa, especially of regions such as Europe where temperatures at time dropped below freezing (10), was tied to the use of fire to bridge gaps in the energy budget and in resource availability during winter (11). For much later periods, a greater control and more extensive use of fire is seen by some (12, 13) as one of the behavioral innovations that emerged in Africa among modern humans, favoring their spread throughout the world and their eventual evolutionary success.

How strong are these hypotheses? To what extent are they backed up by archeological data on hominin use of fire? Our focus in this review is on Europe, an area of the Old World for which we have a rich record with a large number of sampling points distributed in time and space, with sites in a wide range of sedimentary contexts, from open-air sites to the closed settings of rock shelters and caves.

Results

Interpreting the Record. For most of prehistory until ~10,000 y ago, hominins all over the world subsisted as hunters and gatherers, with a generally highly mobile lifestyle. Until the later phases of the Paleolithic, these mobile foragers invested very little in camp layout, in dwelling structures, or in the construction of formal hearths (14). The overwhelming majority of their traces consist of stone tools, the debris of stone tool production, and often but not always food remains. With few exceptions (see below), preserved fireplaces are simple clusters of burnt materials occurring as flat lenses or in small hollows. The most common proxies for fire use consist of various find categories that display traces of having been submitted to heating: the reddened sediments on which a fire was built, heated stone artifacts, charred bone fragments, and pieces of charcoal. The problem is that other processes than human activities can create such findings too. Volcanic eruptions can be an important factor in driving the natural fire regime in volcanically active areas. Lightning strikes—with an average global flash rate of an estimated 44 ± 5 flashes per second (15)—or spontaneous combustion cause natural fires that can burn archeological camp sites. The remains of such grass and forest fires can become associated with archeological find materials. Hence, charcoal, charred bone material, and heated flints do not necessarily indicate anthropogenic fires (2). At open-air sites, direct evidence for human fires, such as charcoal, can be easily removed by natural processes, including erosion by water or by wind (16). Thus, the context of possible fire indicators is important. 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. Much of the debate on the history of human control of fire relates to the problem of the correct interpretation of possible fire indicators, especially in the absence of modern excavation techniques and detailed studies of site formation processes. In this last domain, significant progress has been made by the application of micromorphological techniques to the study of combustion features in rock shelters and caves (17–20).

European Record. The earliest traces of hominin presence in Europe come from its southern parts and date to more than one million y ago (21). Recent data from the English site Happisburgh 3 suggest that hominins may already have been adapted to the challenging environments of the boreal zone in the Early Pleistocene, more than 800,000 y (800 ka) ago (10). Fire would have

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been an important tool in such environments. However, surprisingly, evidence for use of fire in the Early and early Middle Pleistocene of Europe is extremely weak. Or, more exactly, it is nonexistent, until ~300–400 ka. Our review of the early European sites (Dataset S1) shows that the earliest possible evidence of fire comes from two sites dated to ~400 ka, Beeches Pit in England and Schöningen in Germany. At Schöningen, the evidence consists of some heated flints (although mostly natural pieces) (22) and charred wood, including a wooden tool, with the studies of possible remains of former hearths still in progress (23). At Beeches Pit, dated to Marine Isotope Stage (MIS) 11 (Dataset S1), the evidence consists of heated lithics and heated sediments (24, 25), interpreted as the remains of hearths. Terra Amata (France) and Vérteszöllös (Hungary) also provide credible evidence of fire, but estimates of their age vary from MIS 11 to 9.

Of direct relevance are sites that do not have traces of fire before MIS 9–11. It could be argued that early open-air sites, such as those in the Orce region in Spain (26) or Isernia (27) and Venosa Notarchirico in Italy (28), have been affected by water transport, which removed traces of former fires. The primary context Acheulian site of Boxgrove (29) in England likewise did not yield any evidence for the presence of fire use, a few scattered charcoal particles aside. The absence of heated material from these and other Lower Paleolithic open-air sites could be ascribed to the short-term occupation character of these sites and/or their sedimentary history. However, open-air sites from comparable settings *do* yield traces of the former presence of fire from MIS 11 onward (e.g., Maastricht-Belvédère and Neumark-Nord 2; Dataset S1).

Human occupations *without fire* also occur at six Lower Paleolithic caves: Treugol'naya (Russia), Kozarnika (Bulgaria), Visogliano (Italy), Sima del Elefante (Spain), Arago (France), and Gran Dolina (Spain) (Dataset S1). The latter four sites also yielded hominin remains. The evidence from three sites, Treugol'naya, Kozarnika, and Sima del Elefante, is not yet sufficient to support a hypothesis of hominin habitation, however. To date, Sima del Elefante has yielded only 32 artifacts (21). The early layers of Treugol'naya and Kozarnika have a complex history of human and carnivore occupation. The first site has yielded a small number of artifacts [395 (30)]; faunal remains represent natural mortality or carnivore accumulations, and there is evidence of stream transport of both lithics and bones (31). The lowest levels at Kozarnika (32) have yielded a large number of artifacts, but contextual and taphonomic data are sparse. In contrast, the rockshelter of Visogliano has yielded 2,000 artifacts together with large numbers of cervids (33). Arago and Gran Dolina contain long sequences and large quantities of lithic and faunal remains, subjected to taphonomic analyses (34–36). Their settings are comparable to the ones that, in later times, have often provided strong evidence of fire, such as Bau de l'Aubesier, Grotte XVI, and Lazaret in France; Bolomor Cave in Spain (Dataset S1); and Middle Paleolithic/Middle Stone age caves in Israel and in South Africa. Traces of fire have been found in the upper part of the sequence at Arago, in layers younger than 350 ka. No charcoal, no burnt bones, nor any other evidence of fire have been reported from any of the assemblages from the lower levels (dated to MIS 10–14). No charred bones or heated artifacts have been reported from the Gran Dolina sequence (TD4–TD10). Rare charcoal particles have been found in thin sections of the TD6 sediments, but these sediments originate from the exterior of the cave, and there is evidence of low-energy transport (37); thus, the charcoal may not be in situ. However, the high density of human, faunal, and lithic remains as well as their state of preservation and refitting studies (38, 39) clearly indicate an occupation in situ with little postdepositional disturbance. The absence of any heated material from the long sequences of Gran Dolina and Arago, both documenting hominin occupations over several hundred thousand years (36, 40), is striking. This is a

strong pattern, which can be tested by future work at other hominin habitation sites. We suggest that the European record displays a strong signal, in the sense that, from ~400 to 300 ka ago, many proxies indicate a habitual use of fire, but from the preceding 700 ka of hominin presence in Europe, we have no evidence for fire use.

From around MIS 9, we find extensive traces of the presence of fire in cave settings as well as in the open (Dataset S1). The evidence from the multilevel site of La Cotte de Saint Brelade (Jersey, UK), for instance, shows that fire was extensively used throughout the MIS 7–MIS 4 occupation periods. There are indications of burning in every occupation layer here, with high densities of burnt material and a predominance of burnt bone over wood charcoal. Apparently, in addition to wood, bone was used as fuel as well (41). Spatial concentrations of heated flint artifacts and/or heated stones and charred faunal remains are a common phenomenon on Middle Paleolithic open-air sites all over Europe (Dataset S1).

It is also from the second half of the Middle Pleistocene onward that we can observe some spectacular cases of pyrotechnological knowledge in the production of hafting materials (42, 43), which some consider a proxy for complex, modern cognition (44) (Fig. 1 and *SI Text*). Significantly, several Middle Paleolithic cave and open-air sites have multiple successive levels representing a long time span with clear evidence of fire. Consider the 187 combustion structures in the many levels of Abric Romani in Spain, the 29 combustion structures of Ksiecia Jozefa in Poland, the multiple levels of El Salt, St. Marcel, Esquilleu Cave, Peyrards, La Combette, La Quina, St. Césaire, Oscurusciuto, and the fireplaces of Roca dels Bous (Dataset S1). Les Canalettes, France, is a well-documented Middle Paleolithic site where lignite was repeatedly imported as fuel from a distance of 8–10 km (45). Fig. 2 and Table 1 show a threefold increase in the number of sites with good evidence of fire during MIS 5 and a steady increase in MIS 4 and 3. Stone-lined or stone-delimited fireplaces are not as common as in the late Upper Paleolithic (46–49), but they have been documented at a number of Middle Paleolithic sites: Vilas Ruivas, Les Canalettes, La Combette, Bolomor layer XIII, Port Pignot, Abri du Rozel, Pech de l'Aze II, Grotte du Bison, and Abric Romani (Dataset S1). Hearth-centered activities have been suggested at the rock shelter site of Abric Romani (50), at the open-air sites of La Folie (France) and Ksiecia Jozefa (Poland) (Dataset S1), and in Western Asia at the

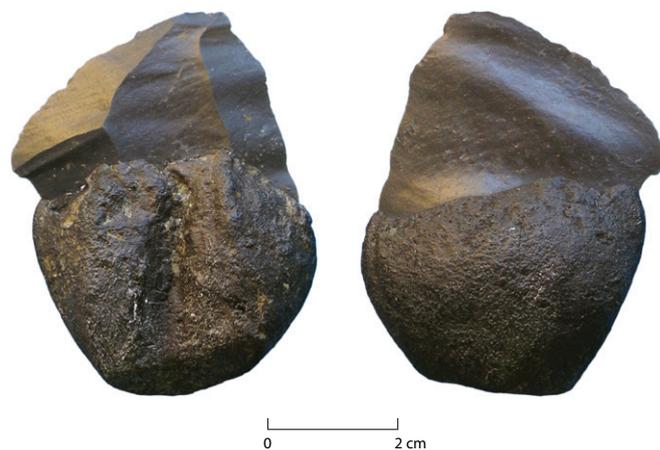**Fig. 1.** Flint flake from Campitello Quarry (Italy), still enclosed in its adhesive, produced more than 200,000 y ago (42) (*SI Text*). Study of such adhesives (42, 43) showed that Neandertals used fire to synthesize from birch bark a pitch for hafting stone tools (photograph courtesy of P. P. A. Mazza, Dipartimento di Scienze della Terra, Università di Firenze, Florence, Italy).
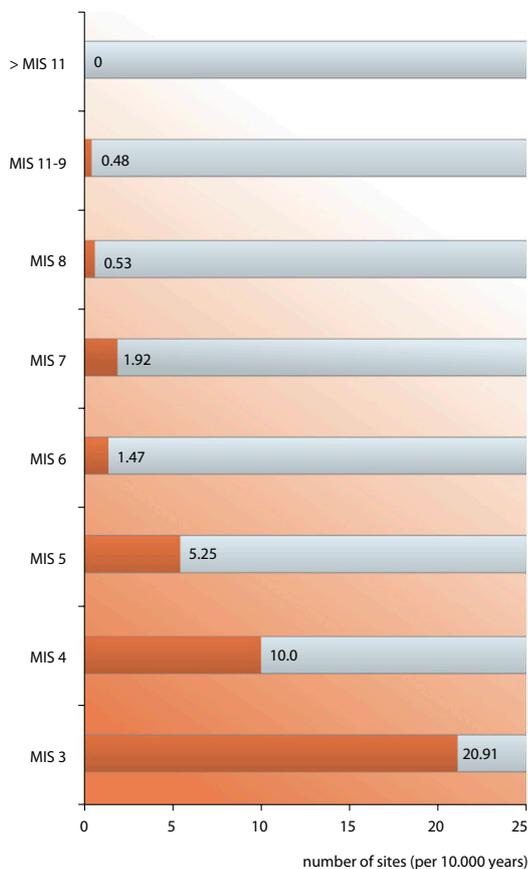
Fig. 2. Number of sites with good evidence of fire (Table 1) per 10 ky. (See Table S1 for age estimates of various MIS stages.) Sites with several layers containing evidence of fire are dated to different MIS score for each MIS concerned.

site of Tor Faraj (51). We conclude 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.

Modern Humans Versus Neandertals. A recent study provides evidence of early modern humans at the site of Pinnacle Point in Southern Africa regular use of heat treatment to increase the

Table 1. Number of sites with good evidence of fire per 10 ky

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

Data based on Dataset S1. Index of confidence 2 and 3.

quality and efficiency of their stone tool manufacture process 164 ka ago (13). The authors infer that the technology required a novel association between fire, its heat, and a structural change in stone with consequent flaking benefits that demanded "an elevated cognitive ability." They also suggest that, when these early modern humans moved into Eurasia, their ability to alter and improve available raw material may have been a behavioral advantage in their encounters with the Neandertals. However, this interpretation ignores that Neandertals used fire as an engineering tool to synthesize birch bark pitch tens of thousands of years before some modern humans at Pinnacle Point decided to put their stone raw material in it. In more general terms, a greater control and more extensive use of fire is sometimes (12) seen as one of the behavioral innovations that emerged in Africa among modern humans and favored the spread of modern humans throughout the world. As stressed by Daniau et al. (52), if extensive fire use for ecosystem management were indeed a component of the modern human technical and cognitive package, one would expect to find major disturbances in the natural biomass burning variability associated with and after the colonization of Eurasia by modern humans. In their study of microcharcoal particles from two deep-sea cores off of Iberia and France, spanning the 70- to 10-ka period of biomass burning, the authors did not recover any sign that Upper Paleolithic humans made any difference: either Neandertals and modern humans did not affect the natural fire regime, or they did so in comparable ways.

Asian and African Records: A Comparison. The European signal for fire use aligns well with what we know from other continents, where indications for habitual use of fire are present from the second half of the Middle Pleistocene onward. As in Europe, fire seems to have become a maintainable technology between ~400 and 200 ka, as illustrated by the evidence from the cave site of Qesem in Israel. Here, micromorphological studies suggest that recrystallized wood ash was a major part of the cave deposits over a long time period and that, at least in the upper part of the sequence, repeated use of fire was common (17). Another signal for habitual fire use in the 300- to 200-ka period comes from a study of heated flints from the Tabun site, also in Israel (53). Many later Middle Paleolithic sites have yielded a wide range of evidence for fire, in the form of the large combustion areas from Kebara or the hearths from Hayonim (54, 55). There are a few claims for earlier use of fire in Asia, however, with the case of Zhoukoudian Locality 1 being the most contested one. Although this site was considered for a long time to be the fire-lit home of *Homo erectus*, studies by Weiner and colleagues (56, 57) showed that the "ashes" supposedly reflecting former hearths were not ashes at all: samples from Layers 10 through 3 showed extensive water deposition of fine silt-sized material (reworked loess), including fine-grained organic matter. The dark, organic-rich unit in Layer 10, often cited as some of the earliest evidence of fire, is in fact a water-laid accumulation. Much of the fine-grained sediment was derived from outside Locality 1. The 4- to 6-m accumulation of supposed ashes in Layer 4 is interpreted as subaerial water-laid silt deposits derived from the loess-covered hill slopes surrounding the site. With such a depositional environment, the presence of charred bone fragments in the sequence can hardly be considered as direct evidence for in situ burning (contra ref. 58).

There is however, one well-established case for earlier repetitive fire use in western Asia: the Acheulian site of Gesher Benot Ya'aqov (GBY) in Israel, dating to ~780 ka ago (59–61). Most of its many find levels might be correlative with MIS 19, i.e., twice as old as the oldest sites with fire indicators in Europe. How strong is the evidence? GBY has both charred plant remains and heated microartifacts (≤2 cm) occurring in localized concentrations in various levels throughout the sequence. Five

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superimposed GBY assemblages contain clusters with frequencies of burned flint microartifacts of 3.7–5.8%. The spatial distributions and the frequencies of burned microartifacts are comparable to those occurring at much younger Magdalenian sites in Western Europe, where knapping near a fireplace was a common occurrence, leading to the accumulation of lithic debris near the hearth (62). The GBY excavators argue that burnt microartifacts and other charred materials are the best indicators of the position of formerly 'invisible" hearths, better than the distribution of macroartifacts that are often rejected away from the combustion area.

For the African record, claims for early fire use from ~1.6 million y ago onward have been made. These claims include 270 charred bones from Swartkrans (5, 63) and red patches of sediments from Chesowanja, Kenya, and from Koobi Fora FxJj 20, thought to be the oxidized remains of 1.5- to 1.6-million-y-old hominin fires (3, 4, 64, 65). These sites do demonstrate that fire-altered materials are associated with early hominin activity areas but not that hominins were involved in the production and/or the use of such fires. When comparing the records of Africa and Europe, one also has to envisage that natural fires were very probably a much more important phenomenon over much of Africa than at northern latitudes. More lightning occurs near the equator than near the poles because of differences in the degree to which daily sunshine heats up the land surface. A recent satellite study shows that ~78% of all global lightning occurs between 30°S and 30°N latitudes, which encompasses most of the African continent (15).

Discussion

In sum, the European evidence strongly suggests that the habitual and *controlled* use of fire was a late phenomenon, dating to the second half of the Middle Pleistocene, which is not to deny the possibility of occasional and opportunistic use of fire in earlier periods (5). In areas that are volcanically active and have high lightning-strike densities, such as the East African Rift and the Afar Triangle, hominins were regularly confronted with natural fires and their results. Early studies of the *Homo erectus*–bearing deposits at Trinil, Java, have already discussed the role of volcanic eruptions in the production of tropical forest fires and the resulting charred plant remains retrieved from the Trinil deposits (66, 67). Living in "fire-rich" environments may have triggered the repeated *opportunistic* use of natural fires in early stages of hominin evolution, but such use did not create an archeologically visible pattern. The evidence from GBY is suggestive of repeated use of fire at *one location only*, at ~800 ka. Together with the claims from some early African sites, the GBY evidence might testify to a sporadic use of fire by hominins before the second half of the Middle Pleistocene. Early hominins had expanded their ranges into the northern temperate latitudes of Eurasia much earlier, however, long before GBY. The finds from Dmanisi, Georgia (68), show that the southern Caucasus was already occupied by 1.7–1.8 Ma, whereas hominins were present in northern China at least by 1.66 Ma, as shown by data from the Nihewan Basin (69). The evidence from Dmanisi and the Nihewan Basin is older than any of the abovementioned African sites with contested traces of fire use. We suggest that early hominins did not need fire for their colonization of these areas where winter temperatures dropped below freezing.

Our interpretation of the record raises the question of how early hominins survived the cold climates of Europe and Asia without fire. A highly active lifestyle and a high-protein diet may have significantly increased their basal metabolic rate as a physiological adaptation to the cold (70). Although the energetic significance of cooking food is clear (7), consumption of raw meat and aquatic resources by hunter-gatherers is well documented

(71). Moreover, extant humans are the product of a long history of genetic adaptations to dietary shifts, of which only a very few and recent ones are relatively well known (72).

From about half a million years ago, Eurasian hominins adapted to a wider range of environments, from milder, interglacial conditions to significantly colder ones. In contrast to the earlier Pleistocene, the archeological record documents a substantial, almost continuous presence of hominins over major parts of Europe and Asia from the middle part of the Middle Pleistocene onward (73–75). The data presented in this article, in combination with the distinct advantages that control of fire would have afforded in higher latitudes, suggest that fire had become a maintainable component of the technology of members of the genus *Homo* around this time.

Conclusion

The pattern emerging is a clear as well as a surprising one: Where we would expect habitual use of fire in the Paleolithic, i.e., the northern latitudes, we do not see any clear traces of it at all until the second half of the Middle Pleistocene. Cave sequences spanning the later part of the Early Pleistocene and the earlier part of the Middle Pleistocene in Europe do not have convincing evidence of fire. The number and quality of these early sites are significant, and this absence of evidence cannot be ignored. The simplest explanation is that there was no habitual use of fire before *ca.* 300–400 ka and therefore that fire was not an essential component of the behavior of the first occupants of the northern latitudes of the Old World. It is only much later, with the Neandertals and their contemporaries elsewhere in the Old World, that fire became an integral part of the technological repertoire of the human lineage. From the late Middle Pleistocene of Europe onward and in the Late Pleistocene of Europe and South Africa, the evidence indicates that Neandertals and (early) modern humans used fire not only for warmth, cooking (76), or extending the length of day but also as an important component of technology for the production of new materials, including adhesives for the hafting of stone artifacts. Contrary to some views (77), European Neandertals had fire-management control not unlike that documented in the Upper Paleolithic.

Materials and Methods

Dataset S1 contains our datasets, which are based on a systematic review of French, English, German, Italian, and Spanish publications. It lists a few Early Pleistocene and several Middle and Late Pleistocene sites with possible evidence of fire associated with Neandertals and earlier hominins. For primary context sites older than MIS 9, negative observations are also recorded. We excluded open-air occurrences in coarse-grained fluvial or clearly disturbed context and sites with underreported, unpublished, or very ambiguous evidence. Several sites where information on charred bone or charcoal or ash lenses was minimal or was provided only in excavation reports with restricted circulation, in theses, and in local journals not easily accessible are not included. The German Late Pleistocene record, for instance, has a number of rich Middle Paleolithic cave sites from which the original excavators reported ample indications for the former presence of fire, including inferred fireplaces, charcoal, and burnt bones, apparently reflecting the use of bones as fuel. However, in the absence of detailed studies, only a few of these sites ended up in Dataset S1. Only sites for which we were able to obtain and check primary sources are included. Sites or layers with so-called "Transitional" industries, e.g., Châtelperronian, Uluzzian, Bohunician, and Streletskyan, are not included.

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