Establishing patterns of early fire use in human evolution

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Abstract

Studying the origins and development of the use of fire as a tool in deep prehistory is challenging, given the mostly ephemeral traces of fire use left behind by mobile hunter-gatherers and their preservation-determined low visibility in the archaeological record. Keeping in mind the incompleteness of that record, we attempt to reconstruct the spatio-temporal patterns of (Early and Middle) Pleistocene fire use in the Old World, building on a series of earlier studies. We briefly review the possible evidence for early fire use in Africa, discuss the evidence from the late Early and early Middle Pleistocene of Africa and Eurasia, and present the rich record of fire use from the second half of the Middle Pleistocene of the Old World. The strong signal for fire use since ~400,000 years ago does not imply that there was no fire use before that period, even though the record for earlier use is ambiguous at best. We infer that, at a minimum, the Middle Pleistocene signal suggests changes in the dynamics of fire use. Despite the fragility of traces of fire use, this change is still visible, hundreds of thousands of years later, in archaeological excavations over major parts of the Old World.

Keywords

Early and Middle Pleistocene, Africa, Eurasia, multi-method approaches, taphonomy

INTRODUCTION

Palaeolithic archaeologists work with notoriously incomplete datasets. The record is biased in many respects, through differential preservation, by visibility and accessibility issues as a result of burial processes, and by imbalances in research intensity between regions, to mention just a few. Despite these limitations, we use this biased record routinely to identify spatiotemporal patterns of hominin activities and to interpret these patterns in terms of former human behaviour. Evaluating the strength of identified patterns and developing testable interpretations that make predictions about what we are going to find in field and laboratory work is the bread and butter of our discipline. Pattern-interpretations generate hypotheses that make predictions that can be tested and can stimulate new work explicitly aimed at proving them wrong, and by doing so, advance our knowledge about the timeline of past behavioural developments.

Here, we will present data that we consider useful to establish patterns of Early and Middle Pleistocene fire use, a topic that has become a major palaeoanthropological research focus in the last decade. This focus is understandable, as systematic interaction with fire, including enhanced maintenance and production (Chazan, 2017), is one of the most important accomplishments within the cultural evolution of humankind. Fire afforded hominins protection against predators and the cold, broadened the range of edible foods and the amount of energy that could be extracted from them through cooking (Wrangham, 2009), allowed manipulation of materials (Mazza et al., 2006), extended the length of the day, impacted the character of human social interactions (Wiessner, 2014), and possibly also the biological adaptations of hominins (Aarts et al., 2016, 2020; Hubbard et al., 2016). Fire gave hominins a tool to increase the productivity of their habitats, over time, through repetitive burning, significantly transforming natural landscapes (Bliege Bird

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et al., 2020; Scherjon et al., 2015). Fire also came with costs (Henry et al., 2018), as fire-using hominins had to collect fuel to be brought to a fireplace, possibly calling for forms of cooperation within a group common in humans today but rare in other primates (Twomey, 2014).

Tracking the development of the earliest uses of fire in time and space is challenging, as identifying traces of fire as anthropogenic is not a straightforward undertaking. One reason for this is the often ephemeral character of fire use by hunter-gatherers, illustrated in these quotes (Woodburn, 1968: 51):

"Vegetable food is collected almost every day by the women of the camp […] Whatever the type of vegetable food, a large proportion is eaten where it is collected. […] Roots are […] in most cases, lightly roasted on an open fire […] The men, like the women, satisfy their hunger at the place where food is obtained. A man on his own will normally light a fire, cook, and eat on the spot any small animal he kills".

This description of foraging and food processing activities by the East African Hadza highlights the short-lived and spatially dispersed use of fire by mobile foragers, who rarely invest in structures around hearths. Materials that have been exposed to heat make up the most common proxies for such fire use and include charcoal, heated lithics, charred bone, and the heat-altered sediments on which a fire was built (James, 1989; Roebroeks and Villa, 2011). In the open air, wind and water easily remove many of the fragile traces (particularly charcoal and ash) (Sergant et al., 2006), while once buried, post-depositional weathering can alter or remove any remaining traces of fire use (for a review, see: Aldeias, 2017). At the same time, natural fires are known to create a range of proxies that can mimic anthropogenic ones (Gowlett et al., 2017).

Given these challenges, many authors argue that the best evidence for anthropogenic fire use comes when several different fire proxies can be demonstrated to be in primary archaeological context (James, 1989; Roebroeks and Villa, 2011). Whether fire occurred where the residues are found can be clarified using micromorphological approaches (Mentzer, 2014). At the same micro-scale techniques can be applied to further understand the archaeological context (Mentzer, 2014), and are particularly effective in cave and rock shelter settings (Braadbaart et al., 2020). An important strand of recent research on the early prehistory of fire use has involved the development and application of new analytical methods to fire residues to deal with these issues, as described in two recent reviews (Mentzer, 2014; Sandgathe and Berna, 2017). This is strengthened by numerous experimental studies testing the effects of heat on wood, bone, and various types of artefacts as well as on sediments underlying fireplaces and the artefacts in those sediments (Reidsma et al., 2016; Aldeias, 2017; van Hoesel et al., 2019). In some cases, such multi-method approaches have shown that inferred traces of early fire use had been diagnosed incorrectly as resulting from heating. Prominent examples have refuted evidence from the South African "Cave of Hearths" (Herries and Latham, 2009) and the ~300 thousand years (ka) old site of Schöningen in Germany (Stahlschmidt et al., 2015).

Given the impact pyrotechnology must have had, understanding the origins and development of fire use is relevant for our understanding of the development of the human niche. Keeping in mind the challenges mentioned above, we will attempt to establish the spatiotemporal pattern of (Early and Middle) Pleistocene fire use in the Old World. We will do this building on a series of earlier studies (James, 1989; Rolland, 2004; Roebroeks and Villa, 2011; Gowlett and Wrangham, 2013) and expanding these with recently published data, profiting from the multi-method approaches mentioned above. We will first briefly review the possible evidence for early fire use in Africa, then discuss the evidence from the late Early and earlier Middle Pleistocene of Africa and Eurasia, and, finally, document the strong signal of fire use from the second half of the Middle Pleistocene of the Old World. We will make a brief attempt to interpret the established pattern in the discussion part of our contribution.

EARLIEST FIRES IN AFRICA?

In contrast to Richard Wrangham's well-known arguments in the fire debate for the role of cooking in the emergence of the *Homo erectus* Bauplan, there exists no archaeological evidence for hominin fire use until minimally half a million years *after* the emergence of the *Homo erectus* lineage (Herries et al., 2020). Even those earliest *possible* traces, dating to around 1.5 million years (Ma), are debated (Brain, 1993; Gowlett and Wrangham, 2013; Hlubik et al., 2017, 2019; Isaac, 1982; James, 1989). The open-air setting of all of these early sites continues to be a problem for interpreting the anthropogenic versus natural origin of the earliest fire evidence, as exemplified by possible fireplaces from the Koobi Fora area with reddened patches of sediment, the origin of which after four decades(!) is still under debate (Gowlett et al., 1981; Isaac, 1982; Clark and Harris, 1985; Hlubik et al., 2017, 2019).

The Wonderwerk Cave (South Africa) is often cited as having the earliest evidence for human knowledge and use of fire (Stahlschmidt et al., 2015: 182), around 1 Ma ago, but the evidence given in the available proxies might not be strong enough to support the significance for early fire given to this site. Peter Beaumont (2011) presented the potential evidence for the presence of anthropogenic fire at Wonderwerk Cave based on macroscopic observations as far back as Stratum 12 (Oldowan) of the cave, while Berna et al. (2012) identified microstratigraphic evidence of "*in situ* fire" from Stratum 10, in the form of heated bone and ashed plant remains. From this evidence, these authors inferred that fire was present during the early Acheulian occupation of the cave, and given the long distance from the present entrance (around 30 m), it was assumed that these fires were introduced by hominins (Berna et al., 2012). However, no data were presented that could confirm that the small materials were indeed heated on the location where they were retrieved. Analyses of new samples from the Wonderwerk sequence furthermore show that the micromorphological evidence published in 2012 "[…] is clouded by the fragments of micritic pseudomorphs of plant tissues", opening "[…] up the possibility that some of the ashes originally identified in a small area […] were in fact calcified plant fragments" (Goldberg et al., 2015: 641). All in all, the evidence for hominin-made fire(s) in the cave is possibly not as strong as originally presented by Berna and colleagues (2012).

Furthermore, and importantly, Chazan (2017) has contrasted the presence of traces of fire in the low-density cave site setting of Wonderwerk on the eastern slopes of the Kuruman Hills with the absence of any traces of fire in the Acheulian and Fauresmith sites of the Kathu complex on the hills' western fringes. The tens of millions of stone tools from these sites have not yielded any (macroscopically visibly) heated lithics. In Chazan's view, the presence of fire in a low-density cave site contemporaneous with the absence of fire traces on sites with massive accumulations of lithics suggests that during this period, aspects of hominin behaviour related to the use of fire and those related to the production and discard of large quantities of artefacts may have been spatially differentiated. In his view, such a spatial differentiation of the use of fire and the discard of stone tools at around 1 Ma is, at the least, difficult to reconcile with the important role of fire in human evolution, which Wrangham's cooking hypothesis suggests (Chazan, 2017).

The current data for early fire use in Africa suggests that the dispersal of early hominins into Eurasia, at around 2 Ma, was *not* associated with any type of archaeologically visible fire use. By this time, hominins were already distributed over major parts of the Old World. As far as the archaeological evidence goes, the Early Pleistocene hominin range expansion into Eurasia seems to have been carried out by hominins who were *not* dependent on the use of fire.

THE LATE EARLY AND EARLY MIDDLE PLEISTOCENE FIRE RECORD

The fire record from about 1.0 to 0.4 Ma might be expected to yield more convincing examples, given the much denser record of sites, wider geographical distribution, and cooler or otherwise more challenging conditions at some locations, but this does not seem to be the case. Roebroeks and Villa's (2011) review of the European evidence of a decade ago identified a distinct change in the European archaeological record around 350-400 ka ago, with the first half of the Middle Pleistocene and earlier periods seemingly devoid of any solid traces of anthropogenic fire use. Long archaeological karstic sequences such as the Atapuerca site complex in Spain or the Caune de l'Arago at Tautavel (France) did not yield any evidence for fires caused by hominins until ca. 350 ka, while fire traces are also absent from open-air sites dating to the late Early and first half of the Middle Pleistocene, including prolific sites such as Boxgrove in the UK (Roebroeks and Villa, 2011).

The Cueva Negra cave site in south-eastern Spain, however, constitutes a possible case of fire use at the very end of the Early Pleistocene. Here indications for anthropogenic fire in the form of very small pieces of heated chert, charred and calcined bone fragments, and heated microfaunal remains within an area of coloured sediment have been reported (Walker et al., 2016; Rhodes et al., 2016). Given the small number of lithics, their very small size (0.5 to 5 mm) and shattered condition, it seems possible that a key part of this evidence is based on a few heat-altered larger stones only. However, it remains open whether or not these stones were artefacts. Initially assigned to the later part of the Middle Pleistocene, the sequence has now been dated by magnetostratigraphy (Scott and Gibert, 2009) and faunal remains (Lopéz Jiménez et al., 2020) to the late Matuyama period (~1.0-0.8 Ma). However, some workers still prefer a late Middle Pleistocene age (e.g., Jimenez-Arenas et al., 2011).

The early Middle Pleistocene Levantine site of Gesher Benot Ya'aqov is often quoted as demonstrating recurrent fire use over tens of thousands of years, in the form of a series of "phantom hearths" with an age of ~780-700 ka. These are identified using maps of the distribution of heated flint (micro-) artefacts at the site. However, some of these "burned flint microartifacts" (Alperson-Afil and Goren-Inbar, 2010: Appendix 1; cf. Goren-Inbar et al., 2004: Suppl. Materials) may not be humanly modified pieces. Although it is difficult to evaluate this on basis of the published picture, certainly the artefactual status of objects b, c, j, and l in Appendix 1 of Goren-Inbar et al. (2004) needs further scrutiny (cf. Stahlschmidt et al., 2015: 183, for comments about the character of the Gesher Benot Ya'aqov evidence).

Absence of evidence is not evidence of absence, especially given the fact that proxies for anthropogenic fire use are generally very ephemeral and bound to easily disappear from the archaeological record. Lebreton et al. (2019) recently analysed micro-charcoal from Middle Pleistocene sediments from sites in the Molise region in southern Italy, where hominins were virtually continuously present. They focused on micro-charcoal to deal with the possibility that weathering, affecting charcoal preservation and fragmentation and dispersion of heated materials, may have destroyed potential proxies for anthropogenic fires. In their study, the authors compared sediments from geological and archaeological sites, focusing on data from 780-300 ka, the period before and after the inferred onset of regular fire use in Europe. Their study concludes that no evidence of anthropogenic fire is present for this whole time window in Molise, either in the form of hearths or high concentrations of micro-charcoal. In the view of Lebreton et al. (2019), the oldest evidence for fire use in Italy thus far documented dates from the Middle Palaeolithic site of Campitello Quarry, which has a minimum age of ~200 ka (Mazza et al., 2006).

Again, such a lack of evidence needs to be treated with caution, given the taphonomic issues with fire proxies mentioned above. This especially applies to the African record for this time trajectory, given the low density of observation points there. In that respect one interesting high altitude area without fire evidence may be worth mentioning here. The Melka Kunturé open-air sites complex, situated in the Upper Awash valley in the northern Ethiopian highlands, is located at about 2,000 m a.s.l., documenting hominin adaptations to high altitude environments over a very long period, from ~1.7 Ma to the Late Stone Age. In the Pleistocene these high altitude environments were affected by severe cold periods, probably too cold for a continuous hominin presence, as suggested for the occupation signal from the 850-700 ka sequence of Gombore II (Mussi et al., 2016). Apart from a single possibly heated pebble from Garba 1, a late Acheulian site (Chavaillon and Berthelet, 2004), there is no evidence for the presence of fire until the Late Stone Age throughout the whole of the spatially extensive Melka Kunturé complex.

This absence (or extreme rarity) of traces of fire use in the late Early Pleistocene and the early Middle Pleistocene, in (high altitude) Africa and western Eurasia, raises important questions about hominin survival strategies. At the least, hominins, distributed over large parts of the Old World from around 2 Ma onward, did not use fire in the regular way suggested by the cooking hypothesis (or minimally: did not do so constantly, i.e., in an archaeologically visible way) for hundreds of thousands of years (MacDonald, 2017). However, as Gowlett and Wrangham (2013: 22) argue, "To postulate that they could manage without fire is to say that they had other strategies for preparing uncooked fat and meat, for maintaining warmth during the ice-age winter and avoiding predators."

Recent work may provide some alternatives for food processing and digestion. Zink and Lieberman (2016) point to the importance of simple food processing techniques like slicing meat and pounding vegetables, while Speth (2017) argues that fermentation of meat, fat and fish could have provided many of the benefits similar to cooking for Neanderthals, as well as a means of storing food and preserving vitamin C. Following Speth's studies, Dunn et al. (2020: 8) suggest that "[…] neither technical nor intellectual barriers would have prevented *H. erectus* or their relatives from fermenting at least some kinds of food". In support, they cite simple ethnographically documented methods of fermentation and examples of carnivores storing and fermenting meat, as well as the likelihood (still to be demonstrated) that a common ancestor of chimpanzees and humans possessed adaptations to tolerate sour tastes and digest alcohol. If they can be applied to early occupants of high altitude settings throughout the Old World, these suggestions help to explain how hominins could have met their nutritional needs without use of fire to cook food. Alternative physiological and cultural ways of controlling body temperature have also been suggested (MacDonald, 2018; Gilligan, 2010), including muscle insulation and a high level of metabolic up-regulation, a thin layer of winter fur, wearing simple clothes, or seasonal migration. Combinations of these strategies could have helped hominins to avoid hypothermia even in winter conditions at sites in North-Western Europe, assuming they got enough food (MacDonald, 2018). These scenarios would seem to make the absence or infrequent use of fire by the earliest occupants of Europe plausible but require testing in the archaeological record and ancient DNA. However, the subsequent strong fire signal change in the middle part of the Middle Pleistocene is beyond any doubt, as discussed in the following section.

A MIDDLE PLEISTOCENE CHANGE IN THE FIRE RECORD?

The later half of the Middle Pleistocene is characterised by a large number of sites with multiple proxies for fire use, in close to primary context, from ~400 ka onwards, with the frequency with which multiple traces of fire are present increasing (James, 1989; Rolland, 2004; Roebroeks and Villa, 2011; Gowlett and Wrangham, 2013). The Gruta da Aroeira cave site in Portugal provides a recent confirmation of this pattern in Europe, where fire proxies in the form of heated bones are found starting ~400 ka (Daura et al., 2017).

Shimelmitz et al. (2014) have tried to put an age estimate on the "emergence of habitual fire use" in the Levant, to a large degree based on the long and well-dated sequence of Tabun Cave, Israel, as well as a review of the evidence from a range of other cave sites (note that the site Gesher Benot Ya'aqov is not even mentioned in this review). In the case of Tabun, Shimelmitz et al. (2014) interpret increases in the frequencies of heated lithics as indicating the onset of "regular fire use" between 357 and 324 ka. The presence of very low numbers of heated lithics further down in the sequence, however, indicates that fire use did occur somewhat earlier at Tabun. Earlier fire use may simply not be reflected well in the excavated assemblages: rock shelters and caves evolve through time, with cliff faces and drip lines receding and the feature finally becoming unsuitable for human habitation. These changes in morphology have consequences for the placement of "site furniture", including fireplaces, in these locales and hence for their visibility in the archaeological record. Locations where fireplaces were positioned in the early phases of a rock shelter (i. e., most likely closer to the drip-line) may already have disappeared through lateral erosion when later occupations occurred (and the drip-line moved backwards), while small-scale excavations may only document specific parts of the former use of a rock shelter (Sorensen and Scherjon, 2018). Nevertheless, while the 324-357 ka date may underestimate the actual age of the onset of regular fire use in the Levant, the Levantine evidence as reviewed by Shimelmitz et al. (2014) strongly suggests that fire use was an integral part of the hominin technological repertoire here during the second part of the Middle Pleistocene.

Beyond the Levant, there is very limited evidence for fire use in the Middle Pleistocene of Asia (Dennell, 2008). Gao et al. (2017) discuss the history of fire research at the Zhoukoudian site in China, where evidence for *Homo erectus* fire use discovered in the 1930s became contested from the 1980s onward. Recent excavations have uncovered unambiguous traces of anthropogenic fires in a layer for which the age estimates obtained vary per dating technique used, but all point to the 500-250 ka range (Gao et al., 2017).

While we have focused thus far on Eurasian and Near Eastern evidence, a good African illustration of the Middle Pleistocene change in fire signal is provided by the occupation traces *Homo sapiens* left at Jebel Irhoud, Morocco, a locality with abundant evidence for anthropogenic fire use at ~300 ka, including numerous heated lithics and heated faunal remains (Richter et al., 2017). The Jebel Irhoud evidence fits very well into the pattern of abundant evidence for anthropogenic fire use also in the African MSA, particularly in South African caves, reflecting the amount of fieldwork done there. Bentsen's (2013) review of the various kinds of fire evidence shows that the regular use of fire was very important in the MSA, as it was in the European and Western Asian Middle Palaeolithic (Roebroeks and Villa, 2011; Shimelmitz et al., 2014; Sorensen, 2019).

In most western Eurasian Middle Palaeolithic sites fire proxies are present, in open-air as well as rock shelter sites (Roebroeks and Villa, 2011). Fire was used for the cooking of foods (Henry et al., 2011), production of pitches (Mazza et al., 2006) and to gain access to deep caves (Jaubert et al., 2016). There are sites at which such fire evidence is repeated many times, over long periods, in open-air contexts, such as at Biache-Saint-Vaast (France) (Hérisson et al., 2013), as well as in karstic settings. For example, at Bolomor Cave, Portugal, 14 hearths associated with heated materials have been excavated from multiple levels dating from 350-100 ka (Peris et al., 2012). Similarly, in the Near East, at Qesem Cave, there is evidence for extensive burning throughout the occupation history of the site, between 400 and 200 ka (Karkanas et al., 2007), and a very large central hearth dating to around 300 ka was used repeatedly (Shahack-Gross et al., 2014). Even though it is difficult to find evidence for fire *production* in this period (Sorensen et al., 2018), the evidence for fire use in the second half of the Middle Pleistocene is very strong.

DISCUSSION

Our review indicates that fire use was very probably a standard part of the hominin technological repertoire from the second half of the Middle Pleistocene onward. In this sense, our review supports suggestions made in previous reviews of the record from Europe and the Levant. We see plausible evidence for "fire at will" (Shimelmitz et al., 2014) in those parts of the Old World that have undergone some form of representative archaeological sampling – and comparable evidence is very probably also hidden in sediments in areas where we have seen far less archaeological fieldwork relative to the size of the regions (and perhaps also in the literature of these areas), such as the Indian subcontinent, China and Southeast Asia. The strong signal for fire use since ~400 ka does not imply that there was no fire use before that period, even if some of the early contested cases may indeed be the result of natural fires. As mentioned above, hominins were distributed over large parts of the Old World from around 2 Ma onward and were probably occasionally exposed to settings that are quite challenging in terms of thermoregulation and diet for present-day humans in our current interglacial, such as the loess plateau of Central China (Zhu et al., 2018). The few cases for which early Middle Pleistocene and Early Pleistocene fire use have been claimed (see above) may indeed testify to earlier use, possibly limited to specific periods and/or regions only: depending on the mode(s) of cultural transmission of knowledge, population density and ecological necessity, new inventions could have flourished for some time and petered out again. Early Pleistocene hominins at the northern edge of their range may have been occasional visitors, expanding their ranges during warm periods, possibly from a source population in a more temperate region, and staying only for the warmer parts of the year (Dennell, 2013). Even if groups or subpopulations on the northern edge of the range were using fire, these skills might have been lost due to local extinctions, and 'source' populations from warmer regions might have had less use for such skills. The costs associated with fire use, and benefits varying with environment, also make it more likely that fire use was patchy and temporary (Henry et al., 2018), at least in its early stages.

We cannot even rule out the possibility that fire use, despite its extreme rarity or complete absence over much of the archaeological record, was ubiquitous in the Old World, long before it became archaeologically visible in the middle part of the Middle Pleistocene. In such an interpretation, its traces simply did not survive or have not been picked up yet. Parker et al.'s (2016) pyrophilic primate hypothesis, for instance, suggests that long before fire use became visible at archaeological sites, where it was used to prepare food, hominins had been experiencing the foraging benefits of freshly burned landscapes and over time actively transported fire from burned to unburned areas, with virtually no traces left in the archaeological record. We have to envisage that the range of purposes for which fire was used broadened over time to incorporate e.g., food preparation and preservation activities and the production of new materials, such as pitches (Mazza et al., 2006), all possibly increasing the archaeological visibility of fire use. Such changes may have occurred at different periods in different regions and within different types of environments.

Also, changes in mobility and land-use strategies that involved longer stays at "base camps" versus an earlier "on the road" and shorter-term use of fire, may have increased the archaeological visibility of its usage and have generated the strong mid-Middle Pleistocene fire signal reported here (cf. Rolland, 2004). Kuhn and Stiner (2019) suggest that changes in social and spatial organisation are evident in the Near Eastern Middle Pleistocene record, reflected in a strong association between fire use and caves; this may be true in other regions as well. Or as Holdaway et al. (2017: S239) suggest, "What may have changed [in the European Middle Palaeolithic] was the locations where fires were created and therefore the probability of their survival in the archaeological record".

Whatever the correct interpretation of the pattern is (cf. MacDonald et al., in prep.), and no matter how "messy" the record for Pleistocene fire use seems to be, we do suggest that amid this taphonomical "noise" the mid-Middle Pleistocene fire signal is a very strong signal: it indicates changes in the dynamics of fire use that despite the fragility of its traces are still visible, hundreds of thousands of years later, in archaeological excavations all over major parts of the Old World.

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