

# Beyond prometheus: pursuing the origins of fire production among early humans

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# Citation

Sorensen, A. C. (2018, December 13). *Beyond prometheus: pursuing the origins of fire production among early humans*. Retrieved from https://hdl.handle.net/1887/67525

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Cover Page



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**Title:** Beyond prometheus: pursuing the origins of fire production among early humans **Issue Date:** 2018-12-13

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 farseen 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)

Whether obtained from Prometheus via the heavens in the form of lightning, or perhaps collected directly from the volcanic forges of Hephaestus, the human acquisition of fire set our hominin ancestors on a trajectory that would in the end culminate in a society today just as dependent on fire, if not more so, than it was long ago amongst early hunter-gatherers. The manipulation and production of fire is an exclusively human trait, arguably to a greater extent than both tool use and language, and one that eventually became universal within the *Homo* lineage (Goudsblom, 1986).

The benefits conferred by fire unto those brave enough to wield it are manifold (for an overview, see Clark and Harris, 1985). It is often said that range expansion into naturally uninhabitable parts of the world is one of the hallmarks of modern behaviour in humans (McBrearty and Brooks, 2000). One could, in many regards, consider fire the ultimate 'range expander'. Fire buffered humans from the cooler conditions associated with a spatial expansion outward to more northerly latitudes and upward into higher altitudes (Gowlett, 2006; Oakley, 1956; Rolland, 2004; Weiner, et al., 1998; but see Perles, 1977; Roebroeks and Villa, 2011a). Since fire can act as a deterrent of dangerous predators (Brain and Sillen, 1988; Goudsblom, 1986), it has been postulated that hominins were unable to securely occupy cave sites until regular use of fire provided a means to drive out cave-dwelling competitor species like hyenas or bears (Oakley, 1956). The added security also translated to added comfort, since fire is an effective means of cleansing sleeping areas of old grass bedding and parasites living therein (Goldberg, et al., 2009; Wadley, et al., 2011), and the smoke from fires helps to keep pesky biting flies and swarming mosquitoes at bay (Binford, 1978; Sharp and Sharp, 2015). Temporally, fire extended the day by providing light to work by and cutting the night chill. The social nature of eating and working around a fire led to an expansion of communication and solidarity within groups (Dunbar, 1998; Dunbar and Gowlett, 2014; Dunbar and Shultz, 2007; Wiessner, 2014) that fostered an environment ripe for cultural and technological advances. Regarding the latter, fire improved the workability of wooden (Aranguren, et al., 2018; Ennos and Chan, 2016; Rios-Garaizar, et al., 2018) and stone tools (Brown, et al., 2009; Schmidt, et al., 2013), as well allowed for the synthesis of entirely new materials like birch bark pitch (Kozowyk, et al., 2017), which was used as a hafting material (Koller, et al., 2001; Mazza, et al., 2006). Fire was also widely used 'off-site' as a tool to aid in hunting or to encourage the growth of edible plants preferred by prey species or by the hominins themselves, in some instances ultimately-by chance or by design-reconfiguring entire landscapes (for an extensive ethnographic and archaeological overview of these phenomena, see Scherjon, et al., 2015 and the sources therein). Finally, of the advantages offered by fire use, the ability to cook food is often the most discussed. Cooking with fire expanded the range of foods consumed by hominins, both in variety and quality (Goudsblom, 1992), including eliminating toxins (Stahl, et al., 1984) or making it easier to access foods with tough skins like tubers (Schnorr, et al., 2015), as well as conferring a number of energetic and health benefits: increased caloric savings (Boback, et al., 2007; Carmody and Wrangham, 2009; Groopman, et al., 2015), reduced cost of digestion (Boback, et al., 2007; Carmody, et al., 2011), decreased time and effort spent chewing (Dominy, et al., 2008; Fonseca-Azevedo and

Herculano-Houzel, 2012; Organ, et al., 2011; Zink, et al., 2014), and decreased risk of food-borne illness (Smith, et al., 2015; but see Speth, 2017).

Humans did not invent fire, but instead harnessed it, giving purpose to an otherwise mostly unwieldy and destructive force. In line with fire myths that claim fire to be a gift instead of a learned skill, it is inferred that hominins initially collected fire from natural conflagrations caused by lightning, volcanism or, more infrequently, the spontaneous combustion of coal, oil-shale or other concentrations of organic plant matter (Oakley, 1956). However, using fire does not necessarily equate to being able to produce it. The purpose of the research proposed here is to move 'beyond Prometheus' and discern when humans no longer needed to rely on higher (natural) forces to provide them with fire, but instead could regularly make it for themselves. The incorporation of fire into the human toolkit was very probably not a singular event, as most fire myths would lead one to believe. Instead, it was an extended and likely punctuated process where hominins first became comfortable around fire, which, through trial and error, eventually led to its acquisition and use and, ultimately, to the ability to produce it at will. When exactly humans (or their ancestors) first developed these abilities is still a source of considerable debate (Berna, et al., 2012; Roebroeks and Villa, 2011a; Wrangham, 2009), as unfortunately for archaeologists, fire production has been notoriously difficult to identify in the archaeological record prior to the Holocene (see Chapter 4).

As pointed out in a recent publication by Sandgathe and Berna (2017), the subject of Palaeolithic fire use has become a hot-button issue in the field of archaeology in recent decades. The primary overarching questions being pursued include: When did hominins begin using fire? What were the behavioural and physiological consequences of infrequent or regular fire use by humans and how do these manifest? When (and where) did fire use become a 'fixed' or 'habitual' element within the human technological repertoire? And when did hominins begin to make fire for themselves? The research conducted for this dissertation concerns itself principally with the final two questions, these focusing more on the latter stages of humankind's love affair with fire. The purpose of this research, therefore, is two-fold: 1) to determine from the archaeological record how and to what extent Neandertals used fire, and 2) to identify artefactual evidence of fire making by these peoples. The first portion of this chapter presents an extensive overview of the research history of human/fire interactions and the means by which researchers attempt to identify transitions to more advanced stages of hominin fire use. The latter section provides a description of the four peer-reviewed papers that comprise the core of the dissertation and the research goals of each.

# 1.1 THE PREHISTORY OF FIRE AND HOMININ FIRE USE

Fire has been a global phenomenon since at least the Devonian period, when the first evidence of fire in the form of fusain or fusinite (fossil charcoal) is observed in the geological record (Scott, 2000). Fusain layers, presumably products of ancient fires ignited by lighting or spontaneous combustion of decaying organic matter, are also a common occurrence within Carboniferous coal beds (see Komarek, 1972). Other notable examples of ancient fire include fire scars on Triassic trees (Byers, et al., 2014), charcoals associated with dinosaur bones dating to the Cretaceous (Brown, et al., 2013), and heated fragments of chert (Bordes, 1957) and bone (Hendey, 1976) from Miocene deposits. Thus, by the time our human ancestors arrived on the scene, fire was a in many environments a common occurrence, and many plants and animals had become at least accustomed to coping with wildfires, while other more pyrophilic species had developed adaptions that made them to varying degrees reliant on the actions of fire for their survival. Among animals, this is reflected in many modern species that show little to no flight response to wildfires, take advantage of recently burned tracts of land for grazing or foraging, or are attracted to smoke and actively interact with burning fires (Komarek, 1969), including some

primate species (Parker, et al., 2016; Pruetz and Herzog, 2017; Pruetz and LaDuke, 2010). Even some birds of prey in Australia often congregate near the edges of bushfires to take advantage of fleeing animals and insects and have been observed actively lighting grass fires by picking up smouldering twigs from one fire and dropping them in unburned areas to ignite another (Bonta, et al., 2017).

This familiarisation with natural fire encompasses the hypothesized first stage of hominin interaction with fire (Parker, et al., 2016), of which there are generally considered three or four, depending on which source one consults. Sandgathe (2017) provides a good overview of the slightly different configurations of these progressive steps towards greater complexity of fire use that have been proffered in the past (see Burton, 2009; Chazan, 2017; Frazer, 1930; Goudsblom, 1986; Parker, et al., 2016; Pruetz and LaDuke, 2010), ultimately combining and distilling them down to four major stages: 1) habituation to natural fire, 2) use of fire, 3) maintenance of fire, and 4) manufacture of fire.

As already alluded to above, the hominin fire habituation phase itself could be subdivided into increasingly more intimate interactions with fire, beginning with the basic suppression of the flight response when encountering a natural fire (Clark and Harris, 1985) and being able to negotiate a burning landscape calmly without panicking (Pruetz and LaDuke, 2010), and then progressing to identifying and exploiting the beneficial consequences of fire for personal gain. Pruetz and Herzog (2017) outline a few possible reasons for why hominins might have been drawn to fire-modified landscapes: 1) changes in the distribution of and access to food, 2) improvements in travel, and 3) decreased threat of predation. The burning away of grassy vegetation allows for easier acquisition of hidden fruits, seed or tubers, while also leaving behind lightly cooked small vertebrate and invertebrate species (Sponheimer, et al., 2005a, 2005b), the latter potentially leading to increased insectivory among some groups (Bogart and Pruetz, 2011; Burton, 2009; Herzog, et al., 2016). Moreover, the reduction of dense vegetation in burned swaths not only reduces the energy required for locomotion, but may also be attractive because of enhanced predator detection (Herzog, 2015).

This passive use of fire would eventually lead to active use of fire (Stage 2). Actively using fire may have been limited at first, with hominins actively feeding a fire in place to artificially prolong its presence, presumably to be used for warmth or for cooking. This would likely have evolved into the ability to transport fire away from where it was initially collected to build it anew and maintain it in another location for a period of time. We generally assume these transitions would have occurred in landscapes where lightning-caused fires predominate. However, as hypothesized by Medler (2011) and Bailey and colleagues (2000), zones of long-term active volcanism (i.e. the African Rift Valley) may have also provided some hominins with extended periods of acclimatisation to a fire-prone environment that they would have eventually learned to use to their advantage. These authors suggest that, perhaps initially, near-surface magma chambers could have been exploited by hominins as warm sleeping locations, while active lava seeps would have later provided hominins with regular, predictable sources where fire could be obtained.

Determining when and where these major transitions took place is at the forefront of early fire research, primarily in that these moments in prehistory are very challenging to pin down. This is partially due to these being gradual processes—much like evolution itself— that do not possess a definitive moment of discovery followed by ubiquitous use of fire technologies. Or, if there were innovative moments where the utility of fire was realised or when techniques for producing fire were identified, they were not one-off events, but were instead likely discovered, lost and rediscovered numerous times and in numerous places by different peoples (Oakley, 1961). Moreover, incorporation of fire into the human tool kit would have manifested differently under different environmental

situations, further muddying the waters. Here, I will outline some of the ways in which researchers have attempted to infer the hominin progression through the various stages of anthropogenic fire use.

# 1.1.1 Transition I: Nature fire habituation (Stage 1) to anthropogenic fire use (Stage 2)

Interestingly, the oldest proposed evidence for hominin fire use is not archaeological, but physiological, and stems from the possible consequences of an inferred introduction of cooked foods into the diet of early *Homo*. The incorporation of more easily digested cooked foods may have been responsible for shortening the human gut, redirecting calories to the brain that would normally go towards digestion (Aiello and Wheeler, 1995), ultimately contributing to an increase in brain size in hominins beginning around 1.9 Ma with the appearance of *Homo erectus* (Wrangham, 2009). This model has been challenged by Cornélio and colleagues (2016), who argue that the use of stone tools by pre-erectine hominins allowed for more efficient processing of food, thereby introducing a greater proportion of meat into their diets. This increase in foraging efficiency, they suggest, better explains this relative increase in brain size given the lack of associated archaeological evidence for fire use during this period.

Other physiological changes have been purported to reflect fire use by early hominins. It has been postulated that the onset of human hairlessness may have stemmed from semi-regular use of fire, either due to the thermoregulatory benefits conferred by fire (Russell, 1978), or perhaps from the need to reduce the risk of one's fur accidentally being set alight by errant sparks while sitting around the hearth (Medler, 2011). While bipedality would not have been a consequence of fire use, it may well have facilitated the early active use of fire, both for the collection of firewood, but also for carrying fire from one place to another (Medler, 2011).

Despite these possible fire-forged shifts in early hominin physiology, as was alluded to above, there is effectively no archaeological evidence to date of fire having been used by hominins in Africa (or anywhere else) until around 1.5 Ma, roughly 400,000 years after the appearance of *Homo erectus*. The earliest Lower Palaeolithic sites containing evidence for fire use, usually in the form of localised patches of thermally altered sediments, lithic artefacts or bones, are found in Africa and include the Kenyan sites Koobi Fora (Bellomo, 1993, 1994; Bellomo and Kean, 1997; Harris, et al., 1997; Hlubik, et al., 2017) and Chesowanja (Gowlett, et al., 1981, 1982; Isaac, 1982), and Gadeb in Ethiopia (Barbetti, 1986; Barbetti, et al., 1980; Clark and Kurashina, 1979), with slightly later occurrences in South Africa around 1.0 Ma at Swartkrans (Brain, 1993; Brain and Sillen, 1988; Pickering, et al., 2005) and Wonderwerk Cave (Beaumont, 2011; Berna, et al., 2012), and at Olorgesailie in Kenya (Isaac, 1977).

After 1.0 Ma, anthropogenic fire use begins to appear outside of Africa. Just outside of Africa in the Levant, Gesher Benot Ya'akov (Israel), which dates to ca. 790 ka, provides the earliest and best evidence for recurrent fire use at an early hominin site evinced by 'phantom hearths' comprised of clusters of heated lithic artefacts and small carbonised plant remains (Alperson-Afil, 2008; Alperson-Afil and Goren-Inbar, 2006; Alperson-Afil, et al., 2007), though the extent of fire use at this site makes it, for the moment, an outlier among the handful of other fire-bearing sites from this period. In Asia, the Chinese sites Xihoudu and Yuanmou contain charcoal and heated bone that could be representative of anthropogenic burning as early as >1.5 Ma (Jia, 1985), though these early dates have been contested (see James, 1989). Perhaps the most well-known of the Chinese early fire sites—if only for the decades of debate surrounding the site—is Zhoukoudian (formerly Choukoutien or Choukou-tien in early literature), which possesses multiple lines of evidence for anthropogenic fire use

spanning upwards of half-a-million years, beginning around 800 ka (Binford and Ho, 1985; Gao, et al., 2017; Wu, 1999; Black, 1932; Goldberg, et al., 2001; Weiner, et al., 1998).

In Europe, perhaps the earliest reported evidence for anthropogenic fire use appears north of the Black Sea on the Taman peninsula at the site of Bogatyri in Russia, at around roughly 900 ka (Bosinski, 2006). Other early European sites exhibiting strong evidence for fire use include the Spanish sites of Cueva Negra (ca. 800 ka) (Rhodes, et al., 2016; Walker, et al., 2016) and La Solana del Zamborino (ca. 750 ka) (Botella López, et al., 1976; Scott and Gibert, 2009; though recent redating of this site suggests it is much younger, around 408–300 ka, see Álvarez-Posada, et al., 2017), both of which possess purported combustion features containing large amounts of charcoal, charred/combusted bone and heated lithic remains, with the Zamborino feature apparently encircled by quartzite cobbles exhibiting thermal alteration of the surfaces facing the interior of the hearth. Fire evidence is comparatively weak at other roughly contemporaneous European sites like the Atapuerca complex in Spain (Expósito, et al., 2017), or the somewhat younger Boxgrove site in England (Roberts and Parfitt, 1999), which only possess occasional dispersed charcoal fragments that could be attributed either to anthropogenic or natural burning. For a more detailed discussion of these early fire sites, see Gowlett and Wrangham, 2013. And for a more critical take on a number of these same sites, see James (1989).

# 1.1.2 Transition II: Fire use (Stage 2) to fire maintenance (Stage 3)

As hominins became more accustomed to using fire, they would have become increasingly reliant on the various advantages that it affords, likely increasing the regularity with which they would have used fire. This regularity perhaps went beyond the frequency with which these groups would have encountered fire naturally, thus reflecting more frequent transportation and maintenance of fires once collected, which, in turn, facilitated the appearance of hearths and combustion features in less fireprone locations like the interiors of caves. This more frequent use of fire, coupled with the greater protection from erosion afforded by placing hearths inside caves, likely increased the visibility of fire in the archaeological record after this point.

Convincing evidence for anthropogenic fire use in Europe does not begin to appear with any regularity until around 400-300 ka, so from around Marine Isotope Stages (MIS) 11-9 onward (Roebroeks and Villa, 2011a). Whether or not this increase in fire sites coincides with the advent of fire production technology or just more concerted efforts by early Neandertals to conserve and transport their fire is difficult say at the moment. Among the earliest sites from this transitional period exhibiting single or multiple combustion zones or hearths are Vérteszöllös in Hungary (Vértes and Dobosi, 1990), Terra Amata in southern France (Villa, 1982, 1983), Menez-Dregan in northwest France (Monnier, et al., 2016; however, see Mercier, et al., 2004, who date the Menez-Dregan deposits to MIS 7) and Beeches Pit in the United Kingdom (Gowlett, et al., 2005; Preece, et al., 2006). While Schöningen in Germany had the potential to be counted among these early European sites with strong evidence of fire use, a recent study has shown the purported combustion structures at this site to be natural geologic features (Stahlschmidt, et al., 2015); though, a handful of heated natural flint fragments do indicate fire (natural or anthropogenic) made an appearance at the site during this period (Richter and Krbetschek, 2015). This trend of increasing fire use continues through MIS 6, with stratified deposits exhibiting recurrent, strong signals for anthropogenic burning occurring at, for example, Bolomor Cave in Spain (Fernández Peris, 2007; Sañudo, et al., 2016), Payre in southern France (Daujeard and Moncel, 2010; Moncel, et al., 2008), La Cotte de St. Brelade on the island of Jersey (Callow, et al., 1986), as well as extensive evidence for fire at open air sites like Biache-Saint-Vaast and Therdonne in northern France (Hérisson, et al., 2013). This pattern of recurrent fire use is perhaps best expressed in a number of late Lower and early Middle Palaeolithic Israeli sites exhibiting stacked central hearth features/combustion

areas, the earliest example appearing at Qesem Cave 400–300 ka (Blasco, et al., 2016; Karkanas, et al., 2007; Shahack-Gross, et al., 2014), and a bit later at Tabun (Jelinek, et al., 1973; Shimelmitz, et al., 2014), Kebara (Albert, et al., 2012; Meignen, et al., 2008; Schiegl, et al., 1996; Speth, 2006) and Hayonim caves (Goldberg, 1979; Meignen, et al., 2008; Schiegl, et al., 1996), and at the open air site of Nesher Ramla (Friesem, et al., 2014; Zaidner, et al., 2014, 2016).

Fire evidence appears in the archaeological record with even greater regularity in Europe during the latter period of Neandertal existence, from the Last Interglacial through the late Last Glacial periods (MIS 5e-3, ca. 130-35 ka). Here, one sees a marked increase in the number of archaeological sites exhibiting overt combustion features and hearths (sometimes occurring as stacked features suggesting repeated relighting of fires in the same location), and, in many cases, greater proportions of fire proxies like heated lithics or bone (for a comprehensive list of Lower and Middle Palaeolithic sites with fire evidence, see Dataset S1 in Roebroeks and Villa, 2011a). Included among the sites with wellpreserved evidence for recurrent fire use by Neandertals are, for example, Abric Romaní (Carbonell 2012, and papers therein; Courty, et al., 2012; Vallverdú, et al., 2012; Vaguero, et al., 2001) and El Salt (Dorta Pérez, et al., 2010; Mallol, et al., 2013; Rodríguez-Cintas and Cabanes, 2017; Vidal-Matutano, 2017) in Spain, Pech de l'Azé IV (Dibble, et al., 2018a, and papers contained therein; Dibble, et al., 2009; Sandgathe, et al., 2011a; Turq, et al., 2011), Roc de Marsal (Aldeias, et al., 2012; Goldberg, et al., 2012; Sandgathe, et al., 2011a), Combe Grenal (Binford, 2007; Bordes, 1955, 1972) and Grotte Mandrin (Giraud, et al., 1998; Vandevelde, et al., 2017, 2018) in France, Gruta da Oliveira in Portugal (Angelucci and Zilhão, 2009; Richter, et al., 2014; Zilhão, et al., 2016), Sesselfelsgrotte in Germany (Richter, 1997, 2006; Richter, et al., 2000), Fumane Cave in Italy (Peresani, et al., 2011), Biśnik Cave in Poland (Cyrek, et al., 2014, 2016). As the list above demonstrates, well-stratified sites with fire evidence are primarily found in cave deposits, due in large part to the fact that karstic systems act as sediment traps. There are, however, a number of open air sites also exhibiting strong, and in some cases, recurrent signals of fire use, including Neumark Nord 2 in Germany (Pop, et al., 2016), Port Racine in France (Cliquet, 1992), Ripiceni Izvor in Romania (Carciumaru, 1999; Mertens, 1996; Pàunescu, 1993), Ksiecia Jozefa in Poland (Zieba, et al., 2008, 2010) and Starosele in Crimea (Demidenko, 1998; Formosov, 1958; Marks, et al., 1998).

It is entirely possible that the diachronic trend of increasing fire evidence has little to do with greater regularity of hominin fire use through time, but instead may be related to taphonomic bias; that is, the older the deposit, the less likely fire remains (or any archaeological material, for that matter) will preserve (Sandgathe, et al., 2011b; Surovell and Brantingham, 2007). Moreover, the increased frequency of fire remains at archaeological sites over the course of the Middle Palaeolithic does not necessarily mean that fire was used constantly by Neandertals, and hence should at some point become a ubiquitous feature at all Neandertal sites. And indeed, it is not. This apparent variability in fire use could be related to any number of causes (discussed in greater detail in Chapter 2). It could simply be a factor of taphonomy, with fire remains preserving differentially between sites or climatic periods. This idea appears to find support in another paper by Surovell and colleagues (2009), somewhat contradicting the previous claims made by these authors. Here they demonstrate through an updated taphonomic bias model that the rate at which archaeological materials are destroyed is not constant through time, but instead declines with the age of a site. In other words, "If a site can survive its first 10,000 years of existence, its annual probability of destruction is reduced to approximately 0.01%, or a 1 in 10,000 chance" (Surovell, et al., 2009; 1718). If this is true, then one could expect differences in the preservation of fire remains between archaeological deposits laid down under different depositional conditions and subjected to variable intensities of post-depositional processes, these likely being mediated by prevailing climatic conditions.

Other researchers point to various cultural responses to changes in climate as the driving force behind variability in Neandertal fire use. In an effort to explain the weaker fire signals observed in archaeological layers deposited under glacial conditions at the French sites of Pech de l'Azé IV and Roc de Marsal, it has been proposed that Neandertals, lacking the ability to make fire, were thus reliant on harvesting flames for their hearths from natural fires ignited by lightning strikes, these being less prevalent during colder climatic conditions (Dibble, et al., 2017, 2018b; Sandgathe, et al., 2011a; 2011b). However, fire use may have also been a matter of choice, where, in certain situations, Neandertals chose to use or not use fire based on the costs and benefits using fire would entail (Henry, et al., in press). A scenario where this could have been a factor is during colder climatic conditions when woody fuel (i.e. trees) was less prevalent in the environment, leading both to greater fuel economisation and preferential location of camps and habitation sites nearer to fuel sources (cf. Binford, 1978). Boiling food in perishable containers (e.g. animal paunches, bladders or hides, or possibly birch bark containers) would have required less fuel and smaller fires than stone-boiling or roasting (Speth, 2012; Speth, 2015), thereby reducing the intensity of fire use (and the resultant archaeological fire signals; see Chapters 2 and 3). Other fire-free methods for preparing food (e.g. pounding, slicing or fermentation) could have further reduced the need to use fire on a day-to-day basis under such conditions (Carmody, et al., 2011; Carmody and Wrangham, 2009; Castel, et al., 2017; Glover, et al., 1977; Heaton, et al., 1988; Speth, 2017; Zink and Lieberman, 2016; Zink, et al., 2014), Moreover, other cultural adaptions, such as the use of clothing and/or shelter (Chu, 2009; Gilligan, 2017), or physiological adaptions, such as increased muscle mass or brown adipose tissue (BAT), metabolic acclimation and/or perhaps even microbiotic responses (Aiello and Wheeler, 2003; Chevalier, et al., 2015; Hammel, et al., 1959; Scholander, et al., 1958a, 1958b; Steegmann, et al., 2002), could have provided enough protection from the elements to negate the absolute need for fire for thermoregulation in instances where making a fire was not possible or the procurement of fuel was prohibitively costly (for overviews, see Churchill, 2014; Hosfield, 2016; MacDonald, 2018; White, 2006). Indeed, the overall effectiveness of fire for thermoregulation, especially while sleeping, has been questioned (Sørensen, 2009). In these instances, however, a reduction in the frequency of fire use is not the same as a reduction in regularity of use, nor is it necessarily related to a reduced reliance on fire. It has also been suggested that Neandertals had at some points acquired the ability to make fire but then lost it (Sandgathe, 2017), as has been demonstrated ethnographically among the Northern Ache of Paraguay (e.g. Hill, et al., 2011). This example is a particularly exceptional case, however, and largely does not apply to Pleistocene hunter-gatherers, in that the prevalence of fire at the edges of the Ache territory caused by adjacent slash-and-burn agriculturalists made for a readily exploitable resource that allowed the Ache to safely forget the methods for making fire they possessed prior to contact with these outside groups. Thus, once having acquired the ability to make fire, it is unlikely that this exceptionally useful tool would simply have been forgotten by Neandertal groups, barring very exceptional circumstances.

#### 1.1.3 Transition III: Fire maintenance (Stage 3) to fire making (Stage 4)

Acquiring the ability to produce fire wherever and whenever one would like is arguably the moment when humans took major step out of the realm of animals' relationships with fires. This ability would have freed hominins from a number of natural constraints with regard to regulating their immediate environment, transforming the environment at large, and altering materials on demand. It is a skill that is unique to our lineage. However, much as it is with the transitions from passive to active fire use and from active fire use to the maintenance and transport of fire, determining approximately when and where hominins developed the technology to produce fire at will has also proven to be problematic.



Figure 1. Chart showing the chronologies of the different families and methods for making fire (following Weiner, 2003), with the ages scaled logarithmically for clarity. Solid red lines indicate known instances of the fire making method, either derived from historical descriptions, ethnographic observations or archaeological findings. Dashed red lines indicate plausible use of a fire making method based on archaeological proxy data (e.g. the presence of pyrite within an archaeological site) or more ambiguous archaeological finds interpreted as fire making equipment. Question marks indicate that the materials necessary for executing the method would have been available to hominins and that the gestures required to produce fire were theoretically possible. The positioning of these various chronological indicators are based primarily on data contained in the following sources: percussion, friction and fire-piston methods (Collina-Girard, 1998; Hough, 1928; Lagercrantz, 1954; Perles, 1977; Roussel, 2005; Weiner, 2003), additionally for the bow drill (d'Errico, et al., 2012) and the fire- or Rudiger-roll (http://www.primitiveways.com/fire\_roll.html); chronological data for the other 'modern' methods of fire making were acquired from the Wikipedia pages discussing the named methods or technologies (note: the chemical fire dates derive from the 'Greek fire' page). See also Kölbl and Conard, 2009.

Of the eight families of fire starting methods (see Fig. 1), only the percussion and friction methods are known from prehistoric and modern pre-metallic societies (e.g. Weiner, 2003); though, both the solar and perhaps the compression technologies would have been possible to produce with Stone Age tools and materials. From an archaeological perspective, both the percussion and friction methods have their respective advantages and disadvantages (this is discussed in greater detail in Chapters 4 and 6). While woody plants are generally more prevalent in the environment and thus more easily exploitable, the preservation potential of tools crafted from these materials is very low, with only a small handful of such artefacts known from Pleistocene contexts (e.g. Allington-Jones, 2015; Aranguren, et al., 2018; Movius Jr, 1950; Rios-Garaizar, et al., 2018; Thieme, 1997; Thieme and Veil, 1985). The percussive method using flint in conjunction with iron sulphide minerals (i.e. pyrite and marcasite), on the other hand, utilises techniques intimately familiar to hominins (e.g. stone knapping and other pounding activities), using materials that are much more robust and more apt to preserve archaeologically. This

latter point applies more to the flint 'strike-a-light' element of the stone-on-stone fire making kit since iron sulphide minerals are prone to a chemically erosive process called 'pyrite decay'. Pyrite decay occurs when the mineral (especially fine-grained species) interacts with the humidity in the air causing a self-perpetuating chemical reaction that breaks down the specimen into various sulphate minerals, sulphur dioxide and sulphuric acid, ultimately causing the complete degradation of the mineral, assuming the process is not halted (Larkin, 2011; Leduc, et al., 2012). However, in depositional environments with higher pH levels (e.g. karstic systems, or perhaps in loess), it is possible for pyrite to re-mineralise in situ to iron oxide (i.e. hematite and/or goethite) (Leduc, et al., 2012), as is often the case for the iron oxide cortex on the outside of pyrite nodules, as well as on the surface of the anthropogenic groove created on the Magdalenian Trou de Chaleaux pyrite nodule, presumably from use for making fire (see Fig. 3 in Chapter 4). The preservation potential for pieces (and their associated use traces) undergoing such a remineralisation process would be much greater than those undergoing the pyrite decay reaction series.

Save for a dozen or so other Middle Palaeolithic pyrite finds (and perhaps around two dozen pyrite finds from the whole of the Upper Palaeolithic) suggesting a plausible use of percussive fire making technology, according to published findings, fire making tools (i.e. flint strike-a-lights) do not really appear in Europe (or elsewhere, for that matter) until the arrival of the Upper Palaeolithic Magdalenian culture after the Last Glacial Maximum (MIS 2) (discussed in more detail in Chapter 4). Given this virtual absence of direct evidence for fire production in the form of fire making tools from Lower and Middle Palaeolithic contexts (discussed further below and in Chapter 4), researchers have traditionally relied on proxy evidences to infer that early hominins were capable of, and indeed did (at least occasionally), make fire. The regular use of fire by hominins appears to be the most common argument given in favour of the presence of fire production. However, even on this point researchers disagree as to what 'regular' means. Roebroeks and Villa (2011a, 2011b) suggest the increased presence of fire at Middle Palaeolithic archaeological sites after 400-300 ka as sufficient evidence to suggest early Neandertals were able to make fire, this point perhaps supported-albeit weakly-by the oldest known archaeological instance of a pyrite nodule appearing around this time at Menez-Dregan (Monnier and Hallegouet, 2004). Conversely, Sandgathe and colleagues (2011a, 2011b) point to apparent discontinuities in the fire record, specifically during colder glacial periods when fire would have presumably been of utmost importance, as evidence that Neandertals did not make fire, but were instead reliant on climate-mediated natural fires to provide the flames they carried back to their habitation sites. They go on to suggest, based on the apparent more systematic occurrence of fire at Upper Palaeolithic sites, that modern humans were the first to make fire (Sandgathe, et al., 2011b); though, Roebroeks and Villa (2011b) counter this claim by demonstrating that fire use does not appear to be continuous nor ubiquitous at many Upper Palaeolithic sites, suggesting Sandgathe et al. are applying a double standard that favours modern humans (cf. Speth, 2004).

While the benefits of fire making are easily relatable at the personal or species levels, given the potentially far-reaching destructive nature of fire, having the ability to create fire at will has major implications for how hominins can potentially alter the landscape. This phenomenon is known among more recent hunter-gatherers (e.g. Bowman, et al., 2011; Jones, 1969; Komarek, 1967; Scherjon, et al., 2015), but remains more elusive for older contexts. Such environmental impacts could potentially serve as another proxy for fire making, or in a similar vein as the above paragraph, at least signal more intensive use or fire. A study attempting to identify human disruption of natural fire regimes in southwestern France around the Middle-to-Upper Palaeolithic transition—when modern humans entered Europe—could not identify an associated change to the fire regime (Daniau, et al., 2010), suggesting either earlier Palaeolithic groups did not apply fire to the landscape with sufficient intensities to make

a noticeable impact, or that early modern human use of fire in the landscape was largely similar to that of Neandertals, with the fire regime in the research area already having been altered much earlier after its initial colonisation by Neandertals. Kaplan and colleagues (2016) suggest this may have also been the case around the LGM, and indeed, fire making tools, while still relatively sparse, begin to become more prevalent in the archaeological record around this period (Stapert and Johansen, 1999). There are a number of Holocene examples for hunter-gatherers altering local or regional fire regimes (e.g. Bos and Urz, 2003; Mason, 2000; Sevink, et al., 2018; Simmons and Innes, 1996), while the most drastic increases in fire prevalence appearing once agricultural practices arrived to the region in the Neolithic (e.g. Bradshaw, et al., 1997; Carcaillet, 1998; Snitker, 2018). By this point, percussive fire making is well-attested to (see Roussel, 2005 for an overview).

Others point to advanced pyrotechnologies like the synthesis of birch bark pitch as far back as 250 ka (Koller, et al., 2001; Mazza, et al., 2006) as tacit evidence for the Neandertal capacity to produce fire (e.g. Cnuts, et al., 2017; Kozowyk, et al., 2017; Roebroeks and Villa, 2011a; Wragg Sykes, 2015), the logic being that if they used pitches as part of their technologies and hence could perform such a complicated task using fire, then they probably did know how to make it. While known Middle Palaeolithic examples of birch bark pitch are clearly anthropogenic, it should be noted, however, that under certain conditions it is possible for small amounts of this material to be produced incidentally when using birch wood as fuel (Cnuts, et al., 2017).Another line of evidence in this vein, though perhaps less convincing, is the Neanderthal use of fire as an aid for producing wooden tools (Aranguren, et al., 2018; Ennos and Chan, 2016; Rios-Garaizar, et al., 2018).

One could also suggest that the knowledge of and capacity for fire making should predate their capacity for symbolic or abstract thought, which has been attested to by their collection and use of colourful iron oxides and black manganese dioxides as pigment material (Demars, 1992; Martí and d'Errico, 2018; Roebroeks, et al., 2012; Soressi and D'Errico, 2007), having fashioned jewellery (Caron, et al., 2011; Hoffmann, et al., 2018a; Hublin, et al., 2012; Radovčić, et al., 2015; Welker, et al., 2016; Zilhão, et al., 2010) and, as demonstrated recently, their having produced parietal art (Hoffmann, et al., 2018b). Moreover, in the latter example, fire was a requisite element in the process of producing this art deep within caves where an artificial light source would have been necessary for the artists to see what they were doing. In a similar instance, at Bruniquel Cave in France, where two large circles were fashioned from hundreds of broken stalagmites, fire was not only needed to venture the 336 m into the cave where these structures were located, but it also appears, based on the 18 combustion zones situated primarily atop the low stalagmite walls themselves, that fire was directly involved in the activities taking place here (Jaubert, et al., 2016). The possible symbolic use of fire by Neandertals has also been suggested at Des-Cubierta Cave in Spain, where more than 30 horn cores from aurochs (Bos primigenius) and bison (Bison priscus) and antlers from red deer (Cervus elaphus) were placed within at least eleven hearths inside the cave (Baquedano, et al., 2016). These, along with the skull of a steppe rhinoceros (Stephanorhinus hemitoechus), have been interpreted as hunting trophies, and the presence of the remains of a Neandertal child in the back of the cave have led to the suggestion that this was some sort of ceremonial gallery. Whether or not one believes this interpretation, the fact remains that the hearths, much like in Bruniquel, do not appear to have served a utilitarian purpose.

While these proxy evidences may indeed be valid, they are not definitive in their support for fire making during the Middle Palaeolithic. This study starts from the proposition that the only way to infer fire making is to identify the tools themselves that were used to make fire.

# 2.1 Research Questions and Outline of Thesis Chapters

The primary goal of the research project described in this dissertation is to try to determine when in the course of humankind our ancestors became proficient producers of fire. While this overarching question of 'When?' potentially opens up the whole of human prehistory to scrutiny—and rightly so!—one must begin the search somewhere. Fire making is a known phenomenon among prehistoric modern humans, and the evidence, while limited, does suggest Upper Palaeolithic modern humans living in Europe from mid-MIS 3 onward were indeed able to produce fire, though this evidence becomes more and more sparse the further back in time we look (see Chapter 4). This issue already suggests that more research should be conducted into the prevalence of early Upper Palaeolithic fire making (see Chapter 6). However, this project uses late Neandertals occupying Western Europe during the Last Glacial period (MIS 5–3) as the logical starting point to look for possible early evidence for fire making, given 1) Neandertals were regular users of fire; 2) the cold conditions endured by the Neandertals inhabiting the higher latitudes of Europe, especially during full-glacial conditions, provided a strong driving force to recognise and develop fire making technologies, and finally, 3) the prevalence of flint and pyrite-bearing carbonate bedrock in Western Europe made readily available (more or less) the requisite materials for making fire.

By gaining a better understanding of how Neandertals used fire, how these fire use practices might relate to the ability to produce fire at will, and how to identify fire making archaeologically, my research applies a multi-pronged approach to answering the question 'Did Neandertals make fire?'. This is reflected in the chapters comprising this dissertation, described in more detail in the sections below, wherein I present various goals and research questions being pursued. All four core chapters have been published in peer-reviewed journals. Chapter 2 confronts the archaeological evidence of fire use by Neandertals, in general, with a focus on the various factors that influence how we as archaeologists interpret fire signals within the Middle Palaeolithic record. Chapter 3 applies computer simulation in an attempt to model how some of the variables outlined in Chapter 2 can influence the relative production of fire proxy evidence under certain environmental conditions. Chapters 4 and 5 zoom in on the possibilities of using microwear analysis as a means for identifying direct evidence of fire making by Neandertals. Chapter 4 is primarily a theoretical and experimental exercise, wherein I describe the physical traces produced during experimental stone-on-stone fire making using flint and pyrite and the conditions whereby such traces are produced and their preservation potential are hypothesised. Chapter 5 applies these findings to a number of late Middle Palaeolithic assemblages of such curated items (bifaces) from France and presents probable microwear evidence for a novel Neandertal fire making method using these tools.

# Chapter 2 – On the relationship between climate and Neandertal fire use during the Last Glacial in SW France

A group of researchers working at the French Middle Palaeolithic sites of Roc de Marsal and Pech de l'Azé IV (Dibble, et al., 2017; 2018b; Sandgathe, 2017; Sandgathe, et al., 2011a, 2011b) propose Neandertals were unable to produce fire for themselves and were thus reliant on natural sources of fire, presumably caused by lightning strikes, to provide opportunities to collect and curate this resource. They suggest reductions in lightning activity during colder climatic stadials during the Last Glacial period (MIS 5–3) led to a suppression of the natural fire regime in southwest France, thereby reducing Neandertal access to wildfires, which led to reduced evidence of fire use by these peoples (at least at the aforementioned sites) during these periods. They go on to suggest that, given this evidence, modern humans were the only hominins capable of making fire. Do the predictions of Sandgathe et al.'s 'very recent origin of fire production' hypothesis (2011a, 2011b) match the data on fire proxies and the environmental settings from Neandertal sites? What environmental, cultural and post-depositional taphonomic factors influence the production and preservation of combustion features (i.e.

hearths) and their associated fire residues (i.e. charcoal and ash) and fire proxy evidences (i.e. fireaffected lithic artefacts, faunal remains and underlying substrates)? And how would possessing the ability to make fire at will influence when and how fire is used, and how would this vary under different climatic conditions? This chapter provides a number of alternative explanations for observed variability in Neandertal fire use signals between cold and warm climatic periods.

# Chapter 3 - fiReproxies: A computational model providing insight into heat-affected archaeological lithic assemblages

Fire size, duration and frequency (a function of the nature and availability of fuel sources) and site occupation dynamics are only a few of the factors discussed in Chapter 2 that can potentially influence the relative strength of anthropogenic fire signals. Site surface area, sedimentation rates, as well as the moisture content and thermal conductivity of the substrate underlying a hearth (among others) can also positively or negatively impact the number of fire proxies (specifically here, heated lithic artefacts) produced within an archaeological layer. Relatively speaking, how do these factors influence the number of heated lithics produced within an archaeological layer? In what ways do changes in site conditions affect these factors and their relative impact on fire signals? And what are the implications of these changes for how we interpret fire signals within or between archaeological sites based on fire proxy data? Chapter 3 attempts to provide quantitative answers to these questions through computer simulation using the 'fiReproxies' model designed for this research using the program R. The model allows users to tabulate the expected percentages of heated lithics produced over the course of multiple occupation episodes within an archaeological layer (of a given surface area) by adjusting the values set for the various parameters listed above per occupation of the site based on hypothetical environmental or cultural conditions. These tabulated percentages can then be compared to known heated lithic percentages from an archaeological site in an effort to understand which combinations of parameter values could have resulted in these values. Which combination of parameter values might be the most parsimonious explanation for the observed percentages can be determined through the comparison with known palaeoenvironmental proxy data (e.g. fauna or pollen assemblages) and other geological (e.g. estimated sedimentation rates) and/or archaeological evidences (e.g. other fire proxy data or evidence pertaining to group mobility or site function).

# Chapter 4 – Fire production in the deep past: The expedient strike-a-light model

The (semi-)regular use of fire by Neandertals is attested to by the presence of combustion features and fire proxy evidence at numerous Middle Palaeolithic archaeological sites throughout Eurasia (Roebroeks and Villa, 2011a). However, the frequency with which fire was used, even if at times very high, says nothing about whether Neandertals were able to produce fire artificially or were just effective collectors and conservators of naturally occurring fire. Ultimately, as stated previously, the only way to determine if a group was capable of producing fire at will is to identify direct evidence of fire making, i.e. the fire making tools themselves. But how might fire making tools from (Middle) Palaeolithic contexts differ from those recovered from later Mesolithic, Neolithic and Bronze Age sites? How would this affect our ability to identify such tools? And is there evidence in the European Middle Palaeolithic record that indicates the utilization of a stone-on-stone method for producing fire? Using a microwear analytical approach and operating under what I call the 'expedient strike-a-light model', I hypothesise in Chapter 4 that within Middle Palaeolithic flake-based industries, the flint 'strike-a-light' elements of the stone-on-stone fire making tool kit were not formalised tools, but were instead selected on an ad hoc basis and were likely only used very briefly before being discarded, reducing their 'findability' in the archaeological record. Through experimentation and microwear analysis, I describe how the classic suite of strike-a-light use traces manifest, as well as how associated

traces may appear on the pyrite 'sparking' element of the fire making kit, thereby providing archaeologists with a 'guidebook' for recognising possible Middle Palaeolithic fire making tools., These ideas were put to the test through the analysis of multiple northwest European Middle Palaeolithic lithic assemblages in an attempt to identify pieces with traces comparable to those observed on my experimental fire making tools, though these analyses ultimately yielded negative results.

# *Chapter 5 – Neandertal fire-making technology inferred from microwear analysis*

Given that no apparent strike-a-lights were observed among these assemblages, it was decided to refocus my efforts on assemblages containing curated tools. As was also postulated within the expedient strike-a-light model, curated tools (like bifaces and large scrapers) should have a higher probability of preserving strike-a-light microwear traces simply due to their longer use lives (assuming that, at some point, they were used to make fire). Moreover, these traces, unless imparted onto the tool late in its use life, could be either obscured through subsequent use of the tool or removed entirely through resharpening, relegating the evidence for fire making to the debitage. Through the course of my earlier research, I learned that unidentified 'mineral traces' had been observed both on a number of late Middle Palaeolithic bifacial tools (often called 'hand axes') and associated bifacial thinning flakes (i.e. biface shaping and resharpening flakes) in lithic assemblages attributed to the Mousterian of Acheulian Tradition (or MTA) in France (Claud, 2008, 2012; Soressi, et al., 2008). How do these mineral traces compare with experimental traces produced during fire making? And how do both the archaeological traces and experimental pyrite traces compare with those produced by other rocks and minerals during various percussive or frictional activities? As with the previous study, answers to these questions were sought through practical experimentation with replica bifacial tools used in conjunction with different mineral materials and the microscopic analysis of the resulting use wear traces.

# Chapter 6 – Conclusion

The final chapter of this dissertation provides a synthesis of the research described in Chapters 2–5, describing how the findings fit into the ongoing debate over when and where fire became an integral part of the hominin technological repertoire and outlining future avenues of research into this most interesting topic.

# REFERENCES

- Aiello, L.C., Wheeler, P., 1995. The Expensive-Tissue Hypothesis: The Brain and the Digestive System in Human and Primate Evolution, *Current Anthropology* 36, 199-221.
- Aiello, L.C., Wheeler, P., 2003. Neanderthal Thermoregulation and the Glacial Climate, in: Van Andel, T.H., Davies, W. (Eds.), *Neanderthals and Modern Humans in the European Landscape during the Last Glaciation: Archaeological Results of the Stage 3 Project*, McDonald Institute for Archaeological Research Monograph Series, Cambridge, pp. 147-166.
- Albert, R.M., Berna, F., Goldberg, P., 2012. Insights on Neanderthal fire use at Kebara Cave (Israel) through high resolution study of Prehistoric combustion features: evidence from phytoliths and thin sections, *Quaternary International* 247, 278–293.
- Aldeias, V., Goldberg, P., Sandgathe, D., Berna, F., Dibble, H.L., McPherron, S.P., Turq, A., Rezek, Z., 2012. Evidence for Neandertal use of fire at Roc de Marsal (France), *Journal of Archaeological Science* 39, 2414-2423.
- Allington-Jones, L., 2015. The Clacton Spear: The Last One Hundred Years, *Archaeological Journal* 172, 273-296.
- Alperson-Afil, N., 2008. Continual fire-making by Hominins at Gesher Benot Ya'aqov, Israel, *Quaternary Science Reviews* 27, 1733-1739.
- Alperson-Afil, N., Goren-Inbar, N., 2006. Out of Africa and into Eurasia with controlled use of fire: Evidence from Gesher Benot Ya'aqov, Israel, Archaeology, Ethnology and Anthropology of Eurasia 28, 63-78.
- Alperson-Afil, N., Richter, D., Goren-Inbar, N., 2007. Phantom hearths and controlled use of fire at Gesher Benot Ya'Aqov, Israel, *PaleoAnthropology* 2007, 1-15.
- Álvarez-Posada, C., Parés, J.M., Sala, R., Viseras, C., Pla-Pueyo, S., 2017. New magnetostratigraphic evidence for the age of Acheulean tools at the archaeo-palaeontological site "Solana del Zamborino" (Guadix – Baza Basin, S Spain), *Scientific Reports* 7, 13495.
- Angelucci, D.E., Zilhão, J., 2009. Stratigraphy and formation processes of the Upper Pleistocene deposit at Gruta da Oliveira, Almonda karstic system, Torres Novas, Portugal, *Geoarchaeology* 24, 277-310.
- Aranguren, B., Revedin, A., Amico, N., Cavulli, F., Giachi, G., Grimaldi, S., Macchioni, N., Santaniello, F., 2018. Wooden tools and fire technology in the early Neanderthal site of Poggetti Vecchi (Italy), *Proceedings of the National Academy of Sciences*, 201716068.
- Bailey, G., Manighetti, I., King, G., 2000. Tectonics, volcanism, landscape structure and human evolution in the African Rift, in: Bailey, G., Charles, R., Winder, N. (Eds.), *Human Ecodynamics. Symposia of the Association for Environmental Archaeology*, Oxbow Books, Oxford, pp. 31-46.
- Baquedano, E., Arsuaga, J., Pérez-González, A., Márquez, B., Laplana, C., Ortega, M., 2016. The Des-Cubierta Cave (Pinilla del Valle, Comunidad de Madrid, Spain): a Neanderthal site with a likely funerary/ritualistic connection, *In Proceedings of the European Society for the study of Human Evolution 5*, European Society for the Study of Human Evolution.
- Barbetti, M., 1986. Traces of fire in the archaeological record, before one million years ago?, *Journal* of Human Evolution 15, 771-781.

- Barbetti, M., Clark, J.D., Williams, F.M., Williams, M.A.J., 1980. Paleomagnetism and the search for very ancient fireplaces in Africa, in: Jelínek, J. (Ed.), *Homo Erectus and His Time*, Anthropologie 18, pp. 299-304.
- Beaumont, P.B., 2011. The Edge: More on Fire-Making by about 1.7 Million Years Ago at Wonderwerk Cave in South Africa, *Current Anthropology* 52, 585-595.
- Bellomo, R.V., 1993. A Methodological Approach for Identifying Archaeological Evidence of Fire Resulting from Human Activities, *Journal of Archaeological Science* 20, 525-553.
- Bellomo, R.V., 1994. Methods of determining early hominid behavioural activities associated with the controlled use of fire at FxJj 20 Main, Koobi Fora, Kenya, *Journal of Human Evolution* 27, 173-195.
- Bellomo, R.V., Kean, W.F., 1997. Evidence of hominid controlled fire at the FxJj20 site complex, Karari escarpment. Appendix 4A, in: Isaac, G., Isaac, B. (Eds.), *Koobi Fora research project*, (Vol. 5): Plio-Pleistocene Archaeology, Clarendon Press, Oxford, pp. 224-233.
- Berna, F., Goldberg, P., Horwitz, L.K., Brink, J., Holt, S., Bamford, M., Chazan, M., 2012. Microstratigraphic evidence of in situ fire in the Acheulean strata of Wonderwerk Cave, Northern Cape province, South Africa, *Proceedings of the National Academy of Sciences* 109, E1215–E1220.
- Binford, L.R., 1978. Nunamiut Ethnoarchaeology, Academic Press, New York.
- Binford, L.R., 2007. The Diet of Early Hominins: Some Things We Need to Know before "Reading" the Menu from the Archaeological Record, in: Roebroeks, W. (Ed.), *Guts and Brains. An Integrative Approach to the Hominin Record*, Leiden University Press, Leiden, pp. 185-222.
- Binford, L.R., Ho, C.K., 1985. Taphonomy at a distance: Zhoukoudian, "the cave home of Beijing Man"?, *Current Anthropology* 26, 413-429.
- Black, D., 1932. Evidences of the use of fire by Sinanthropus, *Bulletin of the Geological Society of China* 11, 107-108.
- Blasco, R., Rosell, J., Sanudo, P., Gopher, A., Barkai, R., 2016. What happens around a fire: faunal processing sequences and spatial distribution at Qesem Cave (300 ka), Israel, *Quaternary International* 398, 190-209.
- Boback, S.M., Cox, C.L., Ott, B.D., Carmody, R., Wrangham, R.W., Secor, S.M., 2007. Cooking and grinding reduces the cost of meat digestion, *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* 148, 651-656.
- Bogart, S.L., Pruetz, J.D., 2011. Insectivory of savanna chimpanzees (Pan troglodytes verus) at Fongoli, Senegal, *American Journal of Physical Anthropology* 145, 11-20.
- Bonta, M., Gosford, R., Eussen, D., Ferguson, N., Loveless, E., Witwer, M., 2017. Intentional Fire-Spreading by "Firehawk" Raptors in Northern Australia, *Journal of Ethnobiology* 37, 700-718.
- Bordes, F., 1955. La stratigraphie de la Grotte de Combe-Grenal, commune de Domme (Dordogne): Note préliminaire, *Bulletin de la Société préhistorique Française* 52, 426-429.
- Bordes, F., 1957. Review of KP Oakley 'Fire as a paleolithic tool and weapon', *L'Anthropologie* 61, 314-317.

Bordes, F., 1972. A Tale of Two Caves, Harper and Row, New York.

- Bos, J.A., Urz, R., 2003. Late Glacial and early Holocene environment in the middle Lahn river valley (Hessen, central-west Germany) and the local impact of early Mesolithic people—pollen and macrofossil evidence, *Vegetation History and Archaeobotany* 12, 19-36.
- Bosinski, G., 2006. Les premiers peuplements de l'Europe centrale et de l'Est, *Comptes Rendus Palevol* 5, 311-317.
- Botella López, M.C., Marqués Merelo, I., de Benito Ontañón, A., Ruiz Rodríguez, A.C., Delgado, M.T., 1976. La excavación y sus resultados arqueológicos, *Cuadernos de Prehistoria y Arqueología de la Universidad de Granada* 1, 25-45.
- Bowman, D.M.J.S., Balch, J., Artaxo, P., Bond, W.J., Cochrane, M.A., D'Antonio, C.M., DeFries, R., Johnston, F.H., Keeley, J.E., Krawchuk, M.A., Kull, C.A., Mack, M., Moritz, M.A., Pyne, S., Roos, C.I., Scott, A.C., Sodhi, N.S., Swetnam, T.W., 2011. The human dimension of fire regimes on Earth, *Journal of Biogeography* 38, 2223-2236.
- Bradshaw, R., Tolonen, K., Tolonen, M., 1997. Holocene records of fire from the boreal and temperate zones of Europe, in: Clark, J.S., Cachier, H., Goldammer, J.G., Stocks, B. (Eds.), *Sediment Records of Biomass Burning and Global Change*, Springer, Berlin, pp. 347-365.
- Brain, C.K., 1993. The occurrence of burnt bones at Swartkrans and their implications for the control of fire by early hominids, in: Brain, C.K. (Ed.), *Swartkrans: A cave's chronicle of early man*, Transvaal Museum, Pretoria, pp. 229-242.
- Brain, C.K., Sillen, A., 1988. Evidence from the Swartkrans cave for the earliest use of fire, *Nature* 336, 464-466.
- Brown, K.S., Marean, C.W., Herries, A.I.R., Jacobs, Z., Tribolo, C., Braun, D., Roberts, D.L., Meyer, M.C., Bernatchez, J., 2009. Fire As an Engineering Tool of Early Modern Humans, *Science* 325, 859-862.
- Brown, S.A., Collinson, M.E., Scott, A.C., 2013. Did fire play a role in formation of dinosaur-rich deposits? An example from the Late Cretaceous of Canada, *Palaeobiodiversity and Palaeoenvironments* 93, 317-326.
- Burton, F.D., 2009. *Fire: The spark that ignited human evolution*, University of New Mexico Press, Albuquerque.
- Byers, B.A., Ash, S.R., Chaney, D., DeSoto, L., 2014. First known fire scar on a fossil tree trunk provides evidence of Late Triassic wildfire, *Palaeogeography, Palaeoclimatology*, *Palaeoecology* 411, 180-187.
- Callow, P., Walton, D., Shell, C.A., 1986. The use of fire at La Cotte de St. Brelade, in: Callow, P., Cornford, J.M. (Eds.), *La Cotte de St. Brelade 1961-1978. Excavations by C.B.M. McBurney*, Geo Books, Norwich, pp. 193-195.
- Carbonell, E., 2012. *High Resolution Archaeology and Neanderthal Behavior : Time and Space In Level J of Abric Romani (Capellades, Spain)*. Springer, Dordrecht.
- Carcaillet, C., 1998. A spatially precise study of Holocene fire history, climate and human impact within the Maurienne valley, North French Alps, *Journal of ecology* 86, 384-396.

Carciumaru, M., 1999. Le Paléolithique en Roumanie, J. Millon, Grenoble.

- Carmody, R.N., Weintraub, G.S., Wrangham, R.W., 2011. Energetic consequences of thermal and nonthermal food processing, *Proceedings of the National Academy of Sciences* 108, 19199-19203.
- Carmody, R.N., Wrangham, R.W., 2009. The energetic significance of cooking, *Journal of Human Evolution* 57, 379-391.
- Caron, F., d'Errico, F., Del Moral, P., Santos, F., Zilhão, J., 2011. The Reality of Neandertal Symbolic Behavior at the Grotte du Renne, Arcy-sur-Cure, France, *PLoS ONE* 6, 11.
- Castel, J.-C., Discamps, E., Soulier, M.-C., Sandgathe, D., Dibble, H.L., McPherron, S.J.P., Goldberg, P., Turq, A., 2017. Neandertal subsistence strategies during the Quina Mousterian at Roc de Marsal (France), *Quaternary International* 433, 140-156.
- Chazan, M., 2017. Toward a long prehistory of fire, Current Anthropology 58, S351-S359.
- Chevalier, C., Stojanović, O., Colin, D.J., Suarez-Zamorano, N., Tarallo, V., Veyrat-Durebex, C., Rigo, D., Fabbiano, S., Stevanović, A., Hagemann, S., 2015. Gut microbiota orchestrates energy homeostasis during cold, *Cell* 163, 1360-1374.
- Chu, W., 2009. A functional approach to Paleolithic open-air habitation structures, *World Archaeology* 41, 348-362.
- Churchill, S., 2014. *Thin on the Ground: Neandertal Biology, Archeology and Ecology*, John Wiley & Sons, Ames, Iowa.
- Clark, J.D., Harris, J.W.K., 1985. Fire and its roles in early hominid lifeways, *The African Archaeological Review* 3, 3-27.
- Clark, J.D., Kurashina, H., 1979. Hominid occupation of the East-Central Highlands of Ethiopia in the Plio-Pleistocene, *Nature* 282, 33-39.
- Claud, É., 2008. Le statut fonctionnel des bifaces au Paléolithique moyen récent dans le Sud-Ouest de la France: Étude tracéologique intégrée des outillages des sites de La Graulet, La Conne de Bergerac, Combe Brune 2, Fonseigner et Chez-Pinaud / Jonzac, Université Bordeaux I, p. 546.
- Claud, É., 2012. Les bifaces: des outils polyfonctionnels? Étude tracéologique intégrée de bifaces du Paléolithique moyen récent du Sud-Ouest de la France, *Bulletin de la Société préhistorique française* 109, 413-439.
- Cliquet, D., 1992. Le gisement Paléolithique Moyen de Saint-Germain-des-Vaux / Port-Racine (Manche) dans son cadre regional. Essai palethnographique, ERAUL 63, Université de Liège, Liège.
- Cnuts, D., Tomasso, S., Rots, V., 2017. The Role of Fire in the Life of an Adhesive, *Journal of Archaeological Method and Theory*, 1-24.
- Collina-Girard, J., 1998. Le Feu avant les allumettes: expérimentation et mythes techniques, Maison des Sciences de l'Homme (CID), Paris.
- Cornélio, A.M., de Bittencourt-Navarrete, R.E., de Bittencourt Brum, R., Queiroz, C.M., Costa, M.R., 2016. Human brain expansion during evolution is independent of fire control and cooking, *Frontiers in Neuroscience* 10, 167.

- Courty, M.-A., Carbonell, E., Vallverdú Poch, J., Banerjee, R., 2012. Microstratigraphic and multianalytical evidence for advanced Neanderthal pyrotechnology at Abric Romaní (Capellades, Spain), *Quaternary International* 247, 294-312.
- Cyrek, K., Sudoł, M., Czyżewski, Ł., 2016. The record of changes in the Middle Palaeolithic settlement zone of the Biśnik Cave, *Anthropologie* 54, 5-20.
- Cyrek, K., Sudoł, M., Czyżewski, Ł., Osipowicz, G., Grelowska, M., 2014. Middle Palaeolithic cultural levels from Middle and Late Pleistocene sediments of Biśnik Cave, Poland, *Quaternary International* 326, 20-63.
- d'Errico, F., Backwell, L., Villa, P., Degano, I., Lucejko, J.J., Bamford, M.K., Higham, T.F.G., Colombini, M.P., Beaumont, P.B., 2012. Early evidence of San material culture represented by organic artifacts from Border Cave, South Africa, *Proceedings of the National Academy of Sciences* 109, 13214-13219.
- Daniau, A.-L., D'Errico, F., Sánchez Goñi, M.F., 2010. Testing the hypothesis of fire use for ecosystem management by Neanderthal and Upper Palaeolithic Modern Human populations, *PLoS ONE* 5, e9157.
- Daujeard, C., Moncel, M.-H., 2010. On Neanderthal subsistence strategies and land use: A regional focus on the Rhone Valley area in southeastern France, *Journal of Anthropological Archaeology* 29, 368-391.
- Demars, P.Y., 1992. Les colorants dans le Moustérien du Périgord. L'apport des fouilles de F. Bordes, Bulletin de la Société préhistorique française 47, 185-194.
- Demidenko, Y., 1998. Starosele: the early excavations and unanswered questions, in: Marks, A.E., Chabai, V.P. (Eds.), *The Middle Paleolithic of western Crimea, Volume 1*, ERAUL 84, Université de Liège, Liège, pp. 53-65.
- Dibble, H., McPherron, S.J.P., Goldberg, P., Sandgathe, D., 2018a. *The Middle Paleolithic Site of Pech de l'Azé IV*, Springer International Publishing.
- Dibble, H.L., Abdolahzadeh, A., Aldeias, V., Goldberg, P., McPherron, S.P., Sandgathe, D.M., 2017. How did hominins adapt to ice age Europe without fire?, *Current Anthropology* 58, S278-S287.
- Dibble, H.L., Berna, F., Goldberg, P., McPherron, S.P., Mentzer, S., Niven, L., Richter, D., Sandgathe, D., Théry-Parisot, I., Turq, A., 2009. A preliminary report on Pech de l'Aze' IV, layer 8 (Middle Paleolithic, France), *Palaeoanthropology*, 182-219.
- Dibble, H.L., Sandgathe, D., Goldberg, P., McPherron, S., Aldeias, V., 2018b. Were Western European Neandertals Able to Make Fire?, *Journal of Paleolithic Archaeology*, 1-26.
- Dominy, N., Vogel, E., Yeakel, J., Constantino, P., Lucas, P., 2008. Mechanical Properties of Plant Underground Storage Organs and Implications for Dietary Models of Early Hominins, *Evolutionary Biology* 35, 159-175.
- Dorta Pérez, R., Hernández Gómez, C.M., Molina Hernández, F.J., Galván Santos, B., 2010. La alteración térmica en los sílex de los valles alcoyanos (Alicante, España). Una aproximación desde la arqueología experimental en contextos del Paleolítico Medio: El Salt, *Recerques del Museu d'Alcoi* 19, 33-64.
- Dunbar, R.I.M., 1998. The Social Brain Hypothesis, Evolutionary Anthropology 6(5), 178-189.

- Dunbar, R.I.M., Gowlett, J.A.J., 2014. Fireside chat: the impact of fire on hominin socioecology, in: Dunbar, R.I.M., Gamble, C., Gowlett, J.A.J. (Eds.), *Lucy to language: the benchmark papers*, Oxford University Press, Oxford, pp. 277-296.
- Dunbar, R.I.M., Shultz, S., 2007. Evolution in the Social Brain, Science 317, 1344-1347.
- Ennos, A.R., Chan, T.L., 2016. 'Fire hardening'spear wood does slightly harden it, but makes it much weaker and more brittle, *Biology letters* 12, 20160174.
- Expósito, I., Burjachs, F., Allué, E., 2017. Filling in the gaps: The contribution of non-pollen palynomorphs to knowledge about the local environment of the Sierra de Atapuerca caves during the Pleistocene, *Quaternary International* 433, 224-242.
- Fernández Peris, J., 2007. La Cova del Bolomor, Diputación provincial de Valencia, Valencia.
- Fonseca-Azevedo, K., Herculano-Houzel, S., 2012. Metabolic constraint imposes tradeoff between body size and number of brain neurons in human evolution, *Proceedings of the National Academy of Sciences* 109, 18571-18576.
- Formosov, A.A., 1958. The cave site Starosele and its place in the Palaeolithic, *Materials and Investigations of the Archaeology of the USSR* 71.
- Frazer, S.J.G., 1930. Myths of the Origin of Fire: An Essay, Macmillan, London.
- Friesem, D.E., Zaidner, Y., Shahack-Gross, R., 2014. Formation processes and combustion features at the lower layers of the Middle Palaeolithic open-air site of Nesher Ramla, Israel, *Quaternary International* 331, 128-138.
- Gao, X., Zhang, S., Zhang, Y., Chen, F., 2017. Evidence of hominin use and maintenance of fire at Zhoukoudian, *Current Anthropology* 58, S267-S277.
- Gilligan, I., 2017. Clothing and Hypothermia as Limitations for Midlatitude Hominin Settlement during the Pleistocene: A Comment on Hosfield 2016, *Current Anthropology* 58, 534-535.
- Giraud, Y., Brugal, J.-P., Jeannet, M., 1998. Un nouveau gisement moustérien en moyenne vallée du Rhône: la grotte Mandrin à Malataverne (Drôme), *Bulletin de la Société préhistorique française* 95, 7-16.
- Glover, E., Forrest, J., Johnson, H., Bramblett, V., Judge, M., 1977. Palatability and cooking characteristics of mechanically tenderized beef, *Journal of food Science* 42, 871-874.
- Goldberg, P., 1979. Micromorphology of sediments from Hayonim cave, Israel, Catena 6, 167-181.
- Goldberg, P., Dibble, H., Berna, F., Sandgathe, D., McPherron, S.J.P., Turq, A., 2012. New evidence on Neandertal use of fire: Examples from Roc de Marsal and Pech de l'Azé IV, *Quaternary International* 247, 325-340.
- Goldberg, P., Miller, C., Schiegl, S., Ligouis, B., Berna, F., Conard, N., Wadley, L., 2009. Bedding, hearths, and site maintenance in the Middle Stone Age of Sibudu Cave, KwaZulu-Natal, South Africa, *Archaeological and Anthropological Sciences* 1, 95-122.
- Goldberg, P., Weiner, S., Bar-Yosef, O., Xu, Q., Liu, J., 2001. Site formation processes at Zhoukoudian, China, *Journal of Human Evolution* 41, 483-530.
- Goudsblom, J., 1986. The human monopoly on the use of fire: its origins and conditions, *Human Evolution* 1, 517-523.

Goudsblom, J., 1992. Fire and Civilization, Viking, London.

- Gowlett, J.A.J., 2006. The early settlement of northern Europe: Fire history in the context of climate change and the social brain, *Comptes Rendus Palevol* 5, 299-310.
- Gowlett, J.A.J., Hallos, J., Hounsell, S., Brant, V., Debenham, N.C., 2005. Beeches Pit archaeology, assemblage dynamics and early fire history of a Middle Pleistocene site in East Anglia, UK, *Eurasian Prehistory* 3, 3-38.
- Gowlett, J.A.J., Harris, J.W.K., Walton, D., Wood, B.A., 1981. Early archaeological sites, hominid remains and traces of fire from Chesowanja, Kenya, *Nature* 294, 125-129.
- Gowlett, J.A.J., Harris, J.W.K., Wood, B.A., 1982. Early hominids and fire at Chesowanja, Kenya (reply), *Nature* 296, 870.
- Gowlett, J.A.J., Wrangham, R.W., 2013. Earliest fire in Africa: towards the convergence of archaeological evidence and the cooking hypothesis, *Azania: Archaeological Research in Africa* 48, 5-30.
- Groopman, E.E., Carmody, R.N., Wrangham, R.W., 2015. Cooking increases net energy gain from a lipid-rich food, *American Journal of Physical Anthropology* 156, 11-18.
- Hammel, H.T., Elsner, R.W., Lemessurier, D.H., Andersen, H.T., Milan, F.A., 1959. Thermal and metabolic responses of the Australian aborigine exposed to moderate cold in summer, *Journal of Applied Physiology* 14, 605-615.
- Harris, J., Isaac, G.L., Kaufulu, Z., 1997. Sites in the upper KBS, Okote, and Chari Members: reports, Clarendon Press, Oxford.
- Heaton, K.W., Marcus, S., Emmett, P., Bolton, C., 1988. Particle size of wheat, maize, and oat test meals: effects on plasma glucose and insulin responses and on the rate of starch digestion in vitro, *The American journal of clinical nutrition* 47, 675-682.
- Hendey, Q.B., 1976. The Pliocene Fossil Occurrences in "E" Quarry, Langebaanweg, South Africa, *Annals of the South African Museum* 69, 215-247.
- Henry, A.G., Büdel, T., Bazin, P.-L., in press. Towards an understanding of the costs of fire, *Quaternary International*.
- Hérisson, D., Locht, J.-L., Auguste, P., Tuffreau, A., 2013. Néandertal et le feu au Paléolithique moyen ancien. Tour d'horizon des traces de son utilisation dans le Nord de la France, *L'Anthropologie* 117, 541–578.
- Herzog, N.M., 2015. Primate behavioral responses to burning as a model for hominin fire use, The University of Utah.
- Herzog, N.M., Keefe, E.R., Parker, C.H., Hawkes, K., 2016. What's burning got to do with it? Primate foraging opportunities in fire-modified landscapes, *American Journal of Physical Anthropology* 159, 432-441.
- Hill, K.R., Walker, R.S., Božičević, M., Eder, J., Headland, T., Hewlett, B., Hurtado, A.M., Marlowe, F., Wiessner, P., Wood, B., 2011. Co-Residence Patterns in Hunter-Gatherer Societies Show Unique Human Social Structure, *Science* 331, 1286-1289.

- Hlubik, S., Berna, F., Feibel, C., Braun, D., Harris, J.W., 2017. Researching the nature of fire at 1.5 mya on the site of FxJj20 AB, Koobi Fora, Kenya, using high-resolution spatial analysis and FTIR spectrometry, *Current Anthropology* 58, S243-S257.
- Hoffmann, D.L., Angelucci, D.E., Villaverde, V., Zapata, J., Zilhão, J., 2018a. Symbolic use of marine shells and mineral pigments by Iberian Neandertals 115,000 years ago, *Science Advances* 4, eaar5255.
- Hoffmann, D.L., Standish, C., García-Diez, M., Pettitt, P.B., Milton, J., Zilhão, J., Alcolea-González, J.J., Cantalejo-Duarte, P., Collado, H., De Balbín, R., 2018b. U-Th dating of carbonate crusts reveals Neandertal origin of Iberian cave art, *Science* 359, 912-915.
- Hosfield, R., 2016. Walking in a Winter Wonderland? Strategies for Early and Middle Pleistocene Survival in Midlatitude Europe, *Current Anthropology* 57, 653-682.
- Hough, W., 1928. Fire-making Apparatus in the United States National Museum, *Proceedings of the United States National Museum* 73.
- Hublin, J.-J., Talamo, S., Julien, M., David, F., Connet, N., Bodu, P., Vandermeersch, B., Richards, M.P., 2012. Radiocarbon dates from the Grotte du Renne and Saint-Césaire support a Neandertal origin for the Châtelperronian, *Proceedings of the National Academy of Sciences* 109, 18743–18748.
- Isaac, G., 1982. Early hominids and fire at Chesowanja, Kenya, Nature 296, 870.
- Isaac, G.L., 1977. *Olorgesailie : archaeological studies of a middle pleistocene lake basin in Kenya*, University of Chicago Press, Chicago.
- James, S.R., 1989. Hominid use of fire in the Lower and Middle Pleistocene: a review of the evidence, *Current Anthropology* 30, 1-26.
- Jaubert, J., Verheyden, S., Genty, D., Soulier, M., Cheng, H., Blamart, D., Burlet, C., Camus, H., Delaby, S., Deldicque, D., 2016. Early Neanderthal constructions deep in Bruniquel Cave in southwestern France, *Nature* 534, 111-114.
- Jelinek, A.J., Farrand, W.R., Haas, G., Horowitz, A., Goldberg, P., 1973. Excavations at the Tabun Cave, Mount Carmel, Israel, 1967-1972: A Preliminary report, *Paléorient* 1, 151-183.
- Jia, L., 1985. China's earliest Palaeolithic assemblages, *Palaeoanthropology and Palaeolithic* Archaeology in the People's Republic of China, 135-145.
- Jones, R., 1969. Fire-stick Farming, Australian Natural History 16, 224.
- Kaplan, J.O., Pfeiffer, M., Kolen, J.C., Davis, B.A., 2016. Large scale anthropogenic reduction of forest cover in last glacial maximum Europe, *PLoS ONE* 11, e0166726.
- Karkanas, P., Shahack-Gross, R., Ayalon, A., Bar-Matthews, M., Barkai, R., Frumkin, A., Gopher, A., Stiner, M.C., 2007. Evidence for habitual use of fire at the end of the Lower Paleolithic: siteformation processes at Qesem Cave, Israel, *Journal of Human Evolution* 53, 197-212.
- Kölbl, S., Conard, N.J., 2009. *Brandheiß. Das–gefährliche–Spiel mit dem Feuer*, Urgeschichtliches Museum Blaubeuren, Blaubeuren.
- Koller, J., Baumer, U., Mania, D., 2001. High-tech in the Middle Palaeolithic: Neandertalmanufactured pitch identified, *European Journal of Archaeology* 4, 385-397.

- Komarek, E., 1972. Ancient fires, *Tall Timbers Fire Ecology Conference Proceedings 12*, Tall Timbers Research Station, pp. 219-240.
- Komarek, E.V., 1967. Fire and the ecology of man, *Tall Timbers Fire Ecology Conference Proceedings 6*, Tall Timbers Research Station, pp. 143-170.
- Komarek, E.V., 1969. Fire and animal behavior, *Tall Timbers Fire Ecology Conference Proceedings* 9, Tall Timbers Research Station, pp. 161-207.
- Kozowyk, P., Soressi, M., Pomstra, D., Langejans, G., 2017. Experimental methods for the Palaeolithic dry distillation of birch bark: implications for the origin and development of Neandertal adhesive technology, *Scientific Reports* 7, 8033.
- Lagercrantz, S., 1954. African methods of fire-making, Almqvist & Wiksells Boktryckeri, Uppsala.
- Larkin, N.R., 2011. Pyrite Decay: cause and effect, prevention and cure, NatSCA News 21, 35-43.
- Leduc, T., Goemaere, É., Jadin, I., Cattelain, P., 2012. L'altération des briquets en «marcassite» du «Trou de Chaleux» (fouilles d'Édouard Dupont) : identification des phases minérales primaires et secondaires, *ArcheoSciences* 36, 85-93.
- MacDonald, K., 2018. Fire-Free Hominin Strategies for Coping with Cool Winter Temperatures in North-Western Europe from Before 800,000 to Circa 400,000 Years Ago, *PaleoAnthropology* 2018, 7-26.
- Mallol, C., Hernández, C.M., Cabanes, D., Sistiaga, A., Machado, J., Rodríguez, Á., Pérez, L., Galván, B., 2013. The Black Layer of Middle Palaeolithic Combustion Structures. Interpretation and Archaeostratigraphic Implications, *Journal of Archaeological Science* 40, 2515–2537.
- Marks, A.E., Demidenko, Y., Monigal, K., Usik, V., 1998. Starosele: The 1993-95 excavations in: Marks, A.E., Chabai, V.P. (Eds.), *The Middle Paleolithic of western Crimea, I*, ERAUL 84, University of Liège, Liège, pp. 67-99.
- Martí, A.P., d'Errico, F., 2018. Seeking black. Geochemical characterization by PIXE of Palaeolithic manganese-rich lumps and their potential sources, *Journal of Anthropological Archaeology* 50, 54-68.
- Mason, S., 2000. Fire and Mesolithic subsistence—managing oaks for acorns in northwest Europe?, *Palaeogeography, Palaeoclimatology, Palaeoecology* 164, 139-150.
- Mazza, P.P.A., Martini, F., Sala, B., Magi, M., Colombini, M.P., Giachi, G., Landucci, F., Lemorini, C., Modugno, F., Ribechini, E., 2006. A new Palaeolithic discovery: tar-hafted stone tools in a European Mid-Pleistocene bone-bearing bed, *Journal of Archaeological Science* 33, 1310-1318.
- McBrearty, S., Brooks, A.S., 2000. The revolution that wasn't: a new interpretation of the origin of modern human behavior, *Journal of Human Evolution* 39, 453-563.
- Medler, M., 2011. Speculations About the Effects of Fire and Lava Flows on Human Evolution, *Fire Ecology* 7, 13-23.
- Meignen, L., Goldberg, P., Albert, R.M., Bar-Yosef, O., 2008. Structures de combustion, choix des combustibles et degré de mobilité des groupes dans le paléolithique moyen du Proche-Orient (grottes de Kébara et d'Hayonim, Israël), in: Théry-Parisot, I., Costamagno, S., Henry, A. (Eds.), Gestion des combustibles au paléolithique et au mésolithique : nouveaux outils,

nouvelles interprétations, UISPP XV congress, BAR International Series 114, Archaeopress, Oxford, pp. 101-118.

- Mercier, N., Froget, L., Miallier, D., Pilleyre, T., Sanzelle, S., Tribolo, C., 2004. Nouvelles données chronologiques pour le site de Menez-Dregan 1 (Bretagne): l'apport de la thermoluminescence, *Quaternaire* 15, 253-261.
- Mertens, S.B., 1996. The Middle Paleolithic in Romania, Current Anthropology 37, 515-521.
- Moncel, M.H., Bahain, J.J., Falguères, C., Patou-Mathis, M., Rousseau, L., Valladas, H., Auguste, P., Ayliffe, L., Bocherens, H., Bouteaux, A., Condemi, S., 2008. *Le site de Payre. Occupations humaines dans la vallée du Rhône à la fîn du Pléistocène moyen et au début du Pléistocène supérieur*, Mémoires de la Société Préhistorique Française, Paris.
- Monnier, J.-L., Ravon, A.-L., Hinguant, S., Hallégouët, B., Gaillard, C., Laforge, M., 2016. Menez-Dregan 1 (Plouhinec, Finistère, France): un site d'habitat du Paléolithique inférieur en grotte marine. Stratigraphie, structures de combustion, industries riches en galets aménagés, *L'Anthropologie* 120, 237-262.
- Monnier, J., Hallegouet, B., 2004. Rapport intermédiaire sur la fouille du gisement paléolithique inférieur de Menez-Dregan I, campagne 2004, UMR 6566 du CNRS, Rennes.
- Movius Jr, H.L., 1950. A wooden spear of third interglacial age from lower Saxony, *Southwestern Journal of Anthropology* 6, 139-142.
- Oakley, K., 1956. Fire as Palaeolithic tool and weapon, *Proceedings of the Prehistoric Society* 21, 36-48.
- Oakley, K.P., 1961. On man's use of fire, with comments on tool-making and hunting, in: Washburn, S.L. (Ed.), *Social Life of Early Man*, Aldine Publishing Co., Chicago, pp. 176-193.
- Organ, C., Nunn, C.L., Machanda, Z., Wrangham, R.W., 2011. Phylogenetic rate shifts in feeding time during the evolution of Homo, *Proceedings of the National Academy of Sciences* 108, 14555-14559.
- Parker, C.H., Keefe, E.R., Herzog, N.M., O'Connell, J.F., Hawkes, K., 2016. The pyrophilic primate hypothesis, *Evolutionary Anthropology* 25, 54-63.
- Pàunescu, A., 1993. Ripiceni-Izvor: Paleolitic și mezolitic, Editura Academiei, București.
- Peresani, M., Chravzez, J., Danti, A., De March, M., Duches, R., Gurioli, F., Muratori, S., Romandini, M., Tagliacozzo, A., Trombino, L., 2011. Fire-places, frequentations and the environmental setting of the final Mousterian at Grotta di Fumane: a report from the 2006-2008 research, *Quartär* 58, 131-151.
- Perles, C., 1977. Préhistoire du Feu, Masson, Paris.
- Pickering, T.R., Domínguez-Rodrigo, M., Egeland, C.P., Brain, C., 2005. The contribution of limb bone fracture patterns to reconstructing early hominid behaviour at Swartkrans Cave (South Africa): archaeological application of a new analytical method, *International Journal of Osteoarchaeology* 15, 247-260.
- Pop, E., Kuijper, W., van Hees, E., Smith, G., García-Moreno, A., Kindler, L., Gaudzinski-Windheuser, S., Roebroeks, W., 2016. Fires at Neumark-Nord 2, Germany: An analysis of fire proxies from a Last Interglacial Middle Palaeolithic basin site, *Journal of Field Archaeology*, 1-15.

- Preece, R.C., Gowlett, J.A.J., Parfitt, S.A., Bridgland, D.R., Lewis, S.G., 2006. Humans in the Hoxnian: habitat, context and fire use at Beeches Pit, West Stow, Suffolk, UK, *Journal of Quaternary Science* 21, 485-496.
- Pruetz, J.D., Herzog, N.M., 2017. Savanna chimpanzees at Fongoli, Senegal, navigate a fire landscape, *Current Anthropology* 58, S337-S350.
- Pruetz, J.D., LaDuke, T.C., 2010. Reaction to fire by savanna chimpanzees (*Pan troglodytes verus*) at Fongoli, Senegal: Conceptualization of 'fire behavior' and the case for a chimpanzee model, *American Journal of Physical Anthropology* 141, 646-650.
- Radovčić, D., Oros Sršen, A., Radovčić, J., Frayer, D.W., 2015. Evidence for Neandertal Jewelry: Modified White-Tailed Eagle Claws at Krapina, *PLoS ONE* 10(3), e0119802.
- Rhodes, S.E., Walker, M.J., López-Jiménez, A., López-Martínez, M., Haber-Uriarte, M., Fernández-Jalvo, Y., Chazan, M., 2016. Fire in the Early Palaeolithic: Evidence from burnt small mammal bones at Cueva Negra del Estrecho del Río Quípar, Murcia, Spain, *Journal of Archaeological Science: Reports* 9, 427-436.
- Richter, D., Angelucci, D., Dias, M., Prudêncio, M., Gouveia, M., Cardoso, G., Burbidge, C., Zilhão, J., 2014. Heated flint TL-dating for Gruta da Oliveira (Portugal): Dosimetric challenges and comparison of chronometric data, *Journal of Archaeological Science* 41, 705-715.
- Richter, D., Krbetschek, M., 2015. The age of the Lower Paleolithic occupation at Schöningen, *Journal of Human Evolution* 89, 46-56.
- Richter, J., 1997. Sesselfelsgrotte III. Der G-Schichten-Komplex der Sesselfelsgrotte. Zum Verständnis des Micoquien, Quartär-Bibliothek 7, Saarbrücken.
- Richter, J., 2006. Neanderthals in their landscape, in: Demarsin, B., Otte, M. (Eds.), Neanderthals in Europe: Proceedings of the International Conference, Held in the Gallo-Roman Museum in Tongeren (September 17-19th 2004), ERAUL 117, University of Liège, Tongeren, pp. 51-66.
- Richter, J., Mauz, B., Böhner, U., Weissmüller, W., Wagner, G.A., Freund, G., Rink, W.J., Richter, J., 2000. Luminescence Dating of the Middle/Upper Paleolithic sites "Sesselfelsgrotte" and "Abri I am Schulerloch", Altmühltal, Bavaria, in: Orschiedt, J., Weniger, G.-C. (Eds.), Neanderthals and modern Humans: Discussing the Transition. Central and Eastern Europe from 50.000 -30.000 B.P., Neanderthal Museum, Mettmann, pp. 30-41.
- Rios-Garaizar, J., López-Bultó, O., Iriarte, E., Pérez-Garrido, C., Piqué, R., Aranburu, A., Iriarte-Chiapusso, M.J., Ortega-Cordellat, I., Bourguignon, L., Garate, D., 2018. A Middle Palaeolithic wooden digging stick from Aranbaltza III, Spain, *PLoS ONE* 13, e0195044.
- Roberts, M.B., Parfitt, S.A., 1999. Boxgrove: A Middle Pleistocene Hominid Site at Eartham Quarry, Boxgrove, West Sussex, English Heritage, London.
- Rodríguez-Cintas, Á., Cabanes, D., 2017. Phytolith and FTIR studies applied to combustion structures: The case of the Middle Paleolithic site of El Salt (Alcoy, Alicante), *Quaternary International* 431, 16-26.
- Roebroeks, W., Sier, M.J., Nielsen, T.K., De Loecker, D., Pares, J.M., Arps, C.E., Mucher, H.J., 2012. Use of red ochre by early Neandertals, *Proceedings of the National Academy of Sciences* 109, 1889-1894.
- Roebroeks, W., Villa, P., 2011a. On the earliest evidence for habitual use of fire in Europe, *Proceedings of the National Academy of Sciences* 108, 5209-5214.

- Roebroeks, W., Villa, P., 2011b. Reply to Sandgathe et al.: Neandertal use of fire, *Proceedings of the National Academy of Sciences* 108, E299.
- Rolland, N., 2004. Was the emergence of home bases and domestic fire a punctuated event? A review of the Middle Pleistocene record in Eurasia, *Asian Perspectives* 43, 248-280.
- Roussel, B., 2005. La production du feu par percussion de la pierre: Préhistoire, ethnographie, expérimentation, Editions Monique Mergoil, Montagnac.
- Russell, C., 1978. Fire Control and Human Evolution, Biology and Human affairs 43, 14-20.
- Sandgathe, D.M., 2017. Identifying and describing pattern and process in the evolution of hominin use of fire, *Current Anthropology* 58, S360-S370.
- Sandgathe, D.M., Berna, F., 2017. Fire and the genus Homo: an introduction to supplement 16, *Current Anthropology* 58, S165-S174.
- Sandgathe, D.M., Dibble, H.L., Goldberg, P., McPherron, S.P., Turq, A., Niven, L., Hodgkins, J., 2011a. On the Role of Fire in Neandertal Adaptations in Western Europe: Evidence from Pech de l'Azé and Roc de Marsal, France., *PaleoAnthropology*, 216-242.
- Sandgathe, D.M., Dibble, H.L., Goldberg, P., McPherron, S.P., Turq, A., Niven, L., Hodgkins, J., 2011b. Timing of the appearance of habitual fire use, *Proceedings of the National Academy of Sciences* 108, E298.
- Sañudo, P., Blasco, R., Fernández Peris, J., 2016. Site formation dynamics and human occupations at Bolomor Cave (Valencia, Spain): An archaeostratigraphic analysis of levels I to XII (100– 200 ka), *Quaternary International* 417, 94-104.
- Scherjon, F., Bakels, C., MacDonald, K., Roebroeks, W., 2015. Burning the Land: An Ethnographic Study of Off-Site Fire Use by Current and Historically Documented Foragers and Implications for the Interpretation of Past Fire Practices in the Landscape, *Current Anthropology* 56, 299-326.
- Schiegl, S., Goldberg, P., Bar-Yosef, O., Weiner, S., 1996. Ash Deposits in Hayonim and Kebara Caves, Israel: Macroscopic, Microscopic and Mineralogical Observations, and their Archaeological Implications, *Journal of Archaeological Science* 23, 763-781.
- Schmidt, P., Porraz, G., Slodczyk, A., Bellot-gurlet, L., Archer, W., Miller, C.E., 2013. Heat treatment in the South African Middle Stone Age: temperature induced transformations of silcrete and their technological implications, *Journal of Archaeological Science* 40, 3519-3531.
- Schnorr, S.L., Crittenden, A.N., Venema, K., Marlowe, F.W., Henry, A.G., 2015. Assessing digestibility of Hadza tubers using a dynamic in-vitro model, *American Journal of Physical Anthropology* 158, 371-385.
- Scholander, P., Hammel, H., Andersen, K.L., Løyning, Y., 1958a. Metabolic acclimation to cold in man, *Journal of Applied Physiology* 12, 1-8.
- Scholander, P.F., Hammel, H.T., Hart, J.S., LeMessurier, D.H., Steen, J., 1958b. Cold adaptation in Australian Aborigines, *Journal of Applied Physiology* 13, 211-218.
- Scott, A.C., 2000. The Pre-Quaternary history of fire, *Palaeogeography, Palaeoclimatology, Palaeoecology* 164, 281-329.
- Scott, G.R., Gibert, L., 2009. The oldest hand-axes in Europe, Nature 461, 82-85.

- Sevink, J., van Geel, B., Jansen, B., Wallinga, J., 2018. Early Holocene forest fires, drift sands, and Usselo-type paleosols in the Laarder Wasmeren area near Hilversum, the Netherlands: Implications for the history of sand landscapes and the potential role of Mesolithic land use, *CATENA* 165, 286-298.
- Shahack-Gross, R., Berna, F., Karkanas, P., Lemorini, C., Gopher, A., Barkai, R., 2014. Evidence for the repeated use of a central hearth at Middle Pleistocene (300 ky ago) Qesem Cave, Israel, *Journal of Archaeological Science* 44, 12-21.
- Sharp, H.S., Sharp, K., 2015. *Hunting Caribou: Subsistence Hunting Along the Northern Edge of the Boreal Forest*, University of Nebraska Press, Lincoln.
- Shimelmitz, R., Kuhn, S.L., Jelinek, A.J., Ronen, A., Clark, A.E., Weinstein-Evron, M., 2014. 'Fire at will': The emergence of habitual fire use 350,000 years ago, *Journal of Human Evolution* 77, 196-203.
- Simmons, I., Innes, J., 1996. Prehistoric charcoal in peat profiles at North Gill, North Yorkshire Moors, England, *Journal of Archaeological Science* 23, 193-197.
- Smith, A.R., Carmody, R.N., Dutton, R.J., Wrangham, R.W., 2015. The significance of cooking for early hominin scavenging, *Journal of Human Evolution* 84, 62-70.
- Snitker, G., 2018. Identifying natural and anthropogenic drivers of prehistoric fire regimes through simulated charcoal records, *Journal of Archaeological Science* 95, 1-15.
- Sørensen, B., 2009. Energy use by Eem Neanderthals, *Journal of Archaeological Science* 36, 2201-2205.
- Soressi, M., D'Errico, F., 2007. Pigments, gravures, parures : les comportements symboliques controversés des Néandertaliens, in: Vandermeersch, B., Maureille, B. (Eds.), *Les Néandertaliens. Biologie et cultures*, Comité des Travaux Historiques et Scientifiques (Documents Préhistoriques 23), Paris, pp. 297-309.
- Soressi, M., Rendu, W., Texier, J.-P., Claud, E., Daulny, L., D'errico, F., Laroulandie, V., Maureille, B., Niclot, M., Schwortz, S., Tillier, A.-M., 2008. Pech-de-l'Azé I (Dordogne, France): nouveau regard sur un gisement moustérien de tradition acheuléenne connu depuis le XIX siècle, in: Jaubert, J., Bordes, J.-G., Ortega, I. (Eds.), *Les sociétés Paléolithiques d'un grand Sud-Ouest: nouveaux gisements, nouvelles méthodes, nouveaux résultats*, Société Préhistorique française, Paris, pp. 95-132.
- Speth, J., 2017. Putrid Meat and Fish in the Eurasian Middle and Upper Paleolithic: Are We Missing a Key Part of Neanderthal and Modern Human Diet?, *PaleoAnthropology* 2017, A1-A41.
- Speth, J.D., 2004. News Flash: Negative Evidence Convicts Neanderthals of Gross Mental Incompetence, *World Archaeology* 36, 519-526.
- Speth, J.D., 2006. Housekeeping, Neandertal-Style. Hearth Placement and Midden Formation in Kebara Cave (Israel), in: Hovers, E., Kuhn, S.L. (Eds.), *Transitions before the Transition*. *Evolution and Stability in the Middle Paleolithic and the Middle Stone Age.*, Springer, New York, pp. 171-188.
- Speth, J.D., 2012. Middle Palaeolithic subsistence in the Near East: zooarchaeological perspectives past, present and future, *Before Farming* 2012/2, 1-45.

Speth, J.D., 2015. When did humans learn to boil, PaleoAnthropology 2015, 54-67.

- Sponheimer, M., de Ruiter, D., Lee-Thorp, J., Spath, A., 2005a. Sr/Ca and early hommin diets revisited: new data from modern and fossil tooth enamel, *Journal of Human Evolution* 48, 147-156.
- Sponheimer, M., Lee-Thorp, J., de Ruiter, D., Codron, D., Codron, J., Baugh, A.T., Thackeray, F., 2005b. Hominins, sedges, and termites: new carbon isotope data from the Sterkfontein valley and Kruger National Park, *Journal of Human Evolution* 48, 301-312.
- Stahl, A.B., Dunbar, R.I.M.H., K., Ikawa-Smith, F., Kortlandt, A., McGrew, W.C., Milton, K., Paterson, J.D., Poirier, F.E., Sugardjito, J., Tanner, N.M., Wrangham, R.W., 1984. Hominid dietary selection before fire, *Current Anthropology* 25, 151-168.
- Stahlschmidt, M.C., Miller, C.E., Ligouis, B., Hambach, U., Goldberg, P., Berna, F., Richter, D., Urban, B., Serangeli, J., Conard, N.J., 2015. On the evidence for human use and control of fire at Schöningen, *Journal of Human Evolution* 89, 181-201.
- Stapert, D., Johansen, L., 1999. Flint and pyrite: making fire in the Stone Age, Antiquity 73, 765-777.
- Steegmann, T.A., Cerny, F.J., Holliday, T.W., 2002. Neandertal cold adaptation: Physiological and energetic factors, *American Journal of Human Biology* 14, 566-583.
- Surovell, T.A., Brantingham, P.J., 2007. A note on the use of temporal frequency distributions in studies of prehistoric demography, *Journal of Archaeological Science* 34, 1868-1877.
- Surovell, T.A., Byrd Finley, J., Smith, G.M., Brantingham, P.J., Kelly, R., 2009. Correcting temporal frequency distributions for taphonomic bias, *Journal of Archaeological Science* 36, 1715-1724.
- Thieme, H., 1997. Lower Palaeolithic hunting spears from Germany, Nature 385, 807-810.
- Thieme, H., Veil, S., 1985. Neue Untersuchungen zum eemzeitlichen Elefanten-Jagdplatz Lehringen, Ldkr. Verden, *Die Kunde* 36, 11-58.
- Turq, A., Dibble, H.L., Goldberg, P., McPherron, S.P., Sandgathe, D., Jones, H., Maddison, K., Maureille, B., Mentzer, S., Rink, J., 2011. Les fouilles récentes du Pech de l'Azé IV (Dordogne), *Gallia Prehistoire* 53, 1-58.
- Vallverdú, J., Alonso, S., Bargalló, A., Bartrolí, R., Campeny, G., Carrancho, A., Expósito, I., Fontanals, M., Gabucio, J., Gómez, B., Prats, J.M., Sañudo, P., Solé, A., Vilalta, J., Carbonell, E., 2012. Combustion structures of archaeological level O and Mousterian activity areas with use of fire at the Abric Romaní rockshelter (NE Iberian peninsula) *Quaternary International* 247, 313–324.
- Vandevelde, S., Brochier, J., Desachy, B., Petit, C., Slimak, L., 2018. Sooted concretions: A new micro-chronological tool for high temporal resolution archaeology, *Quaternary International* 474, 103-118.
- Vandevelde, S., Brochier, J.É., Petit, C., Slimak, L., 2017. Establishment of occupation chronicles in Grotte Mandrin using sooted concretions: Rethinking the Middle to Upper Paleolithic transition, *Journal of Human Evolution* 112, 70-78.
- Vaquero, M., Vallverdú, J., Rosell, J., Pastó, I., Allué, E., 2001. Neandertal behavior at the Middle Palaeolithic site of Abric Romaní, Capellades, Spain, *Journal of Field Archaeology* 28, 93-114.

- Vértes, L., Dobosi, V.T., 1990. Fireplaces of the settlement, in: Kretzoi, M., Dobosi, V.T. (Eds.), Vértesszöllös, Akademiai Kiado, Budapest, pp. 519-521.
- Vidal-Matutano, P., 2017. Firewood and hearths: Middle Palaeolithic woody taxa distribution from El Salt, stratigraphic unit Xb (Eastern Iberia), *Quaternary International* 457, 74-84.
- Villa, P., 1982. Conjoinable Pieces and Site Formation Processes, American Antiquity 47, 276-290.
- Villa, P., 1983. *Terra Amata and the Middle Pleistocene Archaeological Record of Southern France*, University of California Press, Berkeley.
- Wadley, L., Sievers, C., Bamford, M., Goldberg, P., Berna, F., Miller, C., 2011. Middle Stone Age Bedding Construction and Settlement Patterns at Sibudu, South Africa, *Science* 334, 1388-1391.
- Walker, M.J., Anesin, D., Angelucci, D.E., Avilés-Fernández, A., Berna, F., Buitrago-López, A.T., Fernández-Jalvo, Y., Haber-Uriarte, M., López-Jiménez, A., López-Martínez, M., 2016. Combustion at the late Early Pleistocene site of Cueva Negra del Estrecho del Río Quípar (Murcia, Spain), Antiquity 90, 571-589.
- Weiner, J., 2003. Friction vs. percussion. Some comments on firemaking from Old Europe, *Bulletin of Primitive Technology* 26, 10-16.
- Weiner, S., Xu, Q., Goldberg, P., Liu, J., Bar-Yosef, O., 1998. Evidence for the Use of Fire at Zhoukoudian, China, *Science* 281, 251-253.
- Welker, F., Hajdinjak, M., Talamo, S., Jaouen, K., Dannemann, M., David, F., Julien, M., Meyer, M., Kelso, J., Barnes, I., Brace, S., Kamminga, P., Fischer, R., Kessler, B.M., Stewart, J.R., Pääbo, S., Collins, M.J., Hublin, J.-J., 2016. Palaeoproteomic evidence identifies archaic hominins associated with the Châtelperronian at the Grotte du Renne, *Proceedings of the National Academy of Sciences* 113, 11162-11167.
- White, M.J., 2006. Things to do in Doggerland when you're dead: surviving OIS3 at the northwesternmost fringe of Middle Palaeolithic Europe, *World Archaeology* 38, 547-575.
- Wiessner, P., 2014. Embers of society: Firelight talk among the Ju/'hoansi Bushmen, *Proceedings of the National Academy of Sciences* 111, 14027–14035.
- Wragg Sykes, R.M., 2015. To see a world in a hafted tool: birch pitch composite technology, cognition and memory in Neanderthals, in: Coward, F., Hosfield, R., Pope, M., Wenban-Smith, F. (Eds.), Settlement, Society and Cognition in Human Evolution: Landscapes in the Mind, Cambridge University Press, Cambridge, pp. 117-137.

Wrangham, R., 2009. Catching fire: How cooking made us human, Basic Books, New York.

Wu, X., 1999. Investigating the possible use of fire at Zhoukoudian, China, Science 283, 299-299.

- Zaidner, Y., Frumkin, A., Friesem, D., Tsatskin, A., Shahack-Gross, R., 2016. Landscapes, depositional environments and human occupation at Middle Paleolithic open-air sites in the southern Levant, with new insights from Nesher Ramla, Israel, *Quaternary Science Reviews* 138, 76-86.
- Zaidner, Y., Frumkin, A., Porat, N., Tsatskin, A., Yeshurun, R., Weissbrod, L., 2014. A series of Mousterian occupations in a new type of site: the Nesher Ramla karst depression, Israel, *Journal of Human Evolution* 66, 1-17.

- Zieba, A., Sitliviy, V.I., Sobczyk, K., 2010. Settlement structure of the Late Middle Paleolithic in the Cracow Region, in: Conard, N., Delagnes, A. (Eds.), *Settlement Dynamics of the Middle Paleolithic and Middle Stone Age*, Kerns Verlag, Tübingen, pp. 235-248.
- Zieba, A., Sitlivy, V., Sobczyk, K., Kolesnik, A.V., 2008. Raw material exploitation and intra-site spatial distribution at two Late Middle and Early Upper Paleolithic sites in the Krakow region: Piekary IIA and Ksiecia Jozefa, *Archaeology, Ethnology & Anthropology of Eurasia* 33, 46-57.
- Zilhão, J., Angelucci, D., Daura, J., Deschamps, M., Hoffman, D.L., Matias, H., Nabais, M., Sanz, M., 2016. The Almonda karst system (Torres Novas, Portugal): a window into half a million years of long-term change in climate, settlement, subsistence, technology and culture, *Proceedings of the European Society for the study of Human Evolution 5 (PESHE 5)*, 253.
- Zilhão, J., Angelucci, D.E., Badal-García, E., d'Errico, F., Daniel, F., Dayet, L., Douka, K., Higham, T.F.G., Martínez-Sánchez, M.J., Montes-Bernárdez, R., Murcia-Mascarós, S., Pérez-Sirvent, C., Roldán-García, C., Vanhaeren, M., Villaverde, V., Wood, R., Zapata, J., 2010. Symbolic use of marine shells and mineral pigments by Iberian Neandertals, *Proceedings of the National Academy of Sciences* 107, 1023-1028.
- Zink, K.D., Lieberman, D.E., 2016. Impact of meat and Lower Palaeolithic food processing techniques on chewing in humans, *Nature* 531, 500-503.
- Zink, K.D., Lieberman, D.E., Lucas, P.W., 2014. Food material properties and early hominin processing techniques, *Journal of Human Evolution* 77, 155-166.