# Fire for a Reason

## Barbecue at Middle Pleistocene Qesem Cave, Israel

### by Ran Barkai, Jordi Rosell, Ruth Blasco, and Avi Gopher

Qesem Cave is a Middle Pleistocene site in Israel occupied between 420 and 200 ka. Excavations have revealed a wealth of innovative behaviors most likely practiced by a new hominin lineage. These include early evidence for the habitual and continuous use of fire, the repeated use of a central hearth, systematic flint and bone recycling, early blade production technologies, social hunting strategies and meat-sharing practices, and more. Fire was used throughout the 200,000 years of human occupation of the cave primarily for meat roasting and cooking. Roasting and cooking, we argue, had an important role in providing the necessary caloric intake of the cave's inhabitants. We see fire as an essential element of the new post-Acheulian human adaptation in the Levant. The ample recurring evidence for focused and repeated use of fire for dietary purposes suggests that fire production, control, use, and maintenance were habitually practiced by the cave's inhabitants and that fire-induced calories became central for their survival. We present an integrative view regarding the use of fire at Qesem Cave and discuss the role of fire within the framework of the significant cultural and biological transformations that took shape in the post-Acheulian Levant during the Middle Pleistocene.

## Introduction

The use of fire at Middle Pleistocene Qesem Cave (Qesem) has been discussed, and the repeated use of a central hearth at 300 ka has been demonstrated in previous publications (Falguères et al. 2015; Karakanas et al. 2007; Shahack-Gross et al. 2014). In this paper, our aim is to view the human use of fire at Qesem in the context of cultural and biological transformations that took shape in the Levant at ca. 400 ka and to specify the major uses of fire at Qesem in particular and in the late Lower Paleolithic period in the Levant in general. We claim that the common and continuous use of fire for roasting meat at 400 ka at Qesem was a Rubicon crossed for the first time, and it characterizes human existence from that time to this very day. We contend that the combination of specific circumstances during the late Lower Paleolithic period in the Levant triggered human communities to make use of their extensive cultural and social capabilities as well as their profound familiarity with their environments and their survival skills by using a new mode of adaptation. The use of fire for roasting meat and for cooking in general was a central element of this new adaptation, and the evidence from Qesem is consistent with this hypothesis. We start with a general introduction about the Acheulo-Yabrudian Cultural Complex (AYCC) as reflected by the plethora of information gathered from the archaeological deposits of Qesem. Then we focus on direct and indirect evidence for the use of fire at the cave (ash, hearths, burned bones and lithics, stone tools used in butchering, and charcoal contained in dental calculus). Finally, we present our hypothesis regarding the earliest, continuous, and common use of fire for roasting meat and cooking and its implications to human diet, culture, and adaptation.

### *The Acheulo-Yabrudian Cultural Complex and the State of the Art of Qesem Cave Studies*

The AYCC is a Middle Pleistocene, late Lower Paleolithic cultural entity of the Levant. The AYCC consists of three distinct lithic industries: the Acheulo-Yabruidan (a flake industry with a notable presence of handaxes), the Yabrudian (a flake industry dominated by Quina and demi-Quina scrapers), and the Amudian (a blade-dominated industry; see Bar-Yosef 1994; Copeland 2000; Rust 1950). Stratigraphically, the AYCC repeatedly postdates the Lower Paleolithic Acheulian and predates the Middle Paleolithic Mousterian. The absolute chronology of the AYCC covers a range of over 200 kyr between ca. 420 and

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200 ka (Barkai et al. 2003; Gopher et al. 2010). New thermoluminescence and electron spin resonance dates from Qesem and Misliya Caves accord well with this range (Falguères et al. 2015; Mercier et al. 2013; Valladas et al. 2013). AYCC sites are known from the central and southern Levant in both caves and open air settings but mostly in caves or rock shelters.

Blade production in the Amudian industry is of special interest and is one of the major innovations of the AYCC (e.g., Bar-Yosef and Kuhn 1999). Middle Pleistocene blade production is a unique "ahead of its time" technological innovation that is part of a set of cultural and behavioral transformations that took shape in the Levant at ca. 400 ka and that should be viewed as a local innovation that persisted for 200 kyr. The Amudian industry is characterized by the systematic production of blades and tools made of blades. Alongside blade production, a significant flake component also appears, including side scrapers in various frequencies (Copeland 2000; Jelinek 1982, 1990). Qesem has shown that the Amudian represents a major industry of the AYCC, equivalent in scale to the other known industries (e.g., Gopher et al. 2005; Shimelmitz, Gopher, and Barkai 2011, 2015).

In the Yabrudian industry, the innovative appearance of the Quina *chaîne opératoire* for the shaping of Quina scrapers (see Bourguignon 2001) is of note. These distinctive scrapers are well known from Middle Paleolithic Mousterian of Europe. However, the Yabrudian is much older than the European manifestations of the Quina phenomenon. In the Levant, Quina scrapers appear in large numbers in the AYCC Yabrudian (by the thousands at Qesem and Tabun caves) but cease to appear in post-AYCC Middle Paleolithic Mousterian sites. The fact that Quina scrapers are not known from earlier Acheulian contexts makes their presence in the Yabrudian unique and quite enigmatic.

As for the makers of the AYCC, this remains an open question. The Galilee Man skull from Zuttiyeh Cave (Freidline et al. 2012; Keith 1927; Zeitoun 2001) and the dental remains from Qesem hint at a new, post-Acheulian, post-*erectus* hominin lineage in the Levant at ca. 400 ka (Ben Dor et al. 2011; Hershkovitz et al. 2011). This statement is supported by new studies of Middle Pleistocene skeletal remains, mainly dental remains from the Levant and beyond (Le Cabec et al. 2013; Liu et al. 2013; Rink et al. 2013), as well as genetic evidence suggesting a Middle Pleistocene (before 300 ka) date for the ancestors of modern humans and/or Neanderthals (e.g., Endicott, Ho, and Stringer 2010; Mendez et al. 2013).

As for the use of fire, the evidence indicates that human use of fire during the AYCC in the Levant was common and relatively widespread (see a recent review in Shimelmitz et al. 2014). Earlier use of fire in the Levant was reported at Gesher Benot Ya'aqov only (Alperson-Afil 2017; Alperson-Afil and Goren-Inbar 2010; Goren-Inbar et al. 2004). Such "early fire" occurrences (Gowlett 2010), or the early interactions between humans and fire, are evident during the Early and Middle Pleistocene in Africa and Asia (e.g., Berna et al. 2012; Chazan 2017; Gao et al. 2017; Gowlett et al. 2017; Hlubik et al. 2017). The turning point from "early fire" to the habitual use of fire is a matter of dispute. Roebroeks and Villa (2011) describe habitual use of fire as a systematically repeated use of fire in specific sites and/or regions. Based on an increased number of archaeological sites associated with evidence for fire being extensively used in domestic contexts, they suggested that the earliest habitual use of fire occurred in Middle Pleistocene (ca. 400–300 ka) Europe and southwest Asia. On top of that, the probable use of fire in the Acheulian was never demonstrated. We argue that starting at ca. 400 ka, hearths were used, first and foremost, for roasting meat, and as a result, burned bones are found in abundance in post-Acheulian sites (Fernández et al. 2012; Karkanas et al. 2007). Thus we concur with the statement that during the Lower Paleolithic, Acheulian meat was most probably consumed raw (Bar-Yosef 2006). As for the AYCC, the evidence from Qesem presented below indicates an unequivocal change regarding the presence and use of fire in archaeological sites from this point in time onward.

## *Qesem Cave*

Qesem is located on the western slopes of the Samarian hills some 12 km east of the Mediterranean at 90 m asl. With nearby large springs and being located at the ecotone between the swampy basins of the coastal plain to the west and the mountainous ridges of Samaria, this location provides a rich Mediterranean biome. To date, the excavation exposed some 70 $m^2$ (130 $m^3$) using 50 × 50 cm spatial units, full recovery through a 2.4 mm net, and screen washing through 0.5–0.8 mm for microfauna-bearing layers.

Qesem is a sediment-filled karstic chamber that became available to humans following slope erosion (Frumkin et al. 2009). The stratigraphic sequence was divided into two major parts: the lower consists of a >6.5 m accumulation of sediments with clastic content, gravel, and clays, and the upper consists of 4.5 m of cemented sediment with a large ash component. The lower part was deposited in a closed karstic chamber, while the upper part was deposited when the cave was more open, as indicated by the presence of calcified rootlets (Karkanas et al. 2007).

Qesem is a Middle Pleistocene (MIS 11-7) site dated by various methods (over 100 dates) to between 420 and 200 ka (Barkai et al. 2003; Falguères et al. 2016; Gopher et al. 2010; Mercier et al. 2013). The whole stratigraphic sequence is assigned to the AYCC (Barkai and Gopher 2011, 2013).

Ongoing research at the site provides ample evidence of innovative behaviors. This pertains, for example, to serial blade production (Shimelmitz, Gopher, and Barkai 2011), the acquisition of raw material for selected tool types from underground sources (Verri et al. 2004), the production of Quina scrapers using Quina debitage and retouch technologies (Lemorini et al. 2016), intensive and varied recycling of flint and bone (Parush, Gopher, and Barkai 2016; Rosell et al. 2015), group hunting of prime-aged animals (mainly fallow deer; Blasco et al. 2014, 2016*a*), specialized butchering techniques and unique meat-sharing habits (Stiner et al. 2009, 2011), intensive use of bone retouchers, the habitual use of fire, hearth-centered and spatially patterned activities, and more—all well established at Qesem and present throughout the cave's sequence. Qesem contains two of the three AYCC industries: the blade-dominated Amudian and the scraper-dominated Yabrudian. Viewing these two as separate entities is at present challenged by data indicating their coexistence at Qesem. Below we will present a summary of the data on the lithics and human remains. The fauna will be presented separately because it directly relates to understanding the use of fire at the cave.

### *The Lithic Assemblage*

While Amudian-bearing levels are dominant throughout the cave's stratigraphic sequence, the Yabrudian is less conspicuous and is stratigraphically and spatially restricted. Raw-material studies were oriented to both characterizing flint types used and locating their sources in the landscape. Preliminary results show the use of a large variety of flint types (over 80), some of which were selected for specific types of tools or technological requirements. A concentration of over 10 geological sources yielding flint types used at the cave was found within 5 km of the site. Several sources are, however, located some 15 km away from the site (Wilson et al. 2016). Earlier raw-material studies provided evidence for flint procurement by both surface collection and quarrying from specific, designated primary subsurface sources (Verri et al. 2004, 2005). Quarried flint was directed toward the production of specific tool types (Boaretto et al. 2009). It is of note that the AYCC of Tabun cave has items made of flint quarried from deep sources as well (Verri et al. 2005).

The Amudian blade industries provide very large samples. Blade production at Qesem shows a full *chaîne opératoire*, including well-selected flat flint nodules, core shaping, and blade production, use, and discard. Amudian blades were mostly used for cutting, butchering, and defleshing activities of soft tissues and for a short time (Lemorini et al. 2006). Moreover, homogeneity in blade production technology and in blade characteristics was discerned throughout the Levant, reflecting a shared AYCC template regarding the properties of the target blades (Shimelmitz, Barkai, and Gopher 2016). Amudian blade production reflects a systematic, intensive, thoughtful, and straightforward technology—a conscious technological choice of skilled flint knappers constantly used for over 200 kyr (Shimelmitz, Barkai, and Gopher 2016; Shimelmitz, Gopher and Barkai 2011). Early blade industries were reported from Africa as well (Johnson and McBrearty 2010; Wilkins and Chazan 2012). The interrelations between these industries and the Amudian is intriguing in light of a multiple origins (convergent) hypothesis for early Middle Pleistocene blade technology (Barkai and Gopher 2013; Wilkins and Chazan 2012).

Recycling flint is a clear component of both Amudian and Yabrudian assemblages at Qesem and in the AYCC as a whole (e.g., Shimelmitz 2015). Detailed studies of recycled items and recycling products indicate technologically well-established trajectories for the production of designated types of specific sharp flakes and blades (Assaf et al. 2015; Barkai, Lemorini, and Gopher 2010; Parush et al. 2015; Parush, Gopher, and Barkai 2016) for targeted purposes (Lemorini et al. 2015). The scale of recycling may reach almost 10% of the debitage at Qesem (the highest densities may reach 180 recycled items per 1 $m^3$; see Gopher et al. 2016), and if recycled patinated items are added, the frequency rises significantly. Recycling is a well-established behavioral feature characterizing the AYCC (as well as earlier Acheulian technologies; see Agam, Marder, and Barkai 2015; Barkai and Gopher 2013; Shimelmitz 2015) and is most probably oriented toward the intensification of cutting activities.

As for tool typology, an "Upper Paleolithic" tool group made on blades is conspicuous (Gopher et al. 2005). Large, wide, and thick blades were selected for tool shaping, and laminar-shaped items are dominated by a variety of retouched and backed items with few end scrapers. Yabrudian assemblages show an abundance of Quina and demi-Quina scrapers making up to 50% of the shaped items, while blades are less abundant.

A small group ($n = 16$) of shaped stone balls (spheroids/polyhedrons) was found concentrated in specific stratigraphic and spatial Amudian contexts (Barkai and Gopher 2016). Whether these were used for specific activities in specific contexts it is too early to say. Biface production continued in the AYCC and was quite conspicuous in the Acheulo-Yabrudian at Tabun. Although bifaces are indeed marginal at Qesem and appear as single items in both Amudian and Yabrudian assemblages (Barkai and Gopher 2013), they seem to have been given special attention. Bifaces appear in different stages—including roughouts. One of the outstanding roughouts is quite large (22 cm long, 15 cm wide, 10 cm thick, and 3,285 g; see Barkai et al. 2013).

Archaeological evidence for knowledge transmission is difficult to attain. We have suggested a change in knowledge-transmission mechanisms between the Acheulian and the AYCC in the Levant in relation to new adaptive strategies and innovations in the lithic sphere, to hunting techniques and butchering practices, to the habitual use of fire (firewood collection, making and maintaining fire), and especially to meat (and maybe other foods) roasting and cooking (Barkai and Gopher 2013). These new AYCC behaviors necessitated knowledge-transmission mechanisms differing to a degree from those practiced in the Acheulian and supported by a new social milieu based on a possible new sociocultural discourse (see Assaf, Barkai, and Gopher 2016; Barkai and Gopher 2013; Ben-Dor et al. 2011). A study of lithic knowledge transmission carried out at Qesem recently relates to the technotypological characteristics of a lithic assemblage from the southern parts of the cave (earlier than 300 ka). The study of knapping trajectories demonstrated distinct features in this assemblage when compared with lithic assemblages from other areas of the cave. These features reflect various levels of knapping skills most probably characterizing both skilled knappers and knappers in the process of learning. This may permit a preliminary assessment of knowledge transmission relating to flint knapping that has taken place in a designated area (Assaf, Barkai, and Gopher 2016; Assaf et al. 2015).

### *Human Remains*

To date, Qesem has yielded dental human remains only; 13 teeth in total from different parts of the stratigraphic column. These included deciduous and permanent teeth of a number of individuals, many of whom were under the age of 20. The basic morphometric study indicates that the Qesem teeth are clearly not of *Homo erectus* (sensu lato). It has highlighted that while some of the traits are more Neanderthal-like, they are generally similar to the Late Pleistocene local populations of Skhul and Qafzeh caves dated to ca. 100 ka, (Hershkovitz et al. 2011, 2016). A 3-D scan of some of the teeth and various subsequent analyses resulted in similar conclusions, although Neanderthal affinities were more emphasized in some of these teeth (Fornai et al. 2016; Weber et al. 2016). While it is quite conceivable that the Acheulian Cultural Complex of the Levant was created by *H. erectus* (sensu lato; see Barkai and Gopher 2013 for details), the dental evidence from Qesem, augmented by the AYCC skull from Zuttiyeh Cave, indicates a new, post-Acheulian, post-*erectus* hominin lineage starting at ca. 400 ka.

We thus see merit in our previous suggestions that the Qesem finds and the AYCC as a whole were produced by a new local human lineage. Obviously the question of why a biological change occurred in the Levant around 400 ka is of major interest. Based on a bioenergetic model conjoined with the cultural transformations demonstrated at Qesem, we offer an explanation accounting for the demise of *H. erectus* and the appearance of a new, locally evolved, post-*erectus* human lineage in the Levant around 400 ka (Ben-Dor et al. 2011). The model suggests that the disappearance of elephants from the human diet in the Levant around this time triggered a selection process in favor of those who were better adapted to hunting larger numbers of smaller, faster animals with high fat content—that is, those who were lighter and more agile. The ingredients of this model include well-known data such as the fact that the elephant is a unique and ideal food package exploited by Lower Paleolithic groups in the Levant for hundreds of thousands of years. It is of note that no elephants are found in Levantine post-Acheulian sites, which suggests this significant part of Acheulian life and diet had ceased in post-Acheulian times. Why elephants disappeared from the human diet in post-Acheulian times in the Levant remains an open question at the moment. However, the fact that elephants are absent from all sites after the Lower Paleolithic implies that rather than a culturally based avoidance or taboo, the most plausible explanation is that elephants were, for some reason, no longer available. Additionally, modern humans have known and generally accepted ceilings on protein and vegetal food consumption, and fat is thus a compulsory component in the human diet for sufficient Daily Energy Expenditure (elephants are a notable package of fat; see details in Ben-Dor et al. 2011). The habitual use of fire for roasting and the new lithic technologies may be listed here as two of the important new cultural elements related to this transformative biological and socioeconomic landscape.

Qesem provides ample evidence on the environment, on human behavioral and cultural adaptation, and on the biology of the hominins that inhabited it. Sealed by sediment accumulation at ca. 200 ka, shortly after desertion, and exposed only 15 years ago, Qesem preserves an outstanding potential not only for studying the communities that inhabited it but also for understanding the AYCC as a whole and its place within the sequence between two relatively intensively studied entities—the Lower Paleolithic Acheulian and the Middle Paleolithic Mousterian. While these two may be regarded as pan-Eurasian phenomena, the AYCC is a local and distinct entity. Although many of the AYCC lithic innovations do not continue into the Mousterian and are replaced by Levallois-dominated industries, some of the most significant cultural and behavioral innovative patterns of the AYCC do continue into later periods (e.g., the habitual use of fire, hunting focused mainly on large and medium-sized ungulates, meat roasting, and more). The AYCC, mainly in its early stage, demonstrates a revolution, so to speak, reflecting a society open to innovative elements. New lithic technologies appeared and were maintained for a period of 200 kyr. Known concepts such as flint recycling have been modified, changed, and intensified. We view the emergence of AYCC blade and Quina technologies in the Levant as an original innovative behavior. The "African connection" of the Qesem assemblages (lithic and faunal) is practically nonexistent, and it has no African counterparts. We suggest that systematic blade production and Quina-scraper production are local innovations aimed at manipulating medium-sized game. A study of Mousterian Quina scrapers from France (Claud et al. 2012) shows their use as butchering tools, and preliminary functional observations on the Qesem scrapers show similar results, although hide working and bone working were observed as well (Lemorini et al. 2016; Zupancich et al. 2016*a*, 2016*b*). Amudian blades and Yabrudian scrapers, augmented by a variety of recycling products, may thus be viewed as components of a new meat-cutting set that was developed in the Levant around 400 ka, replacing the long-lived Acheulian meat-cutting tool kit based on flakes and handaxes. This may have accompanied new hunting and meat-sharing practices following the loss of calories previously obtained from elephants. This particular combination of blades and Quina scrapers (as well as recycled products) reflects a specific adaptation that has no counterparts in Africa or Europe.

## Fire Use at Qesem

The use of fire is apparent throughout the sequence at Qesem, both directly by the large amounts of wood ash and the presence of hearths (Karkanas et al. 2007; Shahack-Gross et al. 2014) and indirectly by the large amounts of burnt flint and burned bones, the organization of activities around the hearth, and the presence of charcoal fragments in human dental calculus. Thus, it is our contention that fire was used habitually, commonly, and repeatedly as early as 400 ka, and one of its most important functions was most likely cooking (see Speth 2012). This section presents this evidence in some detail.

### *Direct Evidence for Fire Use*

The direct evidence from Qesem clearly indicates extensive, repeated use of fire between 420 and 200 ka. Micromorphological and isotopic evidence indicates recrystallization of wood ash. Large quantities of burnt bone, characterized by a combination of microscopic and macroscopic criteria, and moderately heated soil lumps are closely associated with the wood ash remains (Karakanas et al. 2007). All the ash structures are related to wood burning and complete combustion. Calcined bones are relatively common as identified, both mineralogically (using the Fourier Transform Infared Spectrometry [FTIR]) and microscopically, by changes in color, birefringence, chemical alteration, and interference colors. Such a mineralogical transformation occurs at either a very high temperature for a short duration (above 650°C) or from prolonged combustion at temperatures as low as 500°C. This temperature range is commonly reached in campfires, and in the case of Qesem, calcined bones are mainly found in the area where the fireplace is located (see below).

A major component of the Qesem deposits consists of recrystallized wood ashes. The upper ca. 4.5 m of the sequence consist mainly of anthropogenic sediments characterized by completely combusted, mostly reworked wood ashes associated with large amounts of burnt bone, lithic artifacts, and moderately heated soil lumps. The strong cementation of the deposits is explained by calcite that precipitated from dripping waters and the recrystallization of the ash. The isotopic analysis supports the presence of both preserved and recrystallized wood ash in the sediments (Karakanas et al. 2007).

A central hearth was identified during fieldwork and confirmed later by mineralogical and microscopic criteria. Micromorphological evidence shows two superimposed use cycles each composed of shorter episodes, possibly the earliest superimposed hearth securely identified to date (Shahack-Gross et al. 2014). The hearth covers ca. 4 $m^2$, making it a uniquely large hearth in comparison with any contemporaneous hearth identified thus far. The hearth is located in the center of the cave and is associated with butchered animal remains and a dense flint assemblage. The central location of the hearth within the cave and the activities associated with it may reflect a pattern of the organization of space by the cave inhabitants. An array of independent lines of evidence was used to analyze this large, central, repeatedly used combustion feature. The evidence for this feature being a hearth is primarily the two microlaminated gray-white layers composed of in situ wood ash that includes charred and calcined bones, microcharcoal, burnt flint, and burnt microscopic clay aggregates. The micro-FTIR data indicate a temperature range that exceeded 500°C (Shahack-Gross et al. 2014). This central hearth—having a uniquely large size, being superimposed, and bearing dense faunal and lithic remains as well as evidence for spatial differentiation of activities around it—provides a glance into fire-related behavior of Middle Pleistocene humans. The sedimentary sequence postdating this hearth at Qesem is characterized by a high content of ash. It is clear that the Qesem hominins possessed fire in the sense of a maintainable technology. They built campfires inside the cave, and a variety of activities were conducted in the vicinity of these fireplaces. The ash-rich contents of the upper strata as well as the abundant burned remains in the lower strata indicate many fire-building events, supporting the interpretation of habitual use of fire in the cave.

### *The Faunal Assemblage*

The Qesem faunal record is extremely rich in all of the layers and is dominated by fallow deer but includes red deer, horse, aurochs, wild pig, and wild ass. Although rare, small ungulates such as goat and roe deer and small prey such as birds are also present (Blasco et al. 2014, 2016*a*; Sánchez-Marco et al. 2016; Stiner, Gopher, and Barkai 2009 2011). Among the small prey, tortoises show a slightly higher level of representation (Blasco et al. 2016*b*). The faunal assemblages are characterized by an extremely rare presence of carnivores (Blasco et al. 2014, 2016*a*; Stiner, Gopher, and Barkai 2009, 2011). A significant amount of anthropogenic bone damage has been detected throughout the stratigraphic sequence, including its earliest levels. The taphonomic characteristics of faunal remains indicate that all assemblages were generated solely by humans occupying the cave and were primarily damaged by their food-processing activities. The ungulate mortality profile is dominated by adult-aged individuals, and in the case of fallow deer, the relative abundance of infantile and young individuals suggests the development of seasonal hunting episodes (Blasco et al. 2014, 2016*a*; Stiner, Gopher, and Barkai 2009, 2011).

Different types of butchery cut marks have been identified in the form of incisions, sawing marks, scraping marks, and chop marks (ratios between <2% and 12% according to Blasco et al. 2014, 2016*a*, and Stiner, Gopher, and Barkai 2009). The ungulate specimens show cut marks distributed over most of the skeletal elements, especially on limb bones (fig. 1). The locations of the cut marks indicate that both long-bone epiphyses and shaft fragments bear cuts, although there is a clear predominance of damage on limb-shaft fragments. Tortoise bones from the earliest levels show a relatively high rate of cut marks (13.2%) on the shell and limbs (Blasco et al. 2016*b*).

The faunal assemblage also includes damage caused during bone breakage to access marrow (fig. 2). The studied samples have preserved diagnostic elements of intentional bone breakage of both long and flat bones, although, as in the case of cut marks, the limb shafts show the highest proportions of damage. The bone surface modification resulting from the anthropogenic breakage includes percussion pits, notches, impact flakes (cortical flakes and scars included), counterblows, and peeling.

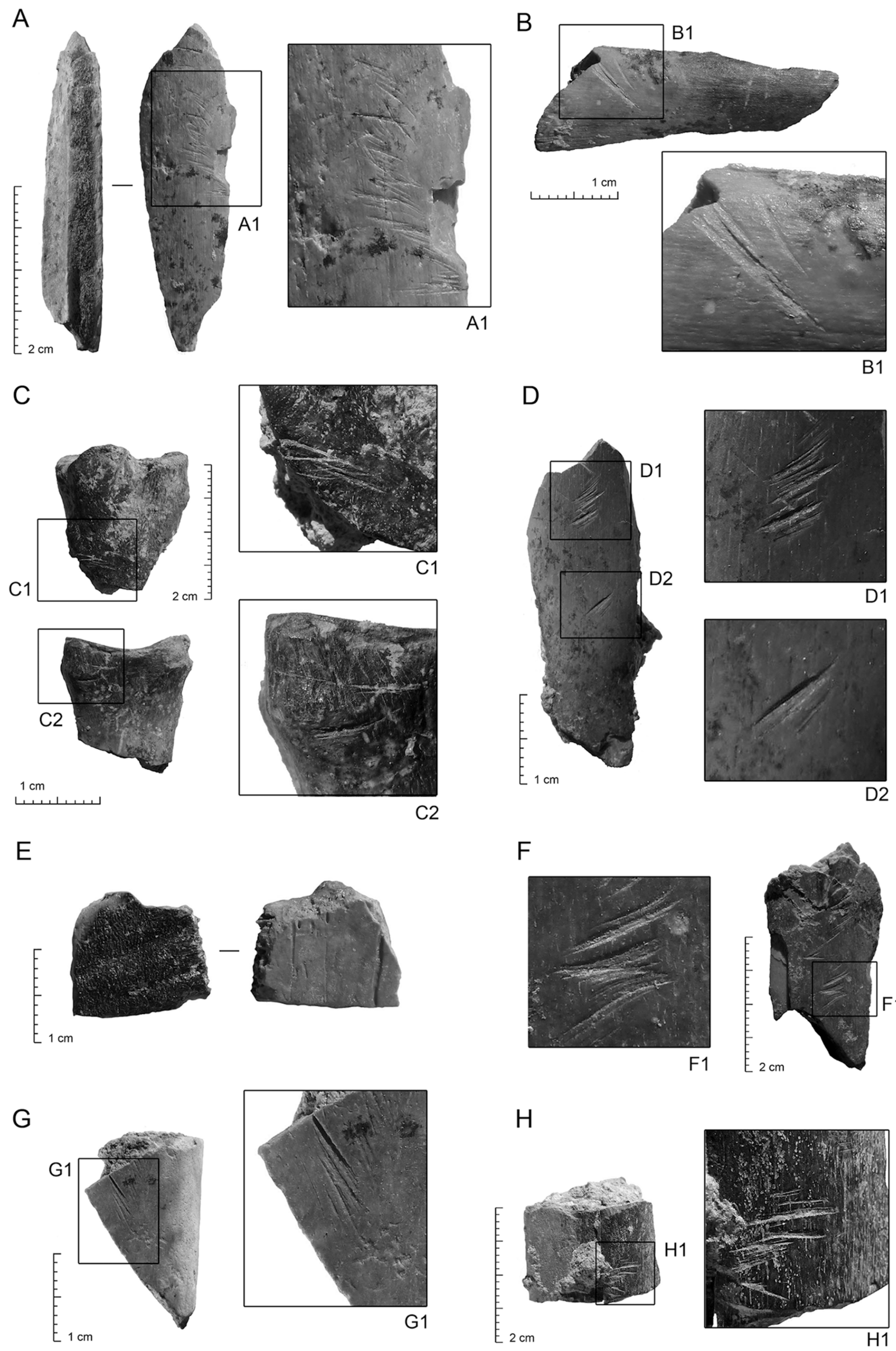


Figure 1. Examples of burned bones bearing cut marks from the hearth faunal assemblage (*A–E*) and the earliest levels of the cave (*F–H*). *A*, Long-bone fragment of a small-sized animal showing "sandwich" coloration. *B*, Long-bone fragment with double coloration on the same surface. *C*, Proximal epiphyses of metapodial bones. *D*, Different burning tonalities on the same bone surface. *E*, Costal-bone fragment of tortoise showing burning (degree 3) on the dorsal surface while ventral surface remains unburned. Long-bone fragments of small-sized animals with degree 2 (*F*), degree 5 (*G*), and double coloration (degrees 0 and 3; *H*). A color version of this figure is available online.

Nine bone fragments from the hearth unit and 15 from earlier levels show percussion marks related to the shaping of stone tools. All of these items correspond to the long-bone shafts of small, medium, and large animals, showing damage typically caused by the use of bone as a retoucher (Blasco et al. 2013*a*; Rosell et al. 2015).

Burning damage affects more than 30% of the bone fragments in all assemblages, including the earliest ones (figs. 1, 3).

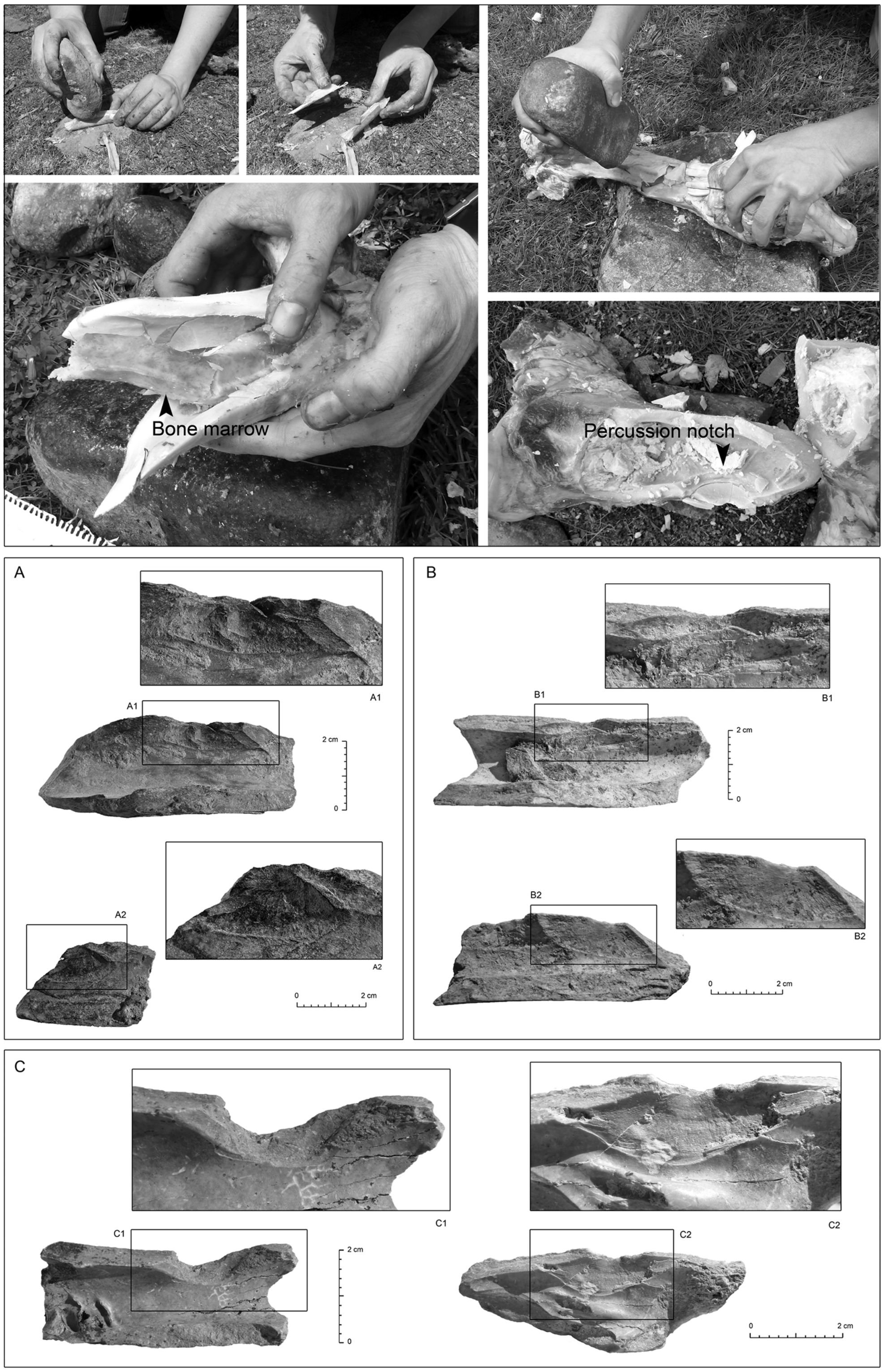


Figure 2. Experimental marrow removal through hammer-stone percussion (*top*) and fossil examples of damage generated during bone breakage to extract marrow in form of percussion notches on limb bones from the hearth assemblage (*A*), area around the hearth (*B*), and area under the shelf (*C*) at Qesem Cave (*bottom*). A color version of this figure is available online.

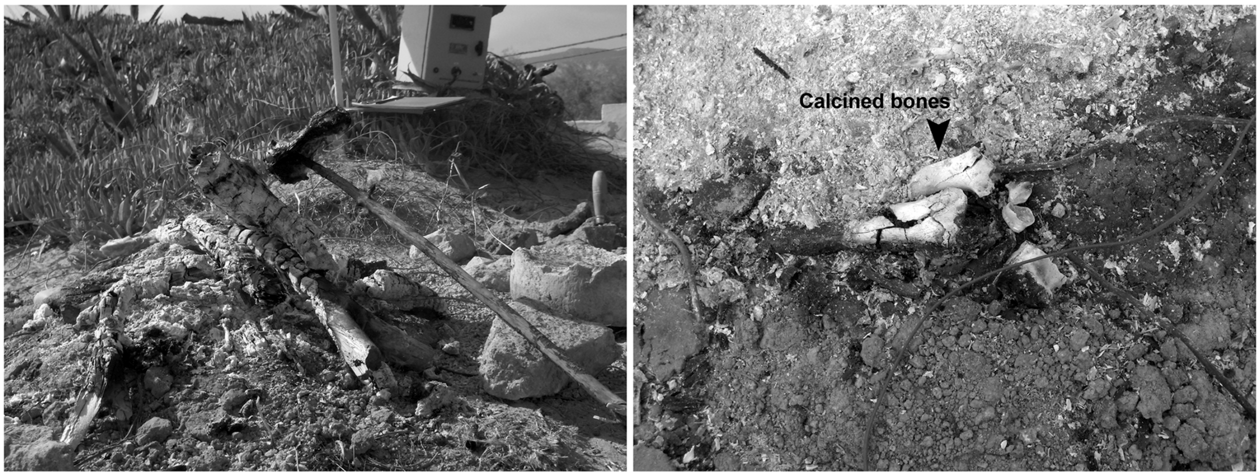


Figure 3. Experimental examples of roasting meat (*left*) and experimental example of calcined bones (degree 5) after being thrown to the hearth for cleaning (*right*). Note the calcined bones become more fragile and susceptible to breakage, a circumstance leading to their fragmentation and destruction in some cases. A color version of this figure is available online.

In the case of the central hearth, this figure rises to 63.95% of the specimens (Blasco et al. 2014). For the study of this specific modification, macroscopic criteria based on color changes have been used. According to several authors, two main variables seem to influence coloration, namely, the heat intensity and the exposure time (e.g., Brain 1981; Buikstra and Swegle 1989; Gilchrist and Mytum 1986; Johnson 1989; Mayne 1997; Nicholson 1993; Shahack-Gross, Bar-Yosef and Weiner 1997; Shipman, Foster, and Schoeninger 1984; Spennemann and Colley 1989; Stiner et al. 1995). The different responses of the organic and inorganic components of the bones to the rise in temperature lead to color changes and different chromatic stages (mainly brown, black, gray, and white; e.g., David 1990; Grayson et al. 1988; Lyman 1994). For Qesem, the degree of alteration due to burning has been classified into six categories of intensity according to the bones' color, structure, and homogeneity, with degree 0 representing unburned and degree 5 representing calcined bones. "Sandwich" coloration has also been detected at Qesem, characterized by different coloration in the intracortical tissue with respect to that observed on the outer sides. This occurs when the skeletal element is subjected to partial thermal action or incomplete combustion while maintaining its fat content (Cerdá, García-Prósper, and Serra 2005).

Thermal alteration has been observed on every type of skeletal element, albeit with a definite predominance on the long-bone shafts of medium- and small-sized ungulates. Degree 3 represents the most abundant damage, followed by degree 2, while degrees 1 and 5 are the least represented (Blasco et al. 2014, 2016*a*; Stiner, Gopher, and Barkai 2011). Some specimens bear "sandwich" coloration predominantly on the long bones.

The presence of burning on bone fragments might reflect several phenomena. The challenge is certainly to identify roasting (e.g., Alhaique 1997; Solari et al. 2015; Speth 2006), as other intentional processes could lead to burning, such as the removal of waste for cleaning purposes (e.g., Yravedra and Uzquiano 2013), the use of bone as fuel (Morin 2010; Théry-Parisot 2002), the preparation of bones to facilitate their breakage (Caceres et al. 2002), or the preparation of bone marrow for removal (Oliver 1993; Speth et al. 2012). Burned bones could also be the unintended (accidental) consequence of postdepositional damage such as secondary burning when fireplaces are set up on bones buried close to the surface (e.g., Aldeias 2017; Bennett 1999; Stiner, Kuhn, and Surovell 2001).

The task becomes complicated when several of these processes occur during the formation of the same sedimentary package. The superposition of different processes could mask the initial hominin activities, such as the roasting of meat before defleshing. As in the case of tortoises, we have tried to detect differential burning patterns on ungulate bones, that is, double colorations on the cortical surface and no alteration on the medullary surface, as it is expected that if bone is exposed when meat is on the fire for roasting, the medullary surface will remain unchanged and the exposed areas (or those covered by only a thin meat layer) will be affected more intensely by the heat, thus acquiring a higher degree of coloration (Gabucio et al. 2014; Gifford-Gonzalez 1989; Rosell et al. 2012). Despite complexities, a pattern based on the absence of burning on the medullar surface of ungulate limb bones was observed at Qesem. This pattern appears on bones that do show heat alteration (uniform or double coloration) on their cortical surfaces (7.32% of specimens bearing differential burning patterns from the hearth archaeological context). In addition, some of these bones (2.1%) show a higher degree of burning on those parts that would normally be exposed to fire when bone is placed on the embers to roast the meat adhering to it (e.g., metaphysis). This fact has been interpreted as the result of episodes related to roasting.

The roasting "signal" could be viewed as weak if we assume that only one fire-related activity occurred in the cave. However, the development of a single activity is unlikely to be identified for the following reasons: (1) the presence of burned bones over the entire excavation surface and volume, (2) alterations affecting all bone surfaces (both medullar and cortical), (3) structural changes of the bone tissues resulting from intense exposure to fire (e.g., fissures, cracking, shrinkage), and (4) significant concentration of burned material in the area of the fireplace (which includes the highest degrees of thermal alteration [calcined bones degrees 4, 5]). In relation to this, Mentzer (2009) proposes that the bone fragments become completely calcined when they are directly exposed to flame. This might occur when bones are thrown into the hearth for cleaning (Yravedra and Uzquiano 2013), when fireplaces are set up on unburied or semiburied bones (Bennett 1999), or when bones are used as fuel (Costamagno et al. 2009). As noted in Blasco et al. (2016*b*:204), these possibilities are not mutually exclusive, as many processes may have occurred concurrently or sequentially, leading to the overlapping of bone alterations and even to the destruction of elements or signatures after a specific primary human activity. For example, some burned bones show no homogeneous degree 2 coloration (brown), which coincides with alterations described by Bennett (1999) of specimens burned after burial, indicating nonnutritive episodes that occurred following the processing sequence. The set of thermal alterations at Qesem certainly shows the complexity of its taphonomic history, where more than one fire-related process, roasting included, seem to have occurred.

The case of *Testudo* sp. is particularly significant because 52.9% of the burned tortoise bones from the central hearth showed thermal alteration on different surfaces, and the highest degree of burning was observed on the dorsal surfaces. This pattern was especially pronounced in the earliest levels of the cave, as 83.33% of the double-colored bones showed a higher degree of burning on the dorsal than on the ventral surface, which tends to appear unburned (Blasco et al. 2016*b*). Although a certain degree of variability is to be expected, this pattern fits well with the idea of roasting tortoises by placing the whole animal upside down directly on the embers and allowing it to cook in the shell. These taphonomic patterns can be used as examples of new human-fauna relationships during the AYCC, which include cooking as a regular component of the human's behavioral repertoire.

### *The Organization of Human Activities around the Central Hearth: The Faunal and Lithic Evidence*

Spatially, the central hearth is an evident focus of intensive activities and is very dense in both faunal and lithic finds. We focus on the hearth itself and the area adjacent to it to the south, which seems to be related to the hearth (Blasco et al. 2016*a*; Shahack-Gross et al. 2014). A preliminary spatial analysis of faunal remains in this area has recently been attempted (Blasco et al. 2016*a*), and the lithic spatial distribution is under study.

The abundant thermally altered items lead us to infer a well-implemented use of fire at Qesem through its whole stratigraphic sequence. The central hearth area has been used here as a model to analyze and elucidate this behavioral pattern (Blasco et al. 2014, 2016*a*). The succession of cycles of combustion at the same location in the cave suggests a repeated behavior and a patterned use of space during recurrent human occupations. This resulted in a significant quantity of faunal and lithic remains as well as evidence of the spatial differentiation of activities around the hearth. The hearth and the area south of it cover an area of approximately 15 $m^2$ excavated to a maximum depth of 60 cm. The faunal assemblage comprises 37,304 specimens (2,995 specimens, or 8.03%, have been identified to the species level) of which 15,464 come directly from the hearth and 21,840 from surrounding zones. The faunal assemblage includes 15 taxa and a minimum number of individuals (MNI) of 81 (fallow deer MNI = 41, red deer MNI = 8, horse MNI = 6, aurochs MNI = 5, wild pig MNI = 3, wild ass MNI = 3, rhinoceros MNI = 2, goat MNI = 1, roe deer MNI = 2, large bird MNI = 3, Carnivore MNI = 1, Cervidae MNI = 2, and the tortoise MNI = 4; Blasco et al. 2014, 2016*a*).

Perhaps one of the best examples of spatial differentiation is the plot based on the size of bone fragments in the assemblage and the degree of thermal alteration of the bones. Density maps were generated using geographic information systems (ArcGIS 10) and include proximity calculations such as kernel estimation or the nearest neighbor algorithm (see details in Blasco et al. 2016*a*). Burned bones, mainly those showing a higher degree of damage (degrees 4 and 5), are clustered in the main combustion area. In contrast, the area around the hearth makes up less than 1% of the total number of specimens retrieved with this degree of damage (Blasco et al. 2016*a*). This apparent organization of the remains is most obvious if we consider the length of the bone fragments. Although the smallest specimens (<20 mm, the most abundant in the assemblage) are distributed over the entire occupied surface, the highest concentration is observed in the hearth area. Yet a most significant observation is the distribution of large bone fragments (>40 mm) in the outer area (Blasco et al. 2016*a*). This spatial distribution seems to fit roughly with the model of cultural formation of hearth-related assemblages observed by Binford (1978, 1983) in Nunamiut camps. The drop area is characterized by small bone splinters and lithic fragments resulting from different domestic activities, such as bone breakage for marrow extraction or the processes of core reduction and stone tool shaping. The toss zone, in contrast, consists of larger fragments that have been intentionally tossed away to areas farther removed from the activity areas. On this basis, a tentative standardized pattern can be observed along the sedimentary formation of the hearth. Both the spatial distribution around the hearth and the subsistence strategies can be considered as factors linked to the emergence of reference places of a residential character—that is, places that would fit with the concept of the home base discussed by Rolland (2004).

Results of spatial density data based on a study of lithics at 18 assemblages throughout the stratigraphic column and in different parts of the cave included the fireplace area and the area to its south (see Gopher et al. 2016). When lithic densities of the hearth area and the area to the south of it are compared with the studied assemblages throughout the cave or, more specifically, with four assemblages of similar stratigraphic position and roughly contemporary, some interesting results are evident. The lithic assemblage of the hearth area consists of 18,837 items and shows the highest density of all the assemblages of the cave (6,144 lithic items per $m^3$ for the hearth itself; see Gopher et al. 2016), indicating intensive lithic production, use, and discard in this area. This is reflected in the relatively high density of cores and core trimming elements (CTEs) as well (61 and 121 per $m^3$, respectively). The area to the south of the hearth is somewhat lower in density (3,106 items per $m^3$) but shows high densities of cores and CTEs (37 and 63 per $m^3$, respectively). A conspicuous aspect of the hearth area and the area south of it is the high density of cutting tools, including blades and naturally backed knives (NBKs) made on blades (both showing a density of 77 per $m^3$) as well as NBKs made on flakes that are prominently dense in the area (98 per $m^3$). Another outstanding aspect is the fact that the highest density of recycling is evident in the hearth area, including both the recycled "parents" and the recycling products (45 and 142 per $m^3$, respectively), and south of the hearth (32 and 134 per $m^3$, respectively). Many of the products of recycling have shown meat-cutting use wear (Lemorini et al. 2015), and the relatively high density of blades and NBKs (Lemorini et al. 2006) in this area suggests that they could be interpreted as a set of meat-cutting tools (Barkai, Lemorini, and Gopher 2010) densely concentrated at the meat-roasting area. Interestingly, the hearth shows a medium-low density of shaped items (tools), while the area south of the hearth shows a very low density of shaped items. This may indicate a frequent use of unshaped items (mostly characterized by sharp edges) in the hearth area and south of it. We may add that while blades and other cutting tools (including recycling products) are conspicuous in the hearth assemblage itself and the area south of it, assemblages of similar stratigraphy to the west and northwest of the hearth are poorer in blades and NBKs, poorer in recycled items and recycling products, and richer in shaped tools, including a conspicuously high density of scrapers (27–43 scrapers per $m^3$ compared to 6 and 5 scrapers per $m^3$ in the hearth and the area to the south of it). This may indicate the use of blades and of recycling products in some areas around the hearth while scraper-related activities have taken place in other distinctive and separated (though nearby and contemporaneous) areas of the cave.

### *Inhaled Charcoal in Dental Calculus*

Potentially inhaled and ingested materials were extracted from dental calculus of the Qesem humans, including, among other things, microcharcoal, starch molecules, and *Pinus* pollen. These finds offer an insight into human diet and the environment around the cave, and the microcharcoal highlights the need for smoke management in the enclosed environment of the cave—a challenge introduced after adopting the habitual use of fire for roasting/cooking by the Qesem humans. Charcoal microparticles up to 70 $\mu$m in diameter enter the mouth during oral breathing, and while these fragments could also result from ingestion of char adhering to roasted food, their size suggests they result from accidental inhalation (Hardy et al. 2016). These findings, combined with the sedimentary and micromorphological evidence from the cave, are indicative of fire and suggest a smoky atmosphere inside the cave. While placing the hearth in a central place well inside the cave may be linked to the increased intensity of roasting/cooking, flint knapping, animal processing, and most, presumably, social interactions, the need for smoke management became necessary. A smoky atmosphere can be an irritant and can at times cause serious health problems. Smoke can cause coughing and eye irritation in addition to potentially more serious lung problems. For a successful use of fire to develop in an internal (cave) location and fulfill its potential functional and social purposes in a way that permitted the population to thrive, the health risks must be resolved.

## Discussion and Conclusions

The Late Lower Paleolithic period in the Levant, and the AYCC in particular, was a period of transformation in human biology and culture. The habitual, common, and repeated use of fire for roasting meat (and possibly cooking in general) should be conceived as an integral part of this set of transformations rather than an isolated phenomenon. We believe that a better acquaintance with the environmental, behavioral, and adaptive contexts of the use of fire at ca. 400 ka in the Levant will promote comprehension of this new aspect and its significance in human evolution.

We claim that in the AYCC starting sometime at 400 ka, the use of fire was clearly aimed at meat roasting and possibly cooking in general, and this innovation continued in the Levant after the AYCC (see a statement on cooking as a Eurasian Middle Pleistocene innovation in Dennell 2009:476–477). A detailed discussion of the sociocultural aspects of fireplaces as central foci of human activity is beyond the scope of this paper (see Wiessner 2014), but the fact that a central hearth was exposed is of major importance in this respect. The use of fire at Qesem is first and foremost related to the dietary practices of the cave's occupants. The diet of the Qesem inhabitants had a major meat component as reflected in the large number of animal bones and the dietary reconstruction we suggested (Ben-Dor et al. 2011). While floral remains were not preserved, we succeeded in extracting ingested floral remains from human dental calculus, including starch granules and chemical compounds, providing a direct link to ingested plant food containing essential nutrients, including polyunsaturated fatty acids and carbohydrates (Hardy et al. 2016). Following the sources on which we based our "fat hunter" model, a human diet based on meat and fat must have been complemented by carbohydrates and thus included three major ingredients: animal proteins, animal fat, and vegetal food. We have no doubt concerning vegetal food consumption in the Paleolithic (e.g., Melamed et al. 2016), and the above-quoted study supports this view, providing direct evidence for the consumption of vegetal food. A point in order here are results of a study of masticatory wear patterns on human teeth carried out recently that provided evidence suggesting that the Qesem people possessed a strong masticatory system and fed on a wide range of food types (Sarig et al. 2016).

A major element in our argument has to do with the absence of elephants from AYCC sites. Elephants were part of the diet of Acheulian humans, and elephant bones, alongside other taxa, were found in Acheulian sites in the Levant throughout the 1-million-year span of the Acheulian Cultural Complex in the region. Elephant bones are present in early, middle, and late Acheulian sites (Ubeidya, Evron, Gesher Benot Ya'aqov, Revadim, and Holon, respectively), and thus we may say that Acheulian human presence in the Levant is constantly associated with elephants and their use as a source of food. It is of course possible that elephants were not consumed at every Acheulian site and that in certain times and at certain places, Acheulian humans in the Levant survived with no elephant meat and fat on the menu. However, this was the exception rather than the rule. Sites of the AYCC as well as later sites in the Levant lack elephant remains. No elephant bones were found at any post-Acheulian site in the Levant, and they were not part of the post-Acheulian human diet, which was based on medium-sized, prime-aged animals both in the late Lower Paleolithic AYCC and the later Middle Paleolithic Mousterian (e.g., Speth 2012).

The significant changes in human behavior during the AYCC necessitated new knowledge-transmission mechanisms in order to cope with the many new aspects of behavior adopted. In addition to the production of flakes and bifaces, AYCC humans had to learn how to produce blades and Quina scrapers following strict standards. Moreover, knowledge and skills regarding the identification of flint sources and quarrying techniques and procedures had to be transmitted as well as the concept and practice of flint recycling. The focus on hunting prime-aged fallow deer (highest fat content) necessitated precise identification of specific deer to be targeted according to the color of the fur and the brightness of the skin. It is not without reason that the Saami of northern Norway, for example, use more than 600 words for describing reindeer according to their age, sex, color, coat, antlers, etc. (Clottes 2013). Tracking and hunting selected fallow deer must have been a practice based on specific knowledge and experience. Because we believe that Acheulian hominins hunted game including elephants and medium-sized animals, it goes without saying that parts of the tracking and hunting procedures of the AYCC were already practiced in the preceding Acheulian. However, because elephants contain large quantities of fat year round (Ben-Dor et al. 2011), fat-content-related choices had been marginal. When elephants were no longer consumed in the AYCC and later, it made a significant difference which deer was being hunted in order to supply not only meat but also fat, and thus new tracking and hunting capabilities took center stage. After hunting, specific butchering practices characterized the AYCC at Qesem, and these had to be culturally transmitted as well (Blasco et al. 2013*b*). Last but not least, the habitual use of fire in the AYCC brought about a new set of knowledge and capabilities that had to do with firewood collection, production and maintenance of fire, ventilation of the cave in order to reduce pollution, and more, so the cost of making and keeping fire must also be taken into account (Henry 2017). Of course, roasting and cooking meat (and maybe other foods) had to be culturally transmitted, too. It is our contention, therefore, that the multitude of new AYCC adaptations necessitated elaborate knowledge-transmission mechanisms quite possibly different from those practiced by the Acheulians and supported by a new social milieu.

We suggest that the disappearance of the elephants at ca. 400 ka triggered the hunting of an increased number of smaller and faster animals to maintain protein supply and an adequate fat content in the diet, and this was the evolutionary drive behind the emergence of the lighter, more agile, and cognitively capable new humans in the Levant. *Homo erectus* in the Levant must have been perfectly adapted to a diet in which the consumption of elephant meat played a significant role. The need to hunt larger numbers of selected medium-sized individuals with high fat content might have encouraged new social relations based on new meat-sharing practices. The habitual use of fire for roasting meat and cooking might be connected to the need to extract more calories from every food item (e.g., Carmody, Weintraub, and Wrangham 2011; Carmody and Wrangham 2009; Groopman, Carmody, and Wrangham 2015; Wrangham 2017), and the new lithic technologies might have been aimed at a better manipulation of smaller game. The use of

Figure 4. Experimental demi-Quina flint scraper replica used to remove meat from bones throughout both longitudinal and transversal motions. An experiment conducted in the framework of a use-wear study of the Qesem cave scrapers. Courtesy of Andrea Zupanchich. A color version of this figure is available online.

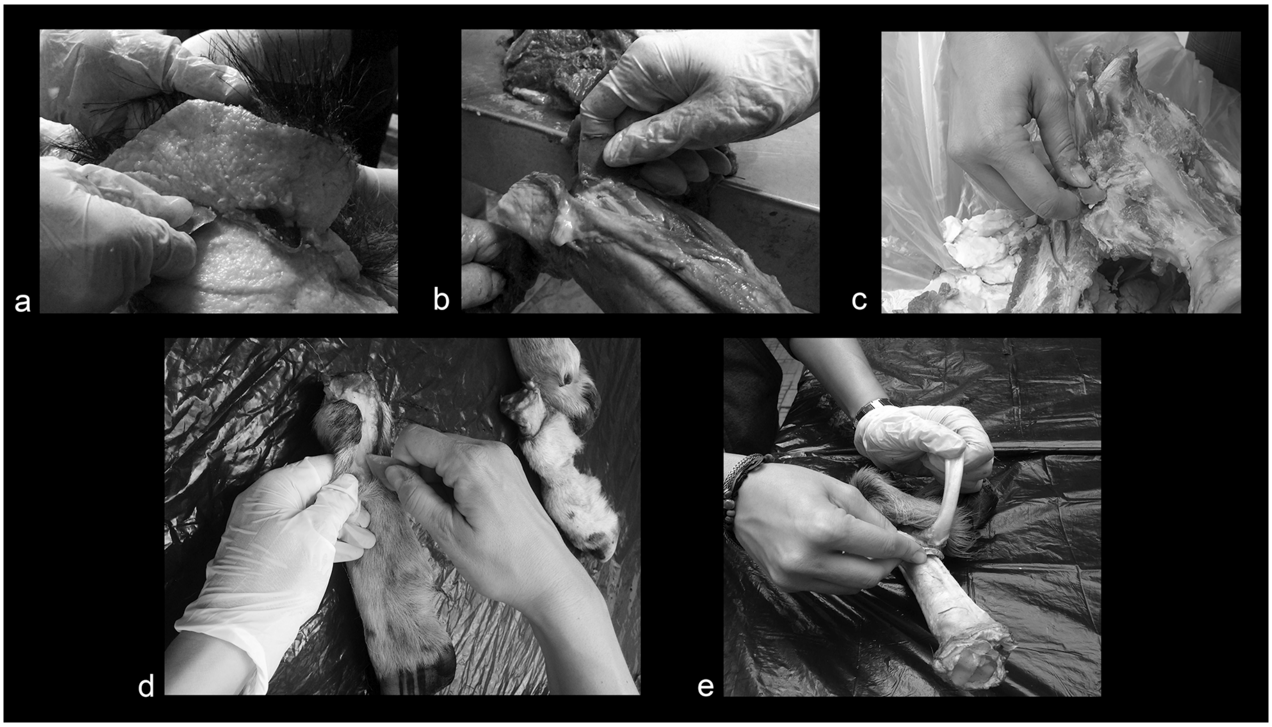

Figure 5. Different moments during a butchery activity using replicas of small recycled flint items. *a*, Defleshing hide of a wild boar. *b*, Disarticulating bone of a wild boar. *c*, Removing meat from a cow bone. *d*, *e*, Processing a sheep metapodium to obtain tendons. Experiment conducted in the framework of a use-wear study of the Qesem cave recycled items. Courtesy of Flavia Venditti. A color version of this figure is available online.

Quina scrapers and small cutting tools made of recycled items might have been related to newly introduced processing methods (figs. 4, 5). Thus, the circumstances for the appearance of the AYCC in the Levant and its characteristics provide a context for the earliest manifestations of the habitual use of fire for roasting and cooking meat. The AYCC provided a context open for innovations and transformations, one of which was the adoption of fire. Such a major change in human behavior and lifeways must have been negotiated and carefully tested before being habitually adopted, and this is the case for many of the other transformations that took shape during AYCC times. We regard Acheulian human adaptation as highly successful and as having enabled Lower Paleolithic communities in the Levant to thrive for over 1 million years without using fire commonly and continuously and without roasting meat. Modifying this long-lived mode of adaptation and introducing a set of innovations such as the one characterizing the Levantine AYCC must have been for very good reasons. At around 400 ka in the Levant, human groups developed a new (post-Acheulian) adaptation mode that enabled them to thrive for another 200 kyr, until the next set of transformations took place, as reflected by the appearance of Middle Paleolithic Mousterian lifeways. We thus see the introduction, assimilation, and adoption of fire as a common human trait used for cooking meat as one of the innovative aspects that characterized the new post-Acheulian mode of adaptation in the Levant. This human trait must have been highly successful, as it characterizes human behavior and adaptation to this very day.

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