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Research

Culture and cognition in the Acheulian industry: a case study from Gesher Benot Yaʿaqov

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The Acheulian presence in the Dead Sea Rift and its environs is characterized by the discontinuity of its cultural manifestations. Nevertheless, the long stratigraphic sequences of the Acheulian Technocomplex provide a unique opportunity for synergetic examination along a temporal trajectory. Hominin cognitive and cultural behaviour are studied at Gesher Benot Yaʿaqov through analyses of lithic, palaeontological and palaeobotanical assemblages, as well as the Early–Middle Pleistocene environment, ecology and climate. The study attempts to reconstruct reduction sequences of some major artefact groups at the site, which include raw material acquisition, production, technology, typology, usage and discard. Experimental archaeology illustrates artefact mobility on the palaeolandscape. Strategies of biomass-exploitation are studied in detail, with other aspects yielding additional information on hominin subsistence and adaptive responses to their environment. The cultural marker of fire and the spatial association of selected categories of finds are integrated in the general synthesis, allowing reconstruction of the cultural and cognitive realm of Acheulian hominins. The synthesis attempts to reassess the abilities, social structure, subsistence and adaptability to the changing environment of hominins in the Levantine Corridor.

Keywords: Acheulian; Gesher Benot Yaʿaqov; Upper Jordan Valley; bifaces (handaxes and cleavers); cognitive abilities; Irian Jaya

1. INTRODUCTION

The unpredictability and low resolution of the archaeological findings dictate the extent of our knowledge of the Acheulian culture, accounting for our only partial success in reconstructing the cognitive abilities, cultural sophistication and complexity of the hominins of those times.

The Acheulian Technocomplex [1] has the most extensive geographical distribution and the longest temporal duration of the Old World's prehistoric cultures [2], spanning some 1.6 Myr. Most of our knowledge of the Acheulian material culture and the abilities of its makers derive from the lithic marker of the Acheulian—the bifaces (handaxes and cleavers).[1] Other issues relating to hominin cognitive capacities are procurement and transportation of raw materials (e.g. [3–5]), technological abilities in general (e.g. [6–8]), variability of lithic assemblages [9–11], subsistence patterns [12], 'cultural zones' [13,14] and to a lesser extent symbolic aspects (e.g. [15]), as well as the hominin species/populations who were the bearers of the culture [16]. Clearly, the lithic artefacts are our main source of information on the culture, and hence the cognition, of the Acheulian hominins [17].

Here, we present various aspects of the Acheulian culture and cognitive abilities as currently known from the multi-disciplinary studies of the Acheulian site of Gesher Benot Yaʿaqov (GBY). The Acheulian sequence of GBY is assigned to a phase, well known in Africa, that is characterized by the production of bifaces on large flakes [2]. The site's data allow us to study Acheulian communities within a discrete timeframe in the Early/Middle Pleistocene in the Levantine Corridor. The present study focuses on issues related to the general theme of the present volume.

Discussion of the environment and ecology of the Acheulian provide the context for in-depth discussion of the complex system of Acheulian lithic production. The early production stages of bifaces contribute much to our knowledge of Acheulian abilities, and the Irian Jaya, present-day knappers producing bifacial tools, represent an analogous technological system. Matters other than lithics that touch on cultural and cognitive abilities will be integrated in a summary of our current knowledge of the GBY site.

2. THE SITE, ITS LOCATION AND ITS ACHEULIAN CHARACTERISTICS

(a) *The evidence of the Levantine Corridor*

The Levantine Corridor furnishes abundant information on the Acheulian Technocomplex. Over 360

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One contribution of 26 to a Discussion Meeting Issue 'Culture evolves'.

find spots are known [18, fig. 4*a*,*b*] from an area of about 22 000 km^2, located in different phytogeographic and climatic zones. Yet, the antiquity of the Acheulian record, the massive impact of tectonic activity on the Dead Sea Rift and a variety of taphonomic processes make research of the Acheulian culture a difficult task. The Levantine Acheulian begins *ca* 1.5 Ma at the site of ʻUbeidiya [19] and ends *ca* 200 Ka as attested by the Acheulo-Yabrudian site of Qesem Cave [20,21].

The identity of the hominins who produced the Levantine Acheulian culture remains unknown. The sites have furnished only scanty skeletal remains, including a few teeth from the Early Acheulian site of ʻUbeidiya [22,23], a single right femur shaft (Layer Ea) and a molar tooth (Layer Eb) from the Acheulo-Yabrudian site of Tabun Cave [24, p. 67] and several teeth from the Acheulo-Yabrudian site of Qesem Cave [20]. The 'Galilee Man' skull found at Zuttiyeh Cave is attributed to an Acheulo-Yabrudian context [25]. One may speculate that in the Early and Middle Pleistocene more than one hominin species produced the Acheulian material culture, owing to the great temporal depth and the fact that different hominin types have been identified in association with Acheulian cultural remains [16]. Possible candidates are *Homo erectus* (*senso lato*), *Homo heidelbergensis*, 'Galilee Man', or other unknown fossil species. Furthermore, there is always the possibility of the temporal co-existence of several hominin types.

In this study, examples are drawn from the entire cultural sequence of the GBY site to illustrate a variety of issues, such as mobility and innovation, that are relevant to Acheulian subsistence, culture and cognitive abilities. The GBY site was selected as the reference base because of the outstanding preservation of its various assemblages (sealed rapidly after deposition in waterlogged conditions) and its meticulous excavation methods, which achieved high precision of the spatial configuration of the assemblages. The material culture, found in association with biological and geological material, allows in-depth and detailed examination of different behavioural and cognitive attributes of the resident hominins. Such a configuration, particularly with respect to organic preservation, is unmatched and hence places the studies of the GBY site in the forefront of studies of mankind's evolution.

(b) *The site*

The Acheulian site of GBY is located 3.5 km south of the Hula Valley, bordered by the basaltic Korazim Saddle in the south, the Golan Heights in the east and the Galilee mountains in the west [26] (electronic supplementary material, figure S1). The site has been exposed on both banks and within the course of the River Jordan. Excavations were carried out in 1989–1997 on the left bank of the river, exposing a 34 m thick depositional sequence of the Benot Yaʻakov Formation [27]. The sequence comprises a series of lake and lake-margin sediments tectonically deformed by the Dead Sea Transform [26,28,29]. The Acheulian archaeological horizons, reflecting hominin occupations on the lake margin, are bedded in these deposits [29], which are dated to the Early Pleistocene/early Middle Pleistocene [30]. Fifteen archaeological horizons are exceptionally rich in palaeontological, palaeobotanical and lithic assemblages, allowing us to study hominin abilities and track the southwest Asian continuum of a cultural phenomenon originating in Africa.

(c) *The characteristics of the Acheulian at GBY*

The Levantine Acheulian material culture is very similar to that of the African record and is observed at GBY in the production of bifaces on volcanic materials (basalt and basanites) [31]. Similarities are also seen in the technological characteristics of biface production: thinning of the butt and minimal flaking on bifaces made on flakes. A further similarity is the presence of the cleaver, an African morphotype [30,31]. It has been securely established that the lithic remains are associated with the floral and faunal finds (see below).

The continuous and long-lasting Acheulian cultural phenomenon at GBY is characterized both by techno-typological conservatism of artefact manufacture and by great variability of the frequencies of lithic types in different archaeological horizons [11].

(d) *Background to the palaeoenvironment*

A high-resolution environment and habitat record of *ca* 100 Ka have been obtained from multi-disciplinary studies at the site (e.g. [32–35]). Those provide data on taxonomy, biodiversity, biogeography and taphonomy that permit a spatial and diachronic reconstruction of the background to hominin activities in the Upper Jordan Valley (UJV). Thousands of plant and faunal remains indicate an environment consisting of a fluctuating freshwater lake and adjacent marshes. Lakeshore and offshore habitats are recorded, as well as riparian and grassland environments and, at a greater distance, field, woodland, parkland and forest environments, all typically Mediterranean in nature.

This reconstructed scenario, which integrates species of diverse origin [36,37], is particularly rich in food resources, both floral [38] and faunal [39]. The environmental and dietary data shed light on the ability of the local communities to forgo their ancestral African adaptations and to adjust to a Mediterranean environment with its particular ecology and habitats.

Clearly, the survival of the Acheulian communities in the UJV necessitated cognitive competence and extensive knowledge of the environment, landscape, ecological niches and their potential for continual existence. These have been investigated at GBY, resulting in the identification of behavioural patterns that shed light on the cognitive abilities of the local hominins.

3. MAPPING THE HOMININS' COGNITIVE ABILITIES

(a) *Exploitation of biological resources*

Skeletal animal remains found at the site reflect carcass processing of large and medium-sized animals, ranging from elephant, large bovids and rhinoceros to gazelle [36,39,40], together with smaller animals like fishes and crabs [32]. There are preferences for particular species, with an emphasis on elephant (*Paleoloxodonta antiquus*) and fallow deer (*Dama* sp.) [41].

The detailed study of cut marks on fallow deer (*Dama* sp.) bones revealed that the processing of the fallow deer carcasses resembles that of the same species by the Upper Palaeolithic *Homo sapiens* of Hayonim Cave (Western Galilee, Israel) [41].

Processing of large game was associated with the production, manipulation and use of handaxes and cleavers [18,42–44]. This entailed knowledge of animal behaviour together with a complex range of techno-morpho-typological expertise in stone tool production and manipulation (e.g. [45]).

Recently, a multi-faceted analysis of one archaeological horizon has provided the earliest documentation of fish processing (Cyprinidae [carp] *Barbus* sp. nov.; [32,46]). While fish processing and consumption have been considered a facet of modern human behaviour (e.g. [47]), it is quite evident that at GBY hominins were already familiar with the process, enabling them to exploit yet another resource niche. There are indications that crustaceans too may have been part of the hominin diet at the site [32].

The exploitation of a wide spectrum of biomass undoubtedly involved knowledge and strategies that included insights into animal behaviour, their life cycles and seasonality, while incorporating other factors such as the mobility options and dietary preferences of the hominin communities.

Plant gathering is attested by the great variety of species identified, among them submerged species like prickly water lily (*Euryale ferox*) and water chestnut (*Trapa natans*) and remains of species that grow at some distance from the lake margin, like acorns, wild grape (*Vitis sylvestris*), olives, white beet (*Beta vulgaris*) and holy thistle (*Silybum marianum*).

The diachronic data relating to animal exploitation [36] clearly demonstrate the continued existence for millennia of the same breadth of ecological knowledge. The exploitation behaviours also relate to the abundant edible botanical remains documented throughout the GBY sequence, which include different parts (nuts, seeds, etc.) of the flora that grew in the vicinity of the site and in adjacent areas [32,45,48]. We interpret this continuity as reflecting hominin ability to transfer inter-generational information throughout the sequence of occupations. This is apparent in the material cultural as well (e.g. the techno-typology of lithic artefacts; [11]).

(b) *Fire and spatial organization*

Each archaeological horizon at GBY holds evidence of fire. While the main source of information is burned flint microartefacts, burned flint macroartefacts and organic material occur as well [48–50]. Detailed analyses have concluded that the fire was an intentional and controlled phenomenon, indicative of developed technological abilities, rather than a natural occurrence [51]. Additional information derived from the detailed spatial analyses, which identified clusters of burned microartefacts ('phantom hearths') that had retained their original spatial location (e.g. [51,52]). Further insight is derived from spatial analyses of other finds (faunal, floral and lithic) [32]. For example, in Layer II-6 Level 2, two main areas of activities were discerned, attesting to a variety of tasks (including stone knapping and modification, wood gathering and nut cracking). Further activities are indicated by the presence of fishes and crab clusters. Near the hearth were clusters of wood fragments, most probably firewood, as indicated by two burned pieces within the hearth itself. The hearth was undoubtedly a focal point of activity, as illustrated by the presence of lithic processing debris including *éclat de taille de biface*. Nut cracking is documented by the presence of several percussors[1] and pitted stones of basalt and limestone, also around the hearth. Most of the crab pincers are also associated with the hearth, indicating their potential as foodstuff. Other activities are located away from the hearth; they include flint knapping, as indicated by the large amount of microdebitage, and fish processing remains.

The control of fire in the UJV undoubtedly increased the number of exploitable niches and facilitated the exploitation of additional resources (e.g. *Euryale ferox*). It had a major impact on hominin subsistence and dietary behaviour. Thus, the association of the seeds and fruits with the hearth and the pitted stones confirms their association with the firing and heating process.

(c) *The lithic assemblages*

The GBY Acheulian is associated primarily with two symmetrical and highly refined bifacial tools—handaxes and cleavers (electronic supplementary material, figures S2 and S3). The site yielded large quantities of these tools as well as giant cores and other associated artefacts. The main products of giant core knapping were large flakes [2,53], which were modified into bifaces. Detailed studies have enabled reconstruction of the *chaîne opératoire*[1] of the bifaces and facilitated understanding of the planning and execution of the bifacial tools by documenting different stages of the reduction process, unseen on the bifaces themselves. Previous analyses demonstrated that the Acheulians applied different core technologies to the production of large flakes. Recent in-depth analyses of the giant cores and their products [54] have revealed the following.

- Giant cores were made on basalt and basanite (henceforth basalt) slabs that were extracted at some distance from GBY at unknown quarry sites in the volcanic bedrock in the vicinity of the site [55]. Quarrying the basalt slabs necessitated in-depth knowledge of the characteristics of the basaltic bedrock.
- The quarrying technology involved several methods that we cannot reconstruct, although one method apparently left its traces on the slabs in the form of 'notches' (figure 1). These could not have been produced by knapping as they lack the characteristic signature of its fracture mechanics. Rather, they may have been caused by the use of a lever. The slabs had a particular morphology that provided a natural sharp angle, facilitating knapping. A variety of additional steps

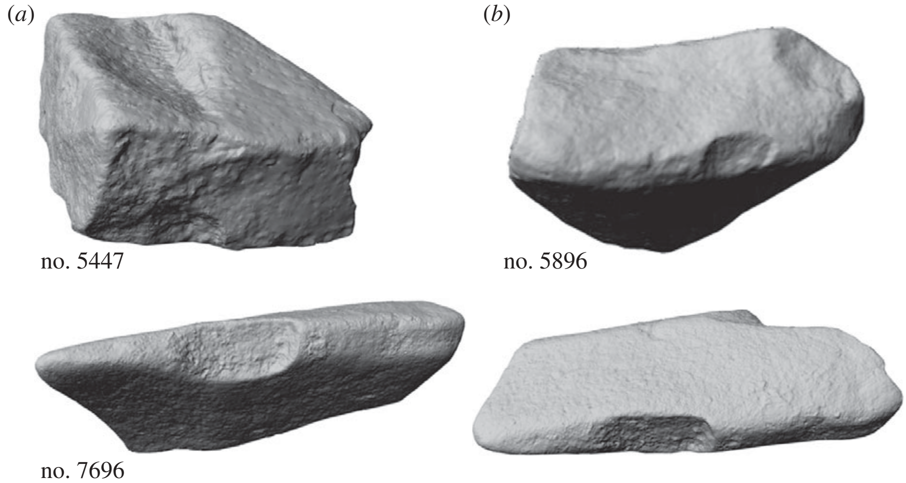

Figure 1. Three-dimensional scanning of notches (not to scale).

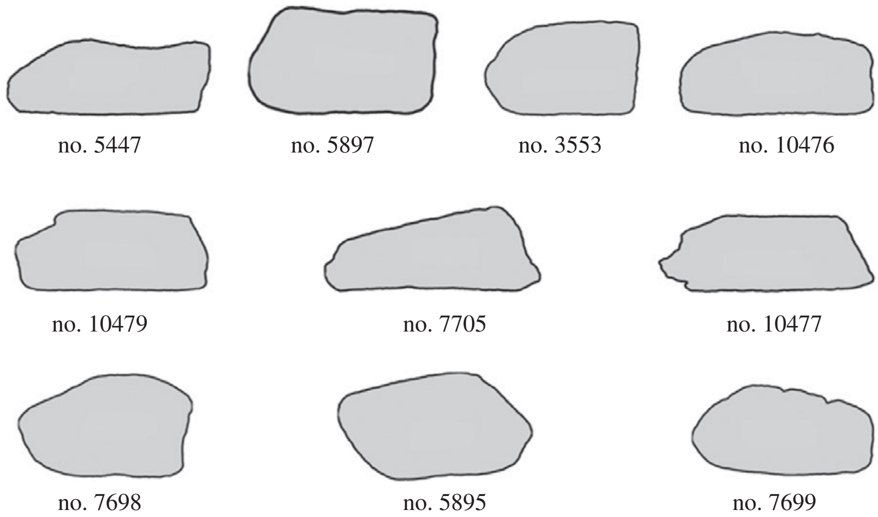

Figure 2. Three-dimensional scanning of slab sections (not to scale).

were taken to reduce the size of the basalt slabs by fracturing, ensuring a more efficient reduction process (figures 2 and 3).

— All slabs were selected from non-vesicular and fine-grained basalts of the highest quality, demonstrating knowledge of the fracture-mechanics characteristics best suited for the production of the intended morphotypes. The knappers were familiar with the bedding plane[1] of the basalt and took it into account while exploiting the giant cores. Detailed observation of the giant cores has enabled the identification of the bedding plane, and it can be demonstrated that the knappers evaluated each blank[1] for optimization of flaking by taking the bedding into consideration. This advanced type of knowledge and the manipulation of the blank to fit the knapper's requirements have been recognized and described in detail [56, figs 5 and 6] in India (figure 4).

— Knapping involved percussors of different types and sizes, evidenced by various flake attributes and the recovery of hard and soft percussors. Basalt percussors range from boulders to fist-sized pebbles, limestone pebbles occur in all of the archaeological horizons and antler percussors have been reported [18,45,57,58]. Although the production process reflects various technological strategies, the final large flakes were all modified into extremely homogeneous bifacial tools of similar sizes and shapes [11,31] (figure 5). Some of the giant cores are exhausted (figure 6), while others show only rudimentary treatment (fragmentation; figure 3).

The above characteristics are represented in all of the archaeological horizons either by the complete set of traits or in different combinations, providing evidence for a particular cultural continuum over at least 50 000 years [11], and probably more. The high degree of variability in the *frequencies* of giant cores, waste products and bifacial tools may reflect different functions in the various archaeological horizons [11].

The reduction sequence[1] study yielded another behavioural insight into the 'mobility' of artefacts in the landscape. We have shown that handaxes and cleavers were produced in, used in and removed from the archaeological horizons. Madsen & Goren-Inbar [53] demonstrated that the number of giant cores present could not have produced the quantity of flakes and

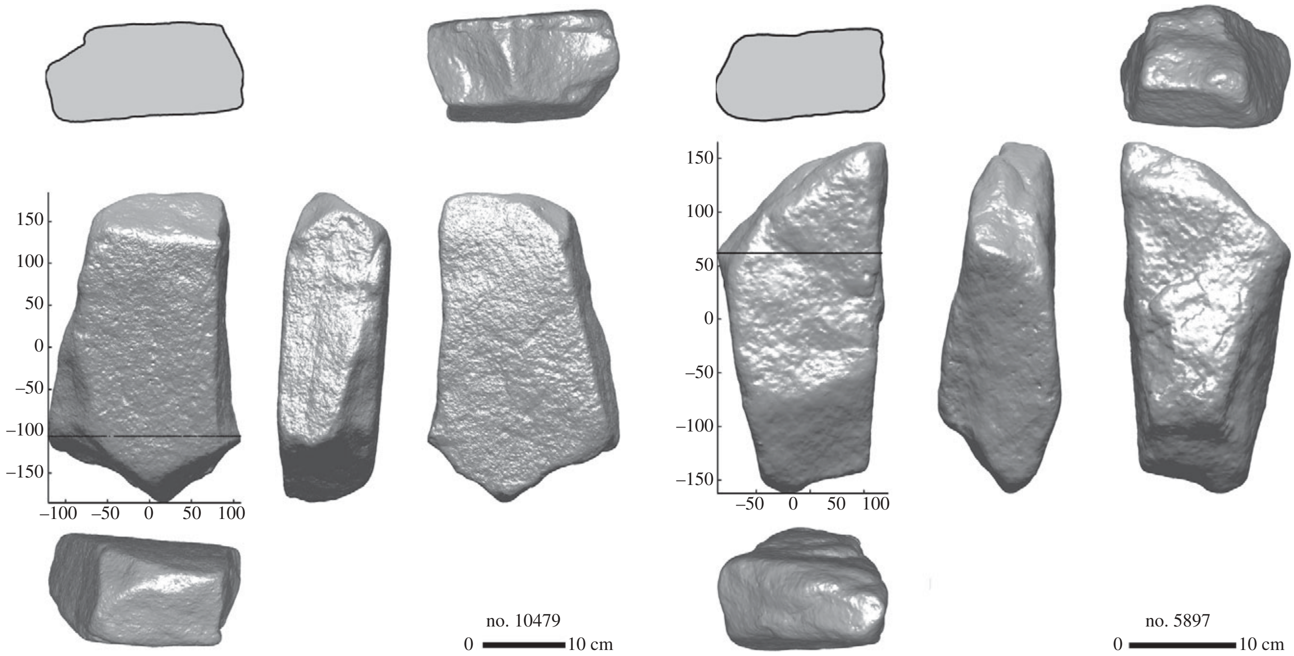

Figure 3. Three-dimensional scanning of fragmented slabs.

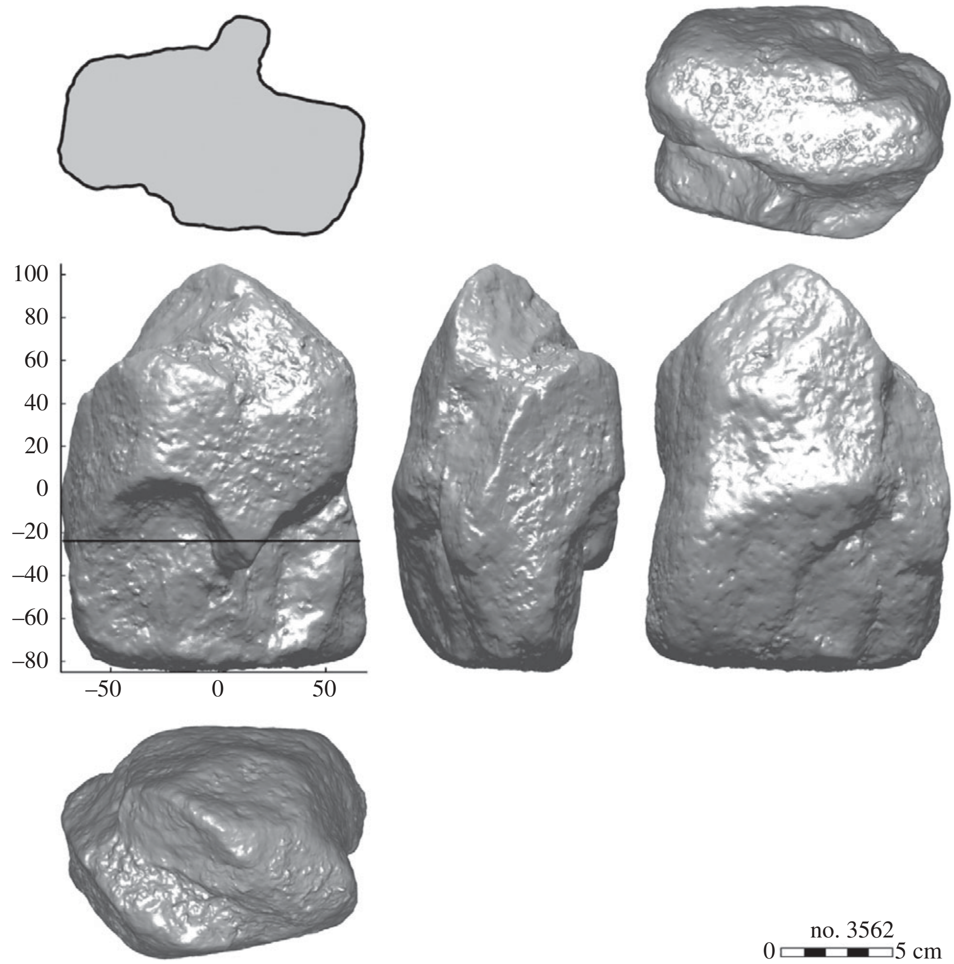

Figure 4. Three-dimensional scanning of exhausted giant core with observable rock bedding.

bifaces recovered from the archaeological horizons. This was supported by the observation that areas with high concentrations of bifaces were characterized by a marked deficit of waste products [53]. Further analyses provided data showing that basalt bifaces were modified and trimmed in particular areas, but the final products were lacking. The same behavioural mode was described for the production of flint bifaces,

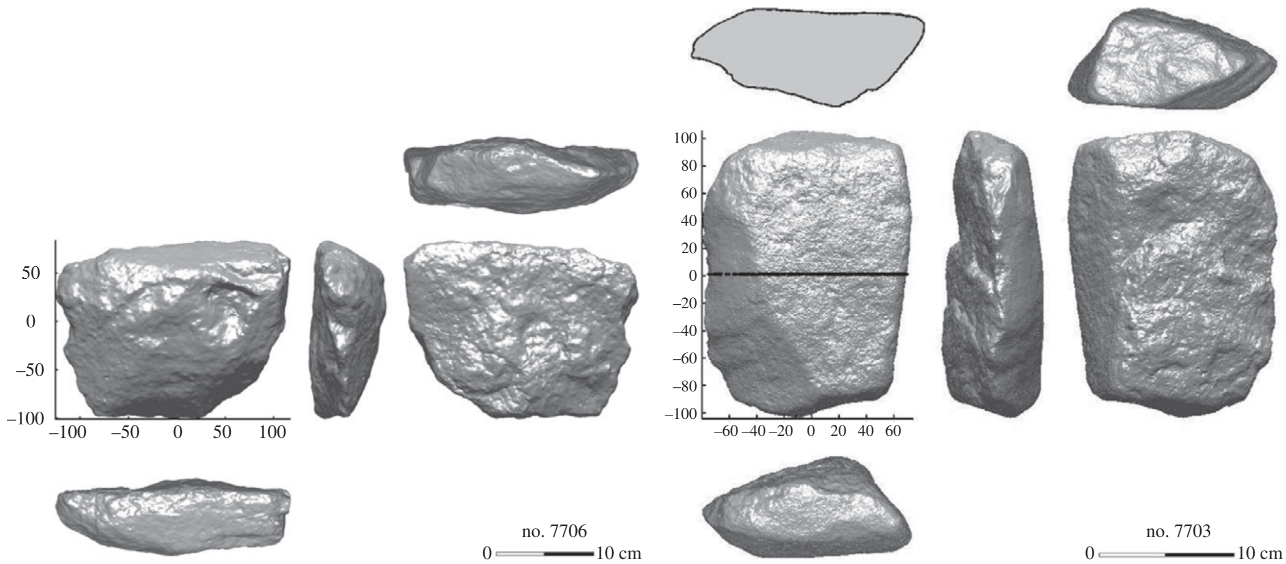

Figure 5. Three-dimensional scanning of large flakes.

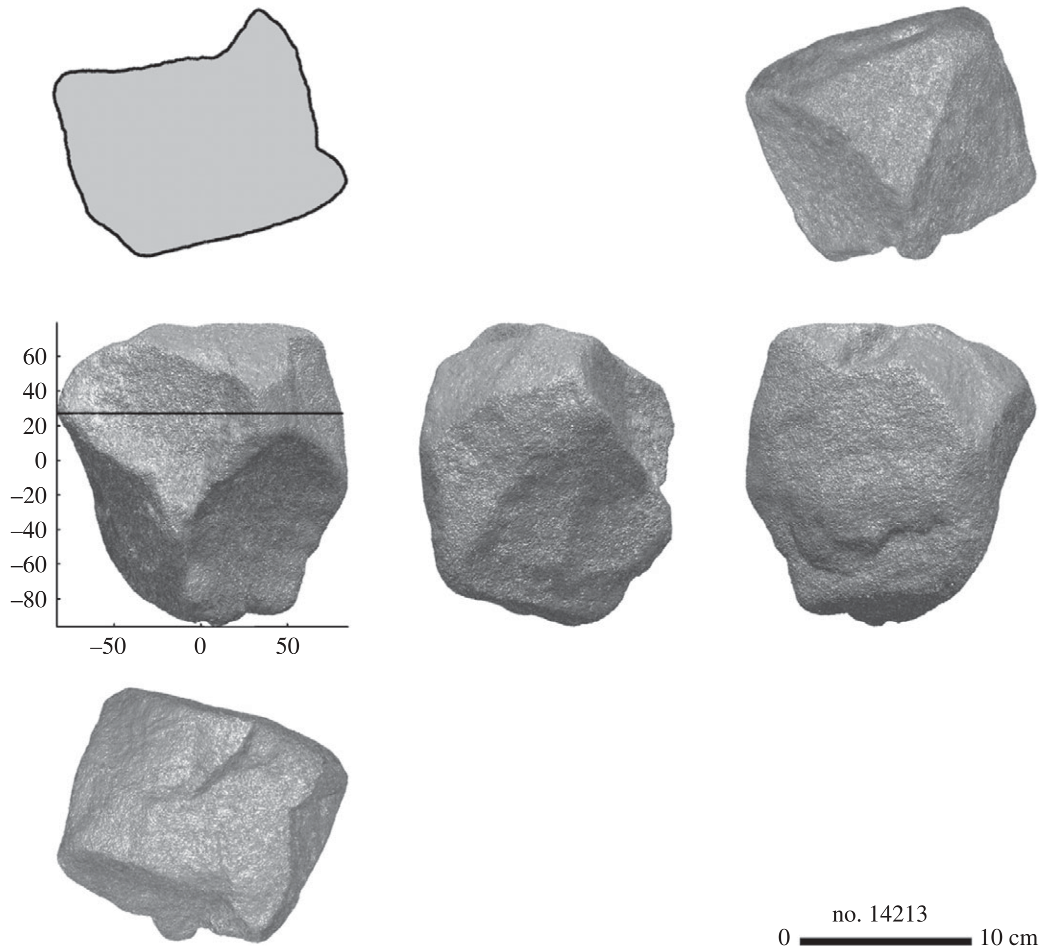

Figure 6. Three-dimensional scanning of exhausted giant core.

which are rare at the site. This helped in discerning a behavioural mode of bifacial reduction in which different raw materials were exploited [57,58].

Further insight into behavioural modes was gained through the study of massive scrapers, tools that also derive from the knapping of giant cores. The hominins apparently used blanks whose morphology and other characteristics made them unsuitable for the production of bifaces for modification into massive scrapers with minimal investment of flaking [59]. It was suggested that these blanks were identified during knapping sessions and set aside to be used later. Present-day knappers use the same decision-making pattern: while using blanks for a particular tool type they may recognize a potential for making a quite different tool.

While the entire reduction process is not available to us, the archaeological record does furnish segments of this complex process. Further understanding of the complexity of the *chaîne opératoire* could be gained by several means, but for the purposes of the current study we selected an ethnographic analogy.

(d) *An ethnographic analogy*

The production of bifacial tools is a complex system integrating long-term planning (using both working memory and planning memory) and its step-by-step implementation to obtain the desired end-product. This requires knowledge, experience, communication and the flexibility to change the procedure according to the circumstances. Complete reconstruction of such a complex system from the archaeological data is impossible, as information on many aspects is lacking.

As an attempt to fill in the gaps, an analogous ethnographic example is presented here. While the difficulties inherent in comparing the community behaviour of extant knappers with products knapped by the Acheulians are self-evident, the insights supplies by this analogy are remarkably instructive.

The detailed ethnographic description is drawn from the seminal work of Pétrequin & Pétrequin [60] in Irian Jaya, a study of the planning, production and distribution of bifacial tools. Among the Irian Jaya schemes we have selected those aimed at the production of bifaces made on volcanic rocks. This procedure requires a combination of knowledge in multiple fields, technological dexterity and know-how.

In the following paragraphs, we present side by side the segments of the *chaîne opératoire* of the Irian Jaya bifaces and those of GBY. The sub-headings bear cognitive titles drawn from ethnographic observations, using the terminology of Coolidge & Wynn [61].

(i) *'Large-scale spatial thinking', 'contingency' and 'long-term memory'*

Knowledge of geography, environments, geology and the knapping properties (suitability) of a variety of rock types are all demonstrated in the behaviour of the Irian Jaya communities. Community members exploit different types of raw materials for the production of bifaces. The precise location of particular quarries has been known for generations and certain localities have been continuously exploited. Strategies shift from one type of quarrying activity to another according to need.

Observing the Irian Jaya knappers at work, it is fascinating to see their ability to produce similar objects from different raw materials by adjusting and modifying the technique (e.g. the selection of different percussors). The process entails lively discussion among the knappers while they confer on which strategy is best.

The archaeological finds at GBY provide unequivocal data that hominins had a similar spatial knowledge of where to find the quarries that supplied the different raw materials, knew how to procure the preferred material and adjusted their production methodology and technology to fit the particular raw material.

(ii) *'Advanced planning', 'cooperative provisioning'*

The planning and organization of quarrying expeditions by the Irian Jaya result from a communal/social decision driven by communal needs as part of an overall strategy rather than an individual decision. This activity is a traditional social event. While the GBY data clearly lack this kind of information, the data indicate a communal effort of procuring large quantities of heavy rocks—a task that cannot be accomplished by a single individual. Considering that the archaeological horizons were sealed very fast and their duration was not a very long one, the presence of giant cores, and the large quantities of their by-products, could be used to illustrate a communal activity.

(iii) *'Spatial cognition' and 'procedural cognition'*

The ethnographic quarrying activities employ a variety of techniques and technologies including construction of scaffolding and platforms, setting fires (in order to crack the face of the rock exposure) and producing percussors and levers of different materials and sizes. The Irian Jaya quarry at rock exposures where, after testing, the selected slabs undergo size reduction (fragmentation) on the spot, followed by the production of several preforms[1]. While little evidence of such activities is present at GBY, one might consider the large percussors (over 15 kg) as pertaining to quarrying activities. The peculiar 'notches' on some of the giant cores (figure 1) indicate that there were other tools ('levers') used to dislodge the basalt slabs found at the site. A fragmentation stage clearly took place at GBY, as most of the items recovered at the site are slab fragments.

The preforms obtained through fragmentation by the Irian Jaya are transported to the village for further modification into the final bifacial form. In contrast with other raw materials, basalt preforms are handed over to experts because of the difficulty of knapping volcanic materials and the need for expertise in the later, more refined stages of their modification.

The complex pattern at GBY is rather different, in that beside preforms there are also unworked basalt slabs, giant cores and their by-products, as well as bifaces that were obviously produced elsewhere [57–59]. These differences may be explained to some extent by the fact that the economy and mode of life of the Acheulian communities differed greatly from those of the Irian Jaya village dwellers.

(iv) *'Technical and procedural know-how', 'communication', 'specialization' and 'social cognition'*

The expert basalt knappers of the Irian Jaya are extremely knowledgeable, and their information includes insight into the importance for flaking quality of the bedding of the volcanic rocks. This is crucial for the ultimate successful production of bifacial tools. The Acheulian knappers at GBY also had knowledge of rock bedding and the ability to exploit it (see above and figure 4). Indeed, the knapping of basalt requires a high level of expertise. This is exemplified by the fact that among the Irian Jaya knappers, those who work basalt are considered the most expert. Knapping knowledge, which incorporates technical know-how as well as the properties of the raw material, is most probably transferred through both intra- and inter-generation communication (there is clear evidence for continuity in the exploitation of quarries of high-quality volcanic rocks for over two millennia). Teaching processes among the Irian Jaya involve learning through close observation, imitation and supervised experimentation, accompanied throughout by verbal guidance. This contradicts the assumption made by Coolidge & Wynn [61, p. 94] that tool cognition is primarily characterized by observation and minimal verbal exchange.

From the GBY data, it can be concluded that the Acheulian hominins were expert in basalt knapping and were able to overcome the obstacles of modifying an extremely hard-to-knap material. This knowledge was retained and transferred through the generations for at least 50 000 years, since comparison with the bifaces from the various layers demonstrates a very high degree of similarity. The main variations between the assemblages are in the frequencies and spatial distribution of the products of the biface *chaîne opératoire* [11]. These variations probably reflect different modes of behaviour responding to different demands, an issue that awaits further study. Unfortunately, the archaeological data are mute on the ways and means by which the lithic expertise was disseminated.

The GBY evidence clearly lacks the entire discourse: the discussion of the goal, the process of raw material procurement, the interaction between teachers and apprentices and the verbal exchanges between the experts during work are all missing. Still, the ethno-archaeological comparison illustrates some great similarities.

(e) *Aspects of social interaction*

Elements of social interaction are observed in many of the domains studied at GBY. Palaeontological, palaeobotanical and technological data provide evidence of cooperative group efforts such as that detailed above.

Although hunting is still debated (but see [45]), carcass processing is evidenced by the presence of bones of medium-sized and large mammals in all of the excavated archaeological horizons [36]. While perhaps only a few individuals were active in the hunt [62,63] or the driving of the animal to the kill site, carcass processing requires the involvement of numerous individuals, as demonstrated ethnographically (e.g. [64–67]). At GBY this is evident through the reconstruction of carcass processing, as in the case of *Dama* sp. in both Layers V-5 and V-6 [41]. The concentration of large fish (*Barbus* sp.) in Layer II-6 Level 7 [32] also points to communal efforts.

The spatially structured co-occurrence of botanical, faunal and lithic finds in the archaeological horizons demonstrate that gathering of nuts and fruit (e.g. [49]), carcass processing, tool production and modification, as well as other activities, were an integral part of hominin activities carried out on the lake margin. Clearly, the Palaeolithic communities practised division of labour by age and gender, sharing the burden of communal survival. Although this social structure is merely implicit, it is widely supported by ethnographic analogies. The retention of cultural components for a long period indicates a shared cultural tradition.

Aspects of social cooperation are documented in the particulars of the spatial configurations of the archaeological horizons as well. Two cases have previously been reported in detail: the elephant kill site [45], and the 'biface pavement' [32]. Each case, but particularly the latter, illustrates a discrete activity area for a particular task, which most probably represents a short temporal event calling for multi-faceted social interaction and cooperation.

(f) *Innovation and creativity*

The long duration of the Acheulian and, the consistently important role of the bifacial tools tend to produce a false impression of stagnation or stasis. 'The task, and the shape of the artefacts, remained essentially unchanged for over 1 million years. Innovation and creativity was not a component, and these are functions of modern working memory' [61, p.122]. The archaeological record, however, furnishes a more complex scenario. There are diverse methods of biface production that clearly display flexibility of decision and creativity, all adhering to the same plan in achieving a predetermined goal. Furthermore, innovations were clearly made: evidence for the appearance of the soft hammer technique is mentioned above, and the beginnings of the Levallois technique that flourished during the Middle Palaeolithic can apparently be traced as well. Neither technique existed during the earlier part of the Levantine Acheulian record. These innovations, together with the creativity expressed in the full control of fire and its uses, clearly negate the notion of stagnation and/or stasis.

(i) *Language*

Long-term planning and its implementation, which involve many aspects of social cooperation, demand an advanced form of communication. From examples like the reduction sequence of basalt bifaces, which involved know-how and expertise shown by the high quality (lack of knapping accidents) and precision (symmetry and refinement) of the end-products, it is thought that the GBY hominins had language abilities. Prolonged observations of modern-day knapping provide some insight into its teaching processes. Knappers learn from each other and knapping sessions, which frequently take place in company, are accompanied by the exchange of ideas and tips. Knapping is not simply a repeated mechanical battering [61] but a blow-evaluation-blow procedure. Knappers strike a blow and then evaluate the results, frequently refitting the last flake removed to the core in order to evaluate the removal [60]. Interestingly, the knappers in Irian Jaya go through the same process; since their knapping sessions take place in a social context, the advantages and disadvantages of particular actions are thoroughly discussed. While the archaeological evidence will never supply evidence for verbal exchanges that took place while knapping, it is obvious that the Acheulian hominins did transmit knowledge and know-how, resulting in the production of similar artefacts by similar procedures. The dynamic decision-making and flexibility that characterize the reduction process of the bifaces is considered here to be an indication of the presence of language.

(ii) *Concluding remarks*

The most common approach to hominin abilities discerns phases in the evolution of cognitive abilities, marked primarily by distinct biological developments. Some scholars consider the prepared core technology and/or mass production of blades that appeared at some 300 Ka to be indicative of evolved planning 'suggesting a greater cognitive competence' [47, p. 3274], related to an increase in brain size. Coolidge & Wynn [61] claim that another leap in cognitive abilities resulted from a neural mutation that took place at *ca* 100–40 Ka, associated with the appearance of developed cognitive abilities that include working memory capacity (modern executive function).

This view of sequential neural evolution reflected in the growing complexity of hominin culture quite late in human history has been undermined by recent findings. These have revealed elaborate and sophisticated technological achievements (prepared core techniques and production of blades) from both East Africa and the Levant that date from a much earlier era, the Acheulian period (*ca* 0.5 Ma) [20,68,69].

Indeed, the record of GBY furnishes newly acquired data that are highly relevant to the extent of Acheulian cognitive abilities. It is clear that these cognitive abilities were quite developed, enabling them to use and exploit a variety of domains within their realm. Deep planning is especially apparent in the production sequence of bifaces and its by-products. The diverse methods of production observed on the site clearly demonstrate flexibility in decision-making as well as creativity in order to achieve the desired goal. In contrast to the view of the lithic reduction sequence as 'repetition and rhythm' [61, p. 93], the evaluation processes of each individual blow and the flexibility shown in selecting a particular method out of a varied repertoire, tailored to the specific circumstances at hand, are clearly indicative of advanced cognitive abilities. Moreover, the entire production system at GBY seems to be dependent on very precise communication, of which verbal language was the most probable means. Explaining bedrock bedding or evaluating the fineness and compactness of grain, crucial for attaining a successful end-result, would be impossible to achieve without language.

What is obvious is that the 'first appearance' of the cultural cognitive markers described here is to a large extent dependent on the archaeological resolution. The existence of these markers in GBY has been revealed through detailed studies. This intensity and scope of research are unfortunately rarely encountered, owing to differing circumstances and the poor archaeological record. Although the Acheulian cultural sequence lasted over 1.5 Myr, the pertinent information is fragmentary and extremely localized and can therefore provide only segments of its evolutionary history. This fragmentation undoubtedly masks the dynamics that are intrinsic to the Acheulian development. Clearly, the lack of information should not be interpreted as lack of change, innovation or cognitive ability. The recent discoveries concerning cognitive aspects of the Oldowan Technocomplex [70], which predates the Acheulian [71,72], serve to illustrate the difficulty of obtaining data to assess hominin cognitive abilities.

There is still a long way for research to go before we will be able to correlate between biological and cultural evolution and make deductions about the one from the other. Still, the data from GBY show that the cognitive abilities of the Acheulian hominins were complex and highly 'modern', at least in the domains that we can explore through the archaeological record.

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ENDNOTE

[1]Marks the first appearance of a term defined in the glossary.

REFERENCES

1 Clarke, D. L. 1968 *Analytical archaeology*. London, UK: Methuen and Company Ltd.

2 Sharon, G. 2007 *Acheulian large flake industries: technology, chronology, and significance*. Oxford, UK: BAR International Series.

3 Ashton, N. & White, M. 2003 Biface and raw materials: flexible flaking in the British Early Palaeolithic. In *Multiple approaches to the Study of Bifacial Technology* (eds M. Soressi & H. Dibble), pp. 109–124. Philadelphia, PA: University of Pennsylvania Museum of Archaeology and Anthropology.

4 Callow, P. 1994 The Olduvai bifaces: technology and raw materials. In *Olduvai Gorge excavations in beds III, IV and the Masek beds 1968–1971* (eds M. D. Leakey & D. Roe), pp. 235–253. Cambridge, UK: Cambridge University Press.

5 Feblot-Augustins, J. 1990 Exploitation des matiers premieres dans l'Acheuleen d'Afrique: perspectives comportementales. *Paléo* **2**, 27–42.

6 Boëda, E. 2001 Techno-functional analysis of bifacial tools from the Acheulean layer C'3 at Barbas I (Dordogne, France). In *Les Industries a Outils Bifaciaux du Paléolithique Moyen d'Europe Occidentale* (ed. D. Cliquet), pp. 51–75. Liège, Belgium: Universite de Liège.

7 Boëda, É., Courty, M.-A., Federoff, N., Griggo, C., Hedley, I. G. & Muhesen, S. 2004 Le site Acheuléen d'El Meirah Syrie. In *From river to the sea: the Palaeolithic and the Neolithic on the Euphrates and in the Northern Levant* (eds O. Aurenche, M. L. Mière & P. Sanlaville), pp. 164–200. Oxford, UK: BAR International Series.

8 Jones, P. R. 1994 Results of experimental work in relation to the stone industries of Olduvai Gorge. In *Olduvai Gorge excavations in beds III, IV, and the Masek beds 1968–1971* (eds M. D. Leakey & D. A. Roe), pp. 254–298. Cambridge, UK: Cambridge University Press.

9 Kleindienst, M. R. 1961 Variability within the Late Acheulian assemblage in East Africa. *South African Archaeol. Bull.* **16**, 35–52. (doi:10.2307/3886868)

10 Lycett, S. J. 2008 Acheulean variation and selection: does handaxe symmetry fit neutral expectations? *J. Archaeol. Sci.* **35**, 2640–2648. (doi:10.1016/j.jas.2008.05.002)

11 Sharon, G., Alperson-Afil, N. & Goren-Inbar, N. 2010 Cultural conservatism against variability in the continual Acheulian sequence of Gesher Benot Yaʿaqov, Israel. *J. Hum. Evol.* (doi:10.1016/j.jheval.2009.11.012)

12 Ungar, P. S., Grine, F. E. & Teaford, M. F. 2006 Diet in early *Homo*: a review of the evidence and a new model of adaptive versatility. *Annu. Rev. Anthropol.* **35**, 209–228. (doi:10.1146/annurev.anthro.35.081705.123153)

13 Clark, D. J. 1975 A comparison of the Late Acheulian industries of Africa and the Middle East. In *After the Australopithecines: stratigraphy, ecology and culture change in the Middle Pleistocene* (eds K. W. Butzer & G. L. Isaac), pp. 605–659. Chicago, IL: Aldine.

14 Gamble, C. & Marshall, G. 2002 The shape of handaxes, the structure of the Acheulian world. In *A very remote period indeed: papers in the Palaeolithic presented to Derek Roe* (eds S. Milliken & J. Cook), pp. 19–27. Oxford, UK: Oxbow Books.

15 Kohn, M. & Mithen, S. 1999 Handaxes: products of sexual selection? *Antiquity* **73**, 518–526.

16 Rightmire, G. P. 2001 Patterns of hominid evolution and dispersal in the Middle Pleistocene. *Q. Int.* **75**, 77–84. (doi:10.1016/S1040-6182(00)00079-3)

17 Gowlett, J. A. J. 1984 Mental abilities of early man: a look at some hard evidence. In *Hominid evolution and community ecology* (ed. R. Foley), pp. 167–192. London, UK: Academic Press.

18 Goren-Inbar, N. In press. Behavioral and cultural origins of Neanderthals: a Levantine perspective. In *150 Years of Neanderthal discoveries. Continuity and discontinuity* (eds S. Condemi & G.-C. Weniger). Berlin, Germany: Springer.

19 Bar-Yosef, O. & Goren-Inbar, N. 1993 The lithic assemblages of the site of ʿUbeidiya, Jordan Valley. Jerusalem, Israel: Hebrew University.

20 Hershkovitz, I., Smith, P., Sarig, R., Quam, R., Rodríguez, L., García, R., Arsuaga, J.-L., Barkai, R. & Gopher, A. In press. Middle Pleistocene dental remains from Qesem Cave, Israel. *Am. J. Phys. Anthropol.* (doi:10.1002/ajpa.21446)

21 Frumkin, A., Karkanas, P., Bar-Matthews, M., Barkai, R., Gopher, A., Shahack-Gross, R. & Vaks, A. 2009 Gravitational deformations and fillings of aging caves: the example of Qesem karst system, Israel. *Geomorphology* **106**, 154–164. (doi:10.1016/j.geomorph.2008.09.018)

22 Belmaker, M., Tchernov, E., Condemi, S. & Bar-Yosef, O. 2002 New evidence for hominid presence in the Lower Pleistocene of Southern Levant. *J. Hum. Evol.* **43**, 43–56. (doi:10.1006/jhev.2002.0556)

23 Tobias, P. V. 1966 Fossil hominid from ʿUbeidiya, Israel. *Nature* **211**, 130–133. (doi:10.1038/211130a0)

24 Garrod, D. A. E. & Bate, D. M. A. 1937 *The Stone Age of Mount Carmel, excavation at Wadi Mughara.* Oxford, UK: Oxford University Press.

25 Turville-Petre, F. 1927 *Research in prehistoric Galilee, 1925–1926.* London, UK: British School of Archaeology in Jerusalem.

26 Belitzky, S. 2002 The structure and morphotectonics of the Gesher Benot Yaʿaqov area, Northern Dead Sea Rift, Israel. *Q. Res.* **58**, 372–380. (doi:10.1006/qres.2002.2347)

27 Goren-Inbar, N. & Belitzky, S. 1989 Structural position of the Pleistocene Gesher Benot Yaʿaqov site in the Dead Sea Rift Zone. *Q. Res.* **31**, 371–376. (doi:10.1016/0033-5894(89)90043-4)

28 Feibel, S. C. 2001 Archaeological sediments in lake margin environments. In *Sediments in archaeological contexts* (eds J. K. Stein & W. R. Farrand), pp. 127–148. Salt Lake City, UT: University of Utah Press.

29 Feibel, C. S. 2004 Quaternary lake margins of the Levant Rift Valley. In *Human paleoecology in the Levantine corridor* (eds N. Goren-Inbar & J. D. Speth), pp. 21–36. Oxford, UK: Oxbow Books.

30 Goren-Inbar, N., Feibel, C. S., Verosub, K. L., Melamed, Y., Kislev, M. E., Tchernov, E. & Saragusti, I. 2000 Pleistocene milestones on the out-of-Africa corridor at Gesher Benot Yaʿaqov, Israel. *Science* **289**, 944–974. (doi:10.1126/science.289.5481.944)

31 Goren-Inbar, N. & Saragusti, I. 1996 An Acheulian biface assemblage from the site of Gesher Benot Yaʿaqov, Israel: indications of African affinities. *J. Field Archaeol.* **23**, 15–30. (doi:10.2307/530606)

32 Alperson-Afil, N. *et al.* 2009 Hearth-related spatial patterning of hominins' activities at the Acheulian site of Gesher Benot Yaʿaqov, Israel. *Science* **326**, 1677–1680. (doi:10.1016/j.quascirev.2008.06.009)

33 Ashkenazi, S., Klass, K., Mienis, H. K., Spiro, B. & Abel, R. 2009 Fossil embryos and adult Viviparidae from the Early–Middle Pleistocene of Gesher Benot Yaʿaqov, Israel: ecology, longevity and fecundity. *Lethaia* **43**, 116–127. (doi:10.1111/j.1502-3931.2009.00178.x)

34 Goren-Inbar, N. & Spiro, B. In press. Early-middle Pleistocene paleoenvironments in the Levant. *J. Hum. Evol.* (Special Issue)

35 Spiro, B., Ashkenazi, S., Mienis, H. K., Melamed, Y., Feibel, C., Delgado, A. & Starinsky, A. 2009 Climate variability in the Upper Jordan Valley around 0.78 Ma, inferences from time-series stable isotopes of Viviparidae, supported by mollusc and plant palaeoecology. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **282**, 32–44. (doi:10.1016/j.palaeo.2009.08.005)

36 Rabinovich, R., Gaudzinski-Windheuser, S., Kindler, L. & Goren-Inbar, N. *The Acheulian site of Geshser Benot Yaʿaqov: mammal taphonomy - the assemblages of layers V-5 and V-6.* Dordrecht, The Netherlands: Springer.

37 Tchernov, E. 1988 The paleobiogeographical history of the southern Levant. In *The zoogeography of Israel* (eds Y. Yom-Tov & E. Tchernov), pp. 159–250. The Hague, The Netherlands: Dr. W. Junk Publishers.

38 Melamed, Y. 2003 Reconstruction of the Hula Valley vegetation and the hominid vegetarian diet by the Lower Palaeolithic botanical remains from Gesher Benot Yaʿaqov. PhD thesis, Bar-Ilan University, Israel.

39 Rabinovich, R. & Biton, R. Submitted. The Early-Middle Pleistocene faunal assemblages of Gesher Benot Yaʿaqov—taphonomy and paleoenvironment. *J. Hum. Evol.*

40 Martínez-Navarro, B. & Rabinovich, R. In press. The fossil Bovidae (Artiodactyla, Mammalia) from Gesher Benot Yaʿaqov, Israel: out of Africa during the Early-Middle Pleistocene transition. *J. Hum. Evol.* (doi:10.1016/j.jhevol.2010.03.012)

41 Rabinovich, R., Gaudzinski, S. & Goren-Inbar, N. 2008 Systematic butchering of fallow deer (*Dama*) at the early Middle Pleistocene Acheulian site of Gesher Benot Yaʿaqov, (Israel). *J. Hum. Evol.* **54**, 134–149. (doi:10.1016/j.jhevol.2007.07.007)
42 Bello, S. M., Parfitt, S. A. & Stringer, C. 2009 Quantitative micromorphological analyses of cut marks produced by ancient and modern handaxes. *J. Archaeol. Sci.* **36**, 1869–1880. (doi:10.1016/j.jas.2009.04.014)
43 Mitchell, J. C. 1997 Quantitative image analysis of lithic microwear on flint handaxe. *Microsc. Anal.* **26**, 15–17.
44 Mitchell, J. C. 1998 A use-wear analysis of selected British Lower Palaeolithic handaxes with special reference to the site of Boxgrove (West Sussex): a study incorporating optical microscopy, computer aided image analysis and experimental archaeology. PhD thesis, Oxford University, UK.
45 Goren-Inbar, N., Lister, A., Werker, E. & Chech, M. 1994 A butchered elephant skull and associated artifacts from the Acheulian site of Gesher Benot Yaʿaqov, Israel. *Paléorient* **20**, 99–112. (doi:10.3406/paleo.1994.4604)
46 Zohar, I. & Biton, R. In press. Land, lake, and fish: investigations of fish remains from Gesher Benot Yaʿaqov (paleo-Lake Hula). *J. Hum. Evol.*
47 Foley, R. & Gamble, C. 2009 The ecology of social transitions in human evolution. *Phil. Trans. R. Soc. B* **364**, 3267–3279. (doi:10.1098/rstb.2009.0136)
48 Goren-Inbar, N., Sharon, G., Melamed, Y. & Kislev, M. 2002 Nuts, nut cracking, and pitted stones at the Gesher Benot Yaʿaqov, Israel. *Proc. Natl Acad. Sci. USA* **99**, 2455–2460. (doi:10.1073/pnas.032570499)
49 Goren-Inbar, N., Werker, E. & Feibel, C. S. 2002 *The Acheulian site of Gesher Benot Yaʿaqov: the wood assemblage*. Oxford, UK: Oxbow Books.
50 Goren-Inbar, N., Alperson, N., Kislev, M. E., Simchoni, O., Melamed, Y., Ben-Nun, A. & Werker, E. 2004 Evidence of hominin control of fire at Gesher Benot Yaʿaqov, Israel. *Science* **304**, 725–727. (doi:10.1126/science.10954)
51 Alperson-Afil, N. & Goren-Inbar, N. 2010 *The Acheulian site of Gesher Benot Yaʿaqov: ancient flames and controlled use of fire*. Dordrecht, The Netherlands: Springer.
52 Alperson-Afil, N. 2008 Continual fire-making by hominins at Gesher Benot Yaʿaqov, Israel. *Q. Sci. Rev.* **27**, 1733–1739. (doi:10.1016/j.quascirev.2008.06.009)
53 Madsen, B. & Goren-Inbar, N. 2004 Acheulian giant core technology and beyond: an archaeological and experimental case study. *Eurasian Prehist.* **2**, 3–52.
54 Goren-Inbar, N., Grosman, L. & Sharon, G. In preparation. The record, technology and significance of the Acheulian giant cores of Gesher Benot Yaʿaqov, Israel.
55 Weinstein, Y., Navon, O., Altherr, R. & Stein, M. 2006 The role of lithospheric mantle heterogeneity in the generation of Plio-Pleistocene alkali basaltic suites from NW Harrat Ash Shaam (Israel). *J. Petrol.* **47**, 1017–1050. (doi:10.1093/petrology/egl003)
56 Petraglia, M., Porta, P. L. & Paddayya, K. 1999 The first Acheulian quarry in India: stone tool manufacture, bifaces morphology, and behaviors. *J. Anthropol. Res.* **55**, 39–70. See http://www.jstor.org/stable/3630977.
57 Goren-Inbar, N. & Sharon, G. 2006 Invisible handaxes and visible Acheulian biface technology at Gesher Benot Yaʿaqov, Israel. In *Axe age: Acheulian toolmaking from quarry to discard* (eds N. Goren-Inbar & G. Sharon), pp. 111–135. London, UK: Equinox.
58 Sharon, G. & Goren-Inbar, N. 1999 Soft percussor use at the Gesher Benot Yaʿaqov Acheulian site? *Mitekufat Haeven* **28**, 55–79.
59 Goren-Inbar, N., Sharon, G., Alperson-Afil, N. & Laschiver, I. 2008 The Acheulian massive scrapers of Gesher Benot Yaʿaqov—a product of the biface *chaîne opératoire*. *J. Hum. Evol.* **55**, 702–712. (doi:10.1016/j.jhevol.2008.07.005)
60 Pétrequin, P. & Pétrequin, A.-M. 1993 *Écologie d'un outil: la hache de pierre en Irian Jaya* (*Indonésie*). Paris, France: CNRS.
61 Coolidge, F. L. & Wynn, T. 2009 *The rise of* Homo sapiens*—the evolution of modern thinking*. Chichester, UK: Wiley-Blackwell.
62 Janmart, J. 1952 Elephant hunting as practiced by the Congo Pygmies. *Am. Anthropol.* **54**, 146–147. (doi:10.1525/aa.1952.54.1.02a00440)
63 Movius, H. L. 1950 A wooden spear of Third Interglacial age from Lower Saxony. *Southwestern J. Anthropol.* **6**, 139–142.
64 Crader, D. C. 1983 Recent single-carcassbone scatter and the problem of 'butchery' sites in the archaeological record. In *Hunters and their prey* (eds J. Clutton-Brock & C. Grigson), pp. 107–141. Oxford, UK: BAR International Series.
65 Fisher, J. W. J. 1992 Observations on the Late Pleistocene bone assemblages from the Lamb Spring Site, Colorado. In *Ice Age hunters of the Rockies* (eds D. J. Stanford & J. S. Day), pp. 51–81. Boulder, CO: Denver Museum of Natural History and University Press of Colorado.
66 Fisher, J. W. J. 2001 Elephant butchery practices in the Ituri Forest, Democratic Republic of the Congo, and their relevance for interpreting human activities at prehistoric Proboscidean sites. In *Proc. of the Int. Conf. on Mammoth Site Studies* (ed. D. West), pp. 1–10. Lawrence, KS: University of Kansas.
67 Marks, S. A. 2005 *Large mammals and a brave people—subsistence hunters in Zambia*. New Brunswick, NJ: Transactions Publishers.
68 Bar-Yosef, O. & Kuhn, S. 1999 The big deal about blades: laminar technologies and human evolution. *Am. Anthropol.* **101**, 1–17. (doi:10.1525/aa.1999.101.2.322)
69 Johnson, C. R. & McBrearty, S. 2010 500,000 year old blades from the Kapthurin Formation, Kenya. *J. Hum. Evol.* **58**, 193–200. (doi:10.1016/j.jhevol.2009.10.001)
70 de la Torre, I. 2011 The origins of stone tool technology in Africa: a historical perspective. *Phil. Trans. R. Soc. B* **366**, 1028–1037. (doi:10.1098/rstb.2010.0350)
71 Hovers, E. & Braun, D. R. 2009 Introduction: current issues in Oldowan research. In *Interdisciplinary approaches to the Oldowan* (eds E. Hovers & D. R. Braun), pp. 1–14. Dordrecht, The Netherlands: Springer.
72 Stout, D., Semaw, S., Rogers, M. J. & Cauche, D. 2010 Technological variation in the earliest Oldowan from Gona, Afar, Ethiopia. *J. Hum. Evol.* **58**, 474–491. (doi:10.1016/j.jhevol.2010.02.005)

GLOSSARY

Bedding plane: A planar or near-planar surface that separates each successive layer of stratified rock (of the same or different lithology) from a preceding or following layer; a plane of deposition. In volcanic rocks: occurs as one of the cooling effects of the hot rock that lead to rock stratification upon consolidation; usually invisible to the naked eye.

Blank: A piece of lithic raw material (either a natural pebble/cobble or a previously detached flake) that is suitable for further modification (mass extraction) by flaking or retouch.

Cleaver: A tool shaped by bifacial removals whereby flakes are detached from both faces of the blank (and hence lenticular in cross section). Typically this tool is U-shaped with a straight distal edge (when viewed in plan view), presumably the tool's cutting edge.

Handaxe: A tool shaped by bifacial removals from both faces of a cobble or large flake (and hence lenticular in cross section). Typically, this tool is distally pointed or teardrop-shaped (when viewed in plan view).

Percussor: A hammer; may be a hard hammer, most commonly made of stone, or a soft hammer made of bone, antler or wood.

Preform: A shaped lithic artefact especially prepared so that its surface and volume facilitate further modification towards its transformation into a tool with a pre-planned shape. Preforms are most often recognized in the context of producing bifacial tools.

Reduction sequence: A series of removals, starting with the natural form of the lithic raw material and ending with a predetermined blank or a retouched tool. In the context of making Acheulian bifaces, the sequence is shaping of the natural piece, removal of the rind (cortex) on the outer surface of the natural form, preparing the appropriate angles that are essential for flaking, preparing the surface for the following mass removal, extracting a sizable flake and shaping the end product, which is the pre-planned tool.

Chaîne opératoire (operational sequence): The technological process of making an object: a sequence that consists of focusing on a mental template (the pre-planned shape of a lithic object), selecting sets of actions needed for its execution, and actualizing them through physical action upon matter. In lithic studies it is used sometimes interchangeably with the term 'reduction sequence'.