PHANTOM HEARTHS AND THE USE OF FIRE AT GESHER BENOT YA`AQOV, ISRAEL

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ABSTRACT

The basic assumption of this study is that hearths are the center of debris accumulation and that the identification of clusters of burned debris testifies to the location of ancient hearths that are no longer visible. We present the results of thermoluminescence (TL) and spatial analyses of flint microartifacts from two Acheulian archaeological horizons at Gesher Benot Ya`aqov. The results obtained by TL measurements confirm the previously reported evidence of fire. The spatial analysis demonstrates clustering of burned microartifacts, which is interpreted as an indicator of ancient hearths. The circumstances that introduced the burned material to the archaeological horizons are examined, suggesting that anthropogenic rather than natural fires are responsible for the observed patterns. Finally, we discuss the issue of hearth-related activities and their resulting spatial patterns, suggesting that the evidence from Gesher Benot Ya`aqov is an ancient example of such patterns.

INTRODUCTION

Controlled use of fire was reported from the Acheulian site of Gesher Benot Ya`aqov (Goren-Inbar et al. 2004). The Early-Middle Pleistocene evidence includes burned flint artifacts, charcoal fragments, burned wood, fruits, and grains. In addition, small-sized burned flint artifacts were found spatially clustered.

In this paper we discuss the small-sized flint artifacts (microartifacts), among which a large assemblage of burned items was documented. Identification of burned items was based on macroscopic signs of heat alteration and confirmed by thermoluminescence (TL) measurements. In order to examine the cause of the burning (i.e., natural vs. anthropogenic fires), the spatial distribution of burned and unburned flint microartifacts is examined. We assume that natural wildfires result in extensive burning while anthropogenic fires, in the form of hearths, result in spatially discerned clusters of burned material, specifically small-sized material. This assumption is based on various ethnographical and archaeological observations of hearth-related activities and hearth-related discard patterns. A detailed discussion of these data suggests that the spatial patterning of flint microartifacts from Gesher Benot Ya`aqov is an ancient indication of such hearth-related social behavior.

HISTORY OF RESEARCH IDENTIFYING THE PRESENCE OF FIRE

The manipulation of fire by hominids led to dramatic changes in behavior connected with diet, defense, and social interaction. Thus, the issue of the antiquity of controlled use of fire has been a focal point for numerous studies and discussions (e.g., Goudsblom 1986; Harrison 1954; James 1989; Oakley 1956, 1961; Olive and Taborin 1989; Stewart 1956) and is often challenged by archaeologists. Review of the early evidence demonstrates the variety of indications and methodologies used to examine the presence of fire.

Sedimentological analyses often are used to determine the presence of burned sediment at archaeological sites. Such studies have focused mainly on cave site deposits that display extensive ash accumulations (e.g., Albert et al. 1999, 2000, 2003; Elbaum et al. 2003; Karkanas et al. 2002; Schiegel et al. 1994, 1996; Weiner et al. 2002).

Identification of burned sediments during fieldwork is usually based on the exposure of areas of discolored soils, commonly interpreted as hearths (e.g., Koobi Fora: Bellomo 1994; Clark and Harris 1985; Rowlett 2000; Chesowanja: Gowlett et al. 1981; Terra Amata: Villa 1983). These sedimentological features often are subjected to magnetic analyses in order to determine whether they are the result of burning (Barbetti 1986; Bellomo 1993, 1994; Bonhomme and Stanley 1985; Jordanova et al. 2001).

Experimental studies demonstrate discoloration (i.e., to dull yellow, red or black) of sediments on the surface directly below the fire. However, such alterations may disappear after a long period of weathering and leaching (Bellomo and Harris 1990). Conversely, other experiments show that the temperature of sediments underneath a hearth remains below 500°C, so that reddening of the soil rarely occurs (Canti and Linford 2000; Linford and Canti 2001). The

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process of iron oxide transformation, which causes soil reddening, varies among different sediments, possibly due to organic matter content, chemical variation in sediments, or the fuel used (e.g., Leesch et al. 2005 and references therein). Thus, it appears that discoloration of sediments is not a reliable measure for the identification of burned soils. At Locality 1 at Zhoukoudian, discoloration of sediments long was considered an indication of ancient fires. However, sedimentological analyses of the "dark ashes" concluded that ash remnants (i.e., siliceous aggregates) are not present there (Goldberg et al. 2001; Weiner et al. 1998).

The presence of burned bones at archaeological sites can result from their use as fuel for hearths (e.g., Théry-Parisot 2001; Vértesszőllős: Vertes and Dobosi 1990), from cooking/roasting of meat (e.g., Swartkrans Cave: Brain and Sillen 1988; Skinner et al. 2004), or from their random proximity to hearths (e.g., Champréveyres and Monruz: Leesch et al. 2005), including bones embedded in the subsurface beneath the fire (Bennett 1999). Identification of burned bones is based on visible discoloration, changes in bone mineral and matrix, and changes in the mechanical properties of bone (Nicholson 1993; Shipman et al. 1984). The latter can increase the fragmentation of burned bones, so that the bulk of these is likely to be of smaller size than unburned ones (Stiner et al. 1995). The preservation of bones varies among sites, as do depositional environments. Therefore blackened bones can indicate fire at one site, while they may be just the result of a particular depositional environment at another (e.g., Shahack-Gross et al. 1997).

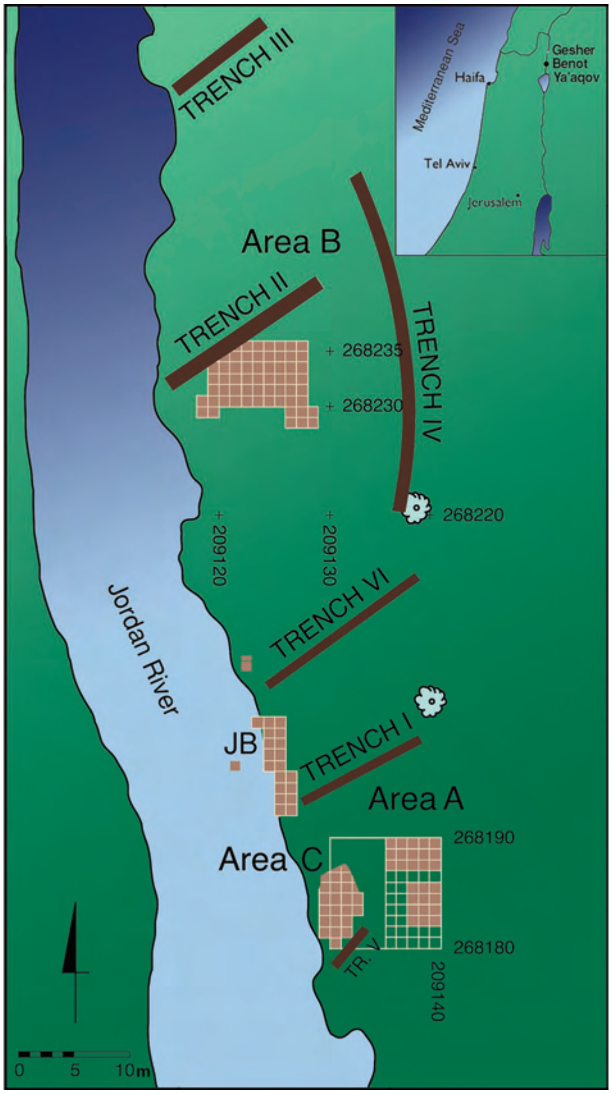

Figure 1. Location of Gesher Benot Ya`aqov and excavation areas.

Exposure to fire changes the mechanical properties of lithic material. Experimental studies have been carried out mostly on flint or chert and demonstrate that exposure to high temperatures (~350-500°C) causes macroscopically identifiable alterations such as discoloration, potlid fractures, crazing, and fragmentation (Julig et al. 1999; Purdy 1975, 1982; Purdy and Brooks 1971).

Though rare, wood and charcoal also are reported from various sites in which unique conditions enabled the preservation of burned specimens (e.g., Kalambo Falls: Clark 2001; Gesher Benot Ya`aqov: Goren-Inbar et al. 2002b; Torralba: Freeman 1975; Howell 1966; Schönigen: Thieme 1997; La Cotte de St. Brelade: Callow et al. 1986).

Scientific ways of detecting heat alteration are Thermoluminescence (TL) and Electron Spin Resonance (ESR) analyses. Both methods can provide a measure of the concentration of radiation-induced defects in solids. Such defects are destroyed (annealed), or, in the case of ESR, even created during heating, and thus their presence/absence indicates past heating of the material. These methods are used to determine the burning of sediments (Bischoff et al. 1984), botanical remains (Hillman et al. 1983) and stones (Hedgcock et al. 1988). TL measurements were carried out on flint samples from Gesher Benot Ya`aqov in order to verify their burning (see below).

The various methods and techniques in use demonstrate the great efforts taken to identify controlled use of fire in archaeological sites. Clearly, the identification of burned materials indicates the presence of fire. However, when attempting to infer human-controlled fire, the mere presence of burned items is not sufficient. In order to differentiate confidently between natural and anthropogenic fire, the archaeological evidence should comprise various burned materials and the spatial association of these should display clustering rather than random or uniform distribution. These aspects were taken into consideration in the study of fire use at the site of Gesher Benot Ya`aqov.

THE SITE

The 790,000-year-old Acheulian site of Gesher Benot Ya`aqov is located on the shores of paleo-Lake Hula in the Levantine Corridor (Figure 1). A 34 m depositional sequence was exposed in the study area (Figure 2). The sediments, documenting an oscillating paleo-lake, are considered to reflect global climatic changes and are assigned to OIS 18–20 (Feibel 2001, 2004). The sequence is estimated to represent some 100,000 years of the freshwater lake. Embedded within the sequence are some 13 archaeological horizons indicating that hominids repeatedly occupied the lake margins

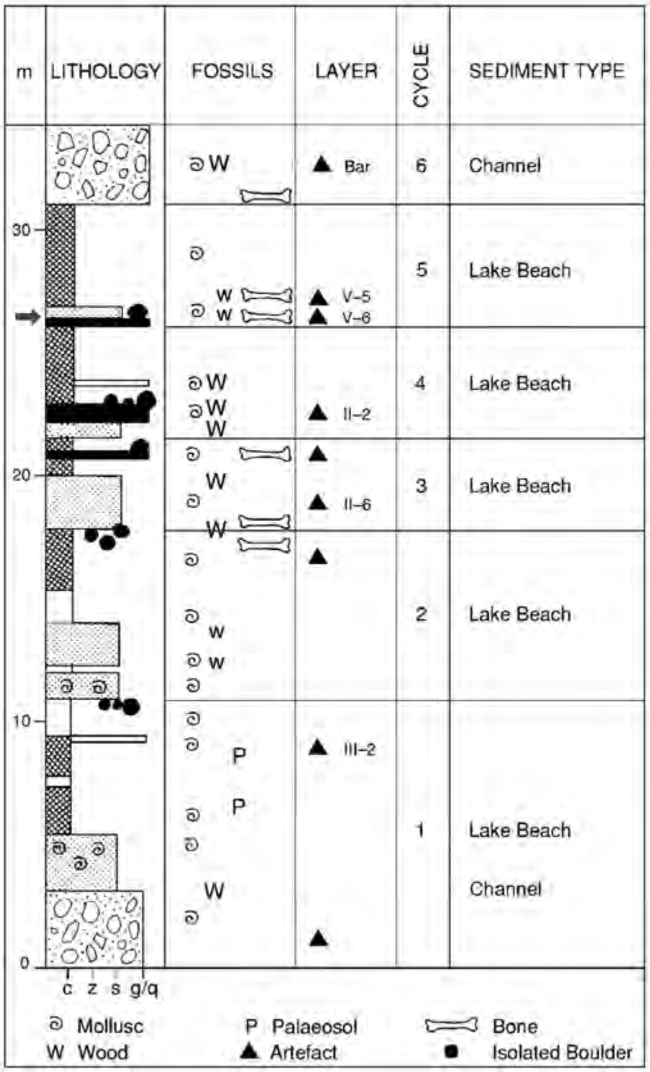

Figure 2. Composite section of Benot Ya`aqov Formation strata at the site (after Goren-Inbar et al. 2002b: 23, Figure 9); the position of Layers V-5 and V-6 is marked.

(Goren-Inbar et al. 2000). Diverse evidence suggests that the Acheulian hominids hunted, processed meat, extracted marrow, quarried and transported different kinds of rock, skillfully produced stone tools, and gathered a vast range of plant food including seven types of nuts, the latter preserved due to the waterlogged environment (Goren-Inbar et al. 1994; Goren-Inbar and Saragusti 1996; Goren-Inbar et al. 2002a, 2002b).

Burned flint occurs in all the excavated archaeological horizons. In this study, we present results concerning burned flint items and their spatial distribution from two archaeological layers (V-5 and V-6), both excavated in Area C (Figures 3–4). The base of Layers V-5 and V-6 is assigned to OIS 18 (Feibel 2001, 2004) and is located a little more than 13 m above the Brunhes-Matuyama chron boundary (Goren-Inbar et al. 2000). These layers contain two types of sediment: coarse (coquina) in Layer V-5 and fine (clay) in Layer V-6 (Figure 2); the shift between these sediment types indicates a change in the water level of the lake (Goren-Inbar et al. 2000). Layer V-5 (0.3 m thick and with an excavated volume of 2.25 m^3) and Layer V-6 (0.25 m thick and with an excavated volume of 1.39 m^3) yielded flint assemblages that are statistically large enough for lithic analysis.

METHODOLOGY

Provenance Recording

The excavation methodology was aimed at exposing the tectonically tilted occupation horizons along the strike and dip of each layer (Figures 3–4) in order to obtain an optimal representation of the spatial organization of each horizon ("living floor"). Once exposed, the horizon was drawn and items were retrieved with a full spatial reference (X, Y and Z coordinates); these include mostly artifacts larger than 2 cm. Other materials were retrieved through excavation of 50-cm^2 quadrants to a depth of 5 cm and thus were given a more general spatial reference (X and Y are 50 cm^2 and Z is a range of heights). The entire excavated deposit of the two layers was wet-sieved during fieldwork and the sediments were bagged with their recorded spatial location.

Lithic Analysis

Sorting of the sieved sediments of Layers V-5 and V-6 yielded rich and varied assemblages (e.g., bones and teeth of micro-mammals, fish, and crabs; fruits, grains, and specks of charcoal). Most of the small-sized lithic items were retrieved through this procedure. These include all stone items (basalt, flint, and limestone) that range in size from 2 to 20 mm (henceforth microartifacts).

Burned flint items (artifacts and microartifacts) were observed during the fieldwork and the subsequent lithic analysis. Differentiation between natural items (e.g., small-sized pebbles) and knapping debris was based on the presence of characteristic knapping features such as a ventral face, striking platform, etc. The bulk of burned flints consist of microartifacts (Table 1).

The identification of burned items was based on the presence of typical macrofractures (potlid fractures), known to result from the exposure of flint to high temperatures

Figure 3. Gesher Benot Ya`aqov: general view of the excavations in Area C; visible (partly shaded area on the left) is the tilted surface of Layer V-6.

Figure 4. Gesher Benot Ya`aqov: excavations of Layer V-6.

(~350–500°C). In doing so we draw from experimental studies which demonstrate that exposure to such temperatures changes the mechanical properties of flint, causing various alterations. These include discoloration, potlid fractures, crazing, and fragmentation (Julig et al. 1999, Purdy 1975, 1982, Purdy and Brooks 1971).

Recent experiments have demonstrated that only those artifacts that were in direct contact with the fire, and which were heated to a temperature above 300°C, will eventually show heat damage (Sergant et al. 2006). Furthermore, these experiments subdivided fire-damaged artifacts into the following classes: 1) *weakly-burnt*: hardly any traces of heat damage, except for a weak reddish shine and a few isolated cracks; 2) *moderately-burnt*: more visible heat damage, such as potlid fractures, cracks, and color changes; and 3) *heavily (overheated) burnt*: displaying total dehydration resulting in a white to grey discoloration (Sergant et al. 2006: 1000). Thus, only direct exposure of flint to fire can result in visible heat damage, and heat damage is diversified and includes a variety of features.

In the attempt to identify the presence of fire at a site as ancient as Gesher Benot Ya`aqov, we chose to be extremely cautious and therefore considered only those items that were unquestionably burned. The identification of burned flints had to rely on features that are clear and uniquely due to exposure to fire. Of the various heat damage patterns, potlidding is the most distinctive feature. Thus, we are aware of the possibility that some of the items classified as unburned flints are actually *weakly-burnt* flints with "hardly any traces of heat damage" (Sergant et al. 2006: 1000).

Thermoluminescence Measurements

A first set of nine samples from the flint microartifacts was analyzed by Thermoluminescence (TL) in order to gain independent verification of the previously observed burning. TL is a useful tool for determining the elapsed time since rock material has been heated. One fundamental requirement for TL dating is past heating to approximately 400°C (Huxtable and Aitken 1985; Valladas et al. 1991) and the method is therefore a simple way to establish the presence of fire.

A number of TL studies have attempted to determine the degree of heating of flint or sandstone from archaeological sites (e.g., Göksu et al. 1990; Valladas 1981, 1983). As the zeroing of the TL signal used for analysis is a function of temperature and time, any attempt to determine the ancient temperature can produce only equivalent temperatures. Results thus are equivalent to the laboratory conditions, and therefore can give only a rough approximation of the ancient temperature.

In light of the above, the aim of this TL study was merely to determine whether the flint samples had been heated in antiquity. This can be achieved by a simple plateau test (Aitken 1985), where the TL signal of the sample (natural TL or NTL) is compared to the signal of the natural plus an additive artificial radiation dose (NTL+β). For a well-heat-

TABLE 1. FREQUENCY OF STONE ARTIFACTS AND MICROARTIFACTS IN AREA C.

LAYER	ARTIFACTS			MICROARTIFACTS		
	Burned Flint	Unburned Flint	Basalt and Limestone	Burned Flint	Unburned Flint	Basalt and Limestone
V-5	1	312	86	550	30,058	5,885
V-6	3	176	66	82	4,415	2,078

TABLE 2. SAMPLES AND RESULTS OBTAINED BY TL MEASUREMENTS FOR THE HIGH TEMPERATURE REGION.

SAMPLE	LAYER	MACROSCOPIC SIGNS OF HEATING	NTL PEAK (°C)	HEATING PLATEAU (°C)	BLEACHABILITY OF 380 °C TL PEAK	ANCIENT HEATING
1	V-5	potlid	380	370 - 410	no	heated
2	V-5	potlids; edge damage	390	375 - 405	no	heated
3	V-6	potlids	390	380 - 410	no	heated
4	V-6	potlids	380	360 - 410	no	heated
6	V-6	potlid	390	370 - 500	not tested	heated
7	V-6	potlids	395	390 - 440	not tested	heated
8	V-5	potlids	390	370 - 410	not tested	heated
10	V-5	none	395, 460	none	no	not heated
11	V-5	none	395	370 - 420	not tested	heated

ed sample, which is not in saturation, the stable (high) temperature range of the TL signal is expected to show a flat ratio of NTL+β over NTL. While this test has been shown to be not always entirely adequate, empirical data on the shape of the glow curve are also used (e.g., Michab et al. 1998; Richter et al. 2002). A flint which has been heated to about 400°C or more is expected to show a single Gaussian-shaped peak at about 380°C at a heating rate of 10 °C s^{-1}. Less severe heating leaves remnants of the geological TL, which is often visible as an additional peak or shoulder at higher temperatures, or a non-Gaussian peak shape.

A total of nine small (0.07 to 0.43 g) flint microartifacts from Layers V-5 and V-6 were analysed (Table 2). The items showed traces of heating and the majority exhibited potlids. Such features can be caused by either heating or freezing, and a reddish colour can occur due to the oxidization of iron with time or heat (e.g., Richter 1998). While freezing is out of the question at the latitude of Gesher Benot Ya`aqov, extended and repeated exposure to sun could be responsible for insolation weathering. However, the temperatures reached by sunlight exposure are lower than those required to affect the high (>350°C) temperature TL. On the other hand, light exposure after excavation could have a superficial effect and thus bleach the TL signal. This is usually a concern only for the outer first 1-2 mm of opaque samples. Since the samples under study were very small, only the outer 0.5-1.0 mm could be removed with a water-cooled diamond saw, while the samples were kept under a constant flow of water during the sawing procedure. The heating of the samples due to the sawing is assumed to be low and localized. Any significant signal reduction would, at best, partially reduce the signal for only a small portion of the sample, resulting in an NTL curve indicating partial (low temperature) heating. However, the small dimensions of the sampled items made it necessary to examine whether the high temperature TL of the samples can be bleached by sunlight, and if so, whether this can be distinguished from ancient heating (discussed below).

After sawing, the samples were gently crushed in a steel mortar, then dry sieved and etched with 10% HCl. Finally, the grains (100-160 μm) were fixed on discs with silicone spray. A heating rate of 10°C s^{-1} was employed, with an immediate subtraction of the background for each disc. The detection window of the bi-alkaline PMT was limited to the UV-blue wavelengths by a BG-25 filter. All measurements were performed in a N_2 atmosphere.

Spatial Considerations and Spatial Plotting

Which circumstances could introduce burned material to the archaeological horizons? We have considered two possible scenarios. The first of this is that natural fires occurred on the paleo-lake shores. In such a case, we would expect to find high frequencies of burned items, *scattered* all over the excavated area. In the second case, hominids carried out knapping activities near hearths, which resulted in accumulations of small-sized debris in these areas, some/all of which were subjected to burning. In such a case, we would expect to find relatively low frequencies of burned items, densely *clustered*.

Since the charred botanical finds could not serve as a spatial indicator (because of their smaller specific gravity and the proximity of the occupation to water), spatial distribution was examined for the flint microartifacts in order to determine whether the burned items display clustering rather than sporadic distribution.

As most microartifacts are assigned a grid reference of sub-square precision (X and Y are 50 cm^2), plotting them spatially required us to assign each of these pieces a ran-

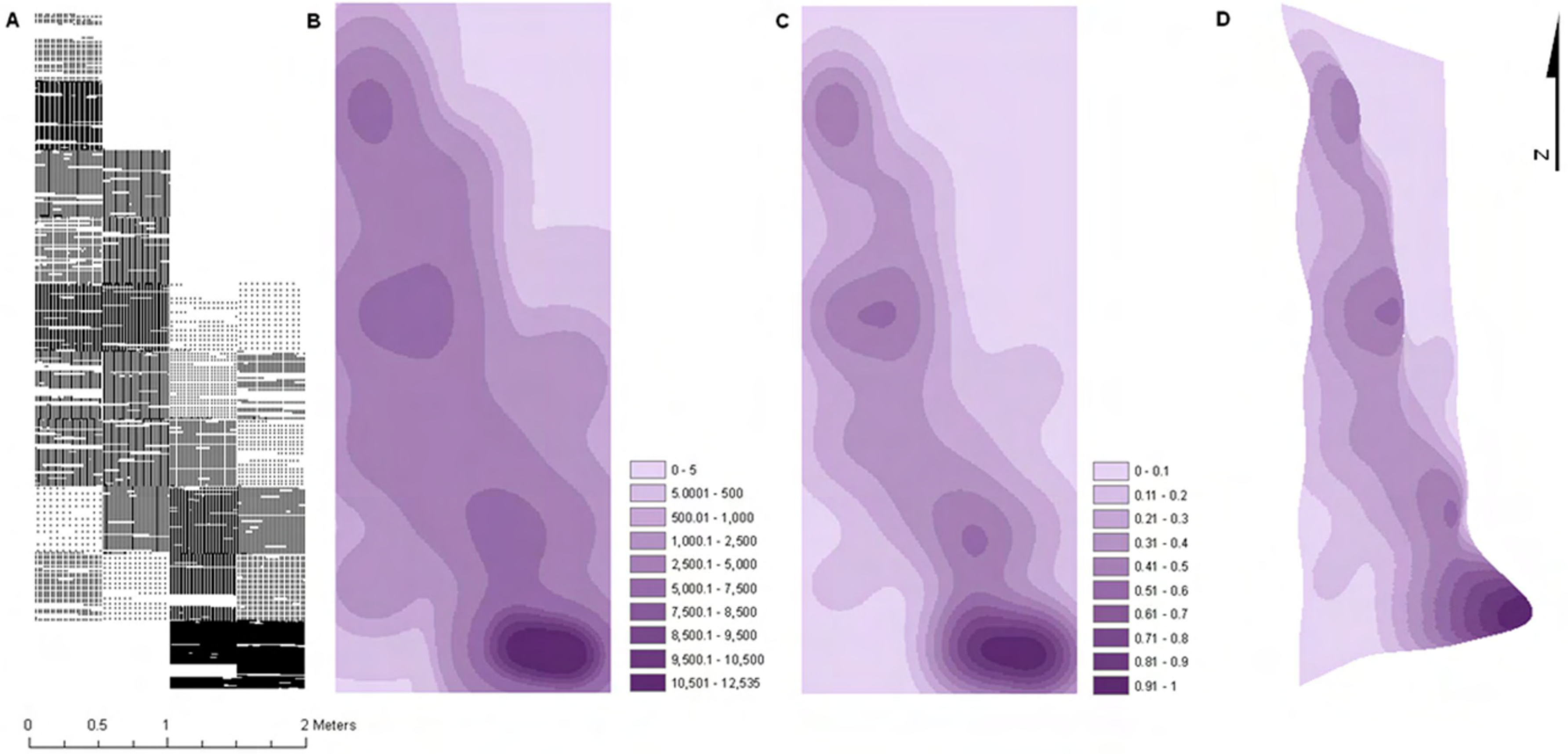

Figure 5. The stages of building density maps, demonstrated using the assemblage of unburned flint microartifacts from Layer V-5. A: point-plotted distribution map; B: density map; C: standardized density map; D: standardized density map in which densities are represented as three-dimensional surfaces.

dom reference point in their quadrant (with *Visual Basic* programming). Such a procedure, in which the spatial reference of excavated material is converted from a general quadrant area into point-plotted items, has been shown to provide reliable distribution patterns (Gilead 2002). Using the ArcGIS 8.2 application (available in the GIS package), the flint microartifacts were point-plotted to form regular distribution maps (Figure 5A). Because of the large quantities of microartifacts, it was not possible to distinguish areas of high density within the general distribution pattern. Thus, the point-plotted distribution maps were converted into density maps (Figure 5B). In order to create a uniform scale (from 0 to 1) that will enable comparison between the different data sets (i.e., burned vs. unburned), the densities have been standardized by the maximum values of each data set (Figure 5C). Finally, in order to give emphasis to areas of high density, the density maps were converted into a three-dimensional representation in which the densities are depicted as three-dimensional surfaces (Figure 5D).

RESULTS

THERMOLUMINESCENCE MEASUREMENTS

In order to determine whether the flint items were heated in antiquity, a number of discs received a β-dose in an external irradiator. They were then measured (NTL+β) together with unirradiated (NTL) discs one week later (Figure 6A). With one exception (Table 2), all samples show a single peak at about 380°C and a heating plateau extending around the NTL peak temperature (Figure 6B). This clearly indicates a zeroing or at least severe reduction of the high temperature TL in the geologically recent history of these eight flint items (Table 2).

Bleaching Experiment

In order to verify that the zeroing was caused by thermal rather than optical processes, a bleaching experiment was performed using both unmeasured and measured NTL discs. In the former, the measurements were performed on bleached and unexposed material, whereas for the latter, a dose was given and some of the discs were then exposed to light. Sun bleaching was simulated by a two-hour exposure to a sunlight simulator (SOL-2 + Uvilex filter). Measurements were performed several days later under the above conditions with an added normalization measurement. No differences were found for the high temperature region between previously measured and unmeasured discs.

The simulation failed to bleach the high temperature TL for all samples (Figure 7A), though a few samples did show a reduced signal for lower temperature peaks (≤300°C). Ratios of unbleached to bleached TL are close to unity, forming a plateau over the peak temperature (Figure 7B). The peak temperatures of the exposed TL were, except for the less stable low-temperature peaks, at the same temperatures as the unexposed NTL. This is an additional indication that the laboratory heating was not the first exposure of the samples to high temperatures, pointing to a heating event in antiquity. Thus, it appears that the high temperature signal of these opaque samples cannot be easily bleached (e.g., by sunlight exposure during excavation).

The TL analysis thus shows that bleaching of the high temperature TL of these samples could not have been achieved by exposure to sunlight. The samples therefore must have been exposed to the high temperatures of a fire in antiquity.

The increase of the TL signal with dose in these samples was significant, indicating that they have not reached their saturation point but are probably close to it. A rough approximation of the palaeodoses gave values of 300–700 Gy, pointing to the antiquity of the site. Despite the antiquity of the heating event, the signal increase shows that these samples are datable by TL methods. Because of the small size of the samples, a recently developed special technique will be applied (Richter and Krbetschek 2006; Richter and Temming 2006).

SPATIAL DISTRIBUTION

A large quantity of flint microartifacts was retrieved from both layers. Nevertheless, the frequencies of *burned* items are low, reaching no more than 2% of the total flint assemblage in each of the layers (Table 1).

The density maps illustrate that the unburned flint microartifacts in Layer V-5 form a single cluster, located in the layer's southeastern area. The burned microartifacts were found in two clusters, one also in the southeast and the other in the northwest. Together, these two clusters contain more than 50% of all the burned microartifacts in this layer (Figure 8A-B). In Layer V-6, unburned flint microartifacts were found spread from the center of the excavated area to the northwest. More than 60% of the burned microartifacts in this layer were found clustered in two concentrations, both located in the center of the excavated area (Figure 8C-D).

These results indicate that the burned and unburned flint microartifacts are not distributed identically, and that their areas of distribution overlap only partially. Moreover, in those clusters where burned flint microartifacts occur, they outnumber the unburned ones, despite the greater overall quantities of the latter. Such multiple clustering suggests that the burning occurred in specific localities and that post-depositional processes (caused, for example, by water waves or currents) had a limited taphonomic effect on the original location of the microartifacts. Based on these results, we suggest that the clustering of the burned microartifacts indicates the original location of Acheulian hearths.

DISCUSSION AND CONCLUSIONS

THE ORIGIN OF FIRE

The identification of burned flint microartifacts (which exhibit macrofractures typical of fire deformation) received independent verification from the TL analysis, clearly attesting to the presence of fire at Gesher Benot Ya`aqov. As mentioned above, two alternative scenarios could have resulted in burned material at the site: natural fire and hu-

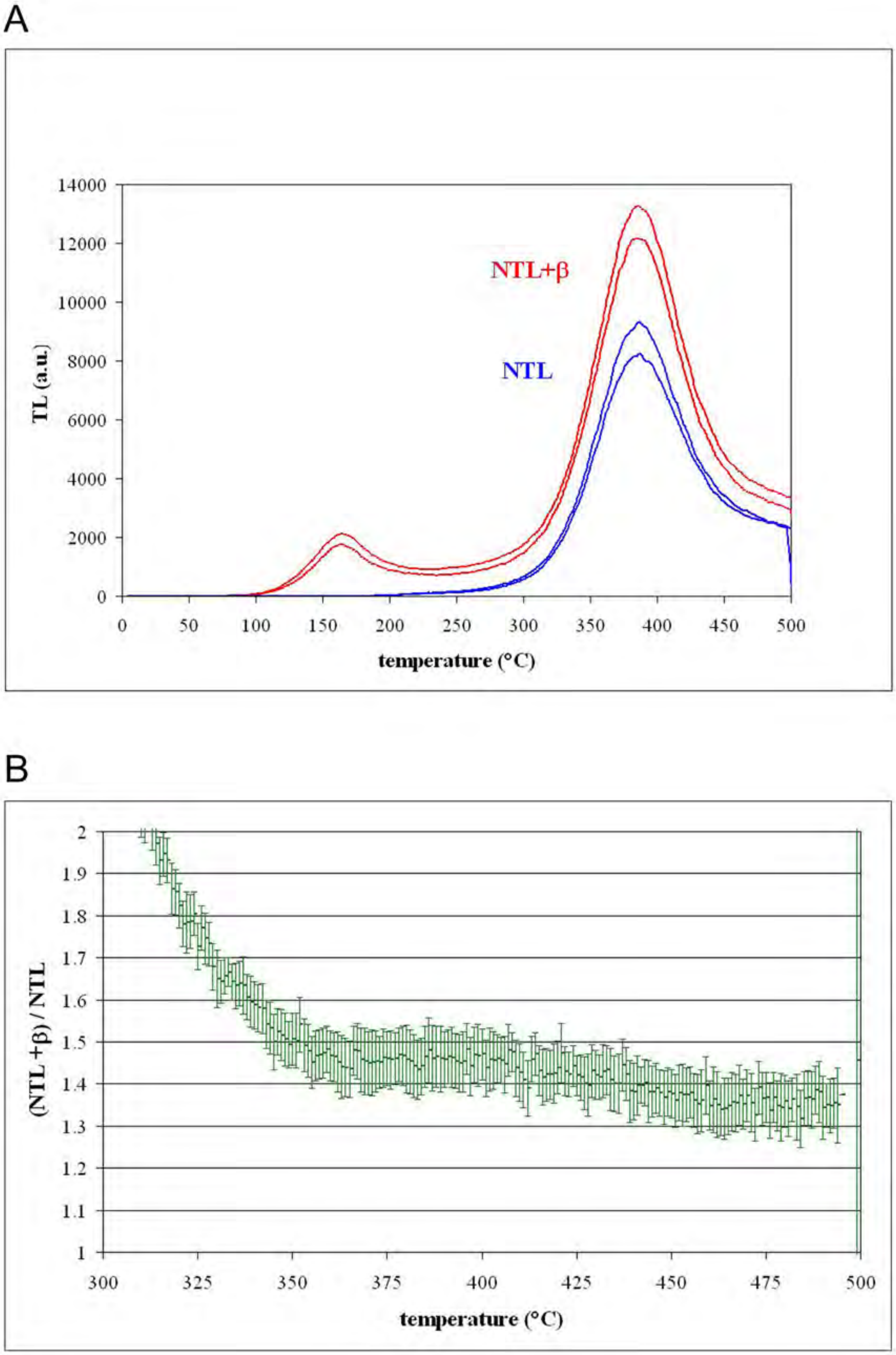

Figure 6. Thermoluminescence (TL) measurements of sample GBY-4 as an example: A, NTL and NTL+β glow curves; B, ratio NTL+β / NTL for 300-500°C, giving a heating plateau of 360–410 °C.

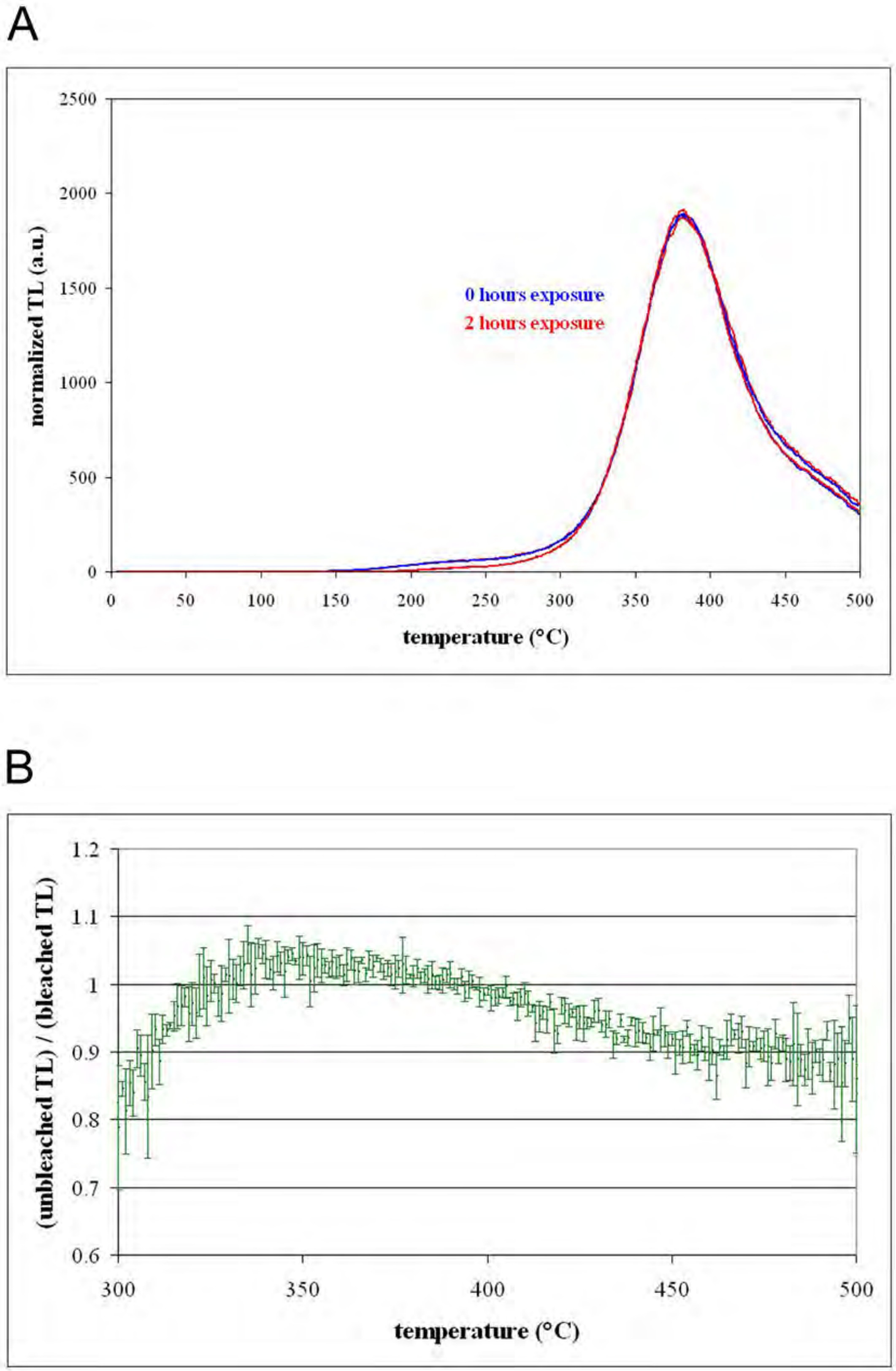

Figure 7. Bleaching of natural discs from sample GBY-4: A, normalized glow curves of NTL (blue) and after two hours (red) of bleaching (note that curves for two discs each are shown); B, ratio of unbleached / bleached TL versus temperature shows a plateau from 340–390°C.

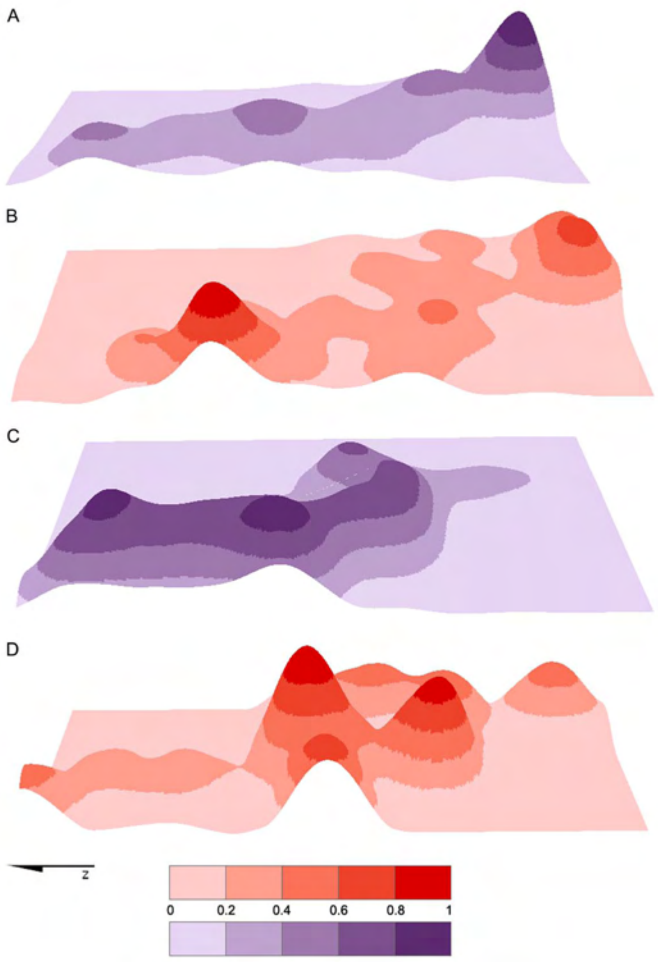

Figure 8. Three-dimensional illustration of the relative densities of flint microartifacts in Area C (20 m^2*), Gesher Benot Ya`aqov. A, Layer V-5, unburned microartifacts; B, Layer V-5, burned microartifacts; C, Layer V-6, unburned microartifacts; D, Layer V-6, burned microartifacts. Relative densities have been standardized by the maximum values of each data set. Densities are represented as surfaces.*

man controlled fire (i.e., hearths).

We considered three types of natural fire: peat fire, volcanic fire, and wildfire. The stratigraphic sequence rules out both peat and volcanic fires; although burned items appear throughout the Acheulian horizons, peat is present in a single thin stratum (stratigraphically much deeper than Layers V-5 and V-6), and there is no evidence of contemporaneous volcanic activity through the depositional sequence in the study area. The most probable type of natural fire in this region would be surface (Kimmins 1997, p. 297) wildfire (Whelan 1995), resulting from natural ignition and combustion. Lightning is the major cause of wildfires in the Mediterranean zone (Whelan 1995). In the present-day Hula Valley, lightning storms are most common from October to March (data from the Israel Meteorological Service); however, at that time of year (the rainy season), very few spontaneous fires occur (Whelan 1995: 26). The Mediterranean wood species identified at the site (Goren-Inbar et al. 2002b) and other paleobiological evidence (e.g., remains of mollusks, crabs, fish, and mammals) strongly suggest that the seasonal climate pattern in the present-day Hula Valley resembles the pattern at the time of deposition. During a wildfire, the highest temperatures occur at the level of the grass canopy, and temperatures in such fires can reach 550°C (Whelan 1995), hot enough to damage flint. Were surface wildfires responsible for the burning of the organic and inorganic material, we would expect to find high frequencies of burned items. However, less than 2% of the excavated flint pieces and wood fragments (charcoal: Goren-Inbar et al. 2004; wood: Goren-Inbar et al. 2002b) are burned. Furthermore, the Gesher Benot Ya`aqov layers yielded large quantities of unburned wood, which was most likely driftwood (Goren-Inbar et al. 2002b)—an excellent fuel that would have fanned any wildfire. Yet another possibility is underground wildfires (such as burning roots and stumps). However, peak temperatures of fires occurring at 2.5 cm below the surface are less than 100°C (Whelan 1995, p. 16) and thus are unlikely to have damaged subsurface flint artifacts at Gesher Benot Ya`aqov.

Another important aspect to be considered is the fact that the efficiency of combustion is largely determined by the moisture level of the fuel and its surrounding soil. At Gesher Benot Ya`aqov, all occupation episodes were on the lake edge. This is highly significant, since soil moisture appears to have a substantial influence on the dynamics of heat transfer (Whelan 1995). In wet deposits, such as in the waterlogged site of Gesher Benot Ya`aqov, moisture reduces underground temperatures. When the surface temperature exceeds the boiling point of water, evaporation delays heating of the underlying soil (Whelan 1995). Thus, moisture increases the amount of heat required. Before a fire can become self-sustaining, sufficient heat must be absorbed by fuels to evaporate much of the water and make it flammable. Accordingly, "*excess heat-absorbing water… can result in a failure of a fire to ignite*" (DeBano 1998:21). Moisture in fuels increases their ignition time and decreases their burning rate. In short, "*dry fuels burn hot, completely and quickly, while moist fuels either do not burn or do so slowly and at lower temperatures*" (DeBano 1998:28). Only continuous conditions of moisture in the depositional environment can explain the unique preservation of seeds, fruits, nuts, grains and the large quantities of unburned wood at the site.

The paucity of burned items, their clustered distributions, and the fact that these are repetitively observed in two occupation levels call for an interpretation other than naturally caused fire. Rather, they suggest that hominids were the agent responsible. Drawing from the vast ethnographic evidence, we interpret the presence of clustered burned flint microartifacts as indications of hearths.

Hearth-Related Spatial Patterns

Human activities are spatially patterned and the fact that humans tend to carry out a vast range of activities in close vicinity to hearths is widely documented. The hearth assembles the social group and is the area in which social interactions, tool production, food processing, food consumption, and ritual ceremonies are carried out (e.g., Binford 1983, 1998; Galanidou 1997, 2000; Spurling and Hayden 1984; Yellen 1977). While a large range of activities (e.g., social interactions) leaves no tangible evidence for us to uncover, other activities (e.g., tool making and food processing) contribute directly to the formation of the archaeological record. Brooks and Yellen (1987) defined *procurement*, *processing*, *consumption* and, *manufacturing* as principal "*debris-generating*" behaviors. The latter involves the manufacturing of artifacts and is strongly associated with hearths (Brooks and Yellen, 1987: 82).

Hearths not only serve as spatial spots of accumulation but they influence the patterns of distribution of certain size groups of the assemblage. Binford (1978, 1983) suggested that in working around a hearth, the formation of certain spatial patterns appears to be universal. More specifically, the distribution of debris often displays two concentric zones around the hearth: the *drop zone* in proximity to the hearth, where small fragments of bone/stone are left in situ (*residual primary refuse* in the terminology of Schiffer [1972, 1987]), and the *toss zone*, an area further away from the hearth to which the larger debris is tossed (*secondary refuse* in the terminology of Schiffer [1972]). Thus the area closest to the hearth is likely to display high quantities of small in situ refuse.

The fact that small items are left in their original location while large items tend to be removed was reported as early as 1961 in Green's pioneering study of discard patterns (Green 1961: 91). Notwithstanding, spatial analysis studies often concentrate on the larger refuse and features, despite the fact that "*…the data most likely to be informative…are very small refuse items, such as chipping debris, small bone fragments, and plant macrofossils, which will often be found in primary context*" (O'Connell 1987: 104). Smaller refuse is more likely to be found in situ for several reasons: small items are less visible and are more likely to be missed during refuse clearance and preventive maintenance of the activity area (e.g., DeBoer 1983; Schiffer 1987), their small dimensions make them less hazardous (e.g., Clark 1991; Hayden and Cannon 1983), and they are more prone to trampling and thus penetrate deeper into the occupation surfaces (see DeBoer 1983 for a detailed discussion).

What is Considered Small?

The fact that small refuse is more likely to be left in situ than large refuse is known as "Mckellar's principle" (first published in Schiffer 1976: 188). Mckellar's work on the litter of the University of Arizona campus indicated that there is a critical size factor in refuse disposal patterns. She found that items above 9 cm were consistently tossed into trash cans, while smaller items were left behind as primary refuse (Rathje 1979: 10; Schiffer 1976: 188, 1987: 62). Mckellar's principle has been confirmed in a variety of ethnoarchaeological settings (e.g., Schiffer 1987: 62 and references therein; Stevenson 1991 and references therein). However, while the general principle has been widely adopted, no conventional limit has been defined for the critical size factor. In other words, what is considered small? One extreme would be particles smaller than 1 mm (*microdebitage* in the terminology of Fladmark [1982], referring only to stone knapping products). Under a microscope, microdebitage can be further divided into *microflakes* and *microchunks* (Vance 1987). A maximum size of 2 mm, *microartifacts* in the terminology of Stein (Dunnell and Stein 1989; Stein and Teltser 1989, referring to all archaeological residues), has also been suggested. These microartifacts have been found to be significant in the study of both natural (see Dunnell and Stein 1989) and cultural formation processes (e.g., lithic manufacturing and discard: Hull 1987; duration of occupation: Simms 1988). Other studies set the limit at 2.5 mm (Metcalfe and Heath 1990), 6 mm (Austin et al. 1999), 10 mm (Nadel 2001), 25 mm (DeBoer 1983) or 50 mm (O'Connell 1987). Nevertheless, the various studies all share the view that small-dimensioned items are essential components in the reconstruction of site structure and are optimal indicators of activity areas (Hayden and Cannon 1983: 134; Cessford 2003: 3; Schiffer 1987: 94; Simms 1988: 208).

In conclusion, ethnographic observations have set the foundations of site structure reconstruction, which is based on the recognition that the association between features (i.e., hearths) and artifact distribution can provide the contextual framework of artifact concentrations (Simek 1984). Consequently, in attempting to reconstruct the formation process of hearth-related spatial patterns, we can draw on the following assertions:

1. A wide range of activities is carried out in close proximity to hearths.
2. Hearths are spatial spots of refuse accumulation.
3. Small refuse is more likely than large refuse to be left in situ.
4. Hearths are thus likely to display dense concentrations of small-sized refuse.

Archaeological evidence of similar hearth-related discard patterns has been reported as early as the Middle Paleolithic (Vaquero and Pasto 2001) and from a variety of archaeological settings. These include open-air sites (e.g., Goring-Morris 1988, in prep; Hietala 1983), rockshelters, and cave sites (e.g., Galanidou 1997), in all of which the hearths are easily identifiable features.

Phantom Hearths

Hearths are spatially bounded features. When uncovered in archaeological sites they often display particular and varied characteristics of color, size, contour, depth, and the use of stones for construction. In addition, serving as focal points of activities, hearths display areas of refuse accumulation, specifically small refuse. These patterns are evident when we examine sites in which the hearths are well preserved. Here we are concerned with *phantom hearths* that display no directly observable features. Leroi-Gourhan's definition of *structures latentes* established the approach to such archaeological features, namely that these can be evident through observable patterns of artifacts' spatial distributions (Leroi-Gourhan and Brezillon 1972). Considering the hearth-related spatial patterning discussed above, we may assume that clusters of debris, specifically small burned debris, are indicators of hearths. If we were to pursue the location of the hearths, we should be able to trace it in the center of these concentrations. At Belvédère quarry (Netherlands), for example, clusters of burned artifacts suggested the presence of a hearth in the center of such a concentration (Stapert 1990). At the Magdalenian sites of Champréveyres and Monruz (Switzerland), hearths are characterized by various amounts of cobbles, stone slabs, and extremely abundant and well-preserved wood charcoal (Leesch et al. 2005). Regardless of the remarkable preservation of these sites, the spatial distribution of burned flint microartifacts has proved to be an optimal indicator for the precise location of the hearths, illustrating "*…the legitimacy of mapping the burned flint chips to locate the combustion areas*" . Interestingly, Leesch et al. (2005) have further observed that "*…the burned and unburned flint chips…are found regularly together in the hearth residues.*"

Similarly, the spatial analysis of flint microartifacts from Gesher Benot Ya`aqov has delimited clusters of small-sized burned items, interpreted here as remnants of hearths.

In conclusion, this study suggests that the Acheulian hominids who frequented the shores of paleo-Lake Hula for thousands of years knew how to use fire and exercised that knowledge repeatedly throughout the archaeological sequence. In addition, the Gesher Benot Ya`aqov evidence of fire use, currently the oldest known from Eurasia, suggests that hearth-related social behavior may be of greater antiquity than was previously assumed.

ACKNOWLEDGMENTS

This research was conducted in the framework of a center of excellence supported by THE ISRAEL SCIENCE FOUNDATION (grant No. 300/06). The Irene Levi-Sala Care Archaeological Foundation, the LSB Leakey Foundation, the German-Israeli Foundation for Scientific Research and Development (GIF), and two grants from the Hebrew University of Jerusalem supported the laboratory analysis. The LSB Leakey Foundation and National Geographic Society supported the fieldwork at Gesher Benot Ya`aqov.

We thank the Gesher Benot Ya`aqov staff and students at the Institute of Archaeology, the Hebrew University of Jerusalem, for sorting the sediments and identifying burned flint microartifacts: Irena Laschiver, Hadas Motro, Talia Goldman, Natalia Gubenko, Chantal Lilly-Tafber, and Keren Finkelstein.

The authors wish to thank Adi Ben-Nun (GIS Center, Hebrew University) and Sue Gorodetsky. Thanks go to Anna Belfer-Cohen and Isaac Gilead for reading an earlier draft of this paper.

DR would like to thank Prof. G.A. Wagner and Dr. A. Kadereit for the permission to use the facilities in Heidelberg, and S. Lindauer (Bsc) for her help with the measurements.

REFERENCES

Aitken, M. J. 1985. *Thermoluminiscence Dating*. Academic Press, London.

Albert, R. M., O. Bar-Yosef, L. Meignen and S. Weiner. 2003. Quantitative phytolith study of hearths from the Natufian and Middle Palaeolithic levels of Hayonim Cave (Galilee, Israel). *Journal of Archaeological Science* 30: 461–480.

Albert, R. M., O. Lavi, L. Estroff, S. Weiner, A. Tsatskin, A. Ronen and S. Lev-Yadun. 1999. Mode of occupation of Tabun Cave, Mt. Carmel, Israel during the Mousterian period: A study of the sediments and phytoliths. *Journal of Archaeological Science* 26: 1249–1260.

Albert, R. M., S. Weiner, O. Bar-Yosef and L. Meignen. 2000. Phytoliths in the Middle Palaeolithic deposits of Kebara Cave, Mt. Carmel, Israel: Study of the plant materials used for fuel and other purposes. *Journal of Archaeological Science* 27: 931–947.

Austin, L. A., C. A. Bergman, M. B. Roberts and K. H. Wilhelmsen. 1999. Archaeology of excavated areas. In *Boxgrove: A Middle Pleistocene Hominid Site at Eartham Quarry, Boxgrove, West Sussex*, edited by M. B. Roberts and S. A. Parfitt, pp. 312–377. English Heritage, London.

Barbetti, M. 1986. Traces of fire in the archaeological record before one million years ago? *Journal of Human Evolution* 15: 771–781.

Bellomo, R. V. 1993. A methodological approach for identifying archaeological evidence of fire resulting from human activities. *Journal of Archaeological Science* 20: 525–553.

Bellomo, R. V. 1994. Early Pleistocene fire technology in Northern Kenya. In *Society Culture and Technology In Africa*, edited by T. S. Childs, pp. 17–28. vol. II. University of Pennsylvania, Philadelphia.

Bellomo, R. V. and J. W. K. Harris. 1990. Preliminary report of actualistic studies of fire within Virunga National Park, Zaire: Towards an understanding of archaeological occurrences. In *Evolution of Environments and Hominidae in the African Western Rift Valley*, edited by N. T. Boaz, pp. 317–338. Virginia Museum of Natural History, Martinsville.

Bennet, J. L. 1999. Thermal alternation of buried bone. *Journal of Archaeological Science* 26: 1–8.

Binford, L. R. 1978. Dimensional analysis of behavior and site structure: Learning from an Eskimo hunting stand. *American Antiquity* 43(3): 330–361.

Binford, L. R. 1983. *In Pursuit of the Past: Decoding the Archaeological Record*. Thames and Hudson, London.

Binford, L. R. 1998. Hearth and home: the spatial analysis of ethnographically documented rock shelter occupations as a template for distinguishing between human and hominid use of sheltered space. In *XIII U.I.S.P.P Congress Proceedings, Forli 8-14 September 1996*, pp. 229–239. A.B.A.C.O. Edizioni, Forli.

Bischoff, J. L., M. Ikeya and F. E. Budinger. 1984. A TL/ESR study of the hearth feature at the Calico archaeological site, California. *American Antiquity* 49(4): 764–774.

Bonhomme, T. and J. Stanley. 1985. Magnetic mapping of prehistoric Aboriginal fireplaces at Bunda Lake, Belarabon Station, Western New South Wales. *Australian Archaeology* 21: 63–73.

Brain, C. K. and A. Sillen. 1988. Evidence from the Swartkrans Cave for the earliest use of fire. *Nature* 336: 464–466.

Brooks, A. S. and J. E. Yellen. 1987. The preservation of activity areas in the archaeological record: Ethnoarchaeological and archaeological work in Northwest Ngamiland, Botswana. In *Method and Theory For Activity Area Research: An Ethnoarchaeological Approach*, edited by S. Kent, pp. 63–106. Columbia University Press, New York.

Callow, P., D. Walton and C. A. Shell. 1986. The use of fire at La Cotte de St. Brelade. In *La Cotte de St. Brelade 1961-1978. Excavations by C. B. M. McBurney*, edited by P. Callow and J. M. Cornford, pp. 193–195. Geo Books, Norwich.

Canti, M. G. and N. Linford. 2000. The effects of fire on archaeological soils and sediments: temperature and colour relationships. *Proceedings of the Prehistoric Society* 66: 385–395.

Cessford, C. 2003. Microartifactual floor patterning: the case at Catalhoyuk. *Assemblage* 7: 1–13. http://www.shef.ac.uk/assem/issue7/cessford.html.

Clark, J. D. 2001. Modified, used and other wood and plant specimens from Bwalya Industry Acheulean horizons. In *Kalambo Falls Prehistoric Site III The Earlier Cultures: Middle and Earlier Stone Age*, edited by J. D. Clark, pp. 481–491. Cambridge University Press, Cambridge.

Clark, J. D. and J. W. K. Harris. 1985. Fire and its roles in early hominid lifeways. *The African Archaeological Review* 3: 3–27.

Clark, J. E. 1991. Flintknapping and debitage disposal among the Lacandon Maya of Chiapas, Mexico. In *The Ethnoarchaeology Of Refuse Disposal*, edited by E. Staski and L. D. Sutro, pp. 63–78. Anthropological Research Papers No. 42. Arizona State University, Arizona.

DeBano, L. F., D. G. Neary and P. F. Ffolliott. 1998. *Fire's Effects on Ecosystems*. John Wiley & Sons, Inc, New York.

DeBoer, W. R. 1983. The archaeological record as preserved death assemblage. In *Archaeological Hammers and Theories*, edited by J. A. Moore and A. S. Keene, pp. 19–36. Academic Press, New York.

Dunnell, R. C. and J. K. Stein. 1989. Theoretical issues in the interpretation of microartifacts. *Geoarchaeology* 4(1): 31–42.

Elbaum, R., S. Weiner, R. M. Albert and M. Elbaum. 2003. Detection of burning of plant materials in the archaeological record by changes in the refractive indices of siliceous phytoliths. *Journal of Archaeological Science* 30: 217–226.

Feibel, C. S. 2001. Archaeological sediments in lake margin environments. In *Sediments in Archaeological Contexts*, edited by J. K. Stein and W. R. Farrand, pp. 127–148. University of Utah Press, Salt Lake City.

Feibel, C. S. 2004. Quaternary lake margins of the Levant Rift Valley. In *Human Paleoecology in the Levantine Corridor*, edited by N. Goren-Inbar and J. D. Speth, pp. 21–36. Oxbow Books, Oxford.

Fladmark, K. R. 1982. Microdebitage analysis: Initial considerations. *Journal of Archaeological Science* 9: 205–220.

Freeman, L. G. 1975. Acheulean sites and stratigraphy in Iberia and the Magreb. In *After the Australopithecines. Stratigraphy, Ecology, and Culture Change in the Middle Pleistocene*, edited by K. W. Butzer and G. L. Isaac, pp. 661–743. Mouton Publishers, Hague.

Galanidou, N. 1997. *'Home is where the hearth is': the spatial organization of the Upper Palaeolithic rockshelter occupations at Klithi and Kastritsa in Northwest Greece*. BAR International Series 687. BAR, Oxford.

Galanidou, N. 2000. Patterns in caves: foragers, horticulturists, and the use of space. *Journal of Anthropological Archaeology* 19: 243–275.

Gilead, I. 2002. Too many notes? virtual recording of artifacts provenance. In *Virtual Archaeology*, edited by F. Niccolucci, pp. 41–43. BAR International Series 1075, Arezzo.

Göksu, H. Y., A. Wieser, D. F. Regulla and A. Vogenauer. 1990. A routine analysis for the determination of the firing temperature of flint tools. *Archaeometry* 90: 247–265.

Goldberg, P., S. Weiner, O. Bar-Yosef, Q. Xu and J. Liu. 2001. Site formation processes at Zhoukoudian, China. *Journal of Human Evolution* 41: 483–530.

Goren-Inbar, N., N. Alperson, M. E. Kislev, O. Simchoni, Y. Melamed, A. Ben-Nun and E. Werker. 2004. Evidence of hominin control of fire at Gesher Benot Ya`aqov, Israel. *Science* 304(5671): 725–727.

Goren-Inbar, N., C. S. Feibel, K. L. Verosub, Y. Melamed, M. E. Kislev, E. Tchernov and I. Saragusti. 2000. Pleistocene milestones on the out-of-Africa corridor at Gesher Benot Ya`aqov, Israel. *Science* 289(5481): 944–947.

Goren-Inbar, N., A. Lister, E. Werker and M. Chech. 1994. A butchered elephant skull and associated artifacts from the Acheulian site of Gesher Benot Ya`aqov, Israel. *Paléorient* 20(1): 99–112.

Goren-Inbar, N. and I. Saragusti. 1996. An Acheulian biface assemblage from the site of Gesher Benot Ya`aqov, Israel: indications of African affinities. *Journal of Field Archaeology* 23: 15–30.

Goren-Inbar, N., G. Sharon, Y. Melamed and M. Kislev. 2002a. Nuts, nut cracking, and pitted stones at Gesher Benot Ya`aqov, Israel. *PNAS* 99(4): 2455–2460.

Goren-Inbar, N., E. Werker and C. S. Feibel. 2002b. *The Acheulian Site of Gesher Benot Ya`aqov: The Wood Assemblage* 1. Oxbow Books, Oxford.

Goring-Morris, A. N. 1988. Trends in spatial organization of terminal Pleistocene hunter-gatherer occupations as viewed from the Negev and Sinai. *Paléorient* 14(2): 231–244.

Goring-Morris, A. N. in prep. *Prehistoric Investigations in the Western Negev. Part 1: The Shunera Dunes, Givat Hayil, Nahal Sekher and Hamifgash*. Qedem, Monographs of the Institute of Archaeology, Jerusalem.

Goudsblom, J. 1986. The human monopoly on the use of fire: its origins and conditions. *Human Evolution* 1(6): 517–523.

Gowlett, J. A. J., J. W. K. Harris, D. Walton and B. A. Wood. 1981. Early archaeological sites, hominid remains and traces of fire from Chesowanja, Kenya. *Nature* 294: 125–129.

Green, H. J. M. 1961. An analysis of archaeological rubbish deposits. *Archaeological News Letter* 7(4): 91–93.

Harrison, H. S. 1954. Fire-making, fuel, and lighting. In *A History of Technology*, edited by C. Singer, E. J. Holmyard and A. R. Hall, pp. 216–237. vol. I. Clarendon Press, Oxford.

Hayden, B. and A. Cannon. 1983. Where the garbage goes: refuse disposal in the Maya highlands. *Journal of Anthropological Archaeology* 2: 117–163.

Hedgcock, F. T., H. Marshall, G. W. Berger and P. E. L. Smith. 1988. Burnt stones from ancient fires. In *Proceedings of the 26th International Archaeometry Symposium*, edited by R. M. Farquhar, R. G. V. Hancock and L. A. Pavlish, pp. 48–52. University of Toronto, Toronto.

Hietala, H. 1983. Boker Tachtit: spatial distributions. In *Prehistory and Paleoenvironments in the Central Negev, Israel*, edited by A. E. Marks, pp. 191–216 vol. III. Southern Methodist University, Dallas.

Hillman, G. C., G. V. Robins, D. Oduwole, K. D. Sales and D. A. C. McNeil. 1983. Determination of thermal histories of archeological cereal grains with Electron Spin Resonance Spectroscopy. *Science* 222: 1235–1236.

Howell, F. C. 1966. Observations on the earlier phases of the European Lower Paleolithic. In *Recent Studies In Paleoanthropology*, edited by J. D. Clark and F. C. Howell, pp. 88–201. American Anthropologist. vol. 68 (2). American Anthropological Association, Wisconsin.

Hull, K. L. 1987. Identification of cultural site formation processes through microdebitage analysis. *American Antiquity* 52(4): 772–783.

Huxtable, J. and M. J. Aitken. 1985. Thermoluminescence dating results for the Palaeolithic site Maastricht Belvédère. In *Maastricht Belvédère: Stratigraphy, Palaeoenvironment and Archaeology of the Middle and Late Pleistocene Deposits.*, edited by T. V. Kolfschoten and W. Roebroeks, pp. 41–44. vol. 18. Analecta Praehistoria Leidensia.

James, S. R. 1989. Hominid use of fire in the Lower and Middle Pleistocene. *Current Anthropology* 30(1): 1–26.

Jordanova, N., E. Petrovsky, M. Kovacheva and D. Jordanova. 2001. Factors determining magnetic enhancement of burnt clay from archaeological sites. *Journal of Archaeological Science* 28: 1137–1148.

Julig, P. J., D. G. F. Long, B. Schroeder, W. J. Rink, D. Richter and H. P. Schwarcz. 1999. Geoarchaeology and new research at Jerf al-Ajla Cave, Syria. *Geoarchaeology* 14: 821–848.

Karkanas, P., J.-P. Rigaud, J. F. Simek, R. M. Albert and J. S. Weiner. 2002. Ash bones and guano: a study of the minerals and phytoliths in the sediments of Grotte XVI, Dorgogne, France. *Journal of Archaeological Science* 29: 721–732.

Kimmins, J. P. 1997. *Forest Ecology*. Prentice Hall, New Jersey.

Leesch, D., J. Bullinger, M.-I. Cattin, W. Müller and N. Plumettaz. 2005. Hearths and hearth-related activities in Magdalenian open-air sites: the case studies of Champréveyres and Monruz (Switzerland) and their relevance to an understanding of Upper Paleolithic site structure. Paper presented at *The Magdalenian in Central Europe: New Finds and Concepts*, 20–23 September 2005, Rzeszów, Poland.

Leroi-Gourhan, A. and M. Brezillon. 1972. *Fouilles de Pincevent: Essai d'Analyse Ethnographique d'un Habitat Magdalenien*. Editions du C.N.R.S., Paris.

Linford, N. T. and M. G. Canti. 2001. Geophysical evidence for fires in antiquity: preliminary results from an experimental study. Paper given at the EGS XXIV general assembly in the Hague, April 1999. *Archaeological Prospection* 8: 211–225.

Metcalfe, D. and K. M. Heath. 1990. Microrefuse and site structure: the hearths and floors of the Heartbreak Hotel. *American Antiquity* 55(4): 781–796.

Michab, M., H. Valladas, L. Forget and N. Mercier. 1998. Distinguishing burnt from partly bleached unburnt quartz pebbles of Pedra Furada, Brazil. *Ancient TL* 16: 5–9.

Nadel, D. 2001. Indoor/outdoor flint knapping and minute debitage remains: The evidence from the Ohalo II submerged camp (19.5 KY, Jordan Valley). *Lithic Technology* 26(2): 118–137.

Nicholson, R. A. 1993. A Morphological Investigation of Burnt Animal Bone and an Evaluation of its Utility in Archaeology. *Journal of Archaeological Science* 20: 411–428.

Oakley, K. 1956. Fire as Palaeolithic tool and weapon. *Proceedings of the Prehistoric Society* 21: 36–48.

Oakley, K. P. 1961. On man's use of fire, with comments on tool-making and hunting. In *Social Life Of Early Man*, edited by S. L. Washburn, pp. 176–193. Aldine, Chicago.

O'Connell, J. F. 1987. Alyawara site structure and its archaeological implications. *American Antiquity* 52(1): 74–108.

Olive, M. and Y. Taborin (editors). 1989. *Nature et Fonction des Foyers Préhistoriques*. Association Pour la Promotion de la Recherche Archéologique en Ile de France, Nemours.

Purdy, B. A. 1975. Fractures for the archaeologist. In *Lithic Technology: Making and Using Stone Tools*, edited by E. Swanson, pp. 133–141. Mouton Publishers, Paris.

Purdy, B. A. 1982. Pyrotechnology: Prehistoric application to chert materials in North America. In *Early Pyrotechnology: The Evolution of the First Fire-Using Industries*, edited by T. A. Wertime and S. F. Wertime, pp. 31–44. Smithsonian Institution Press, Washington.

Purdy, B. A. and H. K. Brooks. 1971. Thermal alternation of silica minerals: An archeological approach. *Science* 173: 322–325.

Rathje, W. L. 1979. Modern material culture studies. *Advances in Archaeological Method and Theory* 2: 1–37.

Richter, D. 1998. *Thermolumineszenzdatierungen erhitzter*

Silices aus paläolithischen Fundstellen. Anwendung und methodische Untersuchungen. unpublished PhD, University of Tübingen.

Richter, D. and M. Krbetschek. 2006. A new Thermoluminescence dating technique for heated flint. *Archaeometry* 48: 695–705.

Richter, D., B. Schroeder, W. J. Rink, P. J. Julig, D. G. F. Long and H. P. Schwarcz. 2002. The Middle to Upper Palaeolithic transition in the Levant and new TL dates for a Late Mousterian assemblage from Jerf al-Ajla Cave near Palmyra, Syria. *Paléorient* 27: 29–46.

Richter, D. and H. Temming. 2006. Dose recovery tests for heated flint. Testing equivalent dose protocols. *Radiation Measurements* 41: 81–825.

Rowlett, R. M. 2000. Fire control by *Homo erectus* in East Africa and Asia. *Acta Anthropologica Sinica* 19: 198–208.

Schiegel, S., P. Goldberg, O. Bar-Yosef and S. Weiner. 1996. Ash deposits in Hayonim and Kebara caves, Israel: macroscopic, microscopic and mineralogical observations, and their archaeological implications. *Journal of Archaeological Science* 23: 763–781.

Schiegel, S., S. Lev-Yadun, O. Bar-Yosef, A. El-Goresy and S. Weiner. 1994. Siliceous aggregates from prehistoric wood ash: a major component of sediments in Kebara and Hayonim caves (Israel). *Israel Journal of Earth Sciences* 43: 267–278.

Schiffer, M. B. 1972. Archaeological context and systemic context. *American Antiquity* 37(2): 156–165.

Schiffer, M. B. 1976. *Behavioral Archeology*. Academic Press, New York.

Schiffer, M. B. 1987. *Formation Processes of the Archaeological Record*. University of New Mexico Press, Albuquerque.

Sergant, J., P. Crombe and Y. Perdaen. 2006. The 'invisible' hearths: a contribution to the discernment of Mesolithic non-structured surface hearths. *Journal of Archaeological Science* 33(7): 999–1007.

Shahack-Gross, R., O. Bar-Yosef and S. Weiner. 1997. Black-coloured bones in Hayonim Cave, Israel: Differentiating between burning and oxide staining. *Journal of Archaeological Science* 24: 439–446.

Shipman, P., G. F. Foster and M. Scheninger. 1984. Burnt bones and teeth: an experimental study of colour, morphology, crystal structure and shrinkage. *Journal of Archaeological Science* 11: 307–325.

Simek, J. F. 1984. Integrating pattern and context in spatial archaeology. *Journal of Archaeological Science* 11: 405–420.

Simms, S. R. 1988. The archaeological structure of a Bedouin camp. *Journal of Archaeological Science* 15: 197–211.

Skinner, A., J. Lloyd, C. Brain and F. Thackeray. 2004. Electron spin resonance and the first use of fire. Paper presented at the Paleoanthropology society annual meeting, Montreal, Canada.

Spurling, B. and B. Hayden. 1984. Ethnoarchaeology and intrasite spatial analysis: a case study from the Australian Western desert. In *Intrasite Spatial Analysis in Archaeology*, edited by H. J. Hietala, pp. 224–241. Cambridge University Press, Cambridge.

Stapert, D. 1990. Middle Palaeolithic dwellings: fact or fiction? Some applications of the ring and sector method. *Palaeohistoria* 32: 1–19.

Stein, J. K. and P. A. Teltser. 1989. Size distributions of artifact classes: Combining macro-and-micro-fractions. *Geoarchaeology* 4(1): 1–30.

Stevenson, M. G. 1991. Beyond the formation of hearth-associated artifact assemblages. In *The Interpretation of Archaeological Spatial Patterning*, edited by E. M. Kroll and T. D. Price, pp. 269–299. Plenum Press, New York.

Stewart, O. C. 1956. Fire as the first great force employed by man. In *Man's Role in Changing the Face of the Earth*, edited by W. L. Thomas, pp. 115–133. The University of Chicago Press, Chicago.

Stiner, M. C., S. L. Kuhn, S. Weiner and O. Bar-Yosef. 1995. Differential Burning, Recrystallization, and Fragmentation of Archaeological Bone. *Journal of Archaeological Science* 22: 223–237.

Théry-Parisot, I. 2001. *Économie des Combustibles au Paléolithique*. Dossier de Documentation Archaeologique 20. CNRS, Paris.

Thieme, H. 1997. Lower Paleolithic hunting spears from Germany. *Nature* 385: 807–810.

Valladas, H. 1981. Thermoluminescence de grès de foyer préhistoriques: éstimation de leur temperature de chauffé. *Archaeometry* 23: 221–229.

Valladas, H. 1983. Estimation of heating temperature of prehistoric burnt flints by thermoluminescence. *PACT* 9: 251–253.

Valladas, H., G. Valladas, O. Bar-Yosef and B. Vandermeersch. 1991. Thermoluminescence dating of Neanderthal and early humans in the Near East. *Endeavour, New Series* 15: 115–119.

Vance, E. D. 1987. Microdebitage and archaeological activity analysis. *Archaeology* 40(4): 58–59.

Vaquero, M. and I. Pasto. 2001. The definition of spatial units in Middle Palaeolithic sites: The hearth-related assemblages. *Journal of Archaeological Science* 28: 1209–1220.

Vertes, L. and V. T. Dobosi. 1990. Fireplaces of the settlement. In *Vertesszőlős Site, Man and Culture*, edited by M. Kretzoi and V. T. Dobosi, pp. 519–521. Akadémiai Kiadó, Budapest.

Villa, P. 1982. Conjoinable Pieces and Site Formation Processes. *American Antiquity* 47(2): 276–290.

Weiner, S., P. Goldberg and O. Bar-Yosef. 2002. Three-dimensional distribution of minerals in the sediments of Hayonim Cave, Israel: Diagenetic processes and archaeological implications. *Journal of Archaeological Science* 29: 1289–1308.

Weiner, S., Q. Xu, P. Goldberg, J. Liu and O. Bar-Yosef. 1998. Evidence for the use of fire at Zhoukoudian, China. *Science* 281: 251–253.

Whelan, R. J. 1995. *The Ecology of Fire*. Cambridge University Press, Cambridge.

Yellen, J. E. 1977. *Archaeological Approaches to the Present: Models for Reconstructing the Past*. Academic Press, New York.