Continual fire-making by Hominins at Gesher Benot Ya‘aqov, Israel

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Abstract
This paper presents the culmination of an extensive study of fire-use at the Early and early Middle Pleistocene site of Gesher Benot Ya‘aqov. Using software available in the GIS package, we have examined the spatial distribution of burned and unburned flint microartifacts from eight Acheulian archaeological horizons. The results of this study demonstrate that the burned microartifacts are never evenly distributed and dense concentrations are observed. The circumstances that introduced these burned flint artifacts to the archaeological layers are examined, suggesting that anthropogenic rather than natural fires are responsible for the observed patterns. As the evidence for the use of fire is recorded throughout the long stratigraphic sequence, it seems that fire was continually used by the Acheulian hominins of the site. This repetitive use of fire indicates that the hominins of Gesher Benot Ya‘aqov had a profound knowledge of fire-making, enabling them to make fire at will.

1. Introduction

We may never be able to ascertain whether early humans were fire-makers from the beginning, as the early stages of human use of fire may have required humans to collect it from natural conflagrations. The likely accidental discovery of fire gradually evolved into controlled use of fire, providing humans with warmth and light, protection from predators, the ability to exploit a new range of foods, and a variety of behavioral and social benefits. The issue of when humans came to obtain the control of fire is controversial, and evaluation of this point in time is fundamentally an archaeological challenge.

1.1. The Acheulian Site of Gesher Benot Ya‘aqov

New evidence from the site of Gesher Benot Ya‘aqov (GBY) sheds light on the question of the fire-making abilities of ancient hominins. Excavations at the waterlogged site of GBY, located on the shores of the paleo-Lake Hula (Israel), have exposed a long occupational sequence in which 13 archaeological levels are recorded. Sedimentological analyses indicate that the archaeological layers are embedded within a generally fine-grained sedimentary sequence (Fig. 1), documenting rapid shifts in abundance of carbonate and organics, typical of a low-energy fluctuating lake margin environment (Feibel, 2001). Magnetostratigraphic analyses illustrate that the sedimentological sequence of GBY encompasses a change, from reversed magnetic polarity at its base to normal magnetic polarity, correlated with the 0.79 Ma Matuyama-Brunhes chron Boundary (MBB); the entire depositional sequence is assigned to OIS 18–20 and its estimated duration is ca 100,000 years (Goren-Inbar et al., 2000).

Archaeological data indicate that hominins regularly occupied the lake margin, where they produced stone tools, processed meat, and gathered a vast range of plant food, the latter preserved due to the waterlogged environment (Feibel, 2001). The lithic assemblages of GBY encompass a change, from reversed magnetic polarity at its base to normal magnetic polarity, correlated with the 0.79 Ma Matuyama-Brunhes chron Boundary (MBB); the entire depositional sequence is assigned to OIS 18–20 and its estimated duration is ca 100,000 years (Goren-Inbar et al., 2000).
technological similarities to their African counterparts, introducing African stone-knapping traditions into the Levantine Corridor (Goren-Inbar et al., 2000; Saragusti and Goren-Inbar, 2001).

1.2. Phantom hearths

Ethnographic and archaeological observations suggest that the spatial patterning of a variety of activities, including the use of fire in the form of hearths, can be implicit in lithic waste products of small size (Alperson-Afil et al., 2007). The hearth assembles the social group, and social interactions, tool production, food processing, food consumption, and ritual ceremonies are carried out in the area around it. Some activities (e.g. tool making and food processing) contribute directly to the formation of the archaeological record and can be traced through waste products of stone or bone. In addition, particular spatial patterns are attributed to hearth-related activities, where the distribution of waste often displays two concentric zones around the hearth: small waste products in situ in proximity to the hearth and larger waste further away from it (Binford, 1983). Thus, the area closest to the hearth is likely to display high frequencies of small refuse in situ.

These patterns are recorded from a variety of ethnographic and archaeological settings in which the hearths are readily identifiable features (e.g. Gilead, 1980; Goring-Morris, 1988; Vaquero and Pastó, 2001; Leesch et al., 2005; Sergant et al., 2006). Here, however, we are concerned with phantom hearths that display no directly observable features such as charcoal or ash. Such latent features can be traced through observable patterns of spatial distributions (Leroi-Gourhan and Brézillon, 1972). Thus, spatially discerned clusters of small burned material are considered remnants of ancient hearths that are no longer visible.

In this study, possible remnants of hearths are explored through analysis of the spatial distribution of flint-knapping waste products.

2. Materials and methods

Large amounts of knapping waste products were recorded within the archaeological layers of GBY (Table 1). These include flint microartifacts (2–20 mm in length) and macroartifacts (longer than 20 mm) recovered during excavation and through post-excavation sorting of the wet-sieved sediments.

2.1. Excavation methods and provenance recording

Excavations at the site of GBY were carried out with a horizontal 1 × 1 m grid (Israel grid). Subsequent tectonic activity of the Jordan Rift Valley has resulted in tilting of the archaeological strata, so that excavation was conducted along the strike and dip of the tilted layers. This procedure enabled the detailed representation of the spatial organization of each occupation surface. The standard unit of excavation was thus the projection of a 1 m2 grid square on the tilted beds. Each 1 m2 square was further subdivided into four quadrants (i.e. sub-squares) and excavated in spits that covered the area of one sub-square to an average depth of 5 cm.

Once exposed, the surface (i.e. the archaeological horizon) was drawn and items were retrieved with three coordinates (X, Y, and Z; “coordinated pieces”). Other items retrieved during excavation, the “uncoordinated pieces”, were labeled according to the spatial reference of the spit (i.e. sub-square and an elevation range). Such items can thus be located with an exactitude of 0.5 × 0.5 × 0.05 m.

In addition to material retrieved during excavation, the entire excavated sediments embodying the archaeological horizons were wet-sieved during field work by a 2 mm sieve. Sorting of the sieved sediments yielded rich and varied assemblages (e.g. specks of charcoal, fruits, seeds, grains, bones and teeth of micromammals, fish, and crabs).

Most of the small lithic items, which are the principal component of this study, were retrieved through this procedure. As the wet-sieved sediments were retrieved from the field with their recorded spit location, these microartifacts can be located with an exactitude of 0.5 × 0.5 × 0.05 m.

2.2. Analyzed material

The analysis of each of the archaeological layers incorporates items retrieved during excavation as well as from the sorting of the wet-sieved sediments. The flint artifacts included in this study comprise both macroartifacts (>2 cm) and microartifacts (≤2 cm), the latter being the principal component of this study.

2.2.1. Macroartifacts

Unlike macroartifacts, flint microartifacts occur in extremely large quantities in each of the archaeological layers of GBY, thereby providing large enough samples of burned items for spatial analysis. In addition, smaller refuse is considered an excellent spatial marker...
and is more likely to be found in situ, for several reasons: small items are less visible, their small dimensions make them less hazardous (e.g. Hayden and Cannon, 1983; Clark, 1991), and they are more prone to trampling and thus penetrate deeper into the occupation surfaces (see DeBoer, 1983 for a detailed discussion). However, no conventional limit has been defined for the size of microartifacts, in other words, what is considered small? One extreme would be particles smaller than 1 mm (microlithic in the terminology of Fladmark (1982), referring only to stone-knapping products). Under a microscope, microdebitage can be further divided into microflakes and microchucks (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 (e.g. Hull, 1987; Simms, 1988) formation processes. 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 (e.g. Hayden and Cannon, 1983; Schiffer, 1987; Simms, 1988; Cessford, 2003).

In the framework of this study, flint microartifacts are defined as items that are not longer than 2 cm, and that are unquestionably the result of stone-knapping. Thus, natural items (e.g. small pebbles) are excluded. Only items that exhibit characteristic knapping features of flaked material (e.g. ventral face, striking platform) are included in this category and are defined as microartifacts.

2.2.2. Identifying burning damage on flint

Exposure to fire changes the mechanical properties of lithic material. Experimental studies, carried out mostly on flint or chert, demonstrated that exposure to high temperatures (≈350–500 °C) causes microscopically identifiable (i.e. eyeball-observable) alterations such as discoloration, potlid fractures, crazing, and fragmentation (Purdy and Brooks, 1971; Purdy, 1975, 1982; Julig et al., 1999; Sergant et al., 2006). Potlids are small, typically “bowl-shaped” pieces of lithic material that are exfoliated from the surface. Their exfoliation creates a depression (i.e. a potlid fracture) in the artifact from the size of a pinhead to larger (DeBano et al., 1998). Recent experiments have demonstrated that only those artifacts that are in direct contact with the fire and heated to a temperature above 300 °C will eventually show heat damage (Sergant et al., 2006). In sum, only direct exposure of flint to fire results in visible heat damage, and heat damage is diversified and includes a variety of features. We chose to be extremely cautious and consider only items that are unquestionably burned. Therefore, the identification of burned flints had to rely on features that are clear and unique to exposure to fire. The use of discoloration of flint as a distinctive feature for the identification of burning is not a reliable measure for the flints of GBY; embedded within the waterlogged sediments, the majority of flint items are darkly patinated. Thus, of the various heat damage patterns, potlidding is the most distinctive feature and can serve as sufficient evidence for burning.

2.3. Assigning artificial coordinates

A large amount of macroartifacts and the majority of microartifacts were retrieved with a general spatial reference which includes the X and Y quadrant (0.5 × 0.5 m) and depth of spit. This spatial recording allows the representation of relative frequencies of lithic items per excavated unit. Other spatial analyses, such as creating a density map, would necessitate measuring the distances between different features and thus require that the data be depicted as distinct points. It has been suggested that assigning a random spatial reference within the excavated subunit provides a reliable, and almost identical, spatial representation (Gilead, 2002). Taking this into consideration, the Access Visual Basic program was applied and items with a general spatial reference were given a new reference point within their recorded sub-square (see Supplementary data).

2.4. Spatial plotting and density maps

The assignment of artificial coordinates enabled the various databases of lithic material to be used as geographical information that can be integrated into GIS software. ArcMap was used for the spatial display and analyses of the archaeological data in this study. In order to illustrate areas of high-density graphically, the point-plotted data of microartifacts distribution were converted into kernel density maps (see Supplementary data).

2.5. Analyses of spatial patterns

The initial stage of spatial analysis, in which distribution and density maps of the flint microartifacts were produced, drew attention to areas of high-density and provided basic evidence for the presence or absence of clusters of burned flint microartifacts. However, in order to verify that these clusters are not the random outcome of the original distribution of the entire flint component, it was essential to determine the degree of overlap between the distribution of the burned and unburned flint microartifacts.

When the burned and unburned flint microartifacts overlap absolutely we cannot rule out the possibility of a natural fire, which deformed flint items wherever they occur. Conversely, when the clusters of burned flint microartifacts do not coincide with those of the unburned flint we can plausibly suggest that an anthropogenic fire is the agent responsible. Several methods were applied to examine the degree of overlap between the burned and unburned flint microartifacts.
2.5.1. Homogeneity analysis: observed and expected burning

This method examines the distribution of the burned flint microartifacts in comparison with that of the unburned ones. In the case of an absolute overlap between the distributions of the burned and unburned flint microartifacts, we expect the relative percentage of burned items to be homogeneous across the exposed surface, displaying similar values in each of the excavated grid units. In order to compare between the observed and expected percentages of burned items in each excavated unit, the expected percentage of burned flint microartifacts was subtracted from the observed percentage. The value obtained through this calculation is the deviation between the observed and expected percentage of burning in each excavated unit; units of positive values are excavated sub-squares in which the observed percentage of burning exceeds the one expected in the case of uniform distribution of the burned flint microartifacts.

2.5.2. Statistical tests

The GIS package supports various types of spatial statistic tools (e.g. cluster analyses, nearest-neighbor analysis, etc.) However, differentiating the patterning of the burned flints from the unburned ones is not a straightforward issue. In each of the analyzed levels, the burned flint microartifacts spatially originate from the larger flint component which may a priori be spatially clustered; thus we cannot consider the burned flint microartifacts a spatially distinct sample on which spatial statistic analyses can be performed. If we did this, we would have failed to notice the possible overlapping of the burned and unburned flints, which is a fundamental factor in a reliable identification of anthropogenic fire. A chi square test, however, can examine the spatial differences between the burned and unburned flint microartifacts, providing a statistical parameter of probability for that differentiation (see Supplementary data).

The chi square goodness of fit supplies a parameter of differentiation between the observed distribution and an expected, uniform, distribution. It does not indicate, however, what specifically is significant. This can be portrayed in the Standardized Residuals (SR), which are the signed square root of each category’s contribution to the chi square (see Supplementary data).

3. Results

This study examines the spatial distribution of flint items from eight archaeological levels at GBY in order to detect possible clusters of burned material. These levels (Layer II-6 levels 1–7) occur some 5 m above the MBB (Fig. 1) and are recorded in a sedimentary setting of gravelly or molluscan sands. Sedimentological studies suggested that these sediments derive from a storm event that deposited coarse sediments from the beach and near-shore environment on the shore face; hominin activity was carried out following the formation of a stable surface on the beach (Feibel, 2001).

Burned flint items occur in all eight levels of Layer II-6 (Table 1). Yet, the frequencies of burning amongst flint microartifacts as well as amongst macroartifacts are relatively low (Table 1).

Spatial analyses have demonstrated that in each of the archaeological levels the burned flint microartifacts do not occur throughout the entire excavated surface but occupy a smaller area. The ratio between the number of excavated sub-squares in which burned flint microartifacts are recorded and the total number of excavated sub-squares ranges in these layers between 0.42 and 0.77 (see Table 1 in Supplementary data).

Examination of the percentages of burned flint microartifacts in each of the excavated units demonstrates that the spatial distribution of the burned flint microartifacts is uneven, and that several sub-squares exhibit higher frequencies. Accordingly, a significant deviation is observed in these layers between the mean percentage (with a range of 0.31–0.69%) and the maximum percentage (with a range of 5.03–16.30%) of burned flint microartifacts per excavated unit (see Table 1 in Supplementary data).

As illustrated in the kernel density maps, in all levels the burned flint microartifacts are not evenly distributed throughout the excavated area, and dense clusters are identified in each of the archaeological levels (Fig. 2 and see Fig. 1 in Supplementary data). The different archaeological levels differ in the number of clusters of burned flint microartifacts. Most layers exhibit a single high-density cluster, while in others two or three clusters are recorded (Fig. 2 and Fig. 1 in Supplementary data).

These clusters are relatively small and incorporate both burned and unburned flint microartifacts. Within the area of the high-density kernel of the clusters, the percentage of burned flint microartifacts is higher than that of the unburned ones. The ratio between the percentage of the burned flint microartifacts and the percentage of the unburned ones within the high-density kernel of the clusters ranges between 1.20 and 6.28 (Table 1 in Supplementary data).

A chi square test on the burned flint microartifacts suggests that in all levels their distribution is significantly different from an expected, uniform distribution (i.e. $p < 0.001$) (Table 1 in Supplementary data).

Fig. 2. The sequential occurrence of phantom hearths in Layer II-6 by level, from the topmost (youngest) level 1 to the lowermost (oldest) level 7; see Table 1 and Fig. 1 in Supplementary data for data on the excavated areas.
With the exception of one level (Layer II-6 level 5), homogeneity analysis indicates that in the sub-squares that encircle the high-density kernels of the burned clusters, the observed percentage of burned flint microartifacts is higher than what we would expect if the distribution of the burning was uniform (Table 1 and Fig. 1 in Supplementary data).

With the exception of two levels (Layer II-6 level 5 and Layer II-6 level 6), calculation of standardized residuals (SR) on the burned flint microartifacts demonstrated that significant SR values are recorded within the burned clusters (Table 1 and Fig. 1 in Supplementary data). This suggests that the concentrations of burned flint microartifacts in these areas are the major contributors to the observed spatial differentiation. The low significance of the SR values in two of the levels, as well as that of the homogeneity analysis of Layer II-6 level 5, results from the high degree of overlap that characterizes the distribution of burned and unburned flint microartifacts in these levels (discussed in Section 4.2).

Thus, concentrations of burned flint microartifacts are documented in each of the examined archaeological levels. When compared, the distributions of the burned and unburned flint microartifacts in each of the analyzed assemblages (Fig. 1 in Supplementary data) were found to exhibit different degrees of overlap, from nearly complete overlap (e.g. Layer II-6 level 6) to distinct segregation (e.g. Layer II-6 level 2).

The following discussion attempts to examine the possible circumstances in which burning deformed flint microartifacts at the different occupational levels of GBY.

4. Discussion

The co-occurrence of burned and unburned flint microartifacts in the vicinity of fireplaces is documented in sites where hearths are readily identifiable features (e.g. Leesch et al., 2005). However, natural fires, which may deform flint items wherever they occur, may likewise result in overlapping patterns of distribution of burned and unburned flints.

4.1. Probability of a natural fire at GBY

Several environmental parameters refute a scenario of natural fires at GBY. Data on fire ecology (Whelan, 1995; Pyne et al., 1996; DeBano et al., 1998) indicate that the necessary conditions for a natural fire to ignite and spread at GBY would have had to include an ignition source (most likely a lightning strike), a dry interval in the cold, wet season (during which lightning strikes occur in the Mediterranean zone), availability of combustible fuel to allow heat transfer, and high combustion temperatures to allow evaporation of soil moisture in the waterlogged setting of GBY. Furthermore, given the fact that fire occurs sequentially throughout the occupational sequence at GBY, we are compelled to accept that such exceptional circumstances occurred repeatedly, frequently setting off natural fires on the lake margin. If such fires indeed occurred, we would expect them to consume the available fuels on the surface, evaporate the soil’s moisture, and extensively damage flint artifacts. The archaeological data, however, do not support such a scenario. If surface wildfires were responsible for the burning, we would expect to find high frequencies of burned material. The GBY layers yielded large quantities of unburned wood interpreted as driftwood (Goren-Inbar et al., 2002), an excellent fuel that would have fanned any wildfire, thus increasing the frequencies of burned material. However, less than 1% of the large (>2 cm) wood segments (Goren-Inbar et al., 2002) and less than 2% of the smaller (<2 cm) botanical remains (Goren-Inbar et al., 2004) are burned. The results of this study also recorded a low percentage of burning in the different lithic categories of flint pieces (a range of 0.76–6.06%; Table 1). Subsurface fire is an alternative scenario, possible in areas where there are heavy accumulations of organic matter that can undergo a ground fire, burning deeply into the organic material above and within the soil profile (DeBano et al., 1998). However, peak temperatures at 2.5 cm below the surface are likely to be well below 100 °C (Whelan, 1995).

The burning of the flint items at GBY required intensive fire at relatively high temperatures and in direct contact with the flints. The facts that fire-damaged flint items occur in relatively low frequencies and that the burned flint microartifacts are found spatially clustered are suggestive of an anthropogenic rather than a natural fire.

4.2. Hominins’ use of fire at GBY

The combination of ecological data and the archaeological record allows the firm rejection of the possibility of recurrent natural fires at the Acheulian lake-shore occupations of GBY. As the scenario of a natural fire is unlikely, we conclude that the concentrations of burned flint microartifacts in the different occupational surfaces of GBY represent phantom hearths, i.e. remnants of hominins’ use of fire.

Comparison between the distribution patterns of the burned and unburned flint microartifacts in each of the analyzed assemblages illustrates a joint occurrence of two different spatial patterns (i.e. overlap vs. differentiation of burned and unburned flints; Fig. 1 in Supplementary data), interpreted here as reflecting variability in spatial patterning of activities throughout the occupational sequence. Thus, in some cases flint-knapping was carried exclusively in vicinity to hearth(s), so that the distributions of the burned and unburned flint microartifacts coincide, and in other cases flint-knapping was not confined to the hearth area, so that the burned and unburned flint microartifacts are distributed in distinctively different clusters.

Thus, concentrations of burned flint microartifacts are recorded throughout the eight archaeological levels of Layer II-6, establishing firm evidence of the use of fire. Furthermore, the long occupational sequence enables us to examine the magnitude of the use of fire and inquire into the extent to which the use of fire characterizes the archaeological sequence. The uninterrupted sequential use of fire at GBY is illustrated in Fig. 2. Concentrations of burned flint microartifacts are recorded in each of the eight occupational levels of Layer II-6. These levels show no similarities in the locations of their phantom hearths, illustrating the stratigraphic distinctiveness of each of the occupational levels. The repetitive occurrence of phantom hearths throughout the occupational sequence indicates a continual use of fire by the Acheulian hominins at the site.

5. Conclusions

The results of this study suggest that the use of fire at GBY is not a unique, accidental phenomenon; rather, it is a routine practice that characterizes the entire Acheulian occupational sequence. This observation provides evidence of the hominins’ technological capabilities with regard to the use, and particularly the control, of fire. While establishing evidence for early use of fire, it is difficult to determine with certainty whether this fire was “collected” by hominins from a natural source or whether they had the ability to set fire at will. However, fire was used continually at the site of GBY, and it is unlikely that the Acheulian hominins were compelled to collect or re-invent it over and over again. Rather, the fact that fire was repetitively used throughout the occupational sequence suggests that the knowledge of fire-making and the technological skills of the Acheulian hominins of GBY enabled them to set fire at will and in diverse environmental settings on the damp lake-shore. These Acheulian hominins most likely possessed the technological
ability to make fire throughout the long duration estimated for the entire stratigraphic sequence of the site (ca 100 Ka). Thus, the evidence from GBY suggests that the ability to make fire was an integral part of the Acheulian tool kit.

From a global perspective, the Acheulians of GBY are representatives of a fundamentally significant event in human evolution and dispersal. The site of GBY displays the introduction of African stone-knapping traditions into the Levantine Corridor, reflecting a wave of human migration out of Africa. Possible evidence for the use of fire at African sites dating from 1.5–1.0 Ma may suggest that the knowledge of fire-making at GBY reflects an additional African tradition. The recorded controlled use of fire by the Acheulian hominins of GBY, in a geographical position midway along the route out of Africa and into Eurasia, further implies that the ability to control and maintain fire may have been a beneficial factor for human migration out of Africa. The powerful tool of fire-making provided ancient hominins with confidence, enabling them to leave their early circumscribed surroundings and eventually populate new, unfamiliar environments.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.quascirev.2008.06.009.

References


