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Evidence of Hominin Control of Fire at Gesher Benot Ya`aqov, Israel

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23. Each decay takes 4.3 min, with 20 s at each of 13 steps, a 10-s measurement of OH plus the background signal, and a 10-s measurement of the background signal alone. The OH signal decreases a factor of 10 to 20 over the 13 steps. The OH reactivity, k_{OH}, is the slope of the logarithm of the OH signal, S_{OH}, as a function of the time (the distance divided by the velocity) minus the OH loss to the flow tube's walls, k_{wall}: $k_{OH} = -\Delta \ln(S_{OH})/\Delta time - k_{wall}$. The OH wall loss, which was determined by flowing ultrahigh-purity zero air down the flow tube, was $2.2 \pm 0.4\ s^{-1}$ for PROPHET 2000 and five subsequent field studies. We calibrated the TOHLM by adding known quantities of CO and some hydrocarbons and comparing the slope of the OH reactivity with the accepted reaction-rate coefficient (18). In the presence of ambient NO, HO_2 reacts with the NO to reform OH, changing the observed slope of the decay. The HO_2 recycling was insignificant during the PROPHET 2000 campaign, when NO was never more than 0.2 ppbv.
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Evidence of Hominin Control of Fire at Gesher Benot Ya'aqov, Israel

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The presence of burned seeds, wood, and flint at the Acheulian site of Gesher Benot Ya'aqov in Israel is suggestive of the control of fire by humans nearly 790,000 years ago. The distribution of the site's small burned flint fragments suggests that burning occurred in specific spots, possibly indicating hearth locations. Wood of six taxa was burned at the site, at least three of which are edible—olive, wild barley, and wild grape.

Archaeological research suggests that the association between hominins and fire (1, 2), including hominins' use (3) and control (4) of fire, dates far back; however, the question of how long ago hominins gained control of fire has been an ongoing debate. By Upper Pleistocene times, cultural data include hearths, burned flint artifacts, and burned bones in Africa [e.g., (5)], the Levant (6, 7), and Europe (8). Several Middle Pleistocene sites (~500,000 years ago) in Europe [e.g., (9, 10)] and the Levant (11, 12) seem to exhibit human exploitation and control of fire. Earlier periods have yielded only fragmentary evidence, interpreted as stemming from natural bush fires (13) or taphonomic disturbances (14). Several Early Pleistocene sites in Africa offer data that consist primarily of sediment coloration (15, 16). We present here archaeological and paleobotanical evidence—burned organic and inorganic materials—that indicates the presence of fire at the Acheulian site of Gesher Benot Ya'aqov (GBY) during the Lower and Middle Pleistocene (17) and suggests that the burning of these materials resulted from hominin activities rather than natural phenomena.

GBY, a waterlogged site on the shores of the paleo–Lake Hula, is located in the northern Dead Sea Rift. Situated on a plate boundary, the site is tectonically disturbed (18). It contains a depositional sequence ~34 m thick, in which Acheulian archaeological horizons are embedded. We excavated archaeological horizons above the Brunhes-Matuyama (B-M) chron boundary (0.79 million years ago), where we uncovered extensive assemblages of artifacts.

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Burned flint artifacts (longer than 20 mm) and microartifacts (2 to 20 mm in length) occur in all the excavated archaeological horizons, including the eight levels of Layer II-6 (table S1), which is located some four meters above the B-M chron boundary. The time span represented by these horizons is tens of thousands of years (17). Flint artifacts were present in the entire sequence, including the unexcavated areas, but we found burned flint items only in the areas that we excavated. This report presents the lithic assemblage from Area C, which is in the upper part of the stratigraphic sequence. The base of layers V-5 and V-6 of Area C (17) is located slightly more than 13 m above the B-M chron boundary.

Layers V-5 and V-6 contain two sediment types—coarse (coquina), in layer V-5, and fine (clay), in layer V-6; the shift between these sediment types indicates a change in the water level of the lake [figure 1 in (17)]. Layer V-5, with an excavated volume of 2.25 m^3, and layer V-6, with an excavated volume of 1.39 m^3, yielded large enough samples for lithic analysis. Of the three rock types used by the Acheulian hominins—flint, basalt, and limestone—flint is the most abundant in these layers, whereas in the other areas of the site, basalt is the most common type of rock. At temperatures of about 350° to 500°C, fire visibly alters and damages flint, as evidenced by typical macrofracture deformations such as pot lids, crazing, shrinkage, fractures, and cracks (*19*). These damage patterns enabled us, without the aid of a microscope, to distinguish between the burned and unburned flint items in Area C (fig. S1).

We retrieved a large quantity of flint microartifacts from both layers. In each layer, the burned flint constituted 1.8% of the flint microartifacts (Table 1) and was clustered in several localities (Fig. 1).

The unburned flint microartifacts in layer V-5 formed a single cluster, located in the layer's southeastern area. The burned flint microartifacts were found in two clusters, one also in the southeast and the other on the northwest side. Together, these two clusters contain more than 50% of all the burned flint microartifacts in the layer. In layer V-6, unburned flint microartifacts were found from the center of the layer to the northwest. More than 60% of the burned flint microartifacts in that layer were collected in two localities in the center of the excavated area. Thus, the burned and unburned microartifacts are not distributed identically, and their areas of distribution overlap only partially. Moreover, in those clusters where burned flint microartifacts occur, they outnumber the unburned ones, despite the greater quantities over-all of the latter. Such multiple clustering suggests that the burning occurred in specific localities and that postdepositional processes (caused, for example, by waves, currents, or a change in the water level of the lake) had a limited taphonomic effect on the original location of the microartifacts. We suggest that the clustering of the burned microartifacts indicates the location of Acheulian hearths.

A parallel can be drawn with Mousterian assemblages, in which the burned bones discovered in the immediate vicinity of hearths were mostly small pieces (*20*). Although it is generally known that the fragments of burned flint discovered near hearths are usually small, no quantitative data are available.

GBY contains a broad assemblage of wood and bark (henceforth referred to collectively as wood). Because the size of these specimens dictates the excavation technique (*21*), we treated the specimens as two separate groups, with 20 mm as the dividing point. Among the wood fragments longer than 20 mm, 1.41% (n = 13) of the specimens from all the excavated areas were identified through microscopic analysis as burned wood. Ranging in length from 23 to 101 mm, these specimens originate in six archaeological horizons; two taxa were identified, *Olea* (wild olive) and *Fraxinus* (Syrian ash) [table 20 in (*22*)].

Fruits and small (3 to 20 mm) pieces of burned wood were found throughout the excavated area. The fruit assemblage consists of 23,454 specimens, of which eight specimens (0.034%) were burned. The wood assemblage consists of 50,582 specimens, of which a random sample of 9,519 specimens was sorted into burned and unburned wood fragments. A total of 426 of the wood sample's fragments (4.47%) were identified as burned; of these, we could botanically classify 31 specimens (Table 2) to six taxa, of which *Fraxinus syriaca* and *Olea europaea* (Fig. 2) were the most abundant. *Periploca graeca*, which is rare in the region today, was identified only among the small wood fragments; all the other species represented by the small burned fragments were also identified among the large unburned ones (*22*, *23*). A few charred remains of grains were identified (e.g., fig. S2) and include four grass specimens (Fig. 3), two twisted awn fragments, and two *Galium* fruitlets (Table 2). Identification of the incomplete grasses was made possible through an electronic grass key (*24*). All the taxa can be found today in the vicinity of the site.

The burned flint and wood attest to the presence of fire at GBY. We considered three types of natural fire—peat fire, volcanic fire, and wildfire. The stratigraphic sequence rules out both peat and volcanic origins: Although burned specimens appear throughout the Acheulian horizons (Table 2 and table S1), peat is present in only one thin stratum, and evidence of contemporaneous volcanic activity is entirely absent from the stratigraphic sequence.

The most probable type of natural fire in this region would be a surface wildfire (*25*, *26*) resulting from natural ignition and combustion. Lightning is the major cause of wildfires in the Mediterranean zone (*26*). In the present-day Hula valley, lightning storms are most common from Octo-

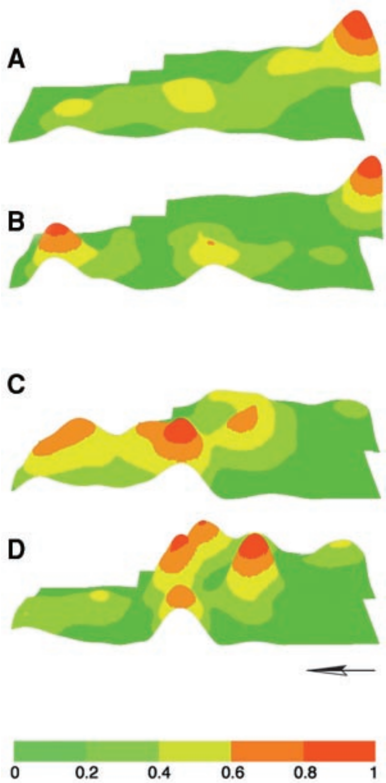

Fig. 1. Three-dimensional illustration of the relative densities of flint microartifacts in Area C (~5 m by 2 m per layer), GBY. (**A**) Layer V-5, unburned microartifacts; (**B**) layer V-5, burned microartifacts; (**C**) layer V-6, unburned microartifacts; (**D**) layer V-6, burned microartifacts. Relative densities have been standardized by the maximum values of each data set. Densities are represented as surfaces.

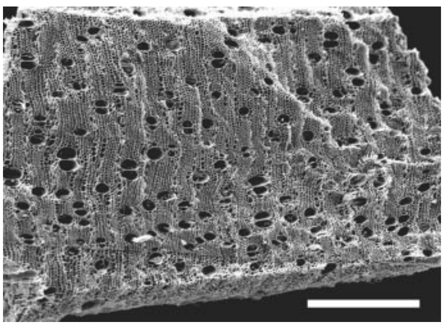

Fig. 2. Cross section of burned *Olea europaea* subsp. *oleaster* (wild olive) specimen. Wood is diffuse porous; vessels are solitary and in short radial multiples. Bar, 0.5 mm.

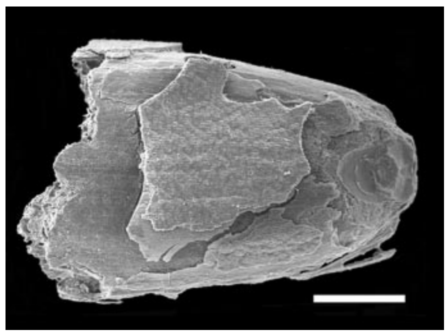

Fig. 3. Burned grain of *Aegilops* cf. *geniculata*: dorsal view of a basal fragment (this grain is also shown in fig. S2). Parts of husk and embryo are clearly seen. Bar, 1 mm.

Table 1. Frequency of stone artifacts and microartifacts in Area C, GBY.

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

ber to March (*27*); however, at that time of year—the rainy season—very few spontaneous fires occur (*26*). The Mediterranean wood species identified at GBY (*22*) and other paleobiological evidence (e.g., remains of mollusks, crabs, fish, and mammals) strongly suggest that the seasonal climate pattern in the Hula valley at the time of deposition resembles the pattern seen today.

During a wildfire, the highest temperatures occur at the level of the grass canopy, and temperatures in such fires can reach 550°C (*26*), hot enough to damage flint. If surface wildfires were 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 are burned. Furthermore, the GBY layers yielded large quantities of unburned wood, which was most likely driftwood (*22*)—an excellent fuel that would have fanned any wildfire.

Yet another possibility exists—underground wildfires (such as burning roots). Peak temperatures of fires occurring at 2.5 cm below the surface are less than 100°C (*26*) and thus are unlikely to have damaged subsurface flint artifacts.

The paucity of burned items and their clustered distribution call for an interpretation other than naturally caused fire. Rather, they suggest that hominins were the responsible agent. We interpret the presence of burned wood coupled with the spatial distribution of the burned flint microartifacts as indications of hearths. Because of the smaller specific gravity of the charred botanical items and the proximity of the occupations to water, the botanical finds under 20 mm cannot serve as a spatial indicator for the hearths.

The producers of the Acheulian material culture have frequently been assumed to be *Homo erectus* or *Homo ergaster* (*5*, *28*); at GBY they may just as well have been archaic *Homo sapiens* (*29*), such as an ancestor of Galilee Man (*30*). No evidence at GBY enables us to associate a particular hominin species (*31*) with the various activities on the shores of the paleo–Lake Hula.

The in situ evidence emanating from the Acheulian horizons at GBY suggests that the hominin inhabitants hunted, processed meat, extracted marrow, quarried and transported different kinds of rock, produced stone tools, gathered plant foods (*17*, *32*), and produced fire.

On the basis of all the GBY archaeological data, we suggest that the hominins who frequented the shores of the lake for over 100,000 years knew how to use fire and exercised that knowledge repeatedly throughout much of the Acheulian cultural period. The domestication of fire by hominins surely led to dramatic changes in behavior connected with diet, defense, and social interaction.

Table 2. Stratigraphic assignment, botanical identification, and size and number of burned wood and fruit specimens at GBY. The layers are presented in stratigraphic order.

Layer	Plant taxon (and identified part)	Common name	Maximum length (mm)	No. of specimens
V-6	*Periploca graeca* (wood)	Greek silk-vine	6.0	1
V-6	*Salix/Populus* (wood)	Willow/poplar	4.0	1
VI-10	*Avena* sp. (awn)	Oat	2.4	1
II-5/6	*Fraxinus syriaca* (wood)	Syrian ash	3.5–6.3	2
II-5/6	*Olea europaea* (wood)	Wild olive	6.0	1
II-5/6	*Vitis sylvestris* (wood)	Wild grape (vine)	4.7	1
II-6 L1	*Fraxinus syriaca* (wood)	Syrian ash	3.0–12.0	17
II-6 L1	*Olea europaea* (wood)	Wild olive	4.0–7.5	3
II-6 L1	*Periploca graeca* (wood)	Greek silk-vine	4.0	1
II-6 L1	*Prosopis?* (wood)	Mesquite	6.0–10.0	2
II-6 L1	*Vitis sylvestris* (wood)	Wild grape (vine)	6.0	1
II-6 L1	Unidentified (wood)		11.0	1
II-6 L2	*Fraxinus syriaca* (wood)	Syrian ash	4.7	1
II-6 L2	*Galium* sp. (fruitlet)	Bedstraw	1.9	1
II-6 L2	Unidentified (wood)		6.0	1
II-6 L4	*Galium* sp. (fruitlet)	Bedstraw	2.9	1
II-9	*Hordeum spontaneum* (grain)	Wild barley	3.2	1
II-11	*Aegilops geniculata/peregrina* (grain)	Goatgrass	5.7	1
II-11	*Stipa bromoides* (grain)	Sharp-awned feather-grass	2.9	1
III-7	Poaceae (awn)	Grass	1.2	1
III-9	*Aegilops* cf. *geniculata* (grain)	Ovate goatgrass	2.9	1

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Supporting Online Material
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Materials and Methods
SOM Text
Figs. S1 to S3
Table S1

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