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Specialized Flint Procurement Strategies for Hand Axes, Scrapers and Blades in the Late Lower Paleolithic: A ^{10}Be Study at Qesem Cave, Israel.

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The procurement and selection of raw materials for producing different stone tools in the past provide invaluable insights into hominid technological capabilities and behavior. Flint has been extensively studied to document its sources, tool production, use, and recycling. Less is known about the procurement strategies used for obtaining the raw materials. Our approach is based on the concentration of cosmogenic *in situ* produced ^{10}Be within the flint. As this is depth dependent, flint material collected from the surface can be differentiated from flint collected at depths or from special environments which protected the flint from cosmic radiation. ^{10}Be concentrations in different tool types from the Lower Paleolithic strata of Qesem cave showed that the raw materials for large scrapers and hand-axes were obtained from deep buried material or recently exposed material. The smaller blades showed a larger distribution of ^{10}Be that resembles the concentrations of ^{10}Be in flint nodules collected from the soil surface around the cave. This is consistent with the observation that the large scrapers and hand-axes were re-sharpened. Therefore some 400,000 years ago the Qesem cave inhabitants possessed a detailed knowledge of the resources, and the capability to procure appropriate raw materials for specific tool types.

KEY WORDS: *Cosmogenic Isotopes, Beryllium-10, flint procurement, flint tools, Lower Palaeolithic*

Introduction

As flint is one of the main raw materials used in the Paleolithic, much research has been invested in the different stages of its "*chaîne opératoire*"-"Operational Sequence." This includes the documenting of flint sources, the production of flint tools, different uses of flint tools and flint recycling and discard (Martinez, 1998; Feblot-Augustinus, 1999; Floss and Kieselbach, 2004; Kuhn, 2004; Roux and Bril, 2005; Stout *et al.*, 2005). Analysis of the flint material by scanning electron microscopy (Fernandes *et al.*, 2007) characterizing the interaction between the flint depositional environment and the flint material, provide insights into the history of the flint prior to its collection. Surprisingly little is known about procurement strategies used for obtaining flint in Paleolithic times throughout the world, including the Levant. A few Middle Pleistocene, Lower Paleolithic flint quarry complexes and surface quarrying sites have been identified in different parts of the world (Petraglia *et al.*, 1999), including several in northern Israel (Barkai *et al.*, 2002). Flint mining and quarrying is also known in the Middle and Upper Paleolithic, including for example extraction from exposed cliffs and an underground chert mine in Egypt (Vermeersch, 2002).

A direct approach is usually used that aims at matching materials properties of the flint found at prehistoric sites with flint at the potential sources where the raw material could have been obtained (Morgenstein, 2006) i.e. provenance studies. Chemical analyses have also been used for this purpose comparing the contents of different elements in the source materials and in the flint tools. This approach is helpful provided the sources are limited in number (Nathan *et al.*, 1999) and have characteristic chemical compositions. Analysis of the cortex of flint nodules may also be informative as this reflects the interaction of the flint with the depositional environment (Floss and Kieselbach, 2004).

In this project we used a different approach. Instead of focusing on the geographic location from which the flint was obtained (provenance), we addressed the type of procurement strategy used. We assumed that the major flint procurement strategies could involve either collecting flint exposed on the surface, and/or extraction from primary sub-surface sources whether shallow or deep, by quarrying or mining. The question was whether we can identify these procurement strategies and differentiate between them based on the analysis of the flint itself as found in prehistoric cave sites. We developed a method based on measuring Beryllium-10 (^{10}Be) content in flint that is capable of indicating whether the flint was deep mined, shallow mined or collected from the surface after a long exposure (Verri et al., 2004; Verri et al., 2005).

We assume that flint users in the past carefully considered the quality of raw materials from different sources and we also assume that the quality of mined or quarried flint for knapping is higher than that of surface collected flint. Underground flint sources generally provide higher quality flint devoid mechanical damage, compared to flint randomly collected from the surface (Barber *et al.*, 1999). Thus we hypothesize that if high quality (optimal) material, without flaws is essential for the production of certain tools, efforts will be made to obtain sub-surface (deep or shallow) material. If this was not necessary, then surface material may have been used. We stress that our method has difficulties in differentiating between mined flint and flint that originated from primary geological contexts that have rapidly eroded. In the latter case the flint is "brought" to the surface by erosion, collected soon after exposure and then transported to a cave. We assume that flint collected from the surface that has a low ^{10}Be concentration was obtained by prehistoric people rather soon after exposure, otherwise it would have been mechanically damaged and would not be suitable for the production of specific tools. Moreover, procuring 'recently exposed' flint as a strategy seems to us opportunistic in nature and can by no means support large scale tool production or reflect a primary procurement strategy. Thus, 'contamination' of seemingly mined flint (^{10}Be -wise) is possible, but it is not likely to be significant.

The method enables the determination of procurement modes of flint and provides a possible means to relate the choice of procurement strategy to flint quality. This might be significant in reconstructing Paleolithic lithic economy, human behavior related to raw material procurement, knowledge possession and personal or communal investment in flint procurement. The issue of provenancing flint sources was not on the agenda of our study, although this could be a by-product in specific circumstances.

The method we developed (Boaretto et al., 2000) is based on the measurement of the concentration of the *in situ* produced ^{10}Be within the flint due to the interaction of cosmic rays with the oxygen atoms present in the silicate (Lal and Peters, 1967). As the secondary protons and neutrons produced by the cosmic rays are almost totally absorbed in the first 2 meters below the soil surface (Gosse and Phillips, 2001), the absence (or the presence of concentrations lower than 0.25 x 10^6 ^{10}Be atoms/gr of flint) of ^{10}Be in a flint tool implies that the raw material was extracted from a deep mined (two meters and more) source or following collection of the flint shortly after erosion exposed the flint at the surface within approximately 10,000 years as defined by the limit of detection (Verri et al., 2004). The presence of small amounts of ^{10}Be in the flint (>0.25 x 10^6 ^{10}Be atoms/gr of flint but <1.00 x 10^6 ^{10}Be atoms/gr of flint) implies that the flint was possibly extracted from shallow depths (less than two meters) beneath the surface or from an eroded flint source that has been exposed for a relatively short period of time (Verri et al., 2004). Such shallow mining sites, where surface quarrying was applied, are known from northern Israel (Barkai *et al.*, 2002; Barkai *et al.*, 2006). High concentrations of ^{10}Be (over 1.00 x 10^6 ^{10}Be atoms/gr of flint) imply that the flint was exposed on the surface for long periods of time, well exceeding the 10,000 year detection limit. The method requires that the flint be deposited after extraction and use in a cave, where it is shielded from cosmic radiation and from further *in situ* production of ^{10}Be in the flint. It also depends upon the flint not being contaminated by atmospheric ^{10}Be present in the meteoric water.

In a pilot study we analyzed flint nodules quarried in an experiment (Verri *et al.*, 2004; Verri et al., 2005) from a source shielded by over a meter of limestone rock at Ramat Tamar (Barkai *et al.*, 2007). We then analyzed flint items, mainly debitage, from a near by (a few meters away) Neolithic flint workshop exposed on the surface. We compared ^{10}Be contents of the quarried nodules to the flint items workshop. These nodules were exposed to the atmosphere close to the source since Neolithic time, for some 10,000 years, and were found to have very low concentrations of ^{10}Be. (As low as 0.08-0.28 x 10^6 ^{10}Be atoms/gr of flint (Verri et al., 2004)). The deep buried nodules experimentally quarried, also showed very low ^{10}Be content (<0.22 x 10^6 ^{10}Be atoms/gr of (Verri *et al.*, 2004)). We also analysed samples close to the exterior and the core of a large flint (15x10x10cm^2) nodule from a location close to the soil surface. The values obtained were in the range for the deep buried nodules (0.15-0.26 x 10^6 at./g SiO_2 this work). This led us to infer that flint is indeed a closed system with respect to meteoric ^{10}Be.

We then concentrated on verifying the validity of the method and the practicability of its application. The first question we addressed was whether flint used in some Middle Pleistocene archeological sites was mined from deep sources. We sampled and analyzed flint artifacts from the Late Lower Paleolithic (Acheulo-Yabrudian complex) at the archaeological cave sites of Tabun Cave and Qesem Cave, Israel. The results showed that deep mined flint was already used around 400,000 years ago as clearly seen for Tabun Cave and in a somewhat less definitive way for Qesem Cave. Both sites also showed use of flint extracted from shallow mined sources and surface collected flints (Verri *et al.*, 2004; Verri *et al.*, 2005).

The present study is another stage in this research program, addressing not only the question of how flint was procured, but also the interesting question of whether a correlation can be found between flint procured by different methods (deep mining, shallow surface quarrying or surface collection) and specific tool type production at Qesem Cave. We thus selected specific tool types including handaxes and side scrapers, as well as blade-tools and blades. We included results obtained for blades and flakes in the earlier stages of this study, and also included some flint nodules exposed on the surface collected around Qesem Cave in both wadi and slope contexts by the authors in 2005. These surface collected items serve as a comparative sample to be checked against the specific tool types studied. The archaeological samples originate from different strata within Qesem Cave, but sampling was not sufficiently extensive to cover the whole sequence in detail or draw conclusions on a stratigraphic basis.

Site Investigated

Qesem Cave is located on the coastal plain east of Tel Aviv, Israel. This cave contains a 7.5m thick stratigraphic sequence dated to a range between 400,000 to 200,000 years BP (Barkai *et al.*, 2003). The lithic assemblages are characteristic of the Amudian industry of the Acheulo-Yabrudian complex – a late Lower Paleolithic entity in the Levant (Jelinek, 1990; Bar-Yosef, 1994; Copeland, 2000). The Amudian industry at Qesem Cave shows a few lithic operational sequences of which blade production is predominant. . The other trajectories of interest here are the production of side-scrapers and hand axes. Analysis of the debitage shows that the blades were, for the most part, produced in the cave (Gopher *et al.*, 2005) using small (around 10cm) and narrow (up to 5cm) nodules, some of which were found on-site (Barkai et al. 2005). Scrapers were usually produced from large (ca 7-12cm) and thick flakes reduced from larger cores. Handaxes were made from very large flakes and nodules 20 cm and more in size. The flint used for each trajectory has specific properties (homogeneity, texture, color) recognizable by the naked eye. The sequence of production of scrapers and handaxes is, for the most part, not represented in the cave's lithic assemblage. Such large flakes were reduced from large cores, that are also not found on-site. These were probably prepared at the source of the raw materials, brought-in and then shaped, used, re-sharpened, recycled and discarded in the cave. Special spalls related to scraper resharpening were found at Qesem Cave, as well as at least one handaxe that was transformed (recycled) into a blade core. A specific scraper dominated assemblage was recently discovered

Qesem cave is located in the B'ina limestone formation. This formation is rich in flint horizons appearing in various shapes and in the area near Qesem Cave. Flint can be found today on the surface as single nodules or blocks in the wadi beds or as fractured flint slabs attached to limestone karrens. The most ubiquitous raw materials found today on the surface at a distance of up to 5 km from Qesem Cave are small nodules and blocks similar to those used for blade production at the site. In a few cases in-situ geological deposits of such small nodules and blocks were identified while currently being eroded and exposed. Our survey in the vicinity of the cave resulted in the identification of geological outcrops of small sized nodules only. Outcrops of large size nodules, such as those used for handaxes and scrapers were not identified thus far.

The many cortical blades produced at Qesem Cave and especially the Naturally Backed Knives, the blade cores that are still covered with cortex and the unused flint nodules found in the cave bear thin and undamaged cortex, indicating that the raw material was not rolled or damaged while exposed on the surface. The same applies to most of the scrapers that have a cortex on their dorsal face.

Materials and Methods

Flint samples g are crushed into powder (grain size < 50 μm) and carbonates and organic material are removed by treatment with HCl and HNO_3. In order to remove any meteoric ^{10}Be a solution of 1%HF is applied in an ultrasonic bath. The powder is then dissolved with HF (40%) and $HClO_4$ and 0.5 mg Be carrier is added. Major ions such as Ca and Fe are removed by selective precipitation, while Be and Al are separated with a cation exchange column. BeOH is then precipitated and baked for 2 hours at 850 °C. The BeO mixed with Nb is inserted into copper holders to be measured by Accelerator Mass Spectrometer (AMS) using the EN Tandem Accelerator at ETH/PSI (Switzerland).

A fraction of the sample material after the last etching is dissolved for determination of the Al, Fe and Ti concentration by Induced Coupled Plasma. For details see (Boaretto et al., 2000; Verri et al., 2004) and (Synal et al., 1997).

The samples

The new series of samples studied included 3 of the 5 handaxes found in the cave and 8 side scrapers. The new series also included a few flint nodules exposed on the surface that were collected in 2005 around Qesem Cave in both wadi and slope contexts. Altogether we present the results of 49 ^{10}Be measurements of flint items from Qesem Cave and 17 surface material nodules collected near by. All the samples comprised between 6 to 15 g of flint material.

Results

Figure 1 shows the distribution of ^{10}Be concentrations per gram in handaxes, scrapers, blades and debitage items; mainly flakes from Qesem Cave analyzed in this and in earlier studies (Verri et al., 2004; Verri et al., 2005). The ^{10}Be concentrations of the blades range from 0.15 to 4.91x10^6 atoms/g, but two thirds of them have a low (<1.0x10^6 atoms/g) concentration. All handaxes have ^{10}Be concentrations between 0.64 and 0.92 x10^6 atoms/g and scrapers range between 0.20-1.08 x10^6 atoms/g. Flakes and other debitage items range between 0.12-2.1x10^6 atoms/g of ^{10}Be concentration. A few (5) have relatively low concentrations, below 0.25 x10^6 atoms/g, whereas the majority (11) are between 0.25 and 1.0 x10^6 atoms/g. Three have concentrations above 1.0 x10^6 atoms/g.

The flint nodules collected on the surface in the vicinity of the cave were small in size (less than 10cm; larger ones were not found) and of sufficient quality for knapping. Most of these samples have ^{10}Be concentrations above 1.0x10^6 atoms/g, except for 3 that contain between 0.70 and 0.83 x 10^6 atoms/g. None have concentrations below 0.25x10^6 atoms/g, which was previously shown to be the cut-off concentration for flint derived from 2 or more meters below the soil surface (Verri et al., 2004; Verri et al., 2005). Interestingly, the 3 samples with concentrations below 1.0 x10^6 atoms/g, were collected from the river bed adjacent to the cave, whereas all the rest, with concentrations higher than 1.0 x10^6 atoms/g, were from hill slopes around and to the north-east of the cave.

Discussion

The method developed provides a new approach for differentiating between various flint procurement strategies that could also indirectly have implications to flint quality. Flint procured from the sub-surface is of better quality than that collected on the surface. This in turn could influence the choice of raw material to be used for different tool types. In this context, we have made the following novel observations:

1. All 3 hand axes studied have ^{10}Be concentrations between 0.6 and 0.9 x10^6 atoms/g – a quite limited range. We therefore suspect that they were all derived from a specific shallow mined or from eroding primary geological sources collected shortly after erosion in which large flint nodules could be found as required for the production of these relatively large tools. The fact that handaxes are usually designed as durable tools for a long use-life may explain why the raw material was less likely to be collected on the surface.

2. All the scrapers, but one (QCS 16), show a concentration range from 0.2-1.0 x10^6 ^{10}Be atoms/g; a somewhat larger range than in the handaxes. This, like the handaxes, is consistent with procurement from shallow mining or collection from a relatively recently eroded primary geological source of flint. Like the handaxes, scrapers funtioned as durable tools intended for long use, including frequent resharpening and maintenance (e.g. (Dibble, 1995). Thus, it is expected that such tools with long life-histories would preferably be made of high quality raw material – i.e found in primary geological sources.

3. The unique aspect of the Qesem Cave lithic assemblages is the abundance of blades that are the major characteristic of the Amudian industry. The blades analyzed show a distribution ranging from 0.15 to 4.91 x10^6 ^{10}Be atoms/g (2 are less than 0.25; 8 are between 0.25 and 1.00, and 6 are above 1.0). Thus half of the blades have ^{10}Be concentrations less than 0.5x10^6 atom/g and 2 more are below 1.0, implying that they were most likely derived from primary geological sources by deep mining, shallow mining (surface quarrying) or were collected from primary geological sources shortly after exposure. The other six blades with high ^{10}Be contents were surface collected. Thus even though blades could be produced from the rather abundant surface collected flint nodules with high ^{10}Be contents, the occupants of the cave did use flint from shallow mining or flint collected shortly after exposure, for over half of their blade production. Assuming that some of the debitage items (mainly flakes) analyzed and presented in Table 1 are related to blade production, we can conclude that some two thirds of the blades were produced from mined raw materials or flint collected shortly after exposure, and only one third from surface collected material. It is of note that many of the blades with the >1.00 ^{10}Be contents are from strata at elevations between 400 and 600cm below datum (the whole sequence ranges from ca. 110-790 cm below datum). This may indicate that blade production from surface collected flint was more common during a specific time interval within the Qesem Cave Amudian sequence. Additional stratigraphically controlled sampling and analysis would be required to assess the significance of this observation.

4. Flakes and other debitage (cores, CTEs, chunks) shown in Table 1. and Figure 1 range from very low to high ^{10}Be concentrations. However, this group too has quite a few items showing ^{10}Be concentrations less than 0.25 x 10^6 atoms/g; the cut-off indicative of deep mining.

5. Raw material (nodules and blocks) from the vicinity of the cave showed that the river bed derived flints were more recently exposed, as compared to those from the hilly slopes. As a first approximation, we therefore assume that the flint tools from the cave that have ^{10}Be concentrations of less than 1.0x10^6 ^{10}Be atom/g but more than 0.25x10^6 ^{10}Be atoms/g, were derived from flint eroded from primary geological sources into the river bed, and was collected shortly after exposure. We note that surface quarrying, such as in the cases of the Mt. Pua and Sede Ilan Middle Pleistocene quarrying complexes, would require extracting flint nodules from depths of up to almost one meter (Barkai et al., 2002; Barkai et al., 2006; Barkai and Gopher, 2009).

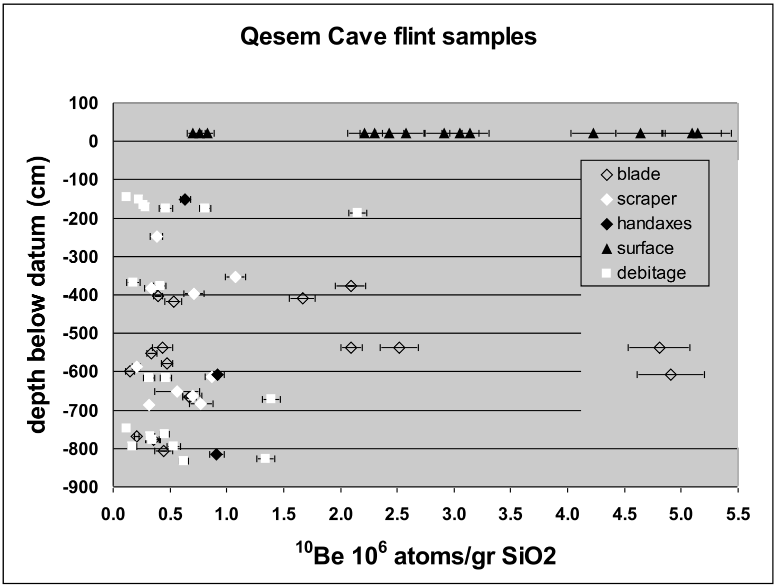

Fig. 1. Plot of the ^{10}Be concentrations in tools and debitage from Qesem cave as a function of depth below datum in the cave. Also shown are the ^{10}Be concentrations in the flint nodules collected from the surface in the vicinity of the cave.

TABLE 1. List of all the samples analysed in the present study, their location, weight of sample (SiO_2 gr) analysed, ^{10}Be concentrations in units of 106 atoms ^{10}Be per gram SiO_2. The ±1σ values represent the standard deviation of the measurement including the standard deviation of standard and background.

Sample #	Sample	LAB #	Square	Depth (cm)	SiO_2 (g)	^{10}Be 10^6 at./g SiO_2	±1 _ 10^6 at./g SiO_2
BLADES							
8	blade	QC8	H18	-600	8.0	0.15	0.04
	blade	QC33	H21	-768	10.2	0.21	0.02
9502	retouched blade	QCB3	G20	-552.5	9.8	0.34	0.05
	blade	QC37	H22	-778	9.3	0.36	0.04
65	blade	QCB65	K10	-402.5	11.9	0.39	0.04
9566	retouched blade	QCB2	G20	-537.5	7.8	0.43	0.09
71	NBK	QCB71	G21	-807.5	11.3	0.45	0.08
67	NBK	QCB67	G19	-577.5	14.0	0.47	0.04
66	blade	QCB66	K10	-417.5	6.3	0.53	0.08
13	blade	QC13	E21	-668		0.67	0.06
64	PEB	QCB64	K10	-407.5	12.0	1.67	0.11
63	NBK	QCB63	K10	-377.5	8.5	2.09	0.14
	endscraper/NBK	QCB4	G19	-537.5	12.2	2.10	0.09
	retouched blade	QCB8	G20	-537.5	8.0	2.52	0.17
9558	retouched blade	QCB6	G19	-537.5	5.0	4.80	0.27
70	blade	QCB70	I16	-607.5	10.7	4.91	0.30
SCRAPER							
10120	convex	QCS9	G19	-587.5	11.6	0.20	0.04
10136	dejete	QCS15	H22	-687.5	12.4	0.31	0.02
		QCS62	K10	-382.5	13.0	0.33	0.05
10088	convex	QCS12	L9	-247.5	8.4	0.38	0.06
10142	straight quina	QCS13	I16	-650	6.9	0.57	0.20
10073	dejete	QCS14	E21	-662.5	9.3	0.70	0.08
		QCS61	K10	-397.5	15.3	0.71	0.09
10121	double quina	QCS11	D22	-682.5	11.4	0.77	0.10
10004	convex	QCS10	G20	-612.5	10.4	0.87	0.06
10021	straight	QCS16	K10	-352.5	12.2	1.08	0.09
HAND AXES							
	Hand-axe	QC 114-1	M9	-152.5	15.4	0.64	0.04
	Roughout	QC 117-1	G22	-815	12.7	0.91	0.06
	Hand-axe	QC 116-1	I15	-607.5	12.0	0.92	0.05
DEBITAGE							
14	chunk	QC21	M9	-145	10.3	0.12	0.02
	flake	QC36	H22	-748	13.7	0.12	0.02
7	flake	QC7	F22	-795	12.1	0.17	0.04
5	flake	QC5	K10	-368	6.6	0.18	0.06
18	chunk	QC23	M9	-153	10.2	0.23	0.03
19	overshot (blade,core)	QC24	M9	-168	9.7	0.27	0.03
21	retouched flake	QC26	M9	-173	12.7	0.29	0.03
10	flake	QC10	I20	-618	20.0	0.32	0.05
	primary flake	QC32	G22	-768	15.4	0.33	0.04
	primary flake	QC30	H22	-778	15.1	0.35	0.06
1	core	QC1	K10	-378	10.9	0.41	0.05
	chunk (broken flake)	QC35	H22	-763	15.3	0.45	0.04
22	retouched flake	QC27	M9	-175	8.0	0.46	0.06
12	core	QC12	F21	-618	15.0	0.46	0.05
14	CTE	QC14	EF22	-795	19.4	0.53	0.06
	flake	QC34	F22	-833	20.3	0.62	0.04
17	flake	QC22	M9	-175	8.4	0.81	0.05
	primary flake	QC31	G22	-828	15.3	1.34	0.08
16	flake	QC16	E21	-673	15.0	1.39	0.08
20	flake	QC25	M9	-188	13.2	2.15	0.08
SURFACE							
		QC 111-1		20	12.1	0.70	0.05
		QC 113-2		20	15.0	0.76	0.05
		QC 110-1		20	13.5	0.83	0.06
		QC 108-1		20	15.5	2.21	0.15
		QC 107-1		20	15.5	2.30	0.13
		QC 112-1		20	13.5	2.43	0.13
		QC 101-1		20	15.1	2.58	0.15
		QC 109-1		20	15.3	2.91	0.16
		QC 105-1		20	15.9	3.05	0.16
		QC 106-1		20	15.6	3.14	0.17
		QC 104-1		20	15.4	4.23	0.20
		QC 103-1		20	15.6	4.64	0.22
		QC 102-1		20	15.8	5.09	0.26
		QC 100-1		20	15.8	5.14	0.30

Conclusion

^{10}Be contents in flint tools from Qesem Cave provide interesting insights into raw material procurement strategies that are not available by other means. The inhabitants of the cave were clearly making special efforts to procure quality (low ^{10}Be) raw material for tool production. This is consistent with the observation that the scrapers and hand axes show signs of being resharpened, indicating that these tool types were made of high quality durable raw materials procured from specific sources. As for blades, these seem to be more expedient, shortly used (Barkai et al., 2005; Lemorini et al., 2005) with no resharpening or maintenance.

The conclusion is that already some 400,000 years ago, the inhabitants of Qesem Cave possessed a detailed knowledge of the environment and the resources, a mastery of a few flint procurement methods and the capability and will to invest in obtaining the appropriate raw material for specific tool types. Most of the flints used, to the extent that our sampling is representative, were not deep mined or surface collected but rather procured from shallow subsurface sources or collected from contexts where primary sources have been eroded shortly after the exposure of the nodules. This seems to indicate a well balanced decision procedure and the possible use of surface quarrying techniques well known at the time (Barkai et al., 2002; Barkai et al., 2006; Barkai and Gopher, 2009).

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