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# Lower Paleolithic bipolar reduction and hominin selection of quartz at Olduvai Gorge, Tanzania: What's the connection?

Alia N. Gurtov<sup>a,\*</sup>, Metin I. Eren<sup>b,c,\*,\*\*</sup><sup>a</sup> Department of Anthropology, University of Wisconsin, Madison, USA<sup>b</sup> Department of Anthropology, University of Kent, Marlowe Building, Canterbury, Kent CT2 7NR, UK<sup>c</sup> Cleveland Museum of Natural History, 1 Wade Oval Drive, Cleveland, OH, USA

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## ABSTRACT

Numerous researchers have noted that at Lower Paleolithic sites in East Africa hominins largely exploited quartz toolstone with the bipolar reduction technique. The choice to pursue bipolar knapping on quartz is often attributed to raw material constraints. Thus, at some East African Lower Paleolithic sites the abundance of bipolar knapping may have simply constituted a response to the local absence of lithic resources other than small quartz pebbles. However, at Olduvai Gorge, Tanzania, where a variety of other stone raw materials were available, the hominin use of bipolar reduction is still predominately tied to quartz. While quartz raw material constraints may explain the use of bipolar reduction on quartz at Olduvai, what they do not explain is the virtual absence of bipolar reduction on non-quartz toolstones. Thus, we ask here two separate, but related questions: (1) why did hominins use bipolar on quartz?; and (2) why did hominins avoid bipolar on non-quartz? To begin to understand this tight technology-toolstone connection, we formulated two simple hypotheses, which we tested via experimental stone tool replication: (1) Quartz bipolar reduction produces flakes that possess “superior” functional characteristics to those produced via non-quartz bipolar reduction; (2) Bipolar reduction is more expedient on quartz than on non-quartz toolstones. Our experimental tests indicated that while quartz and basalt bipolar reduction yield flakes with similar attributes, bipolar reduction on quartz is significantly more expedient than it is on basalt. As such, the close technology-toolstone association between quartz and bipolar can be explained by constraints and advantages of both quartz and basalt alike. Bipolar reduction is already widely acknowledged to be an expedient technology requiring little to no skill. By applying bipolar reduction exclusively to quartz, hominins at Olduvai appear to have only enhanced this reduction strategy's features. Overall, our experimental results are consistent with the widely-held notion that Lower Paleolithic hominins recognized the differences in the physical properties of different types of raw material, and that it is the interplay between raw material and reduction strategy that governed hominin association between bipolar reduction and quartz at Olduvai.

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## 1. Introduction

*What is the relationship between artifact type and raw material type? Do certain artifact forms tend to be made in certain raw materials? If so, might this result as a byproduct, with the nature of the raw material influencing patterns of fracture and modification, or is there good reason to invoke intentional selection of certain raw materials for the manufacture of certain artifact forms? (Schick and Toth, 2006:26).*

\* Corresponding authors.

\*\* Current Address. Department of Anthropology, University of Kent, Marlowe Building, Canterbury, Kent CT2 7NR, UK.

E-mail addresses: [alia.n.gurtov@gmail.com](mailto:alia.n.gurtov@gmail.com) (A.N. Gurtov), [metin.i.eren@gmail.com](mailto:metin.i.eren@gmail.com), [M.I.Eren@kent.ac.uk](mailto:M.I.Eren@kent.ac.uk) (M.I. Eren).

Bipolar reduction can be defined as a percussion technique in which a stone core is placed on an anvil and struck with a hammer to produce flakes. Numerous researchers have noted that at Lower Paleolithic sites in East Africa hominins largely exploited quartz toolstone with the bipolar reduction technique (e.g. Carbonell et al., 2009:28; Diez-Martin et al., 2010, 2011:690; Hovers, 2003; Ludwig and Harris, 1998:90; Merrick and Merrick, 1976:579; Mgeladze et al., 2011:592–593; Schick and Toth, 1994:120). The choice to pursue bipolar knapping on quartz is often, and reasonably, attributed to raw material constraints. Quartz fractures less predictably relative to other toolstones and has a tendency to shatter and fragment, while small, rounded nodules of quartz may be difficult to break open with freehand percussion (Barham, 1987; Tallavaara et al., 2010; Driscoll, 2011). Thus, rather than waste

effort attempting to constantly overcome these constraints, and possibly risk injury (Schick and Toth, 1994:120), through the use of freehand percussion techniques, it is logical that hominins who exploited quartz typically used bipolar reduction. This choice also makes sense given that experimental analysis indicates there is no difference in production efficiency between bipolar and freehand knapping of quartz. Although experimental replication has suggested that freehand percussion of quartz produces a larger amount of total cutting edge per core than does bipolar reduction (Diez-Martin et al., 2011:706), freehand and bipolar knapping strategies on quartz cannot be differentiated according to cutting edge per core mass, nor by the number of usable cutting edges per flake (Diez-Martin et al., 2011:706). Furthermore, bipolar reduction has the capacity to produce a greater frequency of intact quartz flakes relative to freehand percussion (Callahan et al., 1992, as cited in Tallavaara et al., 2010:2447). Finally, bipolar reduction is widely touted to be a more expedient technique requiring lower amounts of skill than freehand percussion (Hiscock, 1996; Eren et al., 2013; Morgan et al., 2013). These latter two factors, expediency and skill, may also be playing a role in the link between bipolar reduction and quartz since intractable toolstones can create significant obstacles for knappers of low skill-levels (Bar-Yosef et al., 2012:16; Stout and Semaw, 2005:314).

Similarly to other East African Lower Paleolithic sites, at Olduvai Gorge, Tanzania, the hominin exploitation of quartz is also closely linked to bipolar reduction:

...Mary Leakey recognized the residual presence of bipolar reduction on quartz (following a typological nomenclature these items were referred to as outils écaillés; for an updated terminological discussion see Shott, 1999:218–219) in several Developed Oldowan sites, namely at BK (Leakey, 1971:221). Jones (1994:10.3) acknowledged that an important proportion of bipolar artifacts could be documented from Middle Bed II upwards. Later on, other authors have confirmed the presence of this reduction method in the same stratigraphic interval. To our knowledge, Potts is the only author who, although in a rather subtle way, acknowledges the recurrent use of bipolar technique for quartz exploitation even during Bed I times (Potts, 1988:245). (Diez-Martin et al., 2011:691; see also Jones, 1994:291; Schick and Toth, 1994:122)

Renewed fieldwork at both BK and FLK-North has uncovered new sample lithic assemblages that are consistent with the hypothesis that bipolar reduction was used to exploit quartz. At BK, without considering shatter (which is “probably related to a great extent to bipolar reduction”, Diez-Martin et al., 2009:281), 63% of the total assemblage, which is predominantly quartz, could be linked to bipolar knapping (Diez-Martin et al., 2009:281,288). At FLK-North, where a variety of stone raw materials were exploited in Bed I, bipolar cores and flakes are only found on quartz toolstone (Diez-Martin et al., 2010:377, Table 1).

**Table 1**  
Metric data on the experimental nodules before reduction.

	Mass (g)		Maximum dimension (mm)		Width (mm)		Thickness (mm)		L:W		L:T		W:T	
	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt
Mean	815	1128	128	136	77	104	66	57	1.74	1.32	2.05	2.52	1.22	1.92
Standard deviation	219	500	15	22	17	18	14	13	0.40	0.17	0.66	0.89	0.41	0.64
Minimum	485	100	102	99	51	76	34	36	1.26	1.08	1.32	1.60	2.05	1.16
Maximum	1285	1785	156	178	107	134	84	81	2.40	1.63	3.75	4.83	0.41	3.37

There is a strong case to be made that the raw material properties of quartz can explain the predominant use of the bipolar technique upon it. Thus, at some East African Lower Paleolithic sites the abundance of bipolar knapping may have simply constituted a

response to the local absence of lithic resources other than small quartz pebbles (e.g. Ludwig and Harris, 1998:90; Diez-Martin et al., 2011:690–691). However, when considering a locality like Olduvai Gorge, where a variety of quartz and non-quartz toolstones were readily available, why do we see bipolar reduction limited exclusively to quartz? In other words, while quartz raw material constraints may explain the use of bipolar reduction on quartz, what they do not explain is the virtual absence of bipolar reduction on non-quartz toolstones. Perhaps at some points in time only quartz was available, but this was not always the case (e.g. Diez-Martin et al., 2009:277, Table 2), and even at sites like FLK-North, where recent excavation in Bed I shows basalts and phonolite to make up to ≈45% of the assemblage, there is no evidence of bipolar reduction on non-quartz materials (see Diez-Martin et al., 2010:380,382,383).

**Table 2**  
Descriptive statistics of experimental variables examined to test hypothesis #1.

	Mass (g)		Maximum dimension (mm)		Length of cutting edge (mm)		Length of cutting edge (mm)/Mass (g)	
	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt
Mean	13.94	15.65	38.04	39.06	29.29	34.82	4.81	5.32
Standard deviation	14.83	16.15	11.06	10.88	18.96	22.30	5.75	6.75
Median	8.00	10.00	36.00	37.00	25.00	31.00	2.80	2.83
Minimum	1.00	1.00	25.00	25.00	1.00	3.00	0.08	0.08
Maximum	102.00	99.00	99.00	80.00	106.00	138.00	65.00	70.00
Quartile #1	4.00	5.00	29.00	31.00	16.00	18.00	1.24	1.21
Quartile #3	17.00	21.00	44.00	46.00	38.00	46.00	6.42	7.37

Schick and Toth (2006:29) suggest that if strong selectivity in use of raw materials is evident, there may exist possible implications with regard to hominin cognitive abilities and their familiarity and experience in tool-making activities. As such, the acute lack of bipolar reduction on non-quartz toolstones at Olduvai sparked our curiosity: is something fundamentally different or advantageous about quartz bipolar reduction, relative to non-quartz bipolar reduction, that would have encouraged hominins to intentionally and consistently make this toolstone-technology association? In other words, we are not just asking “why did hominins use bipolar on quartz?”; we are also asking a separate, but related question: “why did hominins avoid bipolar on non-quartz?” To begin to investigate this subject, we formulated two simple hypotheses, which we tested via experimental stone tool replication:

**Hypothesis #1:** Quartz bipolar reduction produces flakes that possess “superior” functional characteristics to those produced via non-quartz bipolar reduction. There are a multitude of ways that flake functional effectiveness may be examined, including in terms of durability and resistance to breakage, efficiency in use,

as well as flake size and shape (e.g. Jones, 1994; Braun and Harris, 2003; Stout et al., 2005, 2010; Prasciunas, 2007; Braun et al., 2008, 2009; Collins, 2008; Braun and Hovers, 2009; Goldman-Neuman and Hovers, 2009; Braun, 2012; Eren and

Lycett, 2012). Here, we look at two morphometric attributes of bipolar stone flakes: flake size and cutting edge. If quartz bipolar reduction produces flakes that possess superior functional characteristics to those produced via non-quartz bipolar reduction, then we can make two empirical predictions: (1) on average, quartz bipolar flakes will be significantly larger than non-quartz bipolar flakes to facilitate ease of use, and, (2) on average, quartz bipolar flakes will possess significantly greater cutting edge length per mass than non-quartz bipolar flakes (Braun, 2012:229; Braun and Harris, 2003:127; Prasciunas, 2007:337–338).

**Hypothesis #2:** *Bipolar reduction is more expedient on quartz than on non-quartz toolstones.* Braun (2012:228) recently revalidated the basic and widely-accepted tenet of Oldowan lithic behavior originally described by Isaac and Harris (1997), namely, that it is “a least effort solution to a sharp edge.” Given a particular reduction strategy, Oldowan knappers should have chosen raw materials that maximized expediency for that reduction strategy. Thus, because bipolar reduction is tied strongly to quartz, it is reasonable to hypothesize that bipolar flake production on quartz is more expedient than bipolar production on non-quartz toolstones. Here we consider “expediency” to be the relationship between the ease of, and time required for, flake removal.

## 2. Materials and methods

Fifteen quartz nodules and fifteen basalt nodules were procured for experimental bipolar production (Fig. 1, Table 1). The quartz was procured from the Naibor Soit source, approximately 3.5 km to the north of the confluence of the two gorges (Fig. 2). The basalt was procured from lava beds in close proximity to FLK (Fig. 3). The nodules were left in their original form for replication and no pre-experiment modification occurred. Thus, on average the basalt nodules were significantly more massive ( $U = 62.5$ , Exact  $p = 0.037$ ). In terms of metric dimensions, the two populations were similar in length ( $U = 95.0$ , Exact  $p = 0.486$ ), but the basalt

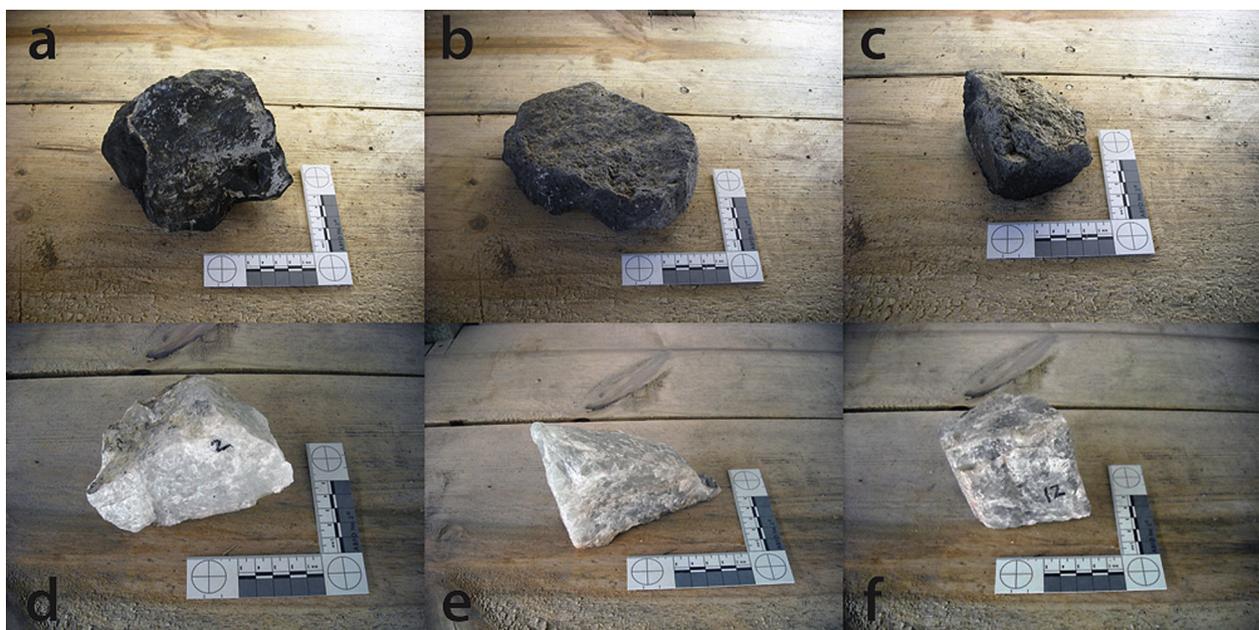
nodules were significantly wider ( $U = 37.0$ , Exact  $p = 0.001$ ), while the quartz nodules were significantly thicker ( $U = 64.0$ , Exact  $p = 0.045$ ). A comparison of L:W ratios indicated that the quartz nodules were significantly longer than the basalt ones ( $U = 40.0$ , Exact  $p = 0.002$ ). However, comparison of W:T ratios demonstrated the basalt nodules were significantly flatter ( $U = 37.0$ , Exact  $p = 0.001$ ). The L:T ratios of the two populations did not show any significant difference ( $U = 70.0$ , Exact  $p = 0.081$ ), but the average L:T value of the basalt nodules indicated that they were slightly flatter.

A large tarpaulin was placed on the ground, and upon that was a large stone anvil on which the bipolar reductions were carried out by MIE. The goal of each reduction was to produce as many “usable flakes” as possible from each nodule in as little time as possible. A usable flake was defined for this experiment as a flake possessing the following two attributes: (1) a maximum dimension of at least 2.5 cm and (2) an edge segment with an angle of no more than  $50^\circ$ . All usable flakes were bagged and individually labeled. From the fifteen quartz reductions 368 usable flakes were produced, while 357 usable flakes were produced from the basalt reductions.

Hypothesis #1 required the measurement of two items: size, and length of cutting edge. We measured size in two ways, via mass (g) and via maximum dimension (mm). Length of cutting edge, i.e. length of all edge segments  $<50^\circ$ , was also measured in mm. We chose  $<50^\circ$  as our cutoff for edge angle following Prasciunas (2007:337), who states “Ethnoarchaeological, archaeological, and experimental studies indicate that  $50^\circ$  is a common and recurring upper edge angle threshold for unretouched tools.”

Hypothesis #2 required a measurement for expediency, which we described above as the relationship between the ease of, and time required for, flake removal. To quantitatively approach this concept we used the number of flakes produced per original core mass (g) per unit time (seconds). The rationale for this measurement choice was that a more expedient raw material should not only permit more productive exploitation of core mass, but also permit that exploitation to occur in less time.

Our use of time in this experiment in no way assumes that modern perceptions of time (or efficiency) are similar to that of



**Fig. 1.** Examples of the raw nodules of each raw material used in the experiment. Top row: basalt nodules #2 (a), #10 (b) and #12 (c). Bottom row: quartz nodules #2 (d), #8 (e), and #12 (f).



**Fig. 2.** The Naibor Soit quartz source.

Oldowan knappers (see discussion in Diez-Martin and Eren, 2012:339–340). Time is used here to understand the properties of toolstones with respect to a specific reduction sequence, not to attempt to gauge prehistoric hominins' conception of time or efficiency. In other words, we are using time here as a way to test the bounds of what is practically achievable in order to understand potential prehistoric motivating factors for raw material selection (see Lycett and Eren, 2013:2386).

A Mann–Whitney  $U$  test was used to detect statistically significant ( $\alpha = 0.05$ ) differences between the measures recorded on the quartz and basalt flakes. The Mann–Whitney  $U$  test is a conservative non-parametric procedure (i.e. minimizes type I errors),

requiring no assumptions of the data in terms of normality of distribution or homogeneity of variances (Dytham, 2003: 101). These tests were undertaken using SPSSv.20.

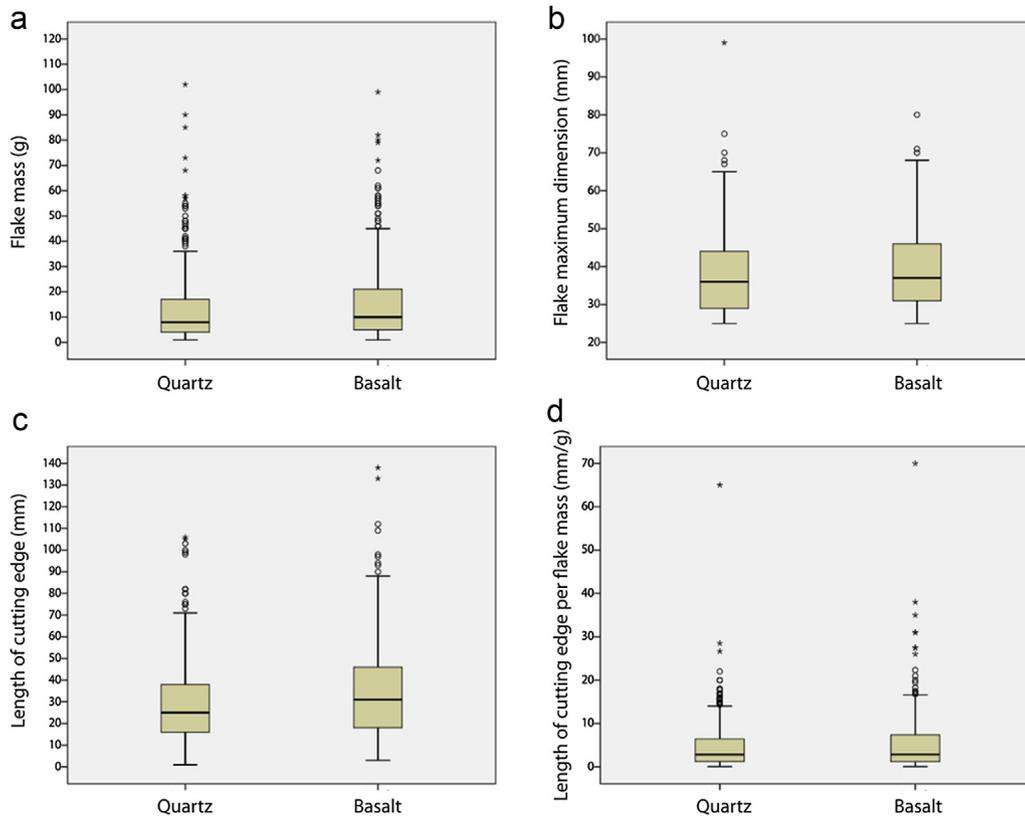
### 3. Results

#### 3.1. Testing hypothesis #1: does quartz bipolar reduction produce “superior” flakes to basalt bipolar reduction?

Overall, quartz bipolar reduction does not produce “superior” flakes to those produced via bipolar reduction on basalt (Table 2). Quartz bipolar flake mass was not significantly larger than basalt



**Fig. 3.** An example of a basalt source in Olduvai Gorge.



**Fig. 4.** Comparisons of the experimental quartz and basalt bipolar flake samples in terms of flake mass (a), flake maximum dimension (b), length of flake's cutting edge (c), and a flake's length of cutting per mass (d).

flake mass (Fig. 4a,  $U = 62237.0$ ,  $p = 0.220$ , Asymp. Sig. 2-tailed), and neither was quartz flake maximum dimension relative to that of the basalt flakes (Fig. 4b,  $U = 61410.0$ ,  $p = 0.129$ , Asymp. Sig. 2-tailed). Indeed, the mean size of basalt flakes for both measures was slightly (though not significantly) larger than quartz flakes (Table 2). Quartz flakes produced significantly less cutting edge than basalt flakes (Fig. 4c,  $U = 55873.0$ ,  $p < 0.000$ , Asymp. Sig. 2-tailed), but given the slight difference in flake size between the two populations, and since larger flakes naturally produce larger cutting edges, we reran this comparison following Braun and Harris (2003) in terms of cutting edge length divided by flake mass. In these terms, quartz flakes and basalt flakes showed no significant difference (Fig. 4d,  $U = 64195.0$ ,  $p = 0.596$ , Asymp. Sig. 2-tailed). In sum, these results do not support the hypothesis that Lower

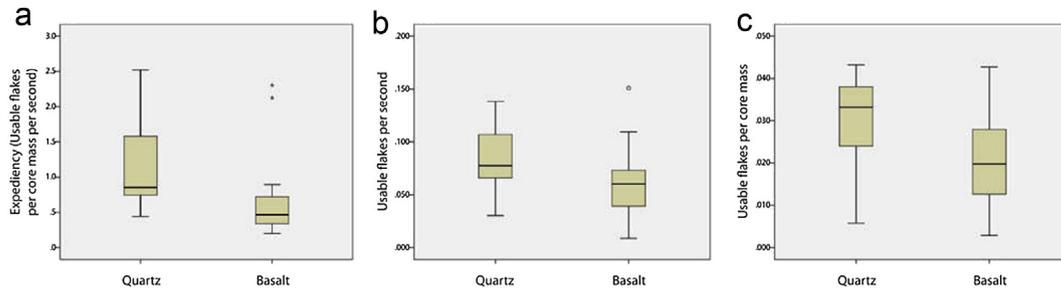
Paleolithic hominins avoided basalt bipolar reduction because quartz bipolar reduction produced flakes with superior attributes.

### 3.2. Testing hypothesis #2: is bipolar reduction more expedient on quartz than basalt?

Quartz bipolar reduction was indeed significantly more expedient than basalt bipolar reduction (Table 3): that is, the former produced significantly more usable flakes per core mass per second than the latter (Fig. 5a,  $U = 49.0$ , Exact  $p = 0.008$ ). Interestingly, quartz bipolar reduction performed significantly better than basalt bipolar reduction in both aspects of “expediency”: usable flakes per second (Fig. 5b,  $U = 61.0$ , Exact  $p = 0.033$ ) and usable flakes per core mass (Fig. 5c,  $U = 62.0$ , Exact  $p = 0.037$ ).

**Table 3**  
Descriptive statistics of experimental variables examined to test hypothesis #2.

	Usable flakes produced per core		Knapping time (seconds)		Usable flakes per core mass (g) per second ( $\times 1000$ )		Usable flakes produced per second		Usable flakes per core mass		% Core mass into usable flakes		% Core mass into shatter		% Core mass unexploited	
	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt	Quartz	Basalt
Mean	24.5	23.8	297	416	1.155	0.710	0.085	0.061	0.031	0.021	42%	32%	58%	36%	0%	31%
Standard deviation	9.0	11.4	126	163	0.616	0.641	0.029	0.035	0.011	0.012	13%	15%	13%	25%	0%	30%
Median	28.0	27.0	269	418	0.85	0.466	0.077	0.060	0.033	0.019	47%	30%	53%	29%	0%	35%
Minimum	4.0	3.0	132	134	0.44	0.201	0.030	0.008	0.005	0.003	11%	10%	41%	4%	0%	0%
Maximum	36.0	38.0	607	687	2.52	2.304	0.138	0.150	0.043	0.042	59%	61%	89%	80%	0%	81%
Quartile #1	18.5	14.5	221	351	0.74	0.339	0.066	0.039	0.024	0.013	36%	22%	49%	15%	0%	0%
Quartile #3	30.5	34.0	360	523	1.57	0.721	0.106	0.073	0.038	0.027	51%	38%	65%	54%	0%	54%



**Fig. 5.** Comparison of the experimental quartz and basalt bipolar core reductions in terms of expediency (a), usable flakes produced per second (b), and usable flakes produced per core mass (c).

Naibor Soit quartz is well known to be a tabular, brittle, coarse-grained, and heterogeneous rock type that possesses a high incidence of accidental snapping, uncontrolled breakage patterns, and high incidence of non-usable by-products (e.g. blocky debris, shatter) (Diez-Martin et al., 2011:705; Hay, 1976:11; Jones, 1994:256–257). While these characteristics are less than ideal for freehand knapping, these qualities turned out to be ideal for bipolar production: they not only facilitated easy ‘smashing’ that required fewer strikes and thus less time to produce flakes, but allowed every single quartz core to be fully exploited (Table 3). On the other hand, the basalt’s toughness required more strikes and, on average, prevented 31% of core mass from being fully exploited – and this was in spite of the basalt nodules’ flatter shape relative to the quartz nodules, which arguably could have aided reduction. Unsurprisingly, the difference in percentage of core mass left unexploited between quartz vs. basalt was significantly different ( $U = 45.0$ , Exact  $p = 0.004$ ). Quartz bipolar reduction did produce significantly more shatter than basalt bipolar reduction (Table 3,  $U = 54.0$ , Exact  $p = 0.015$ ), but as this ultimately resulted in more usable flakes and less time to produce them, it seems increased shatter is well worth the cost.

#### 4. Discussion

Braun and Hovers (2009) state that, “there is no doubt that the nature of raw material resources around Oldowan sites plays a major role in shaping the strategies of reduction.” This is true, but, they also note that “the influence of raw material availability does not take the form of determinism, emphasizing instead that Oldowan-hominins were engaged in active problem-solving.” As such, while raw materials in part shaped Oldowan strategies of reduction, it must also be acknowledged that the strategies of reduction might have also been shaping the raw materials that Oldowan hominins ultimately selected (Stout et al., 2005; Braun, 2012). Our experimental results are consistent with the notion that it is this *interplay* between raw material and reduction strategy that governed hominin association between bipolar reduction and quartz at Olduvai (Stout et al., 2010). Given its fracture properties, quartz is highly amenable to bipolar knapping. But, as our experimental results suggest, bipolar knapping is significantly more expedient on quartz than on basalt. So the reason we fail to see bipolar knapping on non-quartz toolstones at Olduvai might reasonably be interpreted to be because hominins recognized the constraints posed by non-quartz toolstones for bipolar reduction. Thus, the close technology-toolstone association between quartz and bipolar can be explained by constraints and advantages of both quartz and basalt alike. In terms of a “least cost solution to a sharp edge”, hominins appear to have found it: bipolar reduction is already widely acknowledged to be an expedient technology requiring little to no skill. By applying bipolar reduction exclusively to quartz, hominins at Olduvai appear to have enhanced this reduction strategy’s features.

The experimental tests should be repeated, and more experimental comparisons should be conducted that directly compare quartz and non-quartz toolstones in terms of quantifiable attributes and other reduction strategies (e.g. freehand unipolar knapping) (Braun and Harris, 2003; Patten, 2005; Surovell, 2009; Lycett and Chauhan, 2010). But thus far our experimental results, when considered within the archaeological context of Olduvai, are consistent more broadly with the notion that Lower Paleolithic hominins appear to have been able to understand the interplay between technology and toolstone: they recognized the differences in the physical properties of different types of raw material, and acted on this knowledge accordingly (Braun and Hovers, 2009:8; see also Braun, 2012; Diez-Martin et al., 2011:704; Goldman-Neuman and Hovers, 2009; Harmand, 2009; Stout et al., 2010). We note, however, that the expediency of bipolar reduction on quartz is not mutually exclusive to other reasons hominins at Olduvai may have preferred Naibor Soit quartz more generally, for example, its professed durable edges relative to other raw materials (Jones, 1994; Tactikos, 2005; Blumenschine et al., 2008). Indeed, it may have been the plethora of advantages quartz bestowed in specific behavioral contexts (bipolar reduction, butchery, etc.) that provided the impetus for hominins to travel substantial distances to procure it (Blumenschine et al., 2008; Hay, 1976; Diez-Martin et al., 2009, 2010, 2011; Schick and Toth 2006:26).

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