Raw material selectivity in Late Pliocene Oldowan sites in the Makaamitalu Basin, Hadar, Ethiopia

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A R T I C L E   I N F O

Article history:
Received 16 December 2010
Accepted 23 May 2011
Available online 8 July 2011

Keywords:
Oldowan
Lithic raw material selectivity
Raw material transport
Land use
Hadar
Makaamitalu Basin

A B S T R A C T

We report the results of an analysis of raw material selection patterns in the assemblages from two Late Pliocene sites in the Makaamitalu Basin (Hadar, Ethiopia). While the same local conglomerate was used as a raw material source for both archaeological occurrences, different selection criteria are identified. At A.L. 894, selection for quality is subtle and the clearest selection is against non-homogeneous raw materials. In the A.L. 666 assemblage, higher-quality raw materials were selected and some rare raw materials reached the locality from unknown sources. A comparison between the Makaamitalu and other Oldowan assemblages reveals an overall shift toward higher complexity of both selectivity and transport behaviors from ca. 2.0 Ma onward, contrasting a typo-technological conservatism that pertains until ~1.6 Ma. It is hypothesized that an increase in complexity of behaviors related to raw material selection and acquisition involved changes in the intensity and fidelity of technological knowledge transmission.

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Introduction

Studies of raw material selectivity have become an integral part of analyses of archaeological lithic assemblages, playing an important part in the understanding of technological decision-making processes. The distributions of subsistence resources and of lithic raw materials on the landscape have been shown to affect the technological organization of extant and prehistoric hunter-gatherers (for recent summaries and references, see, for example, Potts, 1994; Kuhn, 1995; Braun et al., 2008a; Hovers, 2009a), as well as land-use patterns of non-human primates (e.g., Boesch and Boesch, 1984; Sanz and Morgan, 2007; Carvalho et al., 2008). A large body of ethnoarchaeological and archaeological research underlines the active role of raw material selectivity and transport in the overall organization of technological behavior (e.g., Tindale, 1965; Munday, 1976; Binford, 1978, 1979, 1986; Binford and O’Connell, 1984; Gould and Sagers, 1985; Parry and Kelly, 1987; Roebroeks et al., 1988; Ambrose and Lorenz, 1990; Hovers, 1990; Petrequin and Petrequin, 1993; Kuhn, 1995, 2004; Moloney, 1996; Féblot-Augustins, 1999, 2009; Mallol, 1999; Stout, 2002; Brantingham, 2003; Sillitoe and Hardy, 2003; Minichillo, 2006; Delage, 2007; Wilson, 2007; Eerkens et al., 2008; Perreault and Brantingham, 2011).

A growing body of research on Late Pliocene assemblages integrates data on raw material-related behaviors into models of the ecological and technological behaviors of the makers of Oldowan assemblages (Plummer et al., 1999; Semaw et al., 2003; de Lumley et al., 2004; de la Torre and Mora, 2005, 2009; Harmand, 2005; Stout et al., 2005; Braun et al., 2008a, 2009a; Hovers and Braun, 2009). Both selection and transport of lithic resources appear to have been an important component of Oldowan stone tool use (e.g., Potts, 1984, 1994; Schick, 1987; de Heinzelin et al., 1999; Potts et al., 1999; Negash et al., 2006; Braun et al., 2008b), and are viewed as one of the defining characteristics of the Oldowan that distinguish it from the behavior of other primates (Davidson and McGrew, 2005).

Most, if not all, Late Pliocene assemblages share some features of Oldowan raw material-related behaviors. There is no evidence to suggest exploitation of raw material sources that were not exposed above ground. With the exception of quartz and chert in Olduvai, which were sometimes acquired from primary outcrops (Leakey, 1971; Hay, 1976; Stiles, 1991; Kimura, 2002; de la Torre and Mora, 2005), raw materials were procured as cobbles from drainages. In most reported cases, a preference for angular natural forms of cobbles was noted, presumably to provide early stone tool makers with suitable flaking angles, thus facilitating initiation of the knapping process. Still, with the increase in the number of analyzed assemblages, variation in aspects of selectivity and transport...
emerges as an important characteristic of Oldowan land-use patterns and the technological organization inferred from it. This variation is only partially explicable by methodological differences in research protocols and is not determined rigidly by raw material availability (Goldman-Neuman and Hovers, 2009; Stout et al., 2010). Raw material quality, suitability for knapping, and edge durability during future use emerge as selection criteria that govern decision-making processes of Oldowan knappers and stone tool-users at the time of raw material acquisition (Braun and Hovers, 2009). The newly-recognized investment of energy in raw material selection and transport supports the view that specific lithological traits conferred adaptive benefits on their users.

In this paper, we document patterns of raw material selection in two Late Pliocene sites in Hadar, Ethiopia. Our analysis supports initial field observations, which indicated that raw materials used in the two assemblages varied in their qualities as a result of different selection criteria. We then move to discuss the findings of the analysis in the context of the growing database on Oldowan raw material exploitation patterns. Finally, we explore some of the possible implications of the Hadar findings for understanding long-term patterns of ecological and technological behaviors between 2.5 and 1.5 Ma.

The sites

Two in situ occurrences, A.L. 894 and A.L. 666, are located in the Makaamitalu Basin of the Hadar Research Project area, some 170 m apart as the crow flies (Fig. 1). Stratigraphically, these sites are situated within the lowermost part of the Busidima Formation, underlying the 2.36 ± 0.07 Ma BKT-3 tephra (Campisano, 2007, 2012; Campisano and Feibel, 2008). Thus, they are among the earliest archaeological sites known to date.

A.L. 666 is a low-density distribution of artifacts and faunal remains exposed over an area of 20 m². An additional area of 4 m², excavated as test pits west of the main excavation area, revealed a single flake in the same stratigraphic horizon. The main archaeological horizon is 30–35 cm thick. Isolated artifacts were found below and above this horizon. Despite post-depositional erosion in antiquity as well as in recent times, lithic artifacts were refitted over short lateral and vertical distances. Most of the artifacts in this assemblage are flakes characterized by cortical elements, plain striking platforms, simple unidirectional scar patterns, and low scar counts. None of the artifacts were retouched. Based on stratigraphic considerations, this locality is slightly younger than A.L. 894 (Kimbel et al., 1996; Hovers et al., 2002; Campisano, 2012; Hovers, in prep.).

The A.L. 894 site is capped by some 3 m of sediments. With the exception of erosion by the modern Makaamitalu drainage on its western side, the artifact cluster is well preserved and its boundaries were exposed by an excavation of 21.5 m². Field observations suggest that the original lateral boundaries of the occurrence were exposed on the northern, southern and eastern edges of the excavated area. Lithic artifacts were spatially clustered; the majority were vertically distributed within a range of 30 cm, with outliers spanning up to 60 cm. Very few isolated artifacts were dispersed over a vertical range of 100 cm. This vertical distribution results mainly from the effects of post-depositional processes (Hovers, 2003). The assemblage is composed largely of whole and broken flakes (“detached pieces”) and angular fragments, while cores (“flaked pieces”) and retouched items occur in low frequencies. Based on the technological characteristics of the lithics and the presence of refits, A.L. 894 may be reconstructed as a knapping location with lithic raw materials and artifacts having been moved into and out of the locality (Hovers et al., 2008; Hovers, 2009b; Hovers and Davidson, in prep.). Due to its better preservation, the A.L. 894 assemblage is the main focus of the current analysis.

In the Makaamitalu Basin, as is the case for other localities of comparable ages, the identification of lithic raw material sources is analytically challenging (see Goldman-Neuman and Hovers [2009] for discussion of pertinent theoretical and methodological aspects). Unless raw materials encountered at a given locality are conspicuously exotic to the immediate surroundings, it is assumed in most studies of Oldowan raw material procurement that cobbles were collected from the closest sources. Typically, such nearby sources are river beds, which occur as conglomerates on the modern landscape or as buried channels in local stratigraphic sequences. Their identification as the sources of lithic raw material is anchored in the assumption that hominins adopted least effort solutions during raw material acquisition processes [Isaac et al., 1981 [1996]; for

Figure 1. Locations of the archaeological sites and KH-7 sampling points in the Makaamitalu Basin, looking northeast. The distance between the two sampling points is ca. 350 m. Inset: a schematic stratigraphic location (redrawn from an original by C. J. Campisano). See text for details on the stratigraphy and site distances.
As a result of sample size and logistical limitations, we did not apply the same detailed analysis to the A.L. 666 assemblage. Unless stated otherwise, comparisons made between the two assemblages are qualitative.

**Raw material analysis**

Some recent raw material studies employed sophisticated, accurate geochemical and material engineering methods to measure certain qualities of rocks that are impossible to grasp by the human eye alone (e.g., Noll, 2000; Braun et al., 2008a). In other cases, hand lens observations and semi-quantitative analyses were used to describe the rocks and their properties (e.g., Stout et al., 2005), sometimes supplemented by experimental work to simulate more accurately decision-making by the prehistoric knappers (e.g., Harmand, 2005, 2009a). This study follows the latter approach, focusing on attributes that were likely more pertinent to the decision-making processes of early hominins, although they are sometime assessed qualitatively (Brantingham et al., 2000; Goldman, 2004; Stout et al., 2005; Harmand, 2009a).

Rock lithology constitutes a formal classification system allowing comparisons between source gravels and archaeological artifacts. One raw material characteristic that would have played an important role in initiating the reduction process is cobbles angularity. Other analyzed raw material attributes were related to the level of rock isotropy, clustering and size of phenocrysts, and homogeneity of the groundmass (e.g., vesicularity, banding, and grain size) (Crabtree, 1967; Faulkner, 1972; Cotterell and Kamminga, 1979; Inizan et al., 1992; Andreksfj, 1994, 2000; Brantingham et al., 2000; Stout et al., 2005). These variables may have influenced overall raw material homogeneity and thus its fracture properties (e.g., brittleness) or practical utility (edge durability).

Raw material variables were documented and semi-quantified by examining fresh breaks on cobbles (broken specifically for this purpose) and artifacts (with excavation or taphonomic breaks) under a hand lens (> x10 magnification).

**Lithology (rock type)**

In principle, chemical analysis is required for definite lithological identification. In this research, rocks in both the conglomerate and the archaeological samples were assigned to rock types based on the mineral appearance, guided by the QAPF diagram for field classification of igneous rocks (Fig. 2; Prinz et al., 1978; Le Maitre, 2002). On this diagram, igneous rocks are distributed in 15 fields. Each corner of the triangle represents 100% of mineral content in the rock sample. The analyst quantifies the relative frequencies of a given mineral in his field of vision and classifies the rock by the appropriate field in the diagram. In the specific case of the Makaamitalu cobbles and artifacts, most rocks were porphyritic (i.e., larger crystals were set in a finer groundmass; Gary et al., 1974) and visual inspection was deemed sufficiently reliable for rock identification. An analyst using the diagram should aim for internal consistency of his categories more than for absolute accuracy in identifying raw materials (Goldman, 2004; Stout et al., 2005). Analytically, there is no reason to expect full agreement of the classifications reached by this analysis with other, more specific methods of classification (see Appendix A). In our case, this low-tech approach is a valid analogue of the visual means available to the ancient tool makers.

A comparative sample of cobbles from the conglomerate was collected and identified lithologically by TGN with one of the Hadar geologists, Craig Feibel, to serve as the standard baseline for the analysis of the geological and archaeological samples. All the studied samples from the archaeological material were compared.
against this baseline. This procedure ensured internal consistency across the various analyses conducted in the study (see Mgeladze et al. [2011] for a similar approach).

A petrographic analysis of samples of cobbles from the KH-7 conglomerate was conducted on a few items from the comparative collection to evaluate the reliability of the initial field identifications (Appendix A).

Phenocryst size and abundance

Data on phenocryst size and frequencies in the cobbles and archaeological artifacts were collected through visual examination. Given the methodology used in this research, we avoided quantitative assessments of phenocryst size or coverage per unit of rock surface area. Instead, we used a scale of “small/medium/large phenocrysts” and “no/few/many phenocrysts” per unit of rock surface area.

Groundmass texture

Observations were standardized through the use of a grain-sizing field folder, which enables field geologists to identify grain size, shape, roundness, sphericity, and degree of sorting in a sample (visual examples can be found online at http://www.forestry-suppliers.com/product_pages/View_Catalog_Page.asp?mi=3077&title=Sand+Grain+Sizing+Folder). Groundmass was characterized by its grain size on a 4-level scale: extra fine (silt size, <1/16 mm); fine (very fine and fine sand, 1/16–1/4 mm); medium (medium-grained sand, 1/4–1/2 mm); and coarse (coarse and very coarse sand, 1/2–2 mm). Some specimens showed a mixture of grain sizes across the sample surface; due to their very low frequency, they were omitted from this particular analysis. Another property that was studied was groundmass homogeneity as affected by the quantity (“few/many”) and size (“big/small”) of vesicles and degree of banding (“weakly banded/banded/flow banding”) in the rock, as observed through the hand lens.

Metrics

To investigate the effects of clast size on the selection process, we conducted metric comparisons between the source clasts and the archaeological artifacts. We expected that if cobble sizes differed according to lithology, this difference would be expressed in the size distribution of the artifacts. One caveat of this
comparison is that the clasts from the conglomerate emulate the archaeological cobbles before initiation of lithic reduction, while detached pieces are products removed from the clasts and by default would tend to be smaller than the source cobbles.

Recorded variables included size (maximum length, width, and thickness) and weight of the cobbles and the archaeological artifacts.

**Shape of raw material**

Angular or sub-angular cobbles/nodules bear natural facets that can be converted into striking platforms. Moreover, selection of the initial cobbles/nodule shape according to a planned technological sequence or anticipated tool shapes simplifies the knapping process. Such procedures are documented ethnographically and archaeologically. For example, in Acheulean-Yabrudian (Barkai et al., 2005) or Upper Paleolithic (Ahmarian; Davidzon and Goring-Morris, 2003) assemblages in the Levant, narrow nodules were selected for the production of blades. In the context of simpler, less structured technological practices, such as the Oldowan, cobbles/nodules with natural angular facets may have been advantageous mainly because they facilitated the first flake removals and the initiation of a knapping process.

In this study, cobbles shapes were classified into six morphological categories (Fig. 3).

**Rock quality**

Typically, rocks that are isotropic, elastic, and at the same time sufficiently brittle, are considered high-quality raw materials because they fracture more predictably and are easier to control during knapping (e.g., Crabtree, 1967; Faulkner, 1972; Cotterell and Kammenga, 1979; Inizian et al., 1992; Luedtke, 1992; Domanski et al., 1994; Andreffsky, 1994, 2000; Brantingham et al., 2000; Webb and Domanski, 2008). Some macroscopic traits can be observed visually (i.e., phenocryst coverage or banding) and some can only be evaluated by testing the cobbles. However, rock quality is a difficult property to measure and rank (Crabtree, 1967; Andreffsky, 2000; Goldman, 2004; Stout et al., 2005). This is partly because the property encompasses many traits that are documented independently (phenocryst size and banding, for example), but also because assessment of rock quality is relative and conditioned by the knapper’s goals. Rock properties that may be conducive toward successful knapping (i.e., reduce the frequencies of flaking accidents and of raw material waste) could be less favorable in terms of edge durability and artifact use-life duration, and vice versa. For instance, Eskimos select anisotropic, banded slate as the raw material for knife production, even though it might be harder to knap (Faulkner, 1972). Selection for “quality” may well aim for raw materials with properties that are a compromise between these two opposing goals (Braun et al., 2009b).

We constructed six groups on the basis of permutations of phenocryst size and abundances, combined with the size of vesicles and bands and their abundances within the studied datasets. The quality groups were ranked on a scale from “lesser quality” (group 1) to “better quality” (group 6) according to their suitability for knapping. Group 1 includes rocks that are anisotropic. They are porphyritic and contain vesicles as well as bands. Group 2 includes rocks that are anisotropic (i.e., they do not include phenocrysts), but they do include vesicles as well as bands. Group 3 includes rocks that are porphyritic and contain many bands or large vesicles. Group 4 includes rocks that are porphyritic and slightly banded or that contain small vesicles; these rocks are anisotropic, but they also contain many bands or large vesicles. Group 5 includes anisotropic rocks that are also slightly banded or contain small vesicles, or porphyritic rocks without vesicles and bands. Group 6 contains rocks that are anisotropic and do not show internal structure.

**Results**

Three raw materials were identified in KH-7 as well as both archaeological samples: basalt, rhyolite, trachyte. A fourth group consists of raw materials that had been weathered beyond reliable identification. Obsidian was encountered in KH-7 and in A.L. 894, whereas quartz and chert were observed only in the A.L. 666 assemblage.

Basalt was recognized as a mafic rock (i.e., a rock relatively enriched in heavier elements such as magnesium and iron), composed chiefly of calcic plagioclase in a glassy or fine-grained groundmass, which was easily identified in the conglomerate by its dark color and high density. Contrary to the Gona basalt (Stout et al., 2005), basalt in the KH-7 conglomerate is mostly, but not exclusively, fine-grained. Felsic rocks (i.e., rocks that are relatively enriched in lighter elements such as silica, potassium, or aluminum) occur mainly as rhyolites (Fig. 4). Trachytes were differentiated from rhyolites mainly by higher frequencies of quartz in the latter and the variable frequencies of feldspar/plagioclase crystals.

**The raw material source: KH-7**

The sample collected from KH-7 consisted of 208 cobbles comprising basalts, rhyolites, trachytes, obsidian, and a few weathered clasts (Table 1; Fig. 4). In the following analyses, we omitted obsidian and weathered clasts from most of the discussion due to their negligible frequencies. The statistically significant differences in rock types within the two conglomerate samples (Table 1) may be the result of differential sampling of raw material sources by the paleo-channel when it occasionally shifted its course (Goldman-Neuman and Hovers, 2009).

The cobbles are mostly angular (ca. 70%; Fig. 5) and fine-grained, and thus adequate for knapping. Vitreous rocks are available but uncommon in any of the lithologies present in the conglomerate. All rock types in the conglomerate were subject to some weathering, mainly by water action, that led to alteration of minerals in the groundmass (C. Feibel, pers. comm.). Seven cobbles that were highly weathered to the extent that raw material could not be identified were excluded from the discussion.

Basalt cobbles are mostly angular and are the smallest in the conglomerate sample (Fig. 6; Table 2). Groundmass is fine-grained;

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Figure 3. Schematic cobbles morphologies, with examples from the KH-7 conglomerate (left: angular cobbles; right: rounded cobbles, elongated and rounded disks).
many cobbles contain bands and vesicles and only some are porphyritic.

Rhyolite was the most common rock type in the conglomerate (Fig. 4), and the one showing the highest levels of weathering. Rhyolite cobbles are, on average, larger than the basalt (Fig. 6; Table 2). Approximately 50% of the cobbles were angular or sub-angular, but if sub-rounded cobbles are taken into account, the majority of rhyolite cobbles present natural flaking angles. Homogeneity (as defined by grain size, phenocryst abundance and distribution, and banding) is the lowest of all rock types. Although rhyolite cobbles show the highest amounts of extrafine groundmass, the number of medium- and coarse-grained cobbles is highest within this raw material. The majority of cobbles are porphyritic with phenocrysts visible to the naked eye.

Trachytes occur as the largest cobbles in the KH-7 conglomerate (Fig. 6; Table 2). They are angular and the most homogeneous, but occur in low frequencies (Fig. 4).

Obsidian appears rarely (ca. 1%, $N = 2$), its cobble size falling within the lower range of the conglomerate clasts. The obsidian cobbles show a weathered cortex and large phenocrysts in a glassy groundmass. As mentioned above, obsidian cobbles were excluded from the statistical analysis and most of the discussion due to their very low frequency.

Selection for rock lithology Data on rock lithology from the archaeological assemblage were compared to those in the conglomerate (KH-7a and KH-7b combined into a single sample; see discussion in Goldman-Neuman and Hovers, 2009). Frequencies of all the raw materials in the archaeological sample correspond to those in the source conglomerate (Fig. 4). This pertains also to obsidian, of which very few flakes and fragments were found. Obsidian items in the archaeological assemblage were highly disintegrated and sometimes reduced to yellow powder, with only few that still showed remnants of the original glassy appearance. Formally, this occurrence constitutes the earliest known appearance of knapped obsidian, but it does not show the structured, lithology-specific reduction sequence observed in some later Oldowan assemblages (e.g., Piperno et al., 2009). This may be due to the bad condition of obsidian in both the conglomerate and the site.

Rhyolites occur in the highest numbers, followed by basalts and trachytes. The differences in the distributions of raw materials between the geological and archaeological samples are statistically significant (Pearson’s $\chi^2 = 6.09$, df = 2, $p = 0.014$). Examination of the standardized residuals (Table 3) indicates that the main contributor to this difference is the basalt, which is underrepresented in the archaeological sample compared to the source (Goldman-Neuman and Hovers, 2009).

When combined, the observations on rock lithology suggest that selectivity for specific rock types did not play a major role in decision-making while acquiring raw materials from the source. At most, the observed pattern implies that A.L. 894 knappers selected against basalts.

Selection for raw material shape For knappers in the A.L. 894 locality, as for those of other early Oldowan sites (e.g., Delagnes and Roche, 2005; Harmand, 2009a), the ease of initiating the knapping process would have been an important selection criterion. The paucity of cores in the site and the spatial fragmentation of the reduction sequences, whereby products and cores were removed into and from the site (Hovers et al., 2008; Hovers, 2009b, in

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**Table 1**

<table>
<thead>
<tr>
<th>Rock type</th>
<th>KH-7a</th>
<th></th>
<th>KH-7b</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$N$</td>
<td>%</td>
<td>$N$</td>
<td>%</td>
</tr>
<tr>
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<td>56</td>
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<td>Basalt</td>
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<td>41.75</td>
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<td>29.52</td>
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<tr>
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<td>3</td>
<td>2.91</td>
<td>14</td>
<td>13.33</td>
</tr>
<tr>
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<td>2</td>
<td>1.94</td>
<td>–</td>
<td>–</td>
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</tr>
<tr>
<td>Total</td>
<td>103</td>
<td>100.00</td>
<td>105</td>
<td>100.00</td>
</tr>
</tbody>
</table>

$\chi^2 = 9.17; \ df = 2; \ p = 0.01$.

*a* Obsidian and weathered cobbles were omitted from the $\chi^2$ test.
did not enable documentation and quantification of initial cobble sizes and shapes in the archaeological sample. Whenever cobble shape was sufficiently retained, cores and flakes in the assemblage appear to have been derived from angular cobbles. Because the majority of cobbles in the source conglomerate were angular (Fig. 5; Goldman, 2004), this trend by itself cannot be taken to indicate selection for specific shapes.

Selection for size Raw materials in the sample appear to track the size distribution in the conglomerate. Since there is no evidence that the A.L. 894 tool makers adjusted their knapping strategies to specific lithologies and the associated differences of dimensions (Hovers and Davidzon, in prep.), it was hypothesized that flake size distribution should reflect the size differences between basalts, rhyolites and trachytes in the source. Therefore, we expected that more basalt flakes will be small compared to flakes of other raw materials. As a rule, flakes in the assemblage are not expected to directly mimic the sizes of the original clasts (see section “Methodology,” above). The length distributions of cobbles in the raw material source and of whole flakes in the archaeological sample are shown in Fig. 6.

We used flakes that bear cortex on the proximal and distal ends to provide first approximations of minimal knapped cobble sizes. In the A.L. 894 assemblage, the length values of such flakes \((N = 30)\) range between 42 and 112 mm (with a single smaller artifact), the mode (3 artifacts) being 68 mm. As flakes in the assemblage were typically removed across the short axis of the cobbles (Hovers and Davidzon, in prep.), this sets a minimal value for the knapped cobble width and suggests that cobbles were initially larger.

Figure 5. Frequencies of cobble morphologies in the KH-7 conglomerate (the samples from KH-7a and KH-7b are combined). Angular and spheroid forms shown in Fig. 3 (“highly angular” and “angular,” “spheroid” and “sub-spheroid”), are combined here into two categories (“angular/sub-angular” and “spheroid/subspheroid”), respectively.

Figure 6. Length distributions by rock type. (A) KH-7 sample; (B) whole flakes in the archaeological sample.
Cobbles of the three main rock types in the conglomerate reach up to 19 cm in length, but their sizes are distributed differently (Table 2). Notably, basalt cobbles are smaller, though the differences in length and thickness are not statistically significant. Width differences are statistically significant between the basalt and the other raw materials (note however that the absolute values are not highly divergent and not easily assessed visually). The relatively high frequencies of small basalt flakes in the archaeological sample are consistent with this observation. The trachyte flakes tend to be larger, again corresponding to the tendencies of size distributions in the cobbles in the source sample. There does not seem to be a consistent trend of size-related selection of raw materials.

Selection for rock quality While artifacts in the archaeological assemblage show some weathering and patination, they are less weathered than sampled cobbles of the KH-7 conglomerate. Most of the weathering and patination of the archaeological material occurred on-site post-depositionally, implying that when collected, cobbles used for flaking were probably of better quality than observed at the time of archaeological discovery (C. Feibel, pers. comm.).

We compared the quality of rocks in the archaeological and geological samples (Fig. 7) according to the six quality groups as defined above. Trachytes are distributed similarly in both samples, most cases being porphyritic rocks without vesicles and bands and falling within quality group 5. The rhyolites show a different pattern, where less homogeneous rocks (groups 3 and 4) are more abundant in the conglomerate compared to the archaeological assemblage. Basalts in the archaeological assemblage are more homogenous than in the raw material source, as indicated by the higher frequencies of quality group 6 in the former.

The various raw materials in the source conglomerate are variably porphyritic. Whereas trachytes in the conglomerate are not aphanitic (an observation possibly due to the small sample size for this lithology), rhyolites and especially basalts do occur as such (Fig. 7). When the variable "phenocryst content" is omitted from the analysis, rhyolites, which at the source contain abundant impurities, seem to have been subjected to stricter selection toward fewer impurities compared to basalts and trachytes. This suggests that A.L. 894 hominins selected against rocks with impurities in the matrix.

**A.L. 666**

Because of its post-depositional history (see above), A.L. 666 yielded a small assemblage (N of flaked and detached pieces = 224). Moreover, on-site observations indicate that the occupation was excavated in its entirety, and sample sizes will not increase as a function of additional fieldwork (E. Hovers, pers. obs.). While the small sample does not allow a rigorous quantitative study, this assemblage provides valuable information about variations in selection behaviors in these two sites.

A total of one hundred and thirty-four artifacts were examined, comprising 59.8% of the total assemblage. Highly fragmented pieces from which raw material characteristics could not be observed were excluded from the analysis. Rock lithology was analyzed and quantified in the same manner as the A.L. 894 sample and is presented quantitatively. Quantitative results of this analysis can be compared to those obtained for the A.L. 894 assemblage (Fig. 4). Rock quality groups were identified based on the same criteria as for A.L. 894 (see above). This variable, as well as breakage patterns, raw material size distributions, and rock quality were noted but not formally quantified. These aspects of the assemblage are not part of our discussion.

Based on the same stratigraphic and petrographic considerations specified above with regard to A.L. 894, KH-7 is the most likely raw material source. As is the case for A.L. 894, rhyolite is the most frequent raw material (Fig. 4). There are hardly any porphyritic rhyolites in A.L. 666; the quality of this rock type is higher, and its variability lower, than in the A.L. 894 assemblage. The majority of rhyolites (70%, N = 61) belong to quality group 6, compared to 20% in A.L. 894.

Quartz is the second most abundant raw material in the A.L. 666 sample. Eighteen quartz artifacts were found, all in very small sizes (the largest is 1.6 cm long). Since no quartz core was identified, the specifics of quartz flaking technology are not fully understood. Quartz might have been knapped differently than other raw materials in the assemblage, possibly using the bipolar method applied to similar raw materials at the Shungura F sites and Fejej (Chavaillon, 1976; Merrick and Merrick, 1976; de Lumley and Beyene, 2004).

The basalts and trachytes used in A.L. 666 are similar to the ones found in A.L. 894 but their frequencies are considerably lower. Three chert flakes also occur in the assemblage, knapped from river pebbles.

**Discussion**

Analyses revealed two main differences between the two Makaamitalu assemblages. The first difference is that raw material textures in A.L. 666 are more homogeneous and fine-grained compared to those utilized in A.L. 894. This is especially notable...
in the rhyolites, which in A.L. 666 are of better quality than at A.L. 894. When compared to the raw material source, in which rhyolites show a wide range of rock qualities, the constrained selection for this lithology in A.L. 666 is even more apparent. Basalts and trachytes in the source were more uniform to begin with and required less selection.

A second important difference between the two Makaamitalu sites is the exploitation of additional raw materials (quartz and chert) in A.L. 666, which were exploited at the expense of the local basalts and trachytes. Since both raw materials appear in very low frequencies in the archaeological assemblage, we cannot rule out the possibility that they originated from the local conglomerate where they also occurred only rarely, and therefore were not sampled by our random cobble sample. Another possibility is that these rocks were transported from an unknown source located at an unknown distance.

That hominins at A.L. 666 applied stricter selective criteria compared to A.L. 894 during raw material acquisition is made most clear by a non-random appearance of some of the lithologies deriving from the nearby source. Also compelling is a conspicuous occurrence of relatively rare, high-quality raw materials in A.L. 666 (i.e., quartz and chert, not found in the KH-7 conglomerate samples or in the much larger A.L. 894 assemblage; Fig. 4), suggesting not only selectivity but possibly also investment in search for high-quality material. In comparison, selection patterns identified in the A.L. 894 assemblage seem at face value almost opportunistic if not nearly non-existent. Differences in rock type frequencies between the archaeological sample and the source are within the range of variability documented across the conglomerate (Goldman-Neuman and Hovers, 2009). Because original cobble morphology can be deduced from only a very small number of artifacts, selection for angular cobbles with natural striking platforms remains a moot point. Regardless, given that angular to sub-angular forms predominate in the source, desirable cobble shape and angularity were easy to come by and careful selection for these properties was not required.

A criterion that does seem to have guided raw material acquisition was discrimination against impurities in the matrix (bands and vesicles) regardless of specific lithology. Additionally, there is a tendency to avoid basalts, possibly due to their unfavorable properties (a combination of brittleness and hardness) for knapping. The evidence for on-site fragmentation of some of the basalt cobbles and higher levels of breakage of large basalt cobbles (Goldman-Neuman and Hovers, 2009; Hovers and Davidzon, in prep.) may be related to their use as hammerstones due to their hardness. Another possible explanation of this phenomenon is that the assemblage represents different levels of knapping skill or experience.

The bulk of raw materials seem to have been brought into the A.L. 894 locality as partly decorticated cobbles or as flakes, despite the short distance from the geological source to the knapping locality (Hovers et al., 2008; Hovers, 2009b; Hovers and Davidzon, in prep.). This behavior may be directly related to the properties of the raw material clasts in the source area: to the prehistoric knapper, cobbles in the conglomerate were sufficiently similar in terms of size, angularity (as well as cortex appearance; pers. obs.) that their field appearance did not serve as a visual “predictor” of rock type or rock quality. To assess these properties, hominins had to test the cobbles, and seem to have done so at the source prior to their transport to a knapping location.

Overall, the analysis reveals selectivity on the part of A.L. 894 knappers, despite the short transport distance involved. Given the availability of cobbles of adequate shape and size for knapping, selection is expressed in more subtle properties of the raw material. The patterns of selectivity inferred from the A.L. 894 lithic assemblage speak to an intimate familiarity with raw material properties and an understanding of their implications for knapping and later use of the artifacts.

The occupants of A.L. 666 applied stricter selection criteria, exercising more careful selection of raw material and targeting more fine-grained, albeit less frequently available cobbles within the KH-7 source or other sources currently unknown to us, which probably incurred higher search costs and, possibly, longer transport distances compared to A.L. 894. Overall, the slightly later assemblage represents higher levels of investment in the acquisition of raw material.

The patterns of selectivity seen in the two Makaamitalu sites fall within the behavioral range recognized in Late Pliocene Oldowan sites. A piecemeal publication of raw material selectivity patterns in the EG-10 and EG-12 sites at Gona, dated 2.5 Ma, indicates lithology-based selection (Stout et al., 2005), mediated by consideration of phenocryst size, percentages of phenocrysts and groundmass texture, as well as a preference for larger cobbles (Stout et al., 2010). This pattern holds across many of the sites in the Gona research area, despite their different chronological assignments (Semaw et al., 2000; Semaw et al., 2003) and the observed variations in the rock type abundances within the sampled conglomerates. In contrast, at the 2.6 Ma site of OGS7 the most frequent rock type in the assemblage

Figure 7. Distribution of rock quality groups (including phenocryst coverage; see methodology section for details) in the archaeological sample (A) and in the geological source (B).
aphanitic and
More recently, Stout et al. (2010) argued that given the scarcity of
have played a role in selection decisions (Stout and Semaw, 2006).
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intentional investment in
cobble shape, reimported for knapping were rounded, massive, and globular in
shape, reflecting the more common shapes found in the raw material
sources (Harmand, 2007, 2005a, b). At Lokalalei 2c, shape selection
was stricter and focused on the presence of natural striking surfaces.
Studies of the lithic assemblages from Kanjera South, dated ca.
2.0 Ma, suggest that certain rock types were transported into the
site in higher proportions than can be expected based on their
availability in the local conglomerates (Braun et al., 2008a). Results
of mechanical tests suggested that selectivity was based primarily
on raw material ability to resist abrasion, and not on fracture
predictability. At the same time, Braun et al. (2009b) noted that the
most frequently selected raw materials contained less impurities and phenocrysts, and were durable as well as more predictable
when knapped, compared to other materials in the drainages.
In the localities of the Shungura member F, quartz is the
predominant raw material by default of regional availability. The
exploited small quartz lumps and pebbles constituted the only
material carried by channels located several kilometers from the
sites (Merrick and Merrick, 1976; Howell et al., 1987). On the other
hand, the predominance of quartz in the assemblage from site Fj-1
in Fejej is due to knapper preference for small-sized pebbles with
natural striking platform angles out of variously sized and shaped
cobbles in the nearby channels. This selection is argued to have
been constrained by the anticipated use of the cobbles/artifacts (de
Lumley et al., 2004).
Oldowan raw material selection and acquisition emerges as
a variable organizational complex that incorporates the separate,
related strategies, of raw material selectivity and its transport
(Goldman-Neuman and Hovers, 2009). Against the variability in selection criteria in the assemblages discussed above,
transport distance in the majority of cases are minimal, on the
order of hundreds of meters to a few kilometers (e.g., A.L. 894, A.L.
666?), OCG7, EG sites, Lokalalei sites, Shungura sites, and Fejej Fj-1.
For the Late Pliocene sites, longer distances were demonstrated
only in Kanjera South (Braun et al., 2008a). The transport distances
involved in the exploitation of non-local raw materials in some
other cases (A.L. 666?), EG sites are not known.
Several hypotheses were offered to explain the differences in
Oldowan raw material selectivity and organization. Some authors
declared that integrated, strategies of raw material selectivity and its
transport (Goldman-Neuman and Hovers, 2009; de la Torre and
Mora, 2005; Blumenschine et al., 2008) not support the hypothesis that raw material selectivity responded to
inhabitat-dependent functional design of artifacts.
Differences in Oldowan raw material-related behavior can also be attributed to variable land-use patterns, reflected, among others,
by distances of raw material transport between localities on the
paleo-landscape (e.g., Plummer, 2004; Toth et al., 2006). The two
Makaamitalu sites are located within similar distances from the
material source (Fig. 1). Technological studies and refits suggest
that A.L. 894 can be interpreted as a knapping station within a
geoarchaeologically more extensive system of mobility and settlement
on the paleo-landscape (Hovers et al., 2008; Hovers, 2009b, Hovers
and Davidson, in prep.). Whether the same is true for A.L. 666 is
unknown as syn- and post-depositional disturbances do not allow
for reliable inferences about the site’s function within its settlement
system.
The failure of simple, single-cause explanations to account for
variability in the Oldowan led many researchers to recognize that
better understanding of the technocomplex calls for a multi-faceted
approach that integrates various behavioral aspects (Braun and
Hovers, 2009; de la Torre and Mora, 2009; Stout et al., 2010).
Such a comprehensive approach recently led Stout et al. (2010)
to reiterate earlier claims (e.g., Semaw, 2000) for the long duration of the
Oldowan as a million-year period of non-directional variations
and lack of cumulative change (‘stasis’). They also predicted that
“...cultural variation in fine-grained technological strategies,
thought not currently evident, may eventually be identified within
this equilibrium” (Stout et al., 2010: 489).
Non-opportunistic, site-specific selectivity of lithic raw materials
is common to early Oldowan assemblages (2.6-1.7 Ma). Its
various manifestations can be viewed along a behavioral continuum
from very simple exploitation, by default of raw material availability
(e.g., the Shungura F sites), to more complex patterns of behavior,
involving a large number of selection criteria. Within this behavioral
range, different combinations and different levels of selectivity,
based on morphometric characteristics (shape and size), raw
material quality (degrees of homogeneity of the matrix), and
lithology, are encountered. Thus, in Lokalalei 2c, all these
characteristics played a role as selection criteria, whereas at A.L. 666 and
Lokalalei 1, lithology and raw material quality were taken into
account. In the EG sites, morphometrics and lithology set the
selection standards. At OCG7 and A.L. 894, raw material selection,
combined with minimal transport distances, perhaps comes closest
to “least effort” strategies as defined by Isaac et al. (1981 [1996]). These two sites, therefore, can be considered as closer to the less complex end of the behavioral continuum. Still, in both instances subtle selection against certain characteristics of raw material quality could be identified.

From ~2.0 Ma and persisting into the Early Acheulian, there are more frequent occurrences when raw material-related behaviors fall closer to the complex end of the continuum (this is not an exclusive pattern, e.g., Dmanisi; Mgeladze et al., 2011). In these assemblages, different raw materials were being selected, either in anticipation of raw material shortage or of the production of specific artifact types for which certain raw materials were deemed more desirable. Examples for such behavior is observed at sites such as Fejej Fj-I, Kanjera South, Olduvai Bed II, Koobi Fora, Melka Kunture, Kokisele 3, Peninj, Gadeb, and ‘Ubeidiya (Clark and Kurashina, 1979; Bar-Yosef and Goren-Inbar, 1993; Isaac and Harris, 1997; de Lumley et al., 2004; Harmand, 2007, 2009a; Braun et al., 2008a, 2009a; de la Torre et al., 2008; de la Torre, 2009, 2011; Piperno et al., 2009). In many of these cases, the increase in the complexity of selectivity is combined with longer raw material transport distances (Féblot-Augustins, 1997; Goldman-Neuman and Hovers, 2009). While distances are sometime compatible with those observed among extant non-human primates, they imply different patterns of home range exploitation (e.g., Marwick, 2003) and indicate more complex behaviors of toolkit procurement, maintenance, and discard (Potts, 1984, 1991, 1994; Blumenschine et al., 2008; Braun et al., 2008b). The more prominent implementation of such complex behaviors by later Oldowan groups would have necessitated the emergence and assimilation of more binding technological norms and conformation to such norms, which over-ruled considerations conditioned by raw material availability at a short distance (see Harmand [2007] for similar insights about the sequence of the Nachukui Formation in Kenya). This implies increased levels of transmission of technological knowledge compared to the earlier Oldowan.

Most Oldowan researchers recognize that the sporadic occurrence of archaeological sites in the time span 2.6–1.6 Ma (and, in fact, even later) is a hindrance to forming testable hypotheses about the tempo and mode of cultural transmission. As it is currently known, the archaeological record of this period is believed by many researchers to show lack of cumulative typological change (but see Texier et al., 2006; Harmand, 2007). If future research corroborates the existence of the hypothesized trend toward more complex raw material procurement strategies, the putative Oldowan typo-technological “stasis” may mask important changes in the adaptive strategies and social relationships of early hominin groups.

Acknowledgments

Fieldwork and laboratory work was carried out as part of the Hadar Research Project and was supported by the National Science Foundation (grant #BCS-080378 to W. H. Kimbel and D. Johanson), the National Geographic Society (grant #7352-02 to E. Hovers), and grants to E. Hovers from the Leakey Foundation. We are grateful to the Institute of Human Origins for logistical help in this research. We thank the Ethiopian Authority for Research and Conservation of Cultural Heritage and the director and staff of the National Museum of Ethiopia in Addis Ababa for their help in carrying out this research. Thanks go to the Afar Regional Government and to the Afar people of the village of Eloha and the Hadar area, and especially to our field crew members, for their help and friendship.

We thank Ilan Sharon for his help with statistics. Nira Alperson-Afil and three other reviewers offered helpful comments on an earlier draft of this paper.

Appendix A. Optical petrographic analysis of rock samples from the KH-7 conglomerate, Makaamitalu Basin, Hadar

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Cobble samples from the KH-7 conglomerate were subject to microscopic petrographic examination for confirmation of preliminary lithological determinations by hand lens performed in the National Museum in Addis Ababa. The cobbles included in this analysis were collected by T. Goldman-Neuman and used in the study of raw material selectivity reported here (see also Goldman-Neuman and Hovers, 2009). The cobbles (N = 85) were imported to Israel under permit from the Authority for Research, Conservation and Cultural Heritage (ARCCH) and Ministry of Mines, Ethiopia. The current analysis was conducted in the Geological Survey of Israel in Jerusalem.

The samples were classified by aid of a ×10 hand lens and grouped into rock types. All of the samples were of magmatic origin. Thirty-nine samples manifesting lesser mineralogical alteration were identified lithologically. Of these, seven samples from different rock types were thin-sectioned and subjected to mineralogical microscopic examination. Analyses were performed with a Zeiss standard petrographic microscope and Olympus BX51 petrographic microscope. The final petrographic definitions were determined according to the results of the microscopic examination.

In the following description, the field designation of the sample, as determined by Goldman-Neuman, is given in parentheses following the sample id#.

Sample 7a 55 (rhyolite with feldspars)

Hand specimen description

Green grayish color, with many black dots, and a porphyritic texture.

Microscopic description

Phenocrysts Plagioclase, close in composition to albite. Crystal sizes range between 1 and 5 mm. Phenocrysts occupy about 20% of the entire thin section area. Most of the phenocrysts appear in small clusters (glomerocrysts) and are euhedral to subhedral in appearance. The phenocrysts are very weathered and the cleavage is hardly noticed. They appear to be detached, through transportation and redistribution via flow.

Matrix Fifty percent of the matrix is feldspar with the same refraction index as the phenocrysts. The other 50% is an aphanitic substrate occupying the space between the feldspar crystals. Opaque minerals are about 2% of the thin section. Some of the opaque minerals are accompanied with reddish staining. In some places, concentrations of small mineral grains (0.1–0.2 mm) were found in the matrix, and are probably quartz grains.

Texture Flow texture is obvious, especially around the phenocrysts.

Definition A pyroclastic rock (flow texture and detached glomerocrysts) with an andesitic (probably close to dacitic) composition.
Sample 7a 67 (basalt)

**Hand specimen description**

Gray weathering color with black mineral grains up to 6 mm in diameter. Black in freshly broken surfaces. Porphyritic texture.

**Microscopic description**

Phenocrysts Mostly olivine. Phenocrysts occupy about 40% of the thin section area. They appear in two modes. One is subhedral and has a beige color; the other is rounded and white. Many phenocrysts show zoning.

Matrix Medium- to fine-grained (0.5–0.25 mm). Feldspars compose about 60% of the matrix, and the other 40% is composed of olivine and some pyroxene. Black opaque minerals occupy about 10–15% of the entire thin section and are made mainly of magnetite with a small amount of rutile and sphene.

Definition Basaltic composition, possibly from a dyke or a median part of a flow.

Sample 7a 103 (rhyolite)

**Hand specimen description**

Weathered brown gray with white phenocrysts. Brown at freshly broken surface.

**Microscopic description**

Phenocrysts Euhedral phenocrysts (0.3–3 mm) displaying zoning. Affected by alteration at the margins or at the center. Probably plagioclase. The phenocrysts occupy about 10% of the thin section area.

Matrix Highly weathered, fine-grained and passing to aphanitic with small feldspar needles and prisms. Brown staining from iron oxide. Minute quartz grains. Few black grains of opaque minerals.

Definition Probably andesite.

Sample 7b 16 (basalt)

**Hand specimen description**

Dark brown to gray. Elongated phenocrysts can be observed on freshly broken surfaces.

**Microscopic description**

Phenocrysts Phenocryst sizes range between 0.2 and 2 mm. The phenocrysts constitute 10–15% of the area of the thin section. Two kinds of phenocrysts were observed. The first kind is feldspars, which constitute the majority of the phenocrysts. These are plagioclase with twinning and zoning. Some crystals display calcitic alteration, which points to original calcitic feldspars (plagioclase). The second kind is amphibole and pyroxene. Phenocrysts of this group are few and appear sometimes in small clusters. They comprise hornblende, clinopyroxene, and perhaps diopside or ugiite.

Matrix Fine, elongated (acicular) plagioclase crystals surround the phenocrysts and are arranged in a flow pattern. Many small amphibole and pyroxene crystals appear between the plagioclase crystals. Opaque minerals constitute about 10% of the thin section area. Plane light observation reveals abundant limonitic staining.

Definition Basalt.

Sample 7b 25 (rhyolite)

**Hand specimen description**

Light brown to beige with reddish limonitic staining. Laminar flow structure that looks in places like fine varves. Light-colored phenocrysts, ranging in size 1–3 mm.

**Microscopic description**

Phenocrysts Mainly feldspars, including K-feldspars, orthoclase, and microcline, which are probably perthite, plagioclase, oligoclase, or andesine. Few amphibole crystals.

Matrix Very fine, almost aphanitic. Laminar accumulations of fine quartz grains parallel to the varves, possibly veins. Opaque minerals constitute about 5–8% of the thin section area.

Definition Due to difficulty in optical mineralogical examination of the matrix, it is impossible to define accurately the petrographic composition of the rock. It is probably a pyroclastic rock of dacitic to rhyolitic composition.

Sample 7b 47 (rhyolite)

**Hand specimen description**

Gray color. Two kinds of phenocrysts were observed: 1) white rectangular or square crystals, and 2) black crystals with rounded corners. Phenocryst sizes range 0.5–2 mm. Fine-grained background.

**Microscopic description**

Phenocrysts Subhedral plagioclase and rounded olivine.

Matrix Very fine-grained to aphanitic. Abundant black material and black opaque minerals.

Definition Olivine basalt.

Sample 7b 68 (rhyolite with feldspars)

**Hand specimen description**

Gray to beige color. On freshly cut surfaces the color is gray. Many light beige to white phenocrysts, in the size range of 0.5–1 mm.

**Microscopic description**

About 80% of the thin section area is occupied by spherulites with a radial structure and dark-colored peripheral margins within the size range of 0.5–1.2 mm (the majority are 1 mm). In some cases, the spherulites appear with two or three concentric dark rings at the margins. At the center of the spherulites lies a cluster of very fine-grained mineral, apparently quartz. In rare cases, the center is occupied by a crystal of quartz or feldspar. Most of the spherulites touch each other and some of them are merged and have common dark margins.

Phenocrysts Weathered, euhedral crystals displaying zoning and lacking twinning occupy about 10–15% of the area; probably feldspars.

Matrix The cement around the spherulites and phenocrysts is quartz. Black opaque grains occupy about 1–2% of the area.

Definition A rock of acidic composition, either rhyolite or dacite.

One sample (7b 47) out of the seven studied by polarizing microscopy had been misidentified in the original preliminary
analyses. One sample (7a 103), initially defined as rhyolite, appears on petrographic examination to be andesitic. Another, 7a 55, displays an andesitic, probably close to dacitic composition. The discrepancy between the two methods of analysis stems from two different reasons. One important factor is the different resolutions of the two analytical methods, especially for rock types that are closer in the mineralogical space displayed in Fig. 2. Comparisons to the hand lens observations should be done on the common ground of the lower resolution available to the latter analysis. The other is the nature of the sampled materials. As indicated by both the field study and the petrographic analysis, all the samples collected were cobbles that had suffered mechanical erosion, and to some extent mineralogical alteration, as result of fluvial transport. When the rocks are fine-grained determining mineralogy by hand lens is less accurate than with fresh materials. This is particularly true for rhyolitic rocks, which are often of aphrican or glassy textures. Moreover, cobbles are detached from their parent rock formation, thus field observations cannot be assisted by typical structures and field relationships which are important clues for definition.

That said, the analyses reported here suggest that rock and mineral properties (i.e., matrix and phenocryst determinations and grain-sizes) had been identified reliably. In the context of the present study, these are the properties that seem to have served as the criteria for rock exploitation by early hominins.

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