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Effects of distance from stone source on landscape-scale variation in Oldowan artifact assemblages in the Paleo-Olduvai Basin, Tanzania

Robert J. Blumenschine [a,*], Fidelis T. Masao [b], Joanne C. Tactikos [c], James I. Ebert [d]

[a] *Center for Human Evolutionary Studies, Department of Anthropology, Rutgers University, 131 George Street, New Brunswick, NJ 08901-1414, USA*

[b] *Archaeology Unit, Department of History, University of Dar es Salaam, Dar es Salaam, Tanzania*

[c] *Archaeological Consulting Services 424 W Broadway Road Tempe, AZ 85282, USA*

[d] *Ebert & Associates, 3700 Rio Grande Blvd. N.W. Suite 3, Albuquerque, NM 87107, USA*

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Abstract

Ongoing excavations at Olduvai Gorge, Tanzania, reveal tremendous variability among stone artifact assemblages across the Plio-Pleistocene Olduvai Lake Basin during Bed I and lower Bed II times. Theoretically, stone artifact traces of Oldowan hominin land use are determined by the distribution of larger mammal carcasses and arboreal refuge from predation as well as proximity to stone material sources.

We provide an initial evaluation of these theoretical expectations, focusing on the effects of distance from stone source on four parameters of Oldowan artifact assemblages from the lowermost Bed II eastern Olduvai Basin. Quartzite artifact assemblages show expected distance-from-material-source trends relative to their straight-line proximity to three of four points along Naibor Soit, a local quartzitic inselberg. The weight density and proportionate weight of quartzite assemblages decrease with increasing distance from Naibor Soit, as do the size of flaked pieces and the proportion of these that are minimally reduced. The results demonstrate predicted behavioral patterning in broad-scale traces of hominin land use, but proximity to Naibor Soit explains the majority of variability in only the weight proportion of stone artifacts made on quartzite. Ecological factors appear to have also influenced the landscape distribution of Oldowan hominin activity traces.

Keywords: Oldowan; Olduvai Gorge; Stone artifacts; Distance-decay; Material transport; Hominin land use

1. Introduction

Stone artifacts in paleolandscape context provide a record of fossil hominin activities in different environmental settings (Isaac, 1981). Unlike conventional large excavations of dense artifact occurrences, sampling of surface or in situ stone artifacts over broad areas for single time intervals permits investigation of landscape patterning in hominin activity traces (Thomas, 1975; Isaac, 1981; Isaac et al., 1981; Foley, 1981a, 1981b; Binford, 1982; Dunnell and Dancey, 1983; Blumenschine and Masao, 1991; Dunnell, 1992; Ebert, 1992; Stern, 1993, 1994; Rogers et al., 1994; Blumenschine and Peters, 1998; Potts et al., 1999; Plummer, 2004; Blumenschine et al., 2005). Detailed paleoenvironmental analysis of deposits containing the stone artifact sample offers the possibility of gaining an ecological understanding of prehistoric hominin behavior (e.g., Peters and Blumenschine, 1995, 1996) within limits imposed by time averaging of the paleo-record (e.g., Stern, 1994). Since 1989, the Olduvai Landscape Paleoanthropology Project (OLAPP) has been documenting the paleolandscape ecology and land use patterns of Oldowan hominins in the Plio-Pleistocene Olduvai Lake Basin during Bed I and

* Corresponding author. Tel.: +1 732 932 6746; fax: +1 732 932 1564.
E-mail address: rjb@rci.rutgers.edu (R.J. Blumenschine).

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lower Bed II times at Olduvai Gorge, Tanzania (Fig. 1, Blumenschine et al., 2005).

Blumenschine and Peters (1998: 587) modeled the relative density, dispersion, and general composition of stone artifact assemblages among 11 landscape facets in the central Olduvai Basin on the basis of several factors: (1) the cover abundance of trees and the inversely correlated intensity of predation hazard, (2) the abundance and variety of resources requiring stone tool use, and (3) stone transport costs from source to use locations. The first two factors had the greatest effect on the predictive model. Higher-density occurrences representing a broad functional range of stone artifacts are expected in safer, well-treed landscape facets affording a variety of resources. Lower-density scatters of knife-like flakes and flaking shatter are hypothesized for more open and dangerous landscape facets. Blumenschine et al. (2005, in press) provide preliminary tests of this hypothesis. Distance of stone-tool-using activities from raw material sources was modeled to influence mainly the relative abundance of tools made on different materials, given differential transport costs, with locally available quartzite dominating assemblages near the central basin source, and artifacts made on lavas becoming more common toward the southeastern volcanic highlands (Fig. 1).

Here, we evaluate the effects of proximity to raw material source on landscape-scale variability in the density and composition of Oldowan stone artifact assemblages excavated by OLAPP. Although we have sampled all exposed portions of the paleo-Olduvai Basin (Blumenschine et al., 2005), we focus on the quartzite artifact assemblages recovered from the basin's Eastern Lake Margin and Eastern Alluvial Plain (Fig. 1). The quartzite source for the artifacts is assumed to be Naibor Soit, an inselberg located within 4 km of the excavations that yielded the artifact sample (Fig. 2). Specifically, we test if predicted behavioral patterning in quartzite assemblages with respect to distance from stone source can be detected with an excavated landscape-scale sample. Given the long time over which activity traces must accumulate to produce a behavioral signal that might be detected through low-density, central-basin-wide excavations, assemblage variability based on distance from a geographically fixed material source should leave a more stable, time-cumulative signal than that based on temporally dynamic ecological factors (cf. Peters and Blumenschine, 1995: Fig. 5; Stern, 1994).

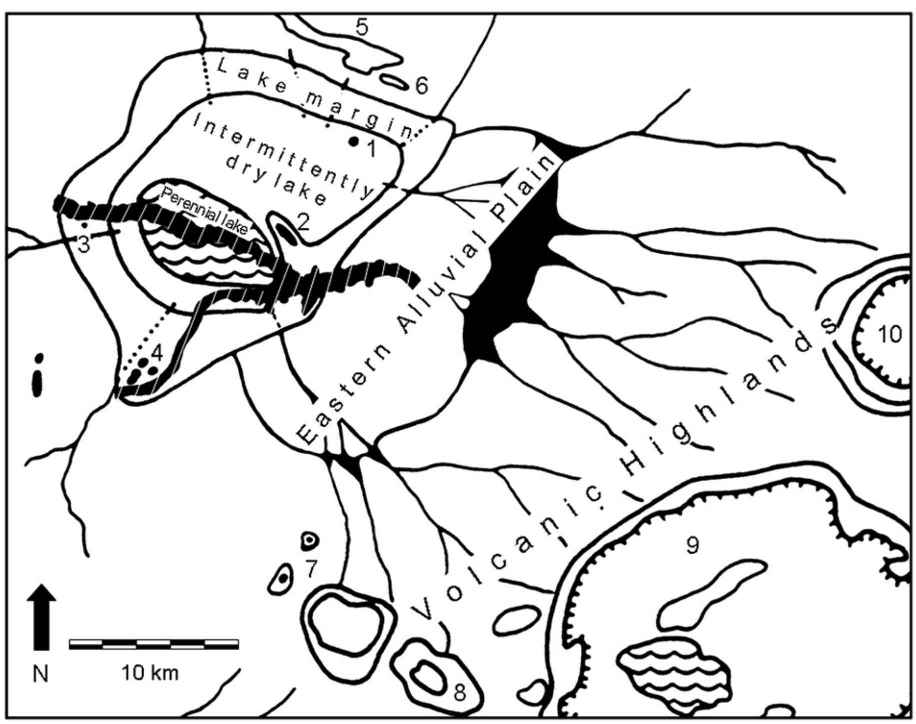

Fig. 1. Map of the Plio-Pleistocene Olduvai Lake Basin [modified from Peters and Blumenschine (1995, Fig. 2); based originally on Hay's paleogeographic reconstruction (1976, Fig. 38)], showing the location of present-day Olduvai Gorge (hatched). The center of the basin was occupied by a shallow, saline and alkaline lake with no outlet. During dry times, the lake was reduced to a perennial portion, expanding intermittently onto an intermediate flood zone. The Lake Margin was flooded during the wettest periods (Hay, 1976). The phonolite volcanic neck, Engelosin (1), is located in the northeastern portion of the intermittently dry lake bed, and would frequently have been an island. Several metamorphic inselbergs are located in the lake margin zone, including Naibor Soit (2) in the Eastern Lake Margin north of the junction of the Main and Side branches of Olduvai Gorge; Naisiusiu (3) in the Western Lake Margin at the western end of the Main Gorge; and Kelogi (4), three hills in the Southwestern Lake Margin at the southern end of the Side Gorge. These inselbergs are reconstructed by Hay to have been islands when the lake margin was flooded. The Serengeti Plain lies to the west of the lake. To its north are exposures of the metamorphic basement complex, the southern-most inselbergs of which are Olongoidjo Ridge (5) and Engitati Hill (6). The broad Eastern Alluvial Plain abuts the Eastern Lake Margin, sloping gently up toward the volcanic Crater Highlands that define the eastern and southern margins of the basin. These highlands include Mt. Lemagrut (7), Mt. Sadiman (8), Mt. Ngorongoro (9) with its large caldera, and Mt. Olmoti (10), with a smaller caldera. Mt. Olmoti was the active volcano during Bed I and lowermost Bed II times (Hay, 1976).

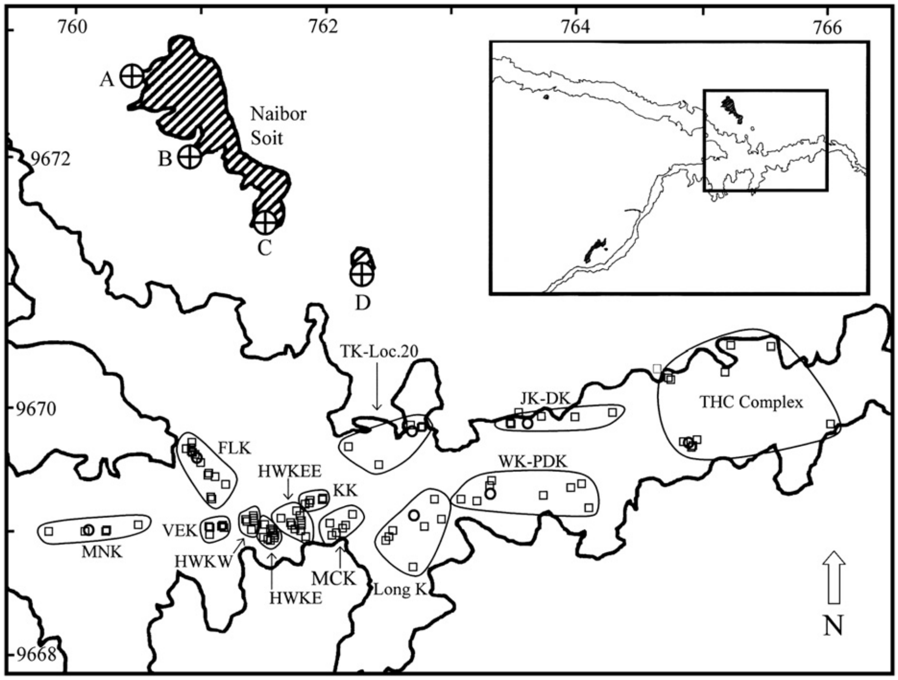

Fig. 2. Location of trenches (squares) in the eastern Olduvai Basin exposing lowermost Bed II, and their grouping into 13 geographic locales (e.g., FLK, MCK). For the areally more extensive locales, the average trench location weighted by the weight of quartzite artifacts recovered is marked by a circle. Four points (A–D) along Naibor Soit from which distance to each locale was calculated (Table 2) are indicated. Border tick marks are at 1 km intervals, in UTM units.

2. Stone material availability and artifact assemblage density and composition

Stone material availability is widely thought to be a determinant of assemblage density and composition. Distance-decay models borrowed from economic geography (e.g., Clark, 1979) predict that as distance from a stone material source increases, artifacts made on that material should be more thoroughly worked and used, and should occur in lower quantities, both absolutely and relative to more local materials. The slope of the distance-decay relationships should be influenced mainly by the efficiency of stone transport and the value per unit weight of the transported material (Clark, 1979). Renfrew's (1969) analysis of the Early Neolithic obsidian trade in the Near East was the first quantitative demonstration of distance-decay effects on stone artifact assemblages. Other examples have since been found throughout the Stone Age, although their statistical strength is evaluated infrequently.

For Holocene stone artifact assemblages along the Rio Grande River, Newman (1994) found that flake volume and thickness were lower for materials from more distant sources. Among 18 Late Prehistoric assemblages in Texas, Ricklis and Cox (1993) found those increasingly distant from sources to contain progressively lower unused flake to tool ratios, higher proportions of biface thinning flakes and flakes with edge utilization, and shorter projectile points. Flake length initially declines with increasing distance before stabilizing, as if a size threshold for usefulness has been reached. Bamforth (1986) found that tools made on non-local materials are more frequently retouched and broken than those made on local materials at the Paleo-Indian site of Lubbock Lake.

Some Middle Paleolithic stone artifact assemblages also manifest expected distance-decay effects. Munday (1976) related the degree of core reduction to distance from stone material sources and water among surface Mousterian occurrences in the Negev. Occurrences near a stone source contain earlier reduction stages, including larger cores with simpler scar patterns and flakes with fewer dorsal scars. These effects are modulated by proximity to water, which Munday thought allowed longer site occupation and promoted greater artifact reduction than expected by distance to stone source alone.

For other Middle Paleolithic assemblages, Roth and Dibble (1998) found that assemblage components at Combe-Capelle Bas made on non-local flint contain a slightly higher proportion of non-cortical flakes, smaller cores, and more retouched tools than those made on local flint. For Mousterian assemblages in Italy, Kuhn (1991) showed that those lacking a local flint source had more thoroughly reduced cores than those with a nearby source. However, the expected distance-decay effects were not found for retouched tools, a result Kuhn used to highlight the importance of the activities for which tools were used, their preferential curation, and the degree of residential mobility.

For the Early Stone Age, Isaac (1986) conceptualized production of stone tools as a "dynamic flow system," with artifacts showing progressively greater use as flow proceeds away from natural sources. Harris (1978) showed that the Early Pleistocene assemblages from East Lake Turkana usually contain higher artifact densities, larger artifacts, and more primary flaking debris in channel contexts at the source of stream-transported cobbles than in floodplain contexts. For the same set of assemblages, Toth (1985, 1987) found that the size of cores, flakes, and unflaked stone decreases with increasing distance from the basin margin source area toward Lake Turkana, a pattern he attributes to the smaller size of natural clasts in secondary sources along lower stretches of drainages. Schick (1987) further noted that low stone availability might account for the low numbers and densities of artifact occurrences close to paleo-Lake Turkana. More generally, Schick (1987) specified that local materials or those commonly encountered during foraging should be represented by all reduction stages, while those obtained at distant sources should enter a site already reduced. She cites Hay (1976) and Leakey (1971) in noting that Oldowan cores made on lava obtained at sources distant from lake margin sites at Olduvai Gorge are associated with few primary, cortical flakes. For the Acheulian at Olorgesailie, Potts et al. (1999) showed that the abundance of bifaces varies directly with proximity to lava sources.

Other studies (e.g., Henry, 1992; Close, 1999) do not reveal expected distance-decay effects, highlighting the role of other factors in determining artifact assemblage density and composition. Key among these for researchers examining Middle Paleolithic and later technologies is the anticipated use and serviceability of artifacts, settlement pattern type, and the availability of pack animals to transport materials (e.g., Binford, 1979; Kuhn, 1991; Nelson, 1991; Close, 1996, 1999; Odell, 2000; Beck et al., 2002).

For the Oldowan, Schick (1987) emphasizes the hypothetical effects of food resource distributions on inter-assemblage variability in artifact counts, abundance of different raw materials, and technological variety. Potts (1984) hypothesizes that Oldowan hominins stockpiled stone at caches across the landscape to reduce transport costs of carcasses and other foods requiring stone tools for processing. Food sharing and safety from predators is hypothesized to have motivated ‘‘home base’’ or ‘‘central place’’ patterns of stone artifact transport, respectively (Isaac, 1978, 1983a). Kimura (1999) argues that raw material selection was task specific, such that relative abundances of materials reflect utilitarian need.

In order to evaluate the potential effects of these ecological and functional factors on Oldowan assemblage composition, effects of raw material availability must first be taken into account (cf. Kuhn, 1991; Andrefsky, 1994). Here, we test for the existence of four distance-decay effects (Table 1). Three of these arise from guidelines used by Blumenschine and Peters (1998: 587) to model the composition of Oldowan stone artifact assemblages in different landscape facets in the paleo-Olduvai Basin:

(1) The quantity of a stone taken to and used, discarded or lost at a locale will decrease with increasing distance from that material's natural source, because of increasing transport costs.
(2) The relative abundance of artifacts made from different materials will be inversely proportional to distance from each source, given relative transport costs.
(3) The size of flaked pieces (cores; Isaac, 1983b) will decrease with increasing distance from a source, because of incentives to reuse previously discarded or lost, but unexhausted pieces.

As a corollary to the above effect, we additionally predict that

(4) The degree of reduction of flaked pieces will increase with increasing distance from a natural material source.

These predictions are based on several assumptions. They assume hominins did not use carrying devices, creating limitations on transportable quantities of stone (Blumenschine and Peters, 1998). They also assume equivalent functional utilities of different stone materials. Further, they apply most readily to hominin transport of stone material through uniform, two-dimensional Euclidean space following straight-line travel routes to use locations. Here, predicted distance-decay effects would be diminished or negated by opportunities and constraints on traveling through ecological space, in which the landscape distributions of critical affordances such as potable water, refuge trees, and resources involving stone use, discard and loss are patchy (Peters and Blumenschine, 1995). Changes in the distributions of these affordances through time would introduce additional assemblage variability unaccounted for by distance from material source.

3. Methods and sample

3.1. Sample characteristics

The stone artifact assemblages reported here were recovered through excavation by OLAPP into lowermost Bed II in

Table 1
Hypothesized distance-decay effects on the density and composition of landscape stone artifacts assemblages, and the measures used in this analysis to test model predictions

Assemblage characteristic	Predicted character state		Parameters used to test predicted effect
	Closer to source	Further from source	
Quantity of stone	Higher	Lower	log weight density (log g/m^3)
Relative abundance of materials	Inversely proportional to distance from each material source		% Weight (g) of each material
Size of flaked pieces	Larger	Smaller	Mean maximum length (mm)
Degree of reduction	Lower	Higher	% of whole flaked pieces that are flaked unifacially around <50% of circumference

the Eastern Lake Margin and Eastern Alluvial Plain, traversing a west–east distance of approximately 7 km (Fig. 2). Lowermost Bed II accumulated over ca. 85,000 years, stratified between Tuff IF (1.785 Ma; Blumenschine et al., 2003) and Tuff IIA/Lemuta Member (1.70 Ma; Peters and Blumenschine, 1996). The range of recovered artifacts includes forms described for the Oldowan at Olduvai by Leakey (1971). The current analysis is restricted to the eastern basin because Naibor Soit provides a local, geographically fixed material source for the quartzite artifacts examined.

Most of the excavations were 1–2 m wide step trenches through all or part of the target stratum. Trenches were located to maximize geographic coverage, constrained by the availability of excavatable exposures. Trenches were placed selectively over dense surface concentrations of artifacts and/or fossils in only a few cases, and trenching was not precluded in any area lacking surface remains.

Our sample includes all quartzite artifacts excavated from lowermost Bed II in the eastern basin between 1989 and 2006. It derives from 100 trenches (13 of which yielded no quartzite artifacts), from which we recovered 8167 stone artifacts, 7359 of which are made on quartzite (Table 2). Most of the remaining artifacts are made on lavas from Mt. Lemagrut and Mt. Sadiman (Fig. 1; Tactikos, 2005). The data we report were collected during end-of-field-season preliminary analyses. Tactikos (2005) conducted a more detailed analysis of the OLAPP sample recovered through 2000, but small artifact numbers for areas sampled more intensively since 2000 preclude use of her data set here.

Table 2
Characteristics of the stone artifact sample for the 13 paleogeographic locales listed west to east in the lowermost Bed II Eastern Lake Margin and Eastern Alluvial Plain (Figs. 1 and 2)

Landscape association and geographic locale	No. excavated		No. artifacts	
	Trenches	Volume (m^3)	Total	Quartzite
Eastern Lake Margin				
MNK	5	17.2	35	14
FLK	14	47.9	190	148
VEK	6	42.6	837	765
HWKW	7	30.4	631	586
HWKE	11	32.0	3421	3260
HWKEE	11	23.0	837	821
KK	5	22.1	1101	1032
MCK	6	44.2	566	302
TK-Loc. 20	5	31.4	253	244
Long K	7	42.2	163	89
Sub-total	77	332.9	8034	7261
Eastern Alluvial Plain				
WK-PDK	9	57.1	37	25
JK-DK	6	45.9	72	58
THC Complex	8	42.6	24	15
Sub-total	23	145.5	133	98
Grand total	100	478.4	8167	7359

The total number of trenches includes 13 that yielded no stone artifacts (two in MNK, two in FLK, three in WK-PDK, six in THC). Sample sizes for each locale are the number of specimens for which general stone material type was assigned.

Several quartzite sources in addition to Naibor Soit lie within 15 km of the eastern basin trenches, but our preliminary analyses did not distinguish among these. They include Naisiusiu Hill at the western end of the gorge (≥12 km from the eastern basin excavations), the more distant Olduvai River upstream from there, and Olongoidjo Ridge and Engitati Hill, located ≥12 km north of the Main Gorge (Fig. 1). In her more detailed analysis, Tactikos (2005) distinguished the quartzites from Naibor Soit, Naisiusiu, and the Olduvai River on the basis of grain size, color, groundmass and crystal orientation. She identified no Naisiusiu quartzite in her eastern basin sample and only rare examples of Olduvai River quartzite, such that Naibor Soit quartzite comprised 99.5% of quartzite artifact weight and 98.6% of the quartzite artifact count. Tactikos did not characterize the Olongoidjo/Engitati quartzites petrologically, which Hay (1976) describes as being similar to Naibor Soit. Our sample might include artifacts from Olongoidjo/Engitati, but the quantity appears to be negligible. This assessment is based on the rare occurrence of Engelosin phonolite, a lava with good conchoidal flaking properties (Jones, 1981) derived from a volcanic neck 8 km north of the eastern basin occurrences, some 4 km closer than Olongoidjo/Engitati (Fig. 1). The great majority of quartzite artifacts from the eastern basin sample appear to derive from Naibor Soit, and all are included in the present analyses.

3.2. Distance-from-source estimates

Four points along the extent of Naibor Soit are used to investigate distance-decay effects (Fig. 2; Table 3). Three of these (A–C) are located along the southwestern-facing base of the main hill at Naibor Soit separated by approximately 1.6 km. The fourth point (D) is located at the southern end of the small hill at Naibor Soit about 0.9 km southeast of

Table 3
Distances of the 13 eastern basin geographic locales from four points (A–D) along the Naibor Soit inselberg (Fig. 2)

Geographic locale	Mean easting (UTM km)	Mean northing (UTM km)	Distance from Naibor Soit (km)			
			A	B	C	D
MNK	760.084	9668.911	3.70	3.20	2.95	3.01
FLK	760.949	9669.581	3.07	2.42	2.00	1.92
VEK	761.059	9669.016	3.64	2.99	2.52	2.31
HWKW	761.355	9669.098	3.63	2.94	2.41	2.10
HWKE	761.527	9668.956	3.81	3.11	2.54	2.17
HWKEE	761.675	9669.098	3.73	3.00	2.41	1.99
KK	761.802	9669.212	3.67	2.93	2.31	1.84
MCK	762.115	9669.088	3.91	3.16	2.49	1.92
TK-Loc. 20	762.668	9669.787	3.61	2.83	2.07	1.28
LONG K	762.711	9669.135	4.17	3.39	2.66	1.92
WK-PDK	763.287	9669.290	4.39	3.61	2.84	2.00
JK-DK	763.573	9669.969	4.12	3.36	2.58	1.68
THC complex	764.921	9669.710	5.37	4.63	3.86	2.97

Distances are based on average UTM easting and northing values of trenches in each locale weighted by the weight of quartzite artifacts from each trench. UTM easting and northing coordinates for source locations along Naibor Soit are point A, 760.40, 9672.60; B, 760.90, 9672.00; C, 761.50, 9671.50; D, 762.25, 9671.00.

the main hill. The inselberg was accessible during periods of low lake level, while high lakes transformed Naibor Soit into an island (Fig. 1; Hay, 1976).

Artifacts from trenches in the eastern basin are grouped into 13 geographic locales (Table 2, Fig. 2), each named for the modern *korongo* (fluvially incised gully, named by the Leakeys) in which they are located. Trenches were grouped on the basis of proximity to one another and combined artifact sample size. Samples from most locales are adequate, derived from at least five moderately to tightly clustered trenches. Several locales do not meet these standards. In the Eastern Lake Margin, MNK has a small artifact sample due to low artifact densities and limited lowermost Bed II exposures. Two locales in the Eastern Alluvial Plain, WK-PDK and THC, are comprised of widely dispersed trenches due to low artifact densities and the tendency for lowermost Bed II to outcrop in cliff faces.

The estimated straight-line distances of a geographic locale from each of the four points along Naibor Soit are calculated using the average UTM coordinates of all trenches within a locale (Table 3), weighted by the total weight of quartzite artifacts from each trench. The minimum distance from source is 1.28 km (TK-Loc. 20 to point D on Naibor Soit), and the maximum is 5.37 km (THC to point A). These distances would have been slightly less during lowermost Bed II times due to the subsequent accumulation on the inselberg's footslopes of approximately 30 m of sediment.

3.3. Assemblage parameters used to test predictions

We use four assemblage parameters to test the predicted distance-decay effects (Table 1). The quantity of quartzite is measured by its weight density (g/m^3 of excavated deposit). The relative abundance of artifacts made on quartzite is measured by its proportionate weight of artifacts made on all materials. The size of whole flaked pieces is measured by their mean maximum length, while their degree of reduction is measured by the proportion that are flaked unifacially around less than 50% of their circumference.

Spearman's rank-order correlation is used to evaluate distance-decay relationships. This non-parametric method is appropriate for the small number of geographic locales into which assemblages are categorized. Correlations yielding probability values ≤ 0.05 are considered statistically significant. One-tailed probability values are reported because the direction of each relationship has been specified.

4. Results

Quartzite artifact assemblages are highly variable among the 13 geographic locales of the eastern Olduvai Basin (Tables 4 and 5, Fig. 3). Their weight density (g/m^3) varies over more than two orders of magnitude (Table 4, Fig. 3a). The lowest densities (<15 g/m^3) occur closest to the perennial lake at MNK, and in the three locales in the Eastern Alluvial Plain. The highest densities (>200 g/m^3) are found in the Eastern Lake Margin (MCK, HWKE). The log of weight density is correlated significantly to distance from the three points along the main Naibor Soit hill, decreasing with greater distance from the source (Fig. 4a; Table 6). It is correlated negatively but insignificantly to distance from the small hill at Naibor Soit (point D). Distance from point C on Naibor Soit explains the most variability (42%) in quartzite artifact density.

The proportion of total artifact weight made on quartzite is also highly variable, ranging from 6% at Long K to almost 77% at TK-Loc. 20 (Table 4, Fig. 3b). All Eastern Alluvial Plain locales have low quartzite weight proportions, while the values for the Eastern Lake Margin are variable. Proportionate quartzite artifact weight is correlated negatively with distance from all four points on Naibor Soit, but once again the relationships are significant for only the three points along the main hill (Fig. 4b, Table 6). Distance from these three points accounts for almost half to over 70% of the variability in this assemblage parameter.

Table 4
Weights (g) and weight densities (log g/m^3 of excavated deposit) of quartzite artifacts, and the proportion of total artifact weight comprised of quartzite from the 13 geographic locales in the eastern basin

Geographic locale	Excavated volume (m^3)	Quartzite artifacts			Total artifact weight (g)	% Quartzite artifact weight
		Weight (g)	Weight density			
			g/m^3	log g/m^3		
MNK	17.2	90	5.2	0.72	244	37.0
FLK	47.9	10355	216.2	2.33	20,283	51.1
VEK	42.6	7382	173.4	2.24	16,895	43.7
HWKW	30.4	4025	132.3	2.12	12,992	31.0
HWKE	32.0	7548	236.2	2.37	35,353	21.4
HWKEE	23.0	1821	79.2	1.90	3122	58.3
KK	22.1	2540	114.9	2.06	7968	31.9
MCK	44.2	11168	252.5	2.40	74,742	14.9
TK-Loc. 20	31.4	1405	44.7	1.65	1829	76.8
LONG K	42.2	1129	26.8	1.43	18,960	6.0
WK-PDK	57.1	311	5.4	0.74	2167	14.4
JK-DK	45.9	617	13.4	1.13	4585	13.5
THC complex	42.6	106	2.5	0.40	1168	9.1

Table 5
Mean maximum length (mm) of whole quartzite flaked pieces (FP), and the proportion of whole quartzite FP flaked unifacially around <50% (UNI < 50%) of the piece's circumference among the 13 geographic locales of the eastern basin

Geographic locale	Total no. FP	Mean max. dimension (mm)	UNI < 50%	
			n	%
MNK	1	50.0	0	0
FLK	18	68.7	3	16.7
VEK	22	59.2	5	22.7
HWKW	13	62.0	2	15.4
HWKE	28	56.0	4	14.3
HWKEE	1	56.0	0	0
KK	14	48.9	4	28.6
MCK	47	63.0	13	27.7
TK-Loc. 20	5	54.2	2	40.0
LONG K	5	47.0	0	0
WK-PDK	3	40.7	0	0
JK-DK	3	51.3	1	33.3
THC complex	1	46.0	0	0

The mean maximum length of whole quartzite flaked pieces ranges from about 4 cm at WK-PDK to large specimens averaging almost 70% at FLK (Table 5, Fig. 3c). MNK and the Eastern Alluvial Plain locales have smaller flaked pieces than all locales in the Eastern Lake Margin except KK. This assemblage parameter is correlated negatively with distance from all four points on Naibor Soit, and again significantly for all but the small hill (Fig. 4c; Table 6), with the points along the main hill explaining about 45% of the variability.

The proportion of whole flaked pieces that are reduced minimally is highest (40%) at TK-Loc. 20. These are absent from five locales, all of which have small numbers of whole flaked pieces (Table 5, Fig. 3d). Their relative abundances are correlated significantly and negatively to distance from all four points along Naibor Soit, including the small hill (Fig. 4d, Table 6). Distance from the small hill at Naibor Soit accounts for the most variability (46%) in this measure of core reduction.

5. Discussion

Some of the variability in the quartzite artifact assemblages of the eastern Olduvai Basin can be explained by proximity to Naibor Soit as predicted by distance-decay effects (Table 1). All assemblage parameters examined are correlated negatively with distance from the four points along Naibor Soit. These relationships are significant for the three points on the main hill, with the weight proportion of quartzite artifacts showing the strongest correlations (cf. Blumenschine and Peters, 1998). This is the only assemblage parameter for which distance from the main hill explains the majority of variability. Factors in addition to proximity to material source appear to have patterned the landscape distribution of quartzite artifacts.

Only the degree of reduction of flaked pieces is correlated significantly with distance from the small hill at Naibor Soit. The small hill would seem to have been the most accessible end of Naibor Soit during intermediate lake levels (Fig. 1), with virtually all geographic locales lying about 0.1–0.9 km closer to it than to any of the three points on the main hill (with the exception of MNK to point C). The lack of significant correlations for the three other variables with distance from the small hill is unexpected and remains unexplained, such that the one significant correlation may be spurious.

The results show that excavated landscape samples of stone artifacts that accumulated over a long time period (in this case 85,000 years) provide an effective means of testing models of Oldowan hominin land use (cf. Stern, 1993) concerning stone material transport from a source with a fixed location. The time averaging of the archaeological record that obscures traces of single behavioral events (Stern, 1994) instead amplifies the fixed-source distance-decay signal to levels that can be detected by the low-density, central-basin-wide trenching we achieved over 13 excavation seasons.

Theoretically, distance-decay effects are related to the cost of stone material transport by hominins from source locations to places where artifacts are made, used, and discarded or lost (cf. Schick, 1987; Potts, 1991; Kuhn, 1991; but see Brantingham, 2003). Low transport costs to locations close to a source reduce incentives to exhaust cores, ease the replacement of discarded or lost material, and minimize the need to import materials from more distant sources. The result is higher-density assemblages containing higher proportions of the local material, and larger cores showing lower degrees of reduction. Use of stone further from its source incurs greater transport costs, providing incentives to use that material more exhaustively before initial discard/loss, to reuse these materials upon subsequent visits to the locale, and to substitute the material with others from sources closer to the use location. The result is assemblages containing relatively low weight densities and proportions of the material, and smaller cores that have been worked more thoroughly if not exhaustively.

The distance-decay effects we found operate over a very short distance, one a human can walk in about one hour (3–5 km). Weight densities less than 6 g/m^3 are observed in the three locales (WK-PDK, MNK, THC) located more than 2.8 km from the southeastern end of the main Naibor Soit hill. Likewise, with the exception of MNK, the weight proportion of quartzite artifacts does not exceed 15% in locales further than 2.6 km from this point. These near-extinction values for transported quartzite at the eastern and western limits of our excavated sample suggest that material transport costs were high, as would be consistent with the lack of a carrying device (cf. Blumenschine and Peters, 1998). However, the results do not preclude longer-distance transport of Naibor Soit quartzite toward the southern and southeastern Crater Highlands, the likely source areas for hominins visiting the central lake basin (Peters and Blumenschine, 1995). Oldowan hominins transported other stone materials over such distances: small quantities of gneiss like that found at Kelogi Hill (>8 km from the eastern basin; Fig. 1) occur in most of Leakey's Oldowan excavations there (Hay, 1976), and one or two pieces of this material are present in 11 OLAPP trenches in the Eastern Lake Margin. Oldowan hominins also transported lava

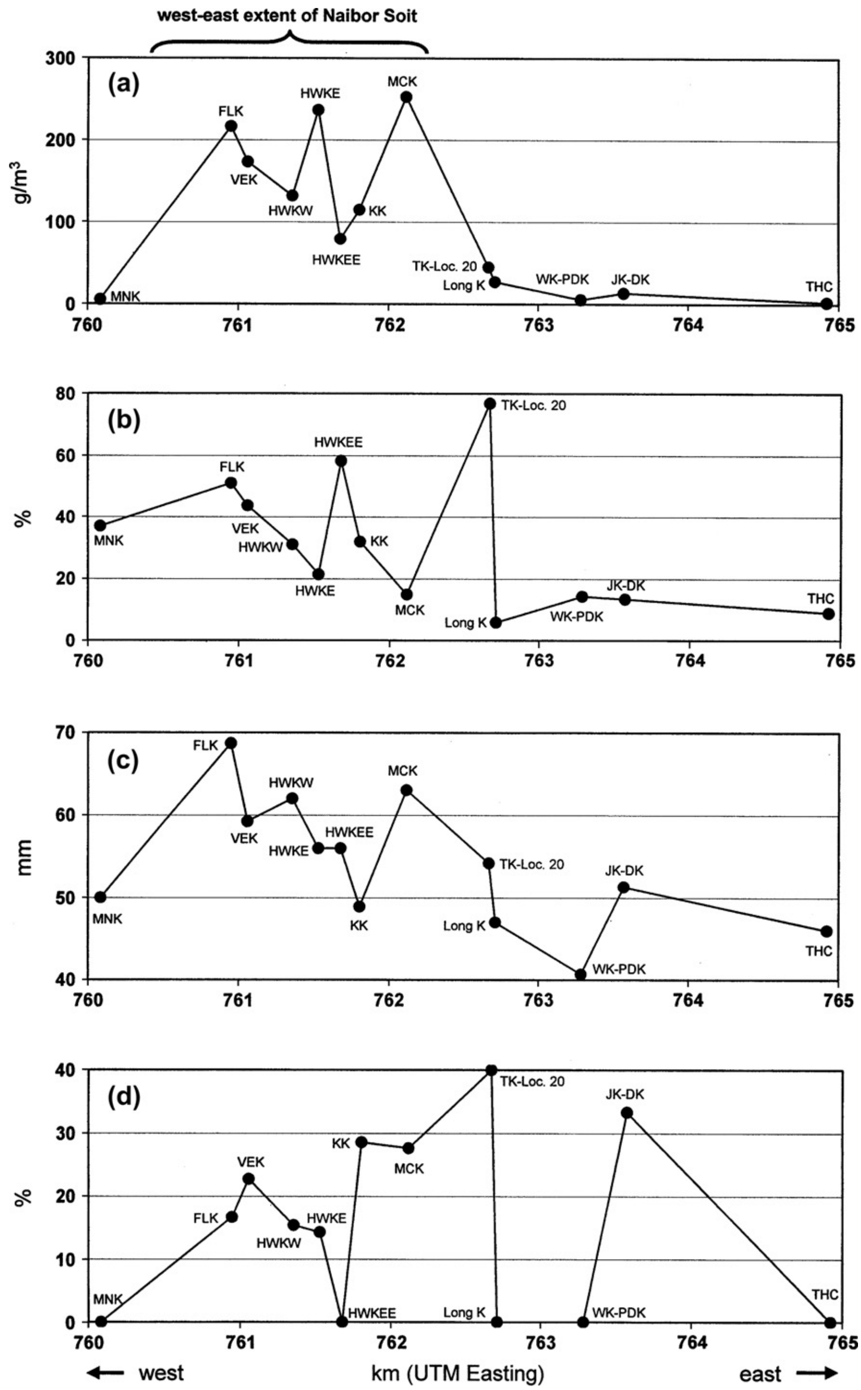

Fig. 3. West-to-east distributions of four parameters of the quartzite artifact assemblages among 13 geographic locales in the eastern lowermost Bed II Olduvai Basin (Tables 4 and 5). (a) Weight density of quartzite artifact assemblages; (b) proportion of total artifact assemblage weight comprised of quartzite; (c) mean maximum length of whole quartzite detached pieces; (d) proportion of whole quartzite flaked pieces that are unifacially flaked around <50% of the circumference. The west–east extent of Naibor Soit is indicated, giving a one-dimensional indication of proximity of the locales to the quartzite material source.

from streams draining Mt. Sadiman over 15 km to the Naisiusiu area (Hay, 1976; Blumenschine et al., 2003).

Substantial reversals of distance-decay expectations exist between adjacent geographic locales with large samples. For example, HWKE and HWKEE ($n = 3260$ and 837 quartzite artifacts, respectively) are separated by 200 m, with HWKEE lying 130 m closer to the southeast end of the main Naibor Soit Hill. Yet, compared to HWKEE, the quartzite artifact weight density at HWKE is three times greater, comprising a weight proportion of all artifacts about 2.7 times lower (Table 4).

Predicted distance-decay effects are based on several assumptions not likely to pertain to the Oldowan at Olduvai. The predicted weight proportion of artifact assemblages made on quartzite assumes that all stone materials have similar utilities. However, modern use trials suggest that some materials may have been task specific. For example, flakes of

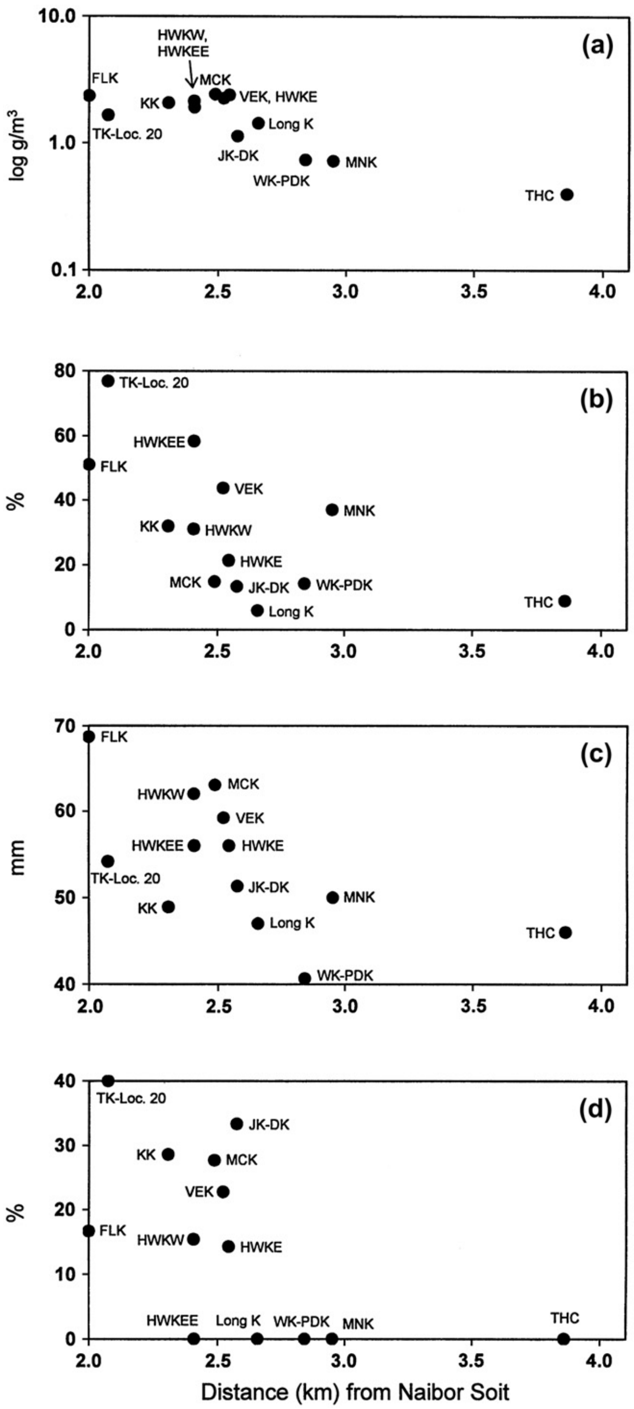

Fig. 4. Scatter plots relating four parameters of the quartzite artifact assemblages from 13 geographic locales in the eastern lowermost Bed II Olduvai Basin to their (weighted) average distance from the southeast end of Naibor Soit's main hill (point C, Fig. 2). (a) log weight density of quartzite artifact assemblages; (b) proportion of total artifact assemblage weight comprised of quartzite; (c) mean maximum length of whole quartzite detached pieces; (d) proportion of whole quartzite flaked pieces that are unifacially flaked around <50% of the circumference.

Table 6
Spearman's rank-order correlation statistics for the relationships between four artifact assemblage characteristics (Tables 4 and 5) and distance from four points (A–D) along Naibor Soit (Table 3, Fig. 2) for 13 geographic locales in the eastern basin

Assemblage characteristic		r_s	r_s^2	p
Weight density (log g/m^3) of quartzite artifacts	A	−0.49	0.24	**0.04**
	B	−0.62	0.38	**0.01**
	C	−0.65	0.42	**0.008**
	D	−0.18	0.03	0.28
Weight proportion of quartzite artifacts	A	−0.84	0.71	**0.0002**
	B	−0.81	0.66	**0.0004**
	C	−0.70	0.49	**0.004**
	D	−0.11	0.01	0.37
Mean maximum length of quartzite flaked pieces	A	−0.66	0.44	**0.007**
	B	−0.67	0.45	**0.006**
	C	−0.66	0.44	**0.007**
	D	−0.09	0.01	0.39
Proportion of quartzite flaked pieces flaked Unifacially around <50% of circumference	A	−0.49	0.24	**0.05**
	B	−0.58	0.34	**0.02**
	C	−0.61	0.37	**0.01**
	D	−0.68	0.46	**0.005**

Probability values are one-tailed, following predictions (Table 1). Probability values ≤0.05 are bold-faced.

Naibor Soit quartzite provide more durable cutting edges than those made from cobbles of Lemagrut lava, which, in turn, are superior pounding tools (Tactikos, 2005). Superior materials for particular tasks might be expected to be conserved and transported further and in greater quantities than poor-performing materials. The magnitude of these departures from distance-decay expectations should increase with greater disparities in the task-specific utility of stone materials.

Likewise, scavengeable carcasses, a resource perhaps most commonly associated with stone tool discard (Blumenschine and Peters, 1998), have been modeled to have been distributed patchily in the paleo-Olduvai Basin (Peters and Blumenschine, 1995, 1996). Wooded settings affording relative safety from predation at or adjacent to places providing carcasses were hypothesized to accumulate relatively dense artifact assemblages (Blumenschine and Peters, 1998; see Blumenschine et al., 2005, in press for preliminary tests) largely independently of distance from the stone source for butchery tools. Here, predation risk is hypothesized to encourage the transport of unexhausted materials and carcass parts to relatively safe locales, where fuller processing, more complete stone tool reduction, and higher levels of material discard and loss can take place. Greater contrasts in carcass distributions and predation hazards among locales should lead to more pronounced departures from distance-decay expectations.

Routes along which stone materials were transported are unlikely to have been straight-line. Variability among landscape facets in substrate and degree of predation risk suggest that travel routes would circumvent muddy and open terrain, instead following corridors providing firmer ground and refuge, such as along the upper edge of the lake margin and stream banks (Peters and Blumenschine, 1995, 1996). In sum, patterns of hominin transport of stone materials across multi-dimensional ecological space were more complex than those predicted for uniform Euclidean space.

Establishing the theoretically strong influence of these ecological factors on material traces of Oldowan hominin land use requires paleoenvironmental reconstructions more highly resolved in time and space than currently available (e.g., Hay, 1976; Bonnefille, 1984; Shipman and Harris, 1988; Plummer and Bishop, 1994; Sikes, 1994; Kappelman et al., 1997; Fernandez-Jalvo et al., 1998). The challenge is great, given the many sources of environmental variability in the paleo-Olduvai Basin (Peters and Blumenschine, 1995: Fig. 5). All contributed to temporal and spatial changes in the cover abundance of trees, the theoretically core influence on Oldowan hominin land use.

Environmental variability would not influence patterns of stone transport from fixed stone material sources such as Naibor Soit. During high lake levels, when Naibor Soit was an island, no traces of hominins and other terrestrial vertebrates would accumulate in the lake margin. Thus, we found distance-decay effects on quartzite artifact assemblages despite their having accumulated throughout the whole of the environmentally dynamic lowermost Bed II interval. Environmental variability would change the location of secondary sources of volcanic materials in stream beds, making it difficult to investigate distance-decay using artifacts made on these materials.

6. Conclusion

Sampling of hominin activity traces through small excavations distributed over landscape scales provides an effective means of investigating stone transport by Oldowan hominins from a fixed source. The density and aspects of the composition of quartzite artifact assemblages in the eastern lowermost Bed II Olduvai Basin correlate significantly and in ways predicted with distance from the main hill at Naibor Soit. The absence of significant correlations for three assemblage parameters with distance from the small hill at Naibor Soit is unexplained. Distance from material source accounts for a majority of variability only for the weight proportion of quartzite artifacts. Ecological factors, fundamentally the distribution of trees, predation hazards and potable water, appear to have also influenced hominin land use and its material traces. Understanding these ecological influences requires a fine exegesis of the paleoenvironmental record, a task complicated by the environmental dynamism that characterized the Plio-Pleistocene Olduvai Basin. Yet, we must focus on landscape paleoecology to identify the factors that selected for the novel adaptations of the earliest stone-tool-using hominins.

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