# STONE AGE INSTITUTE PUBLICATION SERIES

*Series Editors Kathy Schick and Nicholas Toth*

Stone Age Institute

Gosport, Indiana

and

Indiana University,

Bloomington, Indiana

---

*Number 1.*
THE OLDOWAN: Case Studies into the Earliest Stone Age
*Nicholas Toth and Kathy Schick, editors*

*Number 2.*
BREATHING LIFE INTO FOSSILS:
Taphonomic Studies in Honor of C.K. (Bob) Brain
*Travis Rayne Pickering, Kathy Schick, and Nicholas Toth, editors*

*Number 3.*
THE CUTTING EDGE:
New Approaches to the Archaeology of Human Origins
*Kathy Schick, and Nicholas Toth, editors*

*Number 4.*
*THE HUMAN BRAIN EVOLVING:*
Paleoneurological Studies in Honor of Ralph L. Holloway
*Douglas Broadfield, Michael Yuan, Kathy Schick and Nicholas Toth, editors*

---

STONE AGE INSTITUTE PUBLICATION SERIES
*NUMBER 3*
*Series Editors Kathy Schick and Nicholas Toth*

# THE CUTTING EDGE:

## New Approaches to the Archaeology of Human Origins

*Editors*

**Kathy Schick**
Stone Age Institute & Indiana University

**Nicholas Toth**
Stone Age Institute & Indiana University

Stone Age Institute Press · www.stoneageinstitute.org
1392 W. Dittemore Road · Gosport, IN  47433

*COVER CAPTIONS AND CREDITS*

*Top: Homo habilis Utilizing Stone Tools. Painting by artist-naturalist Jay H. Matternes. Copyright 1995, Jay H. Matternes. Inspired by a prehistoric scenario by K. Schick and N. Toth in Making Silent Stones Speak: Human Origins and the Dawn of Technology (1993), Simon and Schuster, New York. Pp.147-149.*

*Lower right: Whole flake of trachyte lava from the 2.6 million-year-old site of Gona EG-10, Ethiopia. Reported by S. Semaw (2006), "The Oldest Stone Artifacts from Gona (2.6-2.5 Ma), Afar, Ethiopia: Implications for Understanding the Earliest Stages of Knapping" in The Oldowan: Case Studies into the Earliest Stone Age, eds. N. Toth and K. Schick. Stone Age Institute Press, Gosport, Indiana. Pp. 43-75. Photo courtesy of Tim White.*

*Lower left: Prehistoric cut-marks from a stone tool on Sterkfontein hominin partial cranium StW 53. Reported by T. Pickering, T. White, and N. Toth (2000) in "Cutmarks on a Plio-Pleistocene hominid from Sterkfontein, South Africa". American Journal of Physical Anthropology 111, 579-584. Scanning electron micrograph by N. Toth.*

Published by the Stone Age Institute.
ISBN-10: 0-9792-2762-3
ISBN-13: 978-0-9792-2762-2

# CHAPTER 1

# Changes in Hominin Transport of Stone for Oldowan Tools Across the Eastern Olduvai Basin During Lowermost Bed II Times

Robert J. Blumenschine, Fidelis T. Masao, and Ian G. Stanistreet

## Introduction

The Oldowan Industry was defined quantitatively by Leakey (1967, 1971) on the basis of frequencies of stone artifact forms in assemblages recovered from the Bed I through Middle Bed II sequence at Olduvai Gorge. Six excavations described by Leakey (1971) span most of this approximately 150,000 year interval of the Plio-Pleistocene. They are distributed across 3–4 km east-west extent of paleo-Lake Olduvai's eastern lake margin (Hay, 1976). Four of the excavations lie within approximately 1 km of the perennial portion of the paleo-lake, including the MNK Skull Site, the youngest Oldowan locality at Olduvai, and FLK *Zinjanthropus*, FLK North, FLK North North, the latter three separated by a total distance of about 200 m. Two other sites, HWK East and DK, are located in the middle and upper portions of the eastern lake margin to the toe of the alluvial fan (Figure 1). Ranging in area from about 30 $m^2$ to almost 300 $m^2$ (Harris and Capaldo, 1993), the excavations expose multiple stratigraphic horizons, some of which yielded low to very high density artifact assemblages comprising various proportions of raw materials, artifact types and manuports (Leakey, 1971; her Tables 6 and 7, Figure 117). Some of this variability has been related to presumed differences between site functions (e.g., occupations floor vs. butchery site; Leakey, 1971), but whether it has a behavioral, geographic, and/or temporal basis cannot be ascertained due to the small number of excavated occurrences dispersed over a large area and during a long time period.

Sampling a single discrete time interval across broad areas with a relatively high density of excavations allows potential geographically and behaviorally-based variability in artifact assemblages to be explored. Comparing a chronological series of such samples further permits exploration of temporal variability based possibly on changes in climate, landscapes, or hominin behavior and technology. Referred to most commonly as landscape archaeology (e.g., Ammerman, 1981; Rossignol and Wandsnider, 1992), such a sampling strategy is relatively common for recent time periods. It is undertaken recognizing that localized site-scale occurrences, the traditional focus of archaeological research, contain an incomplete variety of hominin activity traces (Isaac et al., 1981; cf. Binford, 1982, 1992; Ebert, 1992; Wandsnider, 1992), and are poorly understood units of behavioral analysis (Dunnell, 1992; Dunnell and Dancey, 1983; Ebert, 1992; Foley, 1981a, 1981b; Thomas, 1975).

Work conducted at Olduvai Gorge by the Olduvai Landscape Paleoanthropology Project (OLAPP) since 1989 (e.g., Blumenschine and Masao, 1991; Blumenschine et al., 2007 a, b) is one of several studies that seek to document penecontemporaneous variability in Early Stone Age artifacts across broad landscape scales in several East African sedimentary basins. Isaac and Harris (1975, 1978) initiated lateral sampling of isochronous surface remains on the Karari Escarpment in the Turkana Basin. Similar studies at East Turkana have followed that sample surface and in situ Oldowan and Developed Oldowan occurrences (Behrensmeyer, 1985; Stern, 1993, 1994; Rogers, 1996, 1997; Rogers and Harris, 1992; Rogers et al., 1994). At Olorgesailie, Potts (Potts et al., 1999; Sikes et al., 1999) has excavated Acheulian occurrences from four Middle Pleistocene strata. Lateral sampling of Early Stone Age occurrences has been initiated at Kanjera (Plummer et al., 1999; Ditchfield et al., 1999), and Peninj (Dominguez-Rodrigo et al., 2002). Some of

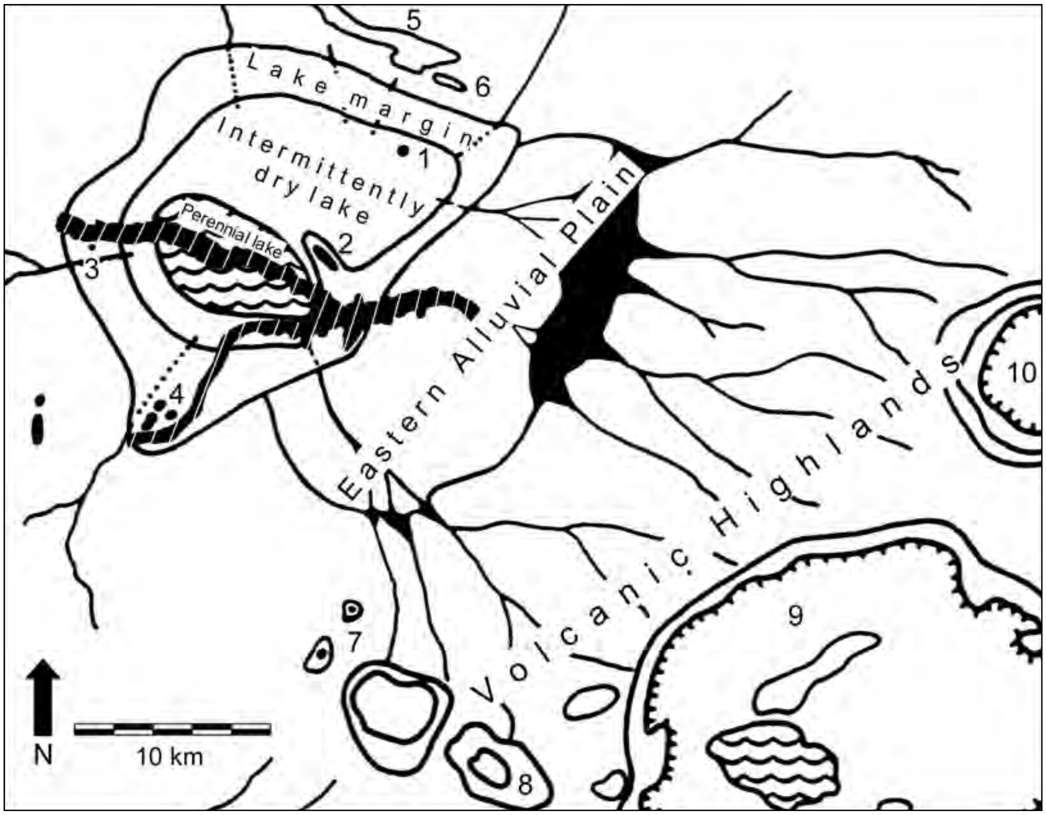



*Figure 1. The Plio-Pleistocene Olduvai Lake Basin [modified from Peters and Blumenschine (1995, Figure 2); based originally on Hay's paleogeographic reconstruction (1976, Figure 38)], showing the location of present-day Olduvai Gorge (hatched). The center of the basin was occupied by a shallow, saline and alkaline lake with no outlet. During dry times, the lake was reduced to a perennial portion, expanding intermittently onto an intermediate flood zone and, during the wettest periods onto the Lake Margin (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. The Serengeti Plain lies to the west of the lake. To its north are exposures of the metamorphic basement complex, the southernmost 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).*

these studies attempt to relate variability in landscape traces of hominin activity to depositional environment, proximity to stone material sources, and/or various proxies for vegetation structure.

OLAPP's landscape paleoanthropological work on the Oldowan has focused on several target intervals in Bed I and Lower Bed II. Through the 2007 field season, OLAPP has excavated 146 trenches into these intervals that sample various lake, lake margin and alluvial fan environmental settings distributed over ca. 130 km$^2$ of the central Olduvai Lake Basin (Figure 1).

Overall, the landscape assemblages of Oldowan artifacts display tremendous variability in the density of the occurrences and in aspects of their composition (e.g., Blumenschine et al., 2005; Tactikos, 2005).

Several factors have been correlated with landscape-scale variability in the Oldowan artifacts assemblages from OLAPP's best-developed sample, the eastern Olduvai Basin during lowermost Bed II times, defined by the interval between Tuff IF and Tuff IIA. Deocampo et al. (2002) found that a geochemical indicator of water freshness correlates positively and significantly with the weight density (g/m$^3$ of excavated deposit) of stone artifacts from the basal waxy claystone of lowermost Bed II in 22 OLAPP trenches in the eastern lake margin. Preliminary analyses by Blumenschine et al. (2005, 2007a) show that the weight density and functional diversity of stone artifacts from a large number of trenches in the eastern lake margin and alluvial fan for the whole of the lowermost Bed II interval correlates in theoretically expected ways to large mammal long bone shaft to end ratios, a measure of predation risk for hominins from large carnivores. Most recently, Blumenschine et al. (2007b) demonstrated that several aspects of the quartzite artifact

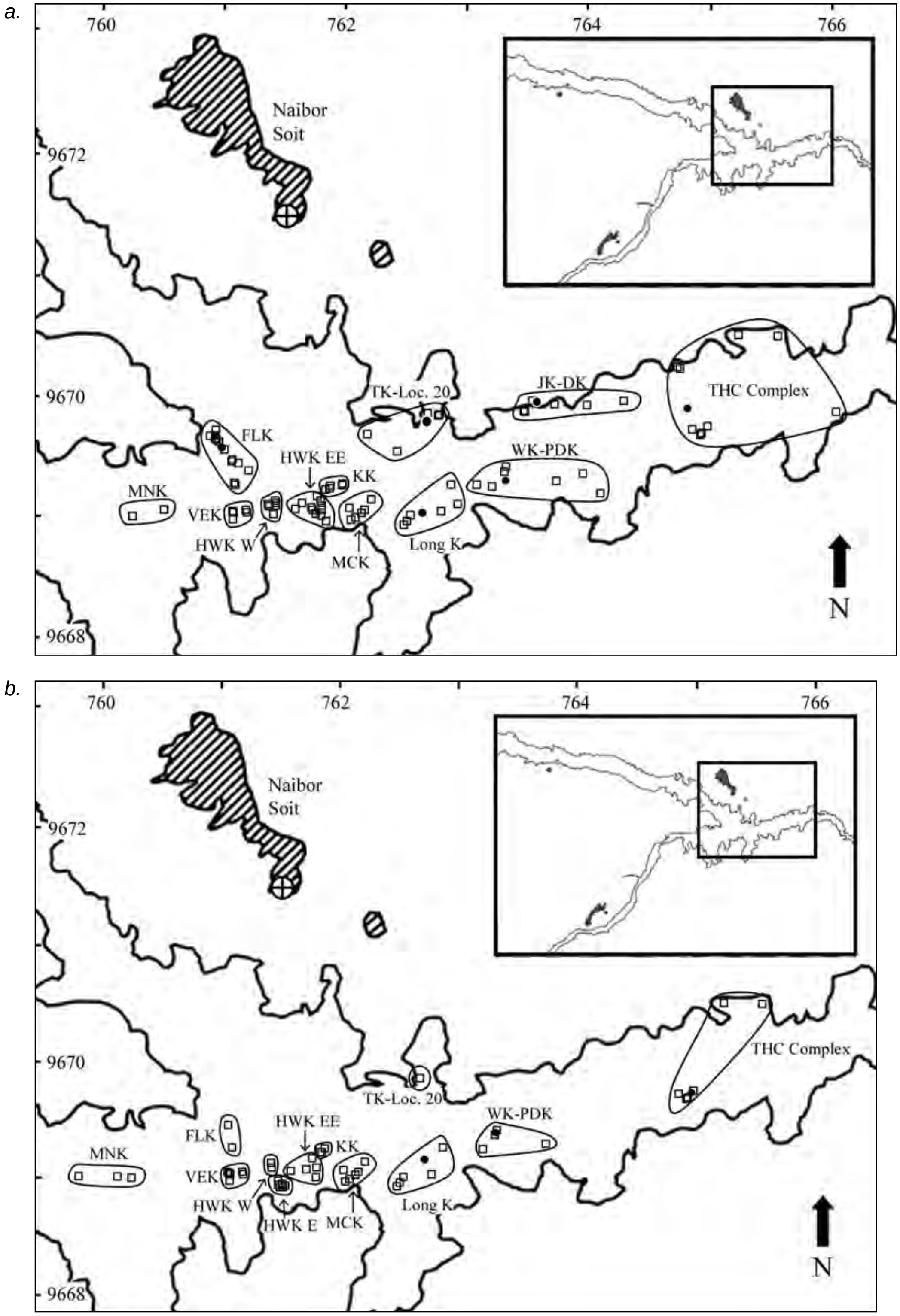



*Figure 2. Grouping of trenches into geographic locales (e.g., FLK, MCK) used to investigate distancedecay effects for the a) pre-incision and b) post-incision intervals of lowermost Bed II. For the areally more extensive locales, the average trench location weighted by the weight of quartzite artifacts recovered is marked by a solid circle. The number and location of trenches, and the weighted average location of trenches differ for the two stratigraphic intervals in all locales. The location at the southeastern end of the main hill at Naibor Soit from which distance to each locale was calculated (Table 2) is indicated. Border tick marks are at 1 km intervals, in UTM units.*

assemblages from 100 trenches sampling the lowermost Bed II eastern lake margin and alluvial fan (Figure 1) over a west-to-east distance of 6 km correlate in theoretically expected ways to distance from Naibor Soit, the inselberg of metamorphic basement rocks that was the likely source used by hominins to manufacture quartzite implements in this part of the Olduvai Basin.

In this paper, we explore effects of distance from stone material source on three characteristics of the quartzite artifact assemblages in the eastern Olduvai Basin (Figure 2) for two time intervals within lowermost Bed II. The time intervals precede and follow valley incision of the eastern basin, and are referred to as pre-incisional and post-incisional lowermost Bed II (Stanistreet, in prep.). This analysis has two major goals. The first is to determine if behavioral patterning following expectations of general distance-decay models of stone material transport can be detected over landscape scales for more discrete time intervals than we demonstrated previously. The second goal is to investigate changes in landscape-scale patterning of stone artifact assemblages that might be related in a preliminary way to landscape evolution and corresponding changes in Oldowan hominin land use. Detection of such changes would enhance future efforts to distinguish the theoretically two major sets of constraints on hominin land use: 1) the distributions of predation risk and resources requiring stone tools for extraction, and 2) transport costs of stone material to manufacture and use locations.

## Sequence Stratigraphy of Lowermost Bed II

### Introduction

As a concept, Sequence Stratigraphy was introduced to explain recurrent sedimentary cyclicities of similar periodicities related to base level changes encountered in marine basins (Vail, 1977; Van Wagoner et al., 1988). Subsequently, such stratigraphies have also been identified in continental basins (Shanley and McCabe, 1994; Ruskin and Jordan, 2007). A cyclic marine to continental Parasequence, related to a single rise and fall of sea-level, is the fundamental building block of a Sequence Stratigraphic framework. Their periodicities are typically of an order greater than tens of thousands of years, and are related to the forcing of Milankovitch climatic cycles (e.g., House and Gale, 1995.).

Lake-levels are the major base level influence in many continental basins, particularly apparent in Plio-Pleistocene basins of East Africa. In analogy with their marine counterparts, phases of pronounced lake level withdrawal or regression, alternating with phases of pronounced lake-level flooding or transgression, produce stratigraphic units that provide a detailed framework (Stanistreet, in prep.) in which to contextualize paleoanthropological finds. In the Olduvai Basin these units are sub-Milankovitch in period and are termed Lake Parasequences in order to distinguish them from their marine counterparts (Stanistreet, in prep.).

Also similar to marine basins, prolonged phases of lake withdrawal initiate erosional phases in its hinterland, represented by broad surfaces of degradation (Type II unconformity). If lake fall is pronounced for a prolonged period, which in the Olduvai Basin can extend to total drying up of palaeo-Lake Olduvai (Hay and Kyser, 2001; Stollhofen et al., 2007), downcutting by rivers sourcing in the Volcanic Highlands to the south and east (Figure 1) can incise a valley, with erosion surfaces cutting down deeply through the pre-existing stratigraphy (Type I unconformity). Such a total drying-up of the lake and major valley incision would occur during major synglacial aridity phases, associated with the weakening of the Indian Ocean monsoon on East Africa (Van Campo et al., 1982; Prell and Van Campo, 1986).

### Lowermost Bed II Valley Incision

Surfaces that have the characteristics of Type I incision have already been described but not identified as such in the Bed I and Bed II stratigraphies at Olduvai Gorge. A particularly good example recognized by Hay (1976) is the widespread surface below the Lower Augitic Sandstone that defines the top of Lower Bed II, termed the Lower Discomformity. Hay (1976, his Figure 27a) portrays the westerly trending extent of the associated incised valley, which at FLK cuts out the whole of the Lemuta Member and Lower Bed II, through Tuff IF into topmost Bed I (Figure 3).

An earlier Type I unconformity is present within lowermost Bed II below the Lower Augitic Sandstone incision. This unconformity divides lowermost Bed II into 1) overlying postincisional wetland-related (Deocampo, 2002) successions dominated by siliceous earths and earthy claystones, developed particularly well, for example, at HWK and MCK (Figure 3 and 2) underlying pre-incisional waxy claystone dominated sequences related to lake transgressions, shown well at VEK, FLK and KK. This incision surface cuts out the whole of the underlying Bed II sequence at HWK East along the axis of a westerly trending incised valley, named Crocodile paleo-Valley, because of the commonness of teeth and feeding traces of these reptiles within its infill in some places (Njau, 2006). This incision surface has not been recognized by previous authors (Leakey, 1971; Hay, 1976; Ashley and Hay, 2002), leading to mistaken correlations.

Estimates of the durations of the pre- and post-incisional sequences are dependent on the reliability of bracketing dates of the tops and bottoms of each, and the lengths of time represented by missing sequence eroded from the sedimentary record. The base of the preincisional sequence is defined by the 1.785 Ma palaeomagnetic boundary between the Olduvai Subchron and Matuyama Reversal as outlined in Blumenschine et al. (2003). This corresponds well with the dating of the aridity that affected the region prior to and during the

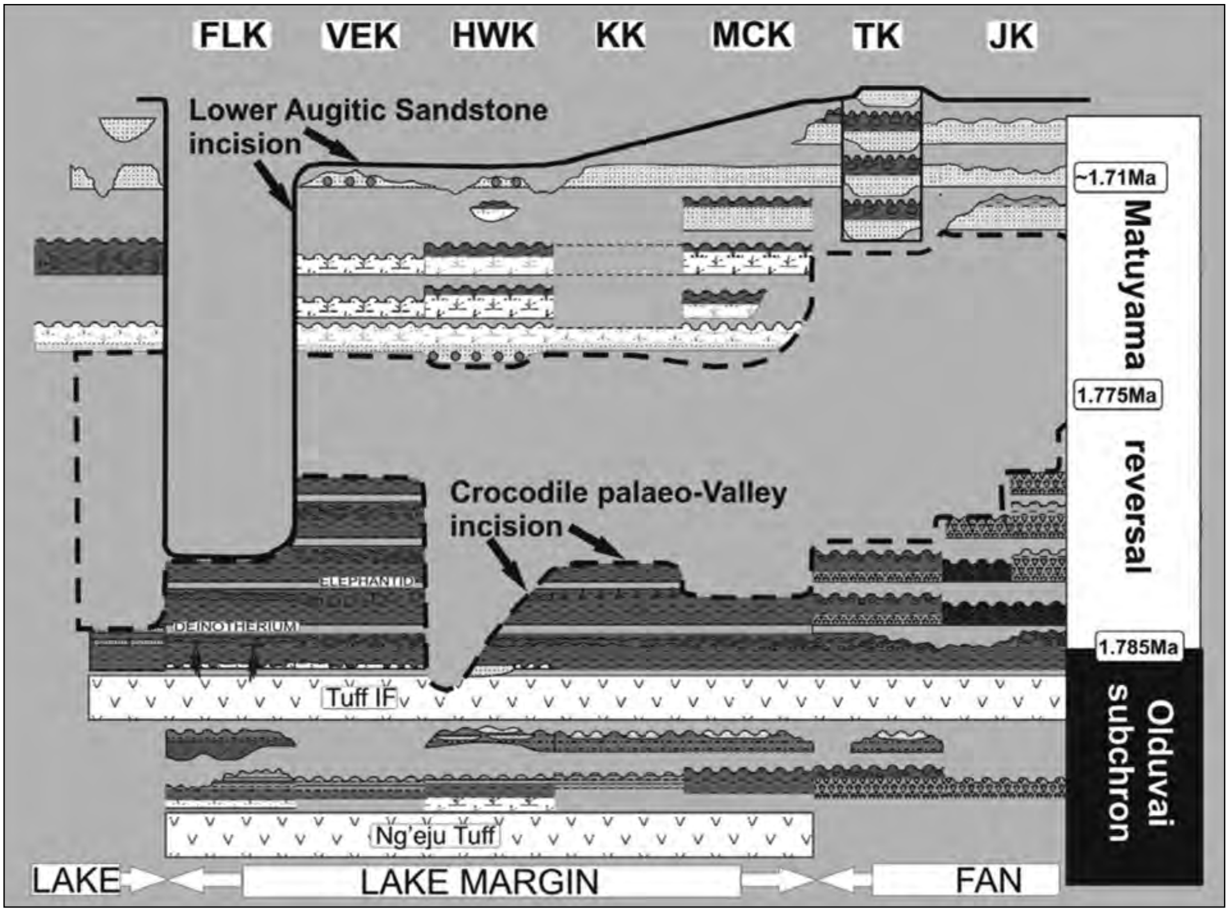



*Figure 3. Sequence stratigraphic cross-section of the eastern Olduvai Basin for the interval between the upper part of Bed I through the Lower Augitic Sandstone showing the Crocodile Valley incision that divides lowermost Bed II into the lower pre-incision phase and the upper post-incision phase.*

emplacement of Tuff IF (Stollhofen et al., 2007), which seems to coincide with a synglacial aridity affecting East Africa dated at 1.795 Ma by deMenocal and Bloemendal (1995) from windblown material in the offshore record. The top of the pre-incisional sequence is the date of the Crocodile Valley incision caused by the next synglacial aridity recorded at 1.775 Ma by deMenocal and Bloemendal (1995) in the offshore record. Thus, the duration of the pre-incisional sequence is presently best estimated at about 20,000 years.

The duration of the post-incisional sequence is less certain. The basal date is defined by the Crocodile Valley incision at dated at 1.775 Ma as discussed above. The top would be judged best from dating of Tuff IIA in the middle of the Lemuta Member, but dating of this tuff has proved to be problematic, and efforts to gain a reliable date are continuing. The potassium-argon biotite age of 1.71 Ma measured by Curtis and Hay (1972) is likely to be too young. However, the stratigraphic framework of the pre-incisional sequence (Figure3) is similar to the stratigraphic framework of the post-incisional sequence, suggesting that the duration of the latter can best be estimated to extend at least another 20,000 years.

## Methods

### *Theory of Variability in Landscape Stone Artifact Assemblages*

Blumenschine and Peters (1998) constructed a model that predicted the density, dispersion, and general composition of stone artifact assemblages from 11 landscape facets in the central Olduvai Basin during lowermost Bed II times. The predictions are based fundamentally on the hypothesized cover abundance of trees in each landscape facet, which is modeled to be inversely correlated to the intensity of predation hazard potentially encountered by hominins and directly correlated to the abundance and variety of food resources requiring stone tool use in each landscape facet. Higher-density occurrences with a broad functional range of stone artifact types are modeled to occur usually in safer, well treed landscape facets affording a variety of resources, while lower-density scatters of mainly knife-like flakes and flaking shatter are hypothesized for most landscape facets affording more open vegetation and higher predation risk.

In the model, stone transport costs from source to use locations also influence the landscape distribution of discarded or lost stone artifacts, because Oldowan hominins are conservatively modeled to lack carrying devices, thus creating severe limitations on transportable quantities of stone. Distance from stone source influences mainly the predicted relative abundance of tools made on different materials, where locally available quartzite is expected to dominate in assemblages near the central-basin source at the inselberg Naibor Soit, while artifacts made on lavas become more common toward the southeastern volcanic highlands (Figure 1). The model also predicts that quartzite artifact assemblage density would decrease with increasing distance from Naibor Soit, as would the degree of reduction of quartzite cores. Still, the influence of material transport costs on predicted landscape assemblages is not as great as those related to cover abundance of trees affording refuge or food.

The above predictions about stone material transport follow those of distance-decay models, borrowed from economic geography (e.g., Clark, 1979). When applied archaeologically, distance-decay models predict that as distance from a stone material source increases, artifacts made on that material should occur in lower quantities, both absolutely and relative to more local materials, and should be more thoroughly worked and used. Following Renfrew's (1969) pioneering analysis of the Early Neolithic obsidian trade in the Near East, quantitative demonstrations of distance-decay effects on stone artifact assemblages have been made for most periods of the Stone Age/Paleolithic, although their statistical strength is evaluated infrequently (see Blumenschine et al., 2007a for a review).

A recent test of hypothetical distance-decay effects on the quartzite artifact assemblages from the 13 geographic locales in the lowermost Bed II eastern Olduvai Basin showed that the proportionate weight of artifacts assemblages made up of quartzite is the assemblage characteristic most highly correlated with distance from Naibor Soit, the presumed source of the quartzite (Blumenschine et al., 2007a). Somewhat weaker, but still significant negative correlations with distance from Naibor Soit are also found for the weight density of quartzite artifacts and for the size and degree of reduction of quartzite cores. The finding suggests that transport costs of quartzite were relatively high, as might expected if hominins lacked carrying devices for stone (cf. Blumenschine and Peters, 1998), because the density and proportionate weight of quartzite assemblages approaches extinction at around 3-4 km from source in the most distant geographic locales sampled. The failure of distance from source to explain more than half of the variability in three of the four assemblage characteristics examined suggests that Oldowan hominin land use was also influenced by the modeled non-uniform landscape distributions of both resources requiring stone tools for extraction and predation risk (Blumenschine et al., 2007a).

## *Stone Artifact Sample Characteristics*

The stone artifact assemblages reported here were recovered between 1989 and 2006 through excavation by OLAPP into lowermost Bed II in the Eastern Lake Margin and Eastern Alluvial Plain, traversing a west-east distance of approximately 6 km (Figure 2). 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 material source from which the vast majority of recovered quartzite artifacts appear to have been made (see Blumenschine et al., 2007a for a discussion).

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 minimally vegetated exposures that were not too steep to excavate. Trenches were located selectively over dense surface concentrations of artifacts and/or fossils in only a few cases, and trenching into outcrops lacking surface remains was not precluded.

The stone artifact samples for pre-incisional (n=2,961 from 50 trenches) and postincisional (n=3,235 from 82 trenches) lowermost Bed II (Table 1) form incomplete subsets of that reported previously for the whole of lowermost Bed II (n=8,167 from 100 trenches). Most of the artifacts excluded derive from the land-surface on top of Tuff IF in HWK East, which will be described in a future report. Further, the location of the incision surface dividing the lowermost Bed II sequence cannot be identified confidently from section drawings of some of the trenches excavated prior to 2000, leading to the exclusion in this analysis of artifacts from these trenches. Finally, the incision surface occurs within some individual levels yielding artifacts, such that these cannot be assigned with confidence to either the pre-incision or the postincision. These artifacts are also excluded from the current analysis.

The artifact sample for each time period is further subdivided into a series of geographic locales (Table 1, Figure 2), each named for the modern *korongo* (fluvially incised gully, named by the Leakeys) in which it is located. Trench assignments to geographic locales are based on a compromise between two competing needs of the distance-decay analysis: 1) ensuring close proximity of constituent trenches so that an accurate average distance of the locale from Naibor Soit can be obtained, and 2) ensuring artifact sample sizes from each locale that are adequate to support analyses. This compromise did not always yield satisfactory results for the sub-divided lowermost Bed II sample.

For the post-incisional sample, very small artifact numbers were recovered from TK-Loc. 20 (n=2 from 1 trench), WK-PDK (n=13 from 4 trenches), and THC Complex (n=14 from 6 trenches). These small samples result from a combination of the thinness of the post-incisional sequence in these locales and their extremely low artifact densities. Further, the tendency for lowermost Bed II to outcrop in cliff faces in WK-PDK and the THC Complex limit excavation locations greatly, resulting in the wide dispersion of trenches in these locales. No post-incision deposits occur in JK-DK. The absence of quartzite artifacts in MNK results from the inability to assign excavation levels to either the pre-incision or the

*Table 1. Characteristics of the stone artifact sample from geographic locales listed west to east in the pre-incisional and post-incisional eastern lowermost Bed II Olduvai Basin (Figures 1 and 2). Two values are given for the number of trenches: those exposing the stratigraphic interval, and, in parentheses, those containing quartzite artifacts. Number of stone artifacts are those for which general stone material type was assigned.*

| Geographic Locale | No. Trenches | Excavated Volume ($m^3$) | No. Artifacts Total | No. Artifacts Quartzite |
|---|---|---|---|---|
| **Post-Incision** | | | | |
| MNK | 3 (2) | 7.5 | 20 | 0 |
| FLK | 2 (1) | 1.2 | 29 | 28 |
| VEK | 6 (6) | 21.2 | 423 | 379 |
| HWK W | 2 (2) | 8.1 | 247 | 231 |
| HWK E | 7 (7) | 24.9 | 1,468 | 1,430 |
| HWK EE | 5 (2) | 11.5 | 39 | 28 |
| KK | 3 (3) | 4.9 | 67 | 58 |
| MCK | 6 (6) | 36.0 | 562 | 300 |
| TK-Loc. 20 | 1 (1) | 1.2 | 2 | 2 |
| LONG K | 5 (5) | 20.3 | 77 | 40 |
| WK-PDK | 4 (3) | 8.8 | 13 | 9 |
| JK-DK | 0 (0) | 0 | 0 | 0 |
| THC-Complex | 6 (2) | 16.0 | 14 | 9 |
| Total | 50 (40) | 161.5 | 2,961 | 2,514 |
| **Pre-Incision** | | | | |
| MNK | 2 (2) | 2.7 | 0 | 0 |
| FLK | 12 (1) | 34.9 | 133 | 98 |
| VEK | 5 (6) | 21.2 | 410 | 382 |
| HWK W | 7 (2) | 15.3 | 365 | 343 |
| HWK EE | 12 (2) | 13.2 | 876 | 865 |
| KK | 5 (3) | 17.2 | 1,034 | 974 |
| MCK | 6 (6) | 8.2 | 4 | 2 |
| TK-Loc. 20 | 5 (1) | 27.8 | 231 | 223 |
| LONG K | 6 (5) | 11.9 | 75 | 45 |
| WK-PDK | 7 (3) | 46.5 | 24 | 16 |
| JK-DK | 6 (0) | 45.9 | 72 | 58 |
| THC-Complex | 9 (2) | 22.1 | 11 | 6 |
| Total | 82 (63) | 266.9 | 3,235 | 3,012 |

*Table 2. Distances of the eastern basin geographic locales from the southeastern end of the main hill at Naibor Soit (761.50 easting, 9671.50 northing; Figure 2) for pre-incisional and postincisional lowermost Bed II. 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. For locales lacking quartzite artifacts, distance is the simple mean of UTM values for the trenches exposing the interval. Distances for a given locale can differ between the two stratigraphic intervals (and from those in Blumenschine et al., 2007a) because of differences in quartzite artifact weight.*

| Geographic Locale | Mean Easting (UTM km) | Mean Northing (UTM km) | Distance from Naibor Soit (km) |
|---|---|---|---|
| **Post-Incision** | | | |
| MNK | 759.878 | 9668.776 | 3.17 |
| FLK | 761.058 | 9669.247 | 2.30 |
| VEK | 761.060 | 9669.008 | 2.53 |
| HWK W | 761.355 | 9669.093 | 2.41 |
| HWK E | 761.521 | 9668.965 | 2.54 |
| HWK EE | 761.672 | 9669.076 | 2.43 |
| KK | 761.751 | 9669.197 | 2.32 |
| MCK | 762.115 | 9669.089 | 2.49 |
| TK-Loc. 20 | 762.761 | 9669.854 | 2.07 |
| LONG K | 762.771 | 9669.195 | 2.63 |
| WK-PDK | 763.278 | 9669.372 | 2.77 |
| THC-Complex | 764.924 | 9669.703 | 3.87 |
| **Pre-Incision** | | | |
| MNK | 760.326 | 9668.933 | 2.82 |
| FLK | 760.950 | 9669.595 | 1.98 |
| VEK | 761.057 | 9669.028 | 2.51 |
| HWK W | 761.355 | 9669.100 | 2.40 |
| HWK EE | 761.658 | 9669.050 | 2.46 |
| KK | 761.803 | 9669.213 | 2.31 |
| MCK | 762.016 | 9668.977 | 2.58 |
| TK-Loc. 20 | 762.714 | 9669.830 | 2.06 |
| LONG K | 762.540 | 9669.019 | 2.69 |
| WK-PDK | 763.289 | 9669.269 | 2.86 |
| JK-DK | 763.573 | 9669.969 | 2.58 |
| THC-Complex | 764.768 | 9669.984 | 3.60 |

post-incision in trenches that had yielded the 14 quartzite artifacts reported for all of lowermost Bed II (Blumenschine et al., 2007a).

The pre-incision is poorly exposed at HWK E, with most pre-incision deposits having been eroded by valley incision. All lowermost Bed II artifacts in HWK E are restricted to the landsurface that developed on top of Tuff IF, which is not considered here, such that there is no pre-incision sample from this locale. As with the pre-incisional sample, none of the levels in trenches in MNK (n=0 artifacts from 2 trenches) could be assigned confidently to the preincision. Very small artifact samples characterize the pre-incision at MCK (n=4 artifacts from 6 trenches), and again the THC Complex (N=11 artifacts from 9 trenches) due to very low artifact densities.

### Estimates of Distance from Source

The point on Naibor Soit used in the distance-decay analyses is the southeast end of the main hill (Figure 2). Two other locations along the main hill that were examined in the previous analysis for the whole of lowermost Bed II yield results similar to the southeastern end, and are not used here. For reasons that remain unknown, distance from the small hill at Naibor Soit, which was apparently the most accessible point on the inselberg when it was a peninsula in paleo-Lake Olduvai (Figure 1; Hay, 1976), did not yield significant results in the prior analysis.

The estimated straight-line distances of geographic locales from 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. These distances for a given locale are in many cases different for the pre-incision and the post-incision samples due to the different series of trenches exposing each interval and their different yield of quartzite artifacts. The estimated 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.

### Assemblage Characteristics Used to Test Predictions

We use three of the four assemblage parameters reported previously to test the predicted distance-decay effects. The quantity of quartzite is measured by its weight density ($g/m^3$ of excavated deposit). Unlike the previous analyses for the whole of lowermost Bed II, weight densities are not transformed logarithmically, allowing the zero values for MNK obtained when lowermost Bed II sample is sub-divided to be graphed and incorporated into the statistical analyses. 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 (cores) is measured by their mean maximum length. Unlike the previous report, we do not report on the degree of reduction of quartzite flaked pieces, which was expressed as the proportion of these that had been flaked unifacially around less than 50% of their circumference. This omission results from the small number of these minimally flaked cores from both the post-incision (n=20) and the pre-incision (n=13) samples.

Spearman's rank-order correlation is used to evaluate the strength of 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 the relationships has been specified.

## Results

The weight density of quartzite artifact assemblages varies over two orders of magnitude among geographic locales for both the pre-incision and post-incision intervals (Table 3). The range of values is greater for the post-incision (from a minimum of 0 $g/m^3$ at MNK to a maximum of 307 $g/m^3$ at MCK). The overall weight density of quartzite artifact assemblages for all locales combined is more that twice as great during post-incision times as during pre-incision times.

Weight densities tend to decrease with increasing distance of locales from Naibor Soit for both time intervals (Figure 4a). However, the relationship is significant only for the pre-incision, in which distance from Naibor Soit accounts for 84% of the rank-order variability in weight density (Table 4). The lack of a significant relationship during the post-incision results in part from the unexpectedly low weight densities encountered at the two localities closest to Naibor Soit, TK-Loc. 20 and FLK. These values are about two times lower than those in the preceding time period for TK-Loc. 20, and almost seven times lower for FLK. Conversely, MCK and VEK display unexpectedly high weight densities during the post-incision, having increased about 2.4 and 5.5 times over their respective values during the pre-incision.

The proportion of total artifact weight comprised of quartzite (Table 3) is again more variable for the post-incision (0% at MNK, 100% at TK-Loc. 20) than of the pre-incision (0.3% for THC Complex, 71% for HWK EE). For all locales combined, the proportionate weight of quartzite artifacts for the post-incision is about two-thirds that for the pre-incision, with most of the difference being accounted for by the large quantity of artifacts and manuports made on volcanic materials at MCK during the post-incision (Table 3).

The expected decrease in the proportionate weight of quartzite artifacts with increasing distance from Naibor Soit is obtained for both the early and late stages of lowermost Bed II (Figure 4b). The negative relationship is significant for both time periods, but the relationship is stronger for the pre-incision, with distance from Naibor Soit accounting for more than two-thirds of the variability in this assemblage parameter (Table 4). TK-Loc. 20 preserves expected high weight proportions of quartzite artifacts for both time periods, given its close proximity to Naibor Soit. Notably lower than expected values are seen at KK, HWK W and MCK for the post-incision, and at FLK during the pre-incision. Higher than expected values are seen at THC Complex for the post-incision, and at HWK EE for the pre-incision.

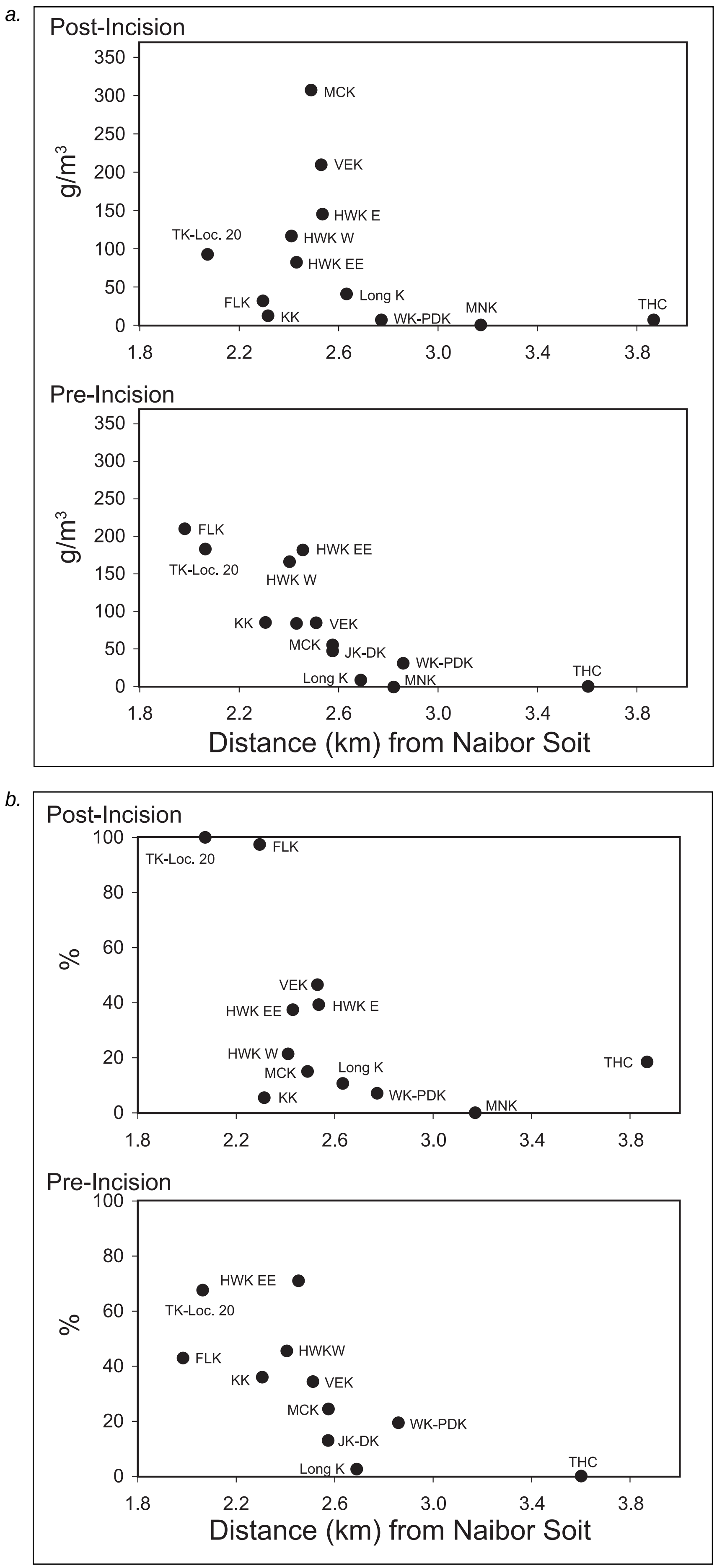
Variability in the mean maximum dimension of whole quartzite flaked pieces is less for the post-incision (46 mm at THC Complex, 63 mm at VEK and MCK) than for the pre-incision (34 mm at Long K, 76 mm at FLK), although this artifact type was recovered from fewer postincision locales (Table 3). The average size of these artifacts for all locales combined is similar for both

*Table 3. Weights (g) and weight densities (g/m$^3$ and log g/m$^3$ of excavated deposit) of quartzite artifacts, the proportion of total artifact weight comprised of quartzite, and the mean maximum length (mm) of whole quartzite flaked pieces (FP) from geographic locales in pre-incisional and post-incisional lowermost Bed II. See Table 1 for excavated volumes.*

| Geographic Locale | Quartzite Artifacts Weight (g) | Quartzite Artifacts Weight density g/m$^3$ | Total Artifact Weight (g) | %Quartzite Artifact Weight | Total No. Quartzite FP | Mean Maximum Dimension (mm) of Quartzite FP |
|---|---|---|---|---|---|---|
| **Post-Incision** | | | | | | |
| MNK | 0 | 0 | 153 | 0.0 | 0 | — |
| FLK | 38 | 31.4 | 39 | 97.4 | 0 | — |
| VEK | 4,437 | 209.3 | 9,573 | 46.3 | 11 | 63.4 |
| HWK W | 940 | 116.3 | 4,370 | 21.5 | 5 | 49.0 |
| HWK E | 3,619 | 145.1 | 9,202 | 39.3 | 18 | 61.8 |
| HWK EE | 941 | 82.1 | 2,517 | 37.4 | 0 | — |
| KK | 58 | 11.9 | 1068 | 5.4 | 0 | — |
| MCK | 11,057 | 307.1 | 74,292 | 14.9 | 46 | 63.0 |
| TK-Loc. 20 | 113 | 92.7 | 113 | 100.0 | 1 | 57.0 |
| LONG K | 816 | 40.2 | 7,706 | 10.6 | 4 | 50.3 |
| WK-PDK | 62 | 7.1 | 898 | 6.9 | 0 | — |
| THC-Complex | 104 | 6.5 | 561 | 18.5 | 1 | 46.0 |
| Total | 22,184 | 137.3 | 110,491 | 20.1 | 86 | 61.1 |
| **Pre-Incision** | | | | | | |
| MNK | 0 | 0 | 0 | — | 0 | — |
| FLK | 5,256 | 210.2 | 12,118 | 43.4 | 13 | 75.6 |
| VEK | 2,322 | 86.0 | 6,699 | 34.7 | 10 | 49.8 |
| HWK W | 2,668 | 166.8 | 5,819 | 45.8 | 6 | 75.7 |
| HWK EE | 1,093 | 182.2 | 1,533 | 71.3 | 1 | 56.0 |
| KK | 2,482 | 85.6 | 6,900 | 36.0 | 14 | 48.9 |
| MCK | 111 | 55.5 | 450 | 24.7 | 1 | 63.0 |
| TK-Loc. 20 | 1,098 | 183.0 | 1,617 | 67.9 | 4 | 53.5 |
| LONG K | 269 | 9.0 | 10,017 | 2.7 | 1 | 34.0 |
| WK-PDK | 249 | 31.1 | 1,269 | 19.6 | 3 | 40.7 |
| JK-DK | 617 | 47.4 | 4,585 | 13.4 | 3 | 51.3 |
| THC-Complex | 2 | 0.4 | 607 | 0.3 | 0 | — |
| Total | 16,167 | 60.6 | 51,614 | 31.3 | 56 | 58.3 |

*Table 4. Spearman's rank-order correlation statistics for the relationships between three artifact assemblage characteristics (Table 3) and distance from Naibor Soit (Table 2, Figure 2) of geographic locales for pre-incisional and post-incisional lowermost Bed II. Probability values are one-tailed, following predictions. Correlation statistics with probability values <0.05 are bold-faced.*

| Assemblage Characteristic | Stratigraphic Interval | No. of Locales | $r_S$ | $r^2_S$ |
|---|---|---|---|---|
| Weight density (g/m$^3$) of quartzite artifacts | Post-incision | 12 | –0.41 | 0.16 |
| | Pre-incision | 12 | **–0.91** | **0.84** |
| Weight proportion of quartzite artifacts | Post-incision | 12 | **–0.55** | **0.30** |
| | Pre-incision | 11 | **–0.83** | **0.69** |
| Mean maximum length of quartzite flaked pieces | Post-incision | 7 | –0.29 | 0.08 |
| | Pre-incision | 10 | **–0.57** | **0.33** |


a.
Post-Incision
g/m3
MCK
VEK
HWK E
TK-Loc. 20
HWK W
HWK EE
Long K
FLK
KK
WK-PDK
MNK
THC
Pre-Incision
g/m3
FLK
TK-Loc. 20
HWK EE
HWK W
KK
VEK
MCK
JK-DK
WK-PDK
THC
Long K
MNK
Distance (km) from Naibor Soit
b.
Post-Incision
%
TK-Loc. 20
FLK
VEK
HWK EE
HWK E
HWK W
MCK
Long K
THC
KK
WK-PDK
MNK
Pre-Incision
%
HWK EE
TK-Loc. 20
FLK
HWKW
KK
VEK
MCK
WK-PDK
JK-DK
Long K
THC
Distance (km) from Naibor Soit

c.

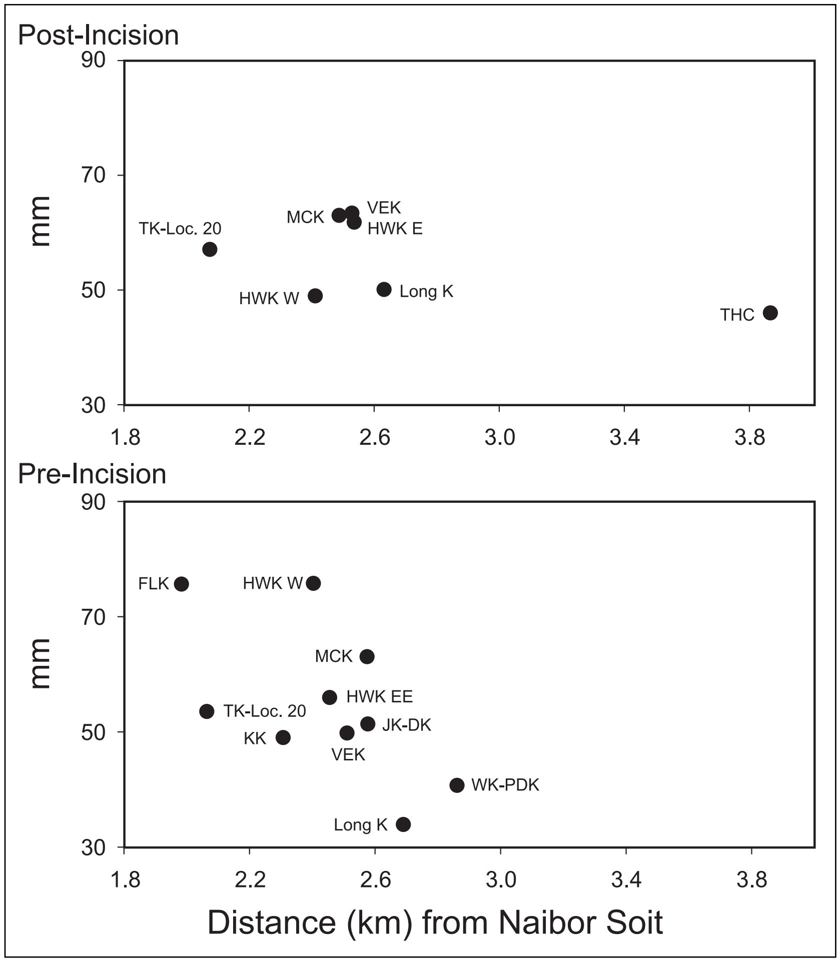



*Figure 4a-c. The relationships between distance from the southeastern end of the main hill at Naibor Soit (Table 2) and three characteristics of stone artifact assemblages from the post-incisional and pre-incisional phases of lowermost Bed II (Table 4). The assemblage characteristics are a) weight density (g/m³) of quartzite artifact assemblages, b) the proportion of total artifact assemblage weight comprised of quartzite, and c) the mean maximum dimension of whole quartzite cores.*

time periods. For locales with good samples during both time periods, flaked pieces from VEK tend to be substantially larger, and those from HWKW substantially smaller during the post-incision.

The expected decrease in mean flaked piece size with increasing distance from Naibor Soit is seen for both time periods (Figure 4c). However, the relationship is significant only for the pre-incision, where distance from source accounts for one-third of the variability in flaked piece size (Table 4). For the pre-incision, larger-than-expected flaked pieces are found at HWK W, while unexpectedly small cores are found at TK-Loc. 20 and KK.

## Discussion

The distance-decay effects documented previously for the whole of the lowermost Bed II interval (Blumenschine et al., 2007a) are shown here to be produced mainly by the sub-sample from the early, pre-incisional stage of this interval, for which significant distance-decay effects are obtained for the three assemblage parameters examined. Distance from source explains over two-thirds of the variation in the weight density and proportionate weight of quartzite artifact assemblages from the pre-incision. The weaker but still significant distance-decay effect for the size of quartzite flaked pieces is obtained despite very small numbers of flaked pieces during the pre-incision interval for most geographic locales.

Expected negative relationships obtained with distance from Naibor Soit exist for the three characteristics of the post-incision quartzite assemblages examined here, but only that for proportionate quartzite weight is significant. The absence of significant relationships for the other two variables is attributable in part to very small excavated volumes of post-incision deposits from FLK and TK-Loc. 20 (1.2 $m^3$ each). If the unexpectedly low weight densities of quartzite artifact assemblages from FLK and TK-Loc. 20 samples are excluded, the correlation between weight density and distance from Naibor Soit among assemblages from the remaining 10 geographic locales improves ($r_s$=–0.55, p=0.05). Still, distance from source during the postincision for this reduced sample explains substantially less of the variability in weight density (30%) than it does for the total pre-incision sample (84%). Excluding TK-Loc. 20 from the postincision analysis of flaked piece size (no quartzite flaked pieces were recovered from FLK) also improves the strength of the distance-decay relationship (n=6, $r_s$=–0.89, $p < 0.05$). Yet, if both FLK and TK-Loc. 20 are excluded from the analysis for proportionate quartzite assemblage weight, the relationship is no longer significant (n=10, $r_s$=–0.21, p=0.28).

Distance-decay effects apply most readily to hominin transport of stone material through uniform, two-dimensional Euclidean space following straight-line travel routes from source to use locations (Blumenschine et al., 2007a). However, for Oldowan hominins in the eastern Olduvai Basin during lowermost Bed II times, patchy landscape distributions have been modeled for critical landscape affordances such as predation hazards from large carnivores, potable water, refuge trees, and food resources involving stone use, discard and loss (Peters and Blumenschine, 1995). In this model, much of the patchy distribution of positive affordances coincides with the distribution of woodland, such as that expected to be concentrated along streams in the alluvial fan and the upper edge of the lake floodplain. Further, the negative affordance of predation risk is concentrated in more open vegetation contexts, such as on the mudflats of the lower lake floodplain and along marshes near stream mouths. In such complex ecological settings, costs of stone transport that underlie distance-decay expectations may become secondary to the avoidance of predation risk and the transport of stone materials to locales where resources are more abundant. The result would be diminished or negated distance-decay effects.

Observations of facies sequences in lowermost Bed II since 2000 by IS show that the landscape of the eastern lake margin prior to the Crocodile Valley incision would have been vastly different than during the infill of the valley, which on-lapped over the erosion surface.

Prior to the incision, the broad (up to ca. 3 km) lake margin of paleo-Lake Olduvai was exposed following lake withdrawals, on which calcareous soils formed that appear to have supported grassy woodland (Bennett et al., in review; cf. Sikes, 1994). Successive lake transgressions would have on-lapped onto the toe of the eastern alluvial fan system, resulting in the relative narrowness of the intermittently dry saline lake zone mapped by Hay (1976, his Fig. 31) in the east compared to other sides of the lake. The aggradation of the eastern alluvial fan deposits would have also resulted in the eastern lake margin being higher and drier than margins to the west, south and north of the lake. Hominin access between Naibor Soit and all unflooded areas of the eastern lake margin was likely to have been relatively unimpeded by geomorphic features, except at the times of the very highest lake-level stands when Naibor Soit formed an island (Hay, 1976), such as that immediately following the emplacement of Tuff IF tephra and its fluvial reworking (Stollhofen et al., 2007).

In contrast, following its incision, Crocodile Valley would have been a major westerly trending feature in the lake margin and distal portion of the alluvial fan. The center of the valley likely trended south through the eastern part of the THC Complex before bending westward, passing through Long K, the southern end of MCK, the three HWK locales, and toward MNK and the lake (Figure 2b). FLK, VEK, TK-Loc. 20, JK-WK and DK were located on the north side of the valley. Except during intervals of high lake-level that transgressed as far as the eastern end of Long K, the center of the valley appears to have been dominated by a stream-fed, freshwater marshland (cf. Peters and Blumenschine, 1995). The marshland would have extended from its junction with palaeo-Lake Olduvai at its western termination eastwards to or beyond MCK as far as the Long K Fault, which runs from the east side of Long K northeastward through JK. The eastward extent of the marshland would probably have depended on the intensity of dry and wet seasons within the range of variability at any one time. Eastward beyond the marshland, the center of the valley was occupied by narrow streams likely to have been lined with trees (cf. Peters and Blumenschine, 1995).

The creation of Crocodile Valley may have altered transport patterns of quartzite from Naibor Soit to use locations in the eastern Olduvai Basin. Valley incision provided for the establishment of an east-to-west trending wetland in the eastern lake margin that may have been a travel barrier over at least a portion of the lake margin and distal alluvial fan, at least during wet time periods. Localities on the north side of the valley would have been most accessible to Naibor Soit, but this resulted in high rates of quartzite artifact discard or loss only at VEK, possibly due to high predation risk and/or low availability of resources at the other northern locales. Nonetheless, the marshland may have impeded access to locales in the center of the valley, obviating straight-line transport routes for quartzite from Naibor Soit to use locations, increasing transport distances and associated costs, and in the process reducing the strength of the distance-decay effects seen for post-incision times compared to pre-incision times.

Perhaps more importantly, Crocodile Valley may have created a more patchy distribution of resources requiring stone tool use than had existed previously during pre-incision times. For example, scavengeable carcasses may have been concentrated along the edge of the marshland near the center of the valley in the lake margin. These as well as other affordances including plant foods, potable water, and refuge trees may have been concentrated along the riverine woodland expected for the streams on the distal alluvial fan, which may also have provided a relatively safe travel corridor for hominins (cf. Peters and Blumenschine, 1995). MCK and the west side of Long K may have provided the most abundant resources in exposed portions of the eastern basin. These are the westernmost of the locales dominated by earthy claystones during the post-incision, suggesting that the area lay at the interface of the lake margin's marshland and the streams of the alluvial fan. Such an ecotonal setting might have promoted the high rate of use, discard and/or loss of the quartzite artifacts as well as those made from various lavas in MCK (Table 3). In fact, the weight density of artifacts made on all materials at MCK is more than seven times greater than the average for the other locales during the post-incision. Preferential transport of quartzite and other materials for tools to MCK and other places affording concentrated resources would also reduce the strength of the distance-decay effects during post-incision times over that seen for the pre-incision.

## Conclusions

Our results show that Oldowan hominin behavior at Olduvai Gorge can be detected at landscape scales for relatively discrete time intervals on the order of approximately 20,000 years during the Plio-Pleistocene. They also suggest that changes in behavioral patterning in the landscape distribution of artifacts are also detectable, and that these might be related to landscape evolution, reinforcing the need to invest heavily in the reconstruction of paleolandscapes at high temporal and spatial resolutions. The ability to detect these patterns is also dependent on production of adequate samples of stone artifacts recovered over large areas, which for the current analysis was generated during 12 seasons of excavation focused at least in part on lowermost Bed II in the eastern basin over a period of 17 years. The introduction in 2000 of sequence stratigraphy to Olduvai allowed the lowermost Bed II sample to be subdivided into pre 20 and post-incision components. It also leads to the possibility of reconstructing patterns of hominin land use across exposed portions of the lake margin and alluvial fan for intervals as short as ca. 4,000 years, the estimated duration of each parasequence during lowermost Bed II times (Stanistreet, in prep.). This unprecedented temporal resolution of traces of hominin land use at landscape scales can only be achieved with further excavation aimed at increasing sample sizes. Meaningful landscape paleoanthropology is a long-term, trans-generational effort (cf. Peters and Blumenschine, 1995), but one that has the potential to reveal aspects of ancestral hominin behavior undetectable through traditional, site-based excavation.

## References


Ammerman, A.J., 1981. Surveys and archaeological research. Annual Review of Anthropology, 10, 63-88.

Ashley, G.M., Hay, R.L., 2002. Sedimentation Patterns in a Plio-Pleistocene volcaniclastic rift-platform basin, Olduvai Gorge, Tanzania. In: Renaut, R.W., Ashley, G.M. (Eds.), Sedimentation in Continental Rifts. SEPM (Society for Sedimentary Geology) Spec. Publ. No. 73, Tulsa, pp. 107-122.

Behrensmeyer, A.K., 1985. Taphonomy and the paleoecologic reconstruction of hominid habitats in the Koobi Fora Formation. In: Coppens, Y. (Ed.), L'Environment des Hominides au Plio-Pleisotcene. Masson, Paris, pp. 309-324.

Bennett, C., Marshall, J., Stanistreet, I.G., n.d. Palaeoenvironmental analysis of palaeosols from Beds I and II of Olduvai Gorge, Tanzania (~1.785Ma). Sedimentology. In review

Binford, L.R., 1982. The archaeology of place. Journal of Anthropological Archaeology 1, 5-31.

Binford, L.R., 1992. Seeing the present and interpreting the past–and keeping things straight. In: Rossignol, J., Wandsnider, L. (Eds.), Space, Time, and Archaeological Landscapes. Plenum Press, New York, pp. 43-59.

Blumenschine, R.J., Masao, F.T., 1991. Living sites at Olduvai Gorge, Tanzania? Preliminary landscape archaeology results in the basal Bed II lake margin zone. Journal of Human Evolution 21, 451-462.

Blumenschine, R.J., Masao, F.T., Peters, C.R., 2005. Broad-scale landscape traces of Oldowan hominin land use at Olduvai Gorge and the Olduvai Landscape Paleoanthropology Project. In: Mapunda, B.B.B., Msemwa, P. (Eds.), Salvaging Tanzania's Cultural Heritage. University of Dar es Salaam Press, Dar es Salaam, pp. 158-189.

Blumenschine, R.J., Peters, C.R., 1998. Archaeological predictions for hominid land use in the paleo-Olduvai Basin, Tanzania, during lowermost Bed II times. Journal of Human Evolution 34, 565-607.

Blumenschine, R.J., Peters, C.R., Masao, F.T., Clarke, R.J., Deino, A.L., Hay, R.L., Swisher, C.C., Stanistreet, I.G., Ashley, G.M., McHenry, L.J., Sikes, N.E., van der Merwe, N.J., Tactikos, J.C., Cushing, A.E., Deocampo, D.M., Njau, J.K., Ebert, J.I., 2003. Late Pliocene Homo and Hominid Land Use from Western Olduvai Gorge, Tanzania. Science 299, 1217-1221.

Blumenschine, R.J., Masao, F.T., Tactikos, J.C., Ebert, J.I., 2007a. Effects of distance from stone source on landscape-scale variation in Oldowan artifact assemblages in the Paleo-Olduvai Basin, Tanzania. Journal of Archaeological Science, in press.

Blumenschine, R.J., Peters, C.R., Capaldo, S.D., Andrews, P., Njau, J.K., Pobiner, B.L., 2007b. Vertebrate taphonomic perspectives on Oldowan hominin land use in the Plio-Pleistocene 22 Olduvai Basin, Tanzania. In: Pickering, T., Schick, K., Toth, N. (Eds.), Breathing Life Into Fossils: Taphonomic Studies in honor of C.K. (Bob) Brain. Stone Age Institute Press, Gosport, Indiana.

Clark, J.R., 1979. Measuring the flow of goods with archaeological data. Economic Geography 55, 1-17.

Curtis, G.H., Hay, R.L., 1972. Further geological studies and the K-Ar dating at Olduvai Gorge and Ngorongoro Crater. In: Bishop, W.W., Milled, J.A. (Eds.), Calibration of Human Evolution. Scottish Academic Press, Edinburg, pp. 289-301.

DeMenocal, P.B., Bloemendal, J., 1995. Plio-Pleistocene climatic variability in subtropical Africa and the paleoenvironment of hominid evolution: a combined data-model approach. In: Vrba, E.S., Denton, G.H., Partridge, T.C., Burckle, L.H. (Eds.), Paleoclimate and Evolution, with Emphasis on Human Origins. Yale University Press, New Haven, pp. 262-288.

Deocampo, D.M., 2002. Sedimentary processes and lithofacies in lake-margin groundwater-fed wetlands in East Africa. In: Renaut, R.W., Ashley, G.M. (Eds.), Sedimentation in Continental Rifts. SEPM (Society for Sedimentary Geology) Spec. Publ. No. 73, Tulsa, pp. 295-308.

Deocampo, D.M., Blumenschine, R.J., Ashley, G.M., 2002, Wetland diagenesis and traces of early hominids, Olduvai Gorge, Tanzania. Quaternary Research 57, 271-281.

Ditchfield, P., Hicks, J., Plummer, T., Bishop, L.C., Potts, R., 1999. Current research on the Late Pliocene and Pleistocene deposits North of Homa Mountain, Southwestern Kenya. Journal of Human Evolution 36, 123–150.

Dominguez-Rodrigo, M., de la Torre, I., de Luque, L., Alcala, L., Mora, R., Serrallonga, J., Medina, V., 2002. The ST Site Complex at Peninj, West Lake Natron, Tanzania: Implications for early hominid behavioural models. Journal of Archaeological Science 29, 639-665.

Dunnell, R.C., 1992. The notion site. In: Rossignol, J., Wandsnider, L. (Eds.), Space, Time, and Archaeological Landscapes. Plenum Press, New York, pp. 21-41.

Dunnell, R.C., Dancey, W.S., 1983. The siteless survey: A regional scale data collection strategy. Advances in Archaeological Method and Theory 6, 267-287.

Ebert, J.I., 1992. Distributional Archaeology. University of New Mexico Press, Albuquerque.

Foley, R.A., 1981a. A model of regional archaeological structure. Proceedings of the Prehistoric Society 47, 1-17.

Foley, R., 1981b. Off-site archaeology: an alternative approach for the short-sited. In: Hodder, I., Isaac, G.Ll., Hammond, N. (Eds.), Patterns of the Past. Cambridge University Press, Cambridge, pp. 157-183.

Harris, J.W.K., Capaldo, S.D., 1993. The earliest stone tools: Their implications for an understanding of the activities and behaviors of Late Pliocene hominids. In: Berthelet, A., Chavaillon, J. (Eds.), The Use of Tools by Human and Non-human Primates. Clarendon Press, Oxford, pp. 196-224.

Hay, R.L., 1976. Geology of the Olduvai Gorge. University of California Press, Berkeley.

Hay , R.L., Kyser, T.K., 2001. Chemical sedimentology and paleoenvironmental history of Lake Olduvai, a Pliocene lake in northern Tanzania. The Geological Society of America Bulletin 113, 1505-1521.

House, M.R. Gale, A.S. (Eds.), 1995. Orbital Forcing Timescales and Cyclostratigraphy. Geological Society London Special Publication 85, 204 pp.

Isaac, G.Ll., Harris, J.W.K., 1975. The scatters between the patches. Kroeber Anthropological Society, University of California, Berkeley.

Isaac, G.L., Harris, J.W.K., 1978. Archaeology. In: Leakey, M.G., Leakey, R.E. (Eds.), Koobi Fora Research Project, Volume 1. Clarendon Press, Oxford.

Isaac, G., Harris, J.W.K., Marshall, F., 1981. Small is informative: the application of the study of mini-sites and least effort criteria in the interpretation of the Early Pleistocene archaeological record at Koobi Fora, Kenya. Proc. Union Internacional de Ciencias Prehistoricas y Protohistoricas; X Congress, Mexico City, pp. 101-119.

Leakey, M.D., 1967. Preliminary survey of the cultural material from Beds I and II, Olduvai Gorge, Tanzania. In: Bishop, W.W. Clark, J.D. (Eds.), Background to Evolution in Africa. University of Chicago Press, Chicago, pp. 417-446.

Leakey, M.D., 1971. Olduvai Gorge: Excavations in Beds I and II, 1960-1963. Cambridge University Press, Cambridge.

Njau, J.K., 2006. The Relevance of Crocodiles to Oldowan Hominin Paleoecology at Olduvai Gorge, Tanzania. Ph.D. Dissertation, Rutgers University.

Peters, C.R., Blumenschine, R.J., 1995. Landscape perspectives on possible land use patterns for early hominids in the Olduvai Basin. Journal of Human Evolution 29, 321-362.

Plummer, T., Bishop, L.C., Ditchfield, P., Hicks, J., 1999. Research on Late Pliocene Oldowan sites at Kanjera South, Kenya. Journal of Human Evolution 36, 151-170.

Potts, R., Behrensmeyer, A.K., Ditchfield, P., 1999. Paleolandscape variation and Early Pleistocene hominid activities: Members 1 and 7, Olorgesailie Formation, Kenya. Journal of Human Evolution 37, 747-788.

Prell, W.L., Van Campo, E., 1986. Coherent response of Arabian Sea upwelling and pollen transport to late Quaternary monsoonal winds. Nature 323, 526-528.

Renfrew, C., 1969. Trade and culture process in European prehistory. Current Anthropology 10, 151-169.

Rogers, M.J., 1996. Landscape archaeology at East Turkana, Kenya. In: Magori, C., et al. (Eds.). Four Million Years of Hominid Evolution in Africa: Proceedings of the International Congress in Honour of Mary Douglas Leakey's Outstanding Contribution to Paleoanthropology. Kaupia, Darmstadter Beitrage zur Naturgeschichte, Darmstadt, pp. 21-26.

Rogers, M.J., 1997. A Landscape Archaeological Study at East Turkana, Kenya. Ph.D. Dissertation, Rutgers University.

Rogers, M.J., Harris, J.W.K., 1992. Recent investigations into off-site archaeology at East Turkana, Kenya. Nyame Akuma, 38, 41-47.

Rogers, M.J., Feibel, C.S., Harris, J.W.K., 1994. Changing patterns of land use by Plio-Pleistocene hominids in the Lake Turkana Basin. Journal of Human Evolution 27, 139-158.

Rossignol, J., Wandsnider, L., (Eds.), 1992. Space, Time, and Archaeological Landscapes. Plenum Press: New York.

Ruskin, B.G., Jordan, T.E., 2007. Climate change across continental sequence boundaries: palaeopedology and lithofacies of Iglesia Basin, northwestern Argentina. Journal of Sedimentary Research 77, 661-679.

Shanley, K.W., McCabe, P.J., 1994. Perspectives on the sequence stratigraphy of continental strata. American Association of Petroleum Geologists Bulletin 78, 544-568.

Sikes, N.E., 1994. Early hominin habitat preferences in East Africa: Paleocarbon isotopic evidence. Journal of Human Evolution 27, 25-45.

Sikes, N.E., Potts, R., Behrensmeyer, A.K., 1999. Early Pleistocene habitat in Member 1 Olorgesailie based on paleosol stable isotopes. Journal of Human Evolution 37, 721-746.

Stanistreet, I.G., in prep. Sequence stratigraphy of the Bed I to Bed II interval, Olduvai Gorge, Tanzania.

Stern, N., 1993. The structure of the Lower Pleistocene archaeological record. Current Anthropology 34, 201-225.

Stern, N., 1994. The implications of time-averaging for reconstructing the land-use patterns of early tool-using hominids. Journal of Human Evolution 27, 89-105.

Stollhofen, H., Stanistreet, I.G., McHenry, L., Mollel, G.F., Blumenschine, R.J., Masao, F.T., 2007. Fingerprinting facies of the Tuff IF marker, with implications for early hominin palaeoecology, Olduvai Gorge, Tanzania. Palaeogeography, Palaeoclimatology, Palaeoecology. Accepted.

Tactikos, J.C., 2005. A Landscape Perspective on the Oldowan from Olduvai Gorge, Tanzania. Ph.D. Dissertation, Rutgers University. 25

Thomas, D.H., 1975. Nonsite sampling in archaeology: Up the creek without a site? In: Mueller, J.W. (Ed.), Sampling in Archaeology. University of Arizona Press, Tucson, pp. 61-81.

Vail, P.R., Mitchum, R.M., Todd R.G., Widmier, J.M., Thompson, S. III, Sangree, J.B., Bubb, J.N., Hatlelid, W.G., 1977. Seismic stratigraphy and global changes of sea level. In: Payton, C.E. (Ed.), Seismic Stratigraphy–Applications to Hydrocarbon Exploration. Mem. American Association of Petrolium Geologists 26, 49-212.

Van Campo, E., Duplessy, J.C., Rossignol-Strick, M., 1982. Climatic conditions deduced from a 150-kyr oxygen isotope-pollen record from the Arabian Sea. Nature 296, 56-59.

van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F.,Loutit, T.S., Hardenbol, J., 1988. An overview of the fundamentals of sequence statigraphy and key definitions. In: Wilgus, C.K., Hastings, B.S., Posamentier, H.W., van Wagoner, J.C., Ross, C.A., Kendall, C.G.St.C. (Eds.), Sea Level Changes: An Integrated Approach. Special Publication of Society of Economic Paleontologists and Mineralogists 42, 39-45.

Wandsnider, L., 1992. Archaeological landscape studies. In: Rossignol, J., Wandsnider, L., (Eds.), Space, Time, and Archaeological Landscapes. Plenum Press, New York, pp. 285-292.