



Universitat Autònoma de Barcelona

**Centre d'Estudis
del Patrimoni Arqueològic
de la Prehistòria**

TREBALLS D'ARQUEOLOGIA, 9

Oldowan: Rather more than smashing stones

First Hominid Technology Workshop

Bellaterra, December 2001

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Bellaterra, desembre de 2003

Technological Developments in the Oldowan of Koobi Fora: Innovative Techniques of Artifact Analysis

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Introduction

The wealth of new information on the Early Stone Age (Kimbel et al. 1999, Kibunjia 1994; Semaw et al. 1997; Plummer et al. 1999) has led to recent discussions on the nature of Oldowan hominid technology (Kibunjia 1994; Semaw 2000; Roche et al. 1999; Roche 2000). The tempo and configuration of technological change in the Plio-Pleistocene has risen as a key factor in understanding early human behavior.

However, the study of early human technology is hindered by the limited ability of contemporary methodologies to tease apart the complex set of influences affecting artifact morphology. The rich history of research in the Oldowan has focused almost exclusively on variation within various forms of Mary Leakey's (1971) typological framework. New manifestations of this landmark work have modified the original typology to rid analysis of a priori functional or cultural assumptions (Isaac 1984; Rogers 1997; Rogers et al. 1994). However, the smallest unit of analysis has usually remained at the level of counts of artifacts within these categories.

To more fully understand behavior in the Plio-Pleistocene it is necessary to explore the ecological clues within hominid technologies. This requires studying technology beyond the inferential level of typological classification.

A study of the complex interaction of hominids and their physical and natural environment would prove very difficult through the filter of typology. We hypothesize that quantifiable differences in the morphotechnical attributes of artifacts represent behaviorally significant changes in resource utilization. This hypothesis implies that access to resources that were vital to the survivorship of Plio-Pleistocene hominids is manifested in variation within the form of artifacts. Hominid technology represents a conduit between the hominid and access to resources such as meat and marrow. The morphology of artifacts is the expression of selection pressures on hominids to gain access to these resources muted by availability of stone on the landscape.

Therefore, to study the ecology of hominids through artifact analysis it is necessary to include factors such as paleoecology and paleogeography. It is also necessary to focus on subtle complexities of form that reflect changes in hominid ecology. Rather than representing artifact form as a nominal attribute (e.g. chopper vs. discoid, or even flaked piece vs. detached piece) it is imperative to study artifact form as a metric attribute.

In this way more complex patterns within hominid technology can be elucidated. Although we do not condone analyses done within a vacuum of typology, we believe that more complex patterns within hominid technology can be elucidated using more finite methodologies.

Here we employ digital image analysis, previously explored in younger archaeological assemblages (McPherron and Dibble 1999), to analyze aspects of Oldowan technology at sites from the Karari Ridge region of the Lake Turkana Basin in the Koobi Fora Formation. The sites in this study (FxJj 1, FxJj 3, FxJj 10, FxJj16, FxJj 18GL, and FxJj 20M) were excavated by a team of archaeologists from University of California, Berkeley during the 1970s under the supervision of one of us (JWKH) and the late G. LI. Isaac (Isaac and Harris 1997).

The application of modern recovery techniques and unbiased selection make this one of the largest and most informative collections of Plio-Pleistocene archaeological material. We apply this new methodology to questions of technological evolution in the Lake Turkana Basin and outline a model for understanding resource use by Plio-Pleistocene hominids.

Background

To test the previously stated hypothesis, assemblages chosen for study must have rich paleoecological contexts. Very few archaeological sites have been subjected to the full suite of paleoecological analyses that allow a complete picture of the environments of early human adaptation. Yet, the large interdisciplinary research projects of the 1970s and 1980s have provided a wealth of information about a handful of archaeological sites (Howell et al 1987; Isaac and Harris 1997).

We chose to test our hypothesis about the morphology of Oldowan artifacts on assemblages from the Koobi Fora Formation on the east side of Lake Turkana in northern Kenya. The Plio-Pleistocene sediments have been under almost continuous study since the late-1960s when Richard Leakey first discovered the region (Leakey 1970). Of particular relevance are the paleogeographical studies conducted by C. Feibel and F. Brown in the 1980s and 90s (Feibel 1988; Feibel et al. 1989; Brown and Feibel 1986).

These studies set the framework for the analysis of hominid behavior in this study. Their research dispelled the previous conception of a lake existing in the Turkana basin over the entire course of hominid occupation in the region (Rogers et al. 1994; Isaac and Harris 1997).

The current paleogeographical interpretation details that although a lake was present for part of the Plio-Pleistocene, a large river (i.e. Proto-Omo) was the major sedimentological agent in the basin. This study focuses on the sub-region known as the Karari/Abergaya Ridge because of the extensive database of information about sites from this area of the basin. Paleogeographic reconstructions posit that during the two main stages of hominid occupation, the east side of Lake Turkana had very variable landscapes (Brown and Feibel 1986; Feibel 1988; Feibel et al. 1989).

These two time periods, which are the focus of this study, are the KBS Member (1.89-1.65 Ma) and Okote Member (1.65-1.39 Ma) of the Koobi Fora Formation. During the Okote Member the Karari Ridge region was host to an oscillating system where a large meandering river gave way to a braided river system.

The KBS member represents a mosaic of landforms, with a large meandering river splaying into an extensive delta front against the shoreline of a diminutive proto-Lake Turkana. It is against this dynamic landscape that the Plio-Pleistocene archaeological evidence from the Koobi Fora Formation has been found.

The variation of archaeological entities within these 600,000 years has been the basis of important findings on ranging patterns, land use, and technological developments by Plio-Pleistocene hominids (Isaac 1976a,b; Harris 1978; Rogers et al. 1994). Initial descriptions of the archaeological material from the Abergaya/Karari Ridge focused on the nature of the archaeological record in this one area through time and across space.

Isaac (1976a,b, 1977, 1978, 1981) used the assemblages from the KBS Member to articulate perspectives on the nature and tempo of technology at the dawn of cultural evolution. Harris (1978; Isaac and Harris 1978) concentrated on the Okote Member, defining the Karari Industry and providing description for a period of the archaeological record that was previously understudied.

These two archaeological collections provide a framework for the current study of technological change in the Lake Turkana Basin. The variation between these two archaeological entities represents technological change which is the focus of our analysis. The sites from the KBS Member (FxJj1, FxJj3, and FxJj10) were excavated out of sediments that reflect the interface between a fluvial and lacustrine environment (Isaac and Harris 1997). The present paleogeographical reconstruction of the Turkana Basin suggests that these sites were situated in small channels that were part of a back delta swamp (Feibel 1988; Rogers et. al. 1994) (figure 1).

The Okote Member sites (FxJj 16, FxJj 18GL and FxJj 20M) were found in a variety of contexts (Harris 1978; Isaac and Harris 1997) but all are situated in an area further from basin axial sediments than the KBS sites. During Okote Member times lacustrine conditions were minimal (Feibel 1988; Rogers et al. 1994). The sites in the Okote Member are often associated with ephemeral stream sediments that had their headwaters on the eastern margin of the basin (Feibel 1988) (see figure 2).

The archaeological character of the two temporally separated groups of assemblages also emphasizes this dichotomy. Previous analyses call attention to the disparity in artifact density between these two groups (Rogers 1997; Rogers et al. 1994). The KBS Member excavations had very low artifact densities (figure 3). Comparatively the Okote Member excavations produced densities almost two orders of magnitude higher than their KBS counterparts.

The techno-typological character of these time periods is also notable. Original descriptions of the Okote Member assemblages underscored the prevalence of the characteristic "Karari Scraper" form (Isaac and Harris 1978; Harris 1978). Various chopper forms dominate the KBS assemblages. Large flake scrapers are rarely present in KBS Member assemblages, and when they appear they do not conform to the technological characteristics of the "single platform core" (Ludwig and Harris 1998).

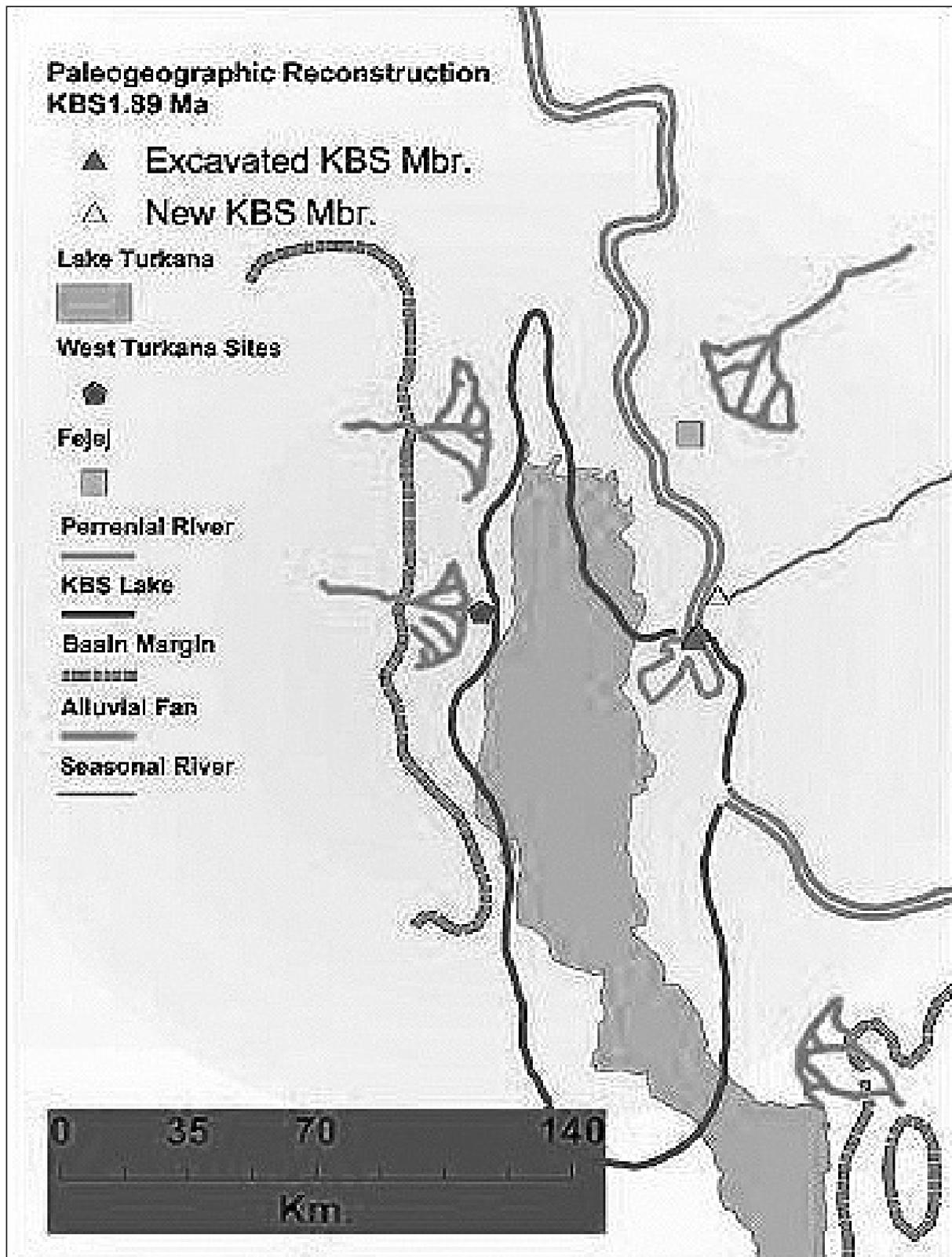


Fig. 1 The present paleogeographical reconstruction and archaeological sites of the Turkana Basin from the KBS Member. Adapted from Feibel 1988.

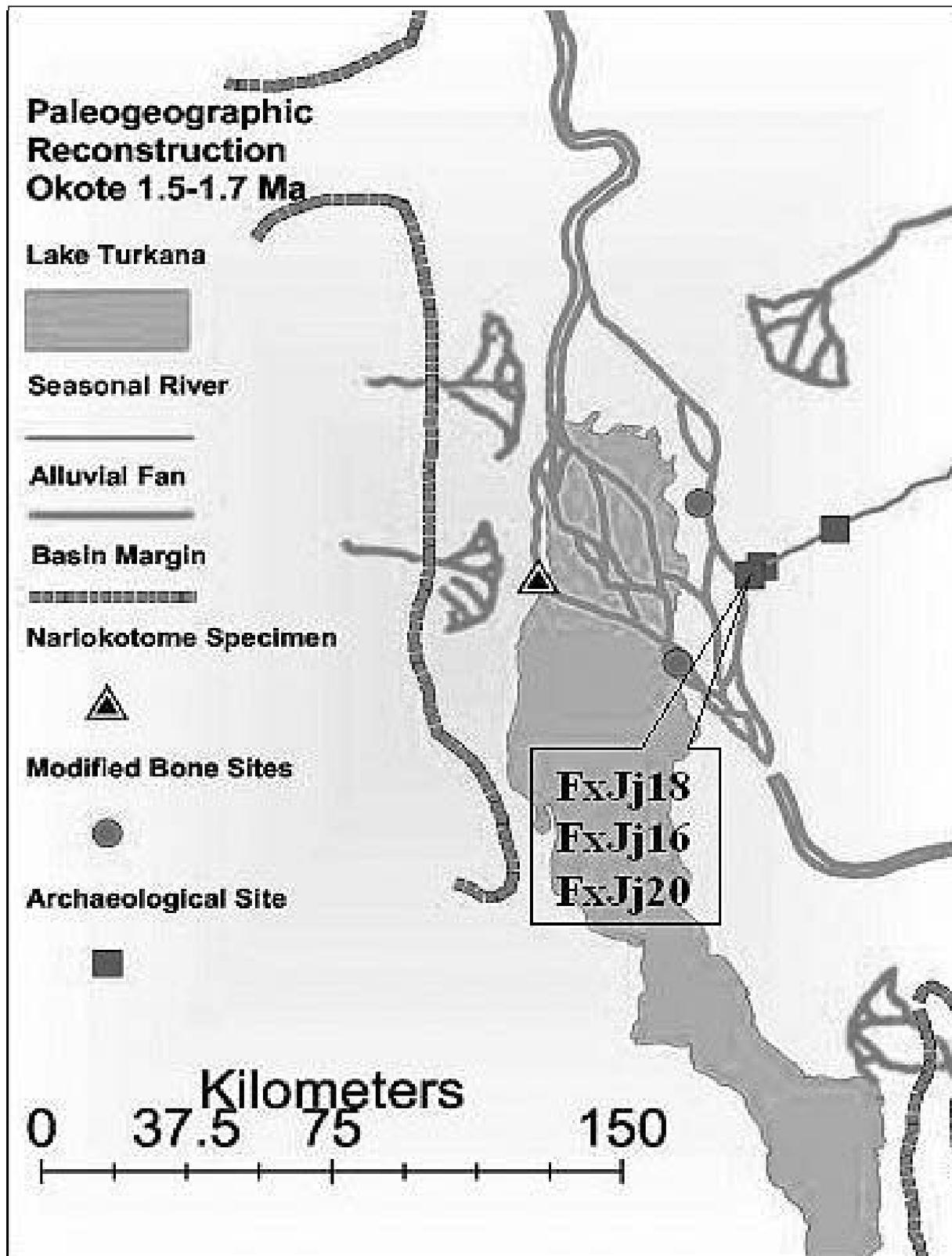


Fig. 2 The present paleogeographical reconstruction and archaeological sites of the Turkana Basin from the Okote Member. Adapted from Feibel 1988.

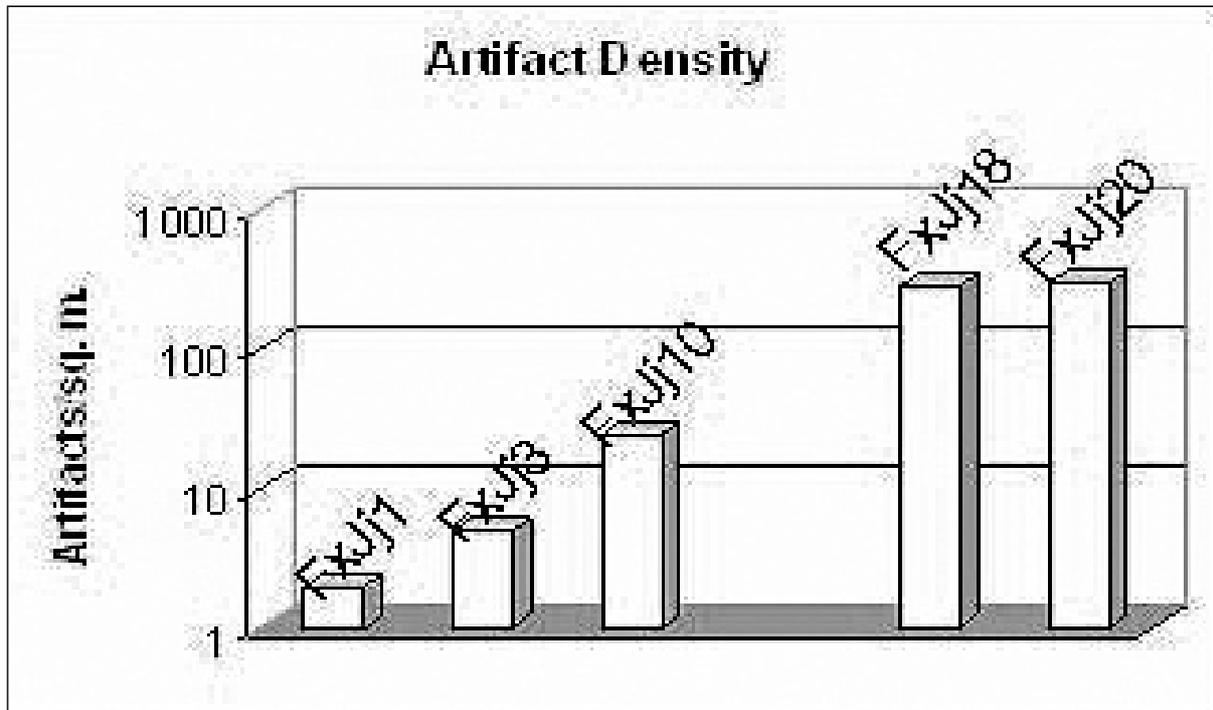
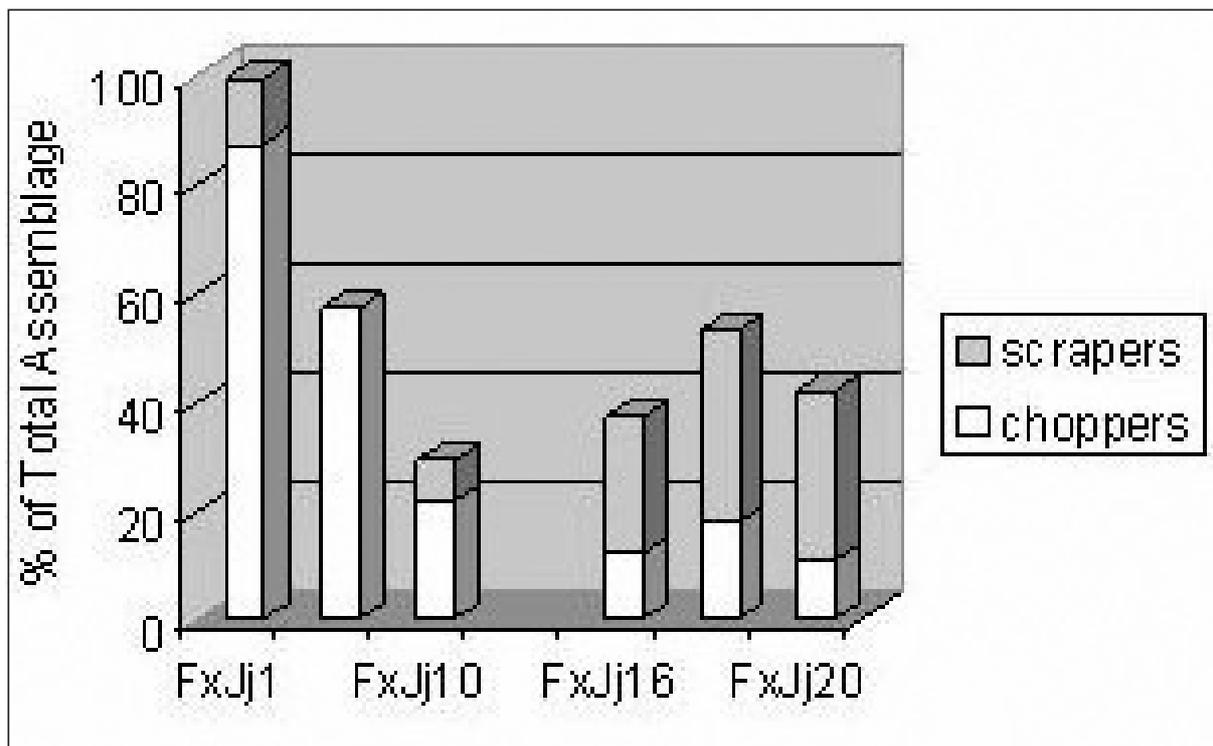


Fig. 3. Artifact Density in different KBS and Okote sites. From Rogers et al. 1994.

Fig. 4. Ratio scrapers/choppers in different KBS and Okote sites. From Isaac 1997.



A ratio of flake scrapers to chopper forms in sites from Koobi Fora reflect this difference (see figure 4). The archaeological assemblages from the Okote member represent a different pattern of behavior than that seen in the KBS member. It is precisely this variation that makes the Koobi Fora Formation a suitable setting for testing hypotheses on the coincidence of hominid behavior and morpho-technical patterns in the stone artifact record.

We believe that the differences in the archaeological record represent separate ecological contexts in the KBS and Okote Members. Artifacts represent the interface between hominids and their environment. Therefore artifact morphology should reflect the reorganization of the relationship between hominids and their natural and physical environment.

Materials and Methods

The Case for Flakes

In this study we focus exclusively on whole flake assemblages from six sites in the Koobi Fora Formations housed in the National Museums of Kenya in Nairobi. This analysis focuses on flakes exclusively because:

1) Whole flakes represent the most abundant artifact class of these Oldowan assemblages;

2) Whole flakes are likely one of the most functionally significant classes in the Oldowan toolkit (see below Toth 1986);

3) Whole flakes represent a singular technological event. In contrast to whole flakes, flaked pieces (FPs i.e. core tools) may be transported and successively modified and therefore may represent several different ecological contexts (i.e. resource availability Binford 1979).

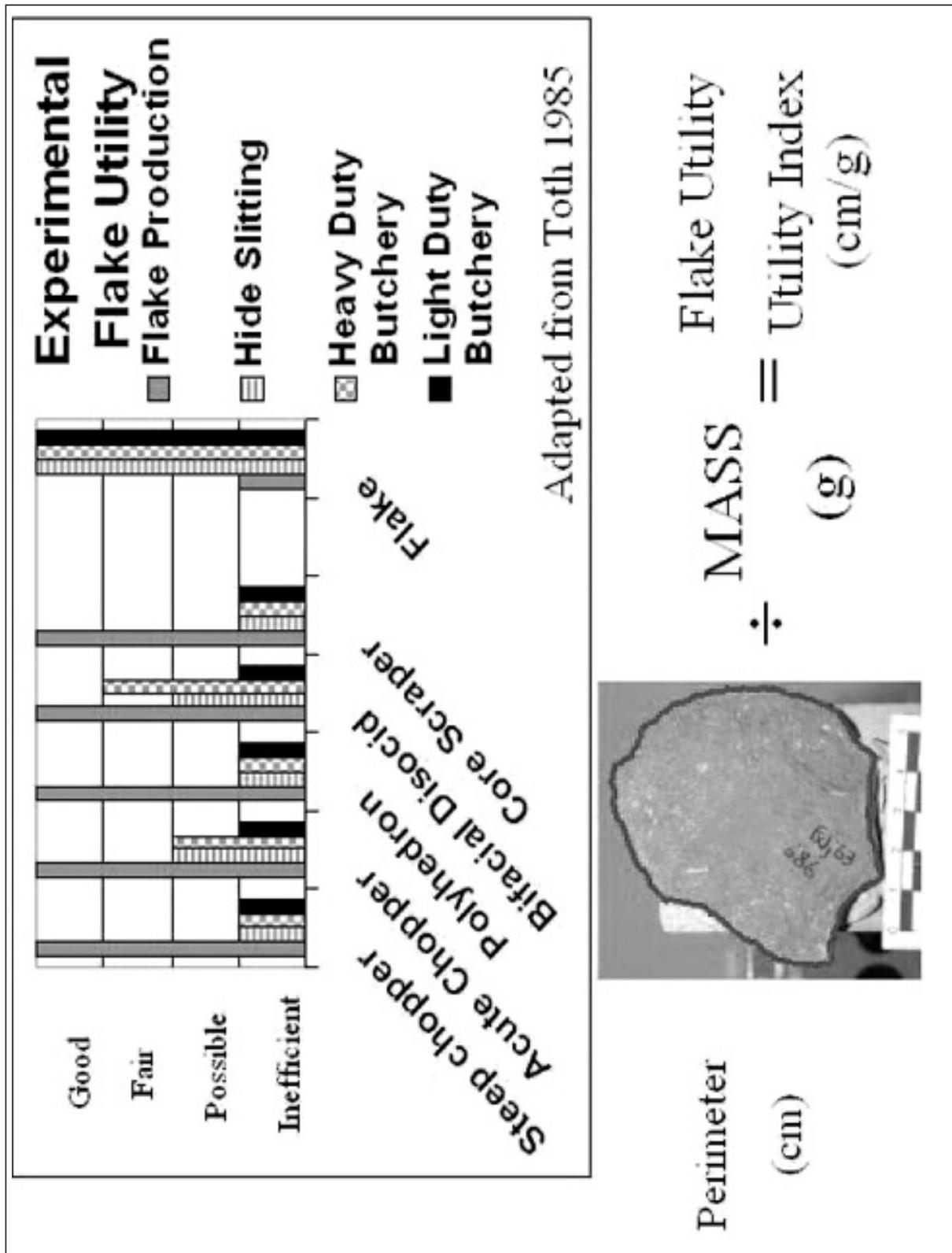


Fig. 5. Experimental flake utility and functional significance of Oldowan tools Adapted from Toth 1985.

In Isaac's (1977) inspection of early hominid technology he investigated the ecologic reason for the origins of cultural behavior. He described this behavior as a "least effort solution" to a sharp edge (Isaac and Harris 1997: 263).

Toth's (1986) work in the Koobi Fora Formation further developed this assertion and provided one of the earliest experimental perspectives on early hominid behavior. Toth's work provided an initial functional qualification of M. G. Leakey's typology (Leakey 1971). Toth's (1986) experiments suggested that although large core tools were an important aspect of early hominid technology, whole flakes were likely the most significant part of the early hominid toolkit.

Toth's experimental work provided a loose framework for understanding the functional significance of Oldowan tools. Toth ranked different tools according to their effectiveness in conducting certain tasks (see figure 5). Whole flakes score the highest in all of Toth's experiments. It is therefore likely that whole flakes represented a significant aspect of early hominid technology.

The importance of whole flakes in the Oldowan tool kit suggests that morpho-technical aspects of these artifacts will be very sensitive to changes in ecology of Plio-Pleistocene hominids. To identify these changes we focused on that aspect of flakes that is most closely tied to the functional impact of these artifacts: the edge (Sheets and Muto 1972).

To investigate edge production we standardized our measurement of flake edges by the mass of the artifact. The resulting formula is simplistic but possibly represents an easy quantification of the meaning of a flake to an early hominid: $(\text{flake edge (cm)}) / (\text{flake mass (g)}) = (\text{"flake utility"} (\text{cm/g}))$. Measures similar to this utility measure have been used experimentally (Sheets and Muto 1972) and in younger assemblages to measure increases in mobility (Roth and Dibble 1998).

Digital Image Analysis

The formula for flake utility is simple yet it reflects very subtle differences in artifact form that are likely significant in the life of early hominids. As artifacts effectively represent access to resources on the Plio-Pleistocene landscape, they are vital to the survival of their makers. Stone tools represent a risk abatement strategy that separates hominids from failing to procure required energy needs (Torrence 1983, 2001; Bamforth and Bleed 1997).

Therefore those hominids that employ adaptive strategies of tool manufacture and use have the potential of defraying resource deficits. A technology that can consistently delay the risk of failing to meet dietary requirements will provide the employers of this technology with increased genetic fitness. Therefore slight differences in technological patterns (e.g. flake utility (cm/g)) that can increase the utility of a given resource (i.e. stone) projected over several hundred artifacts could represent significant differences in individual fitness.

Considering the potential effect on hominid ecology of subtle changes in the “flake utility” attribute, it is necessary to accurately and consistently quantify this attribute. We chose to quantify this measure using digital image analysis. The use of digital images to capture information about artifacts has recently received attention. The decrease in cost of high quality digital cameras and the availability of software to analyze these images allows large amounts of information to be captured relatively easily with an acceptable amount of error (McPherron and Dibble 1999).

In our analysis we used an Olympus 2500L Digital Camera to capture 2.6 megapixel images of the ventral surface of 847 flakes from 6 sites housed at the National Museums of Kenya. Our emphasis on perimeter measurements forced us to curtail analysis to only those whole flakes, which did not display damage or chipping that would have modified measurements of the edge of a flake.

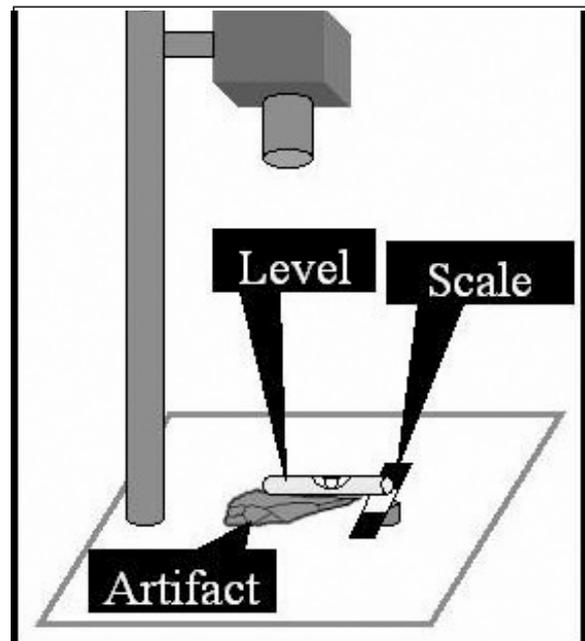
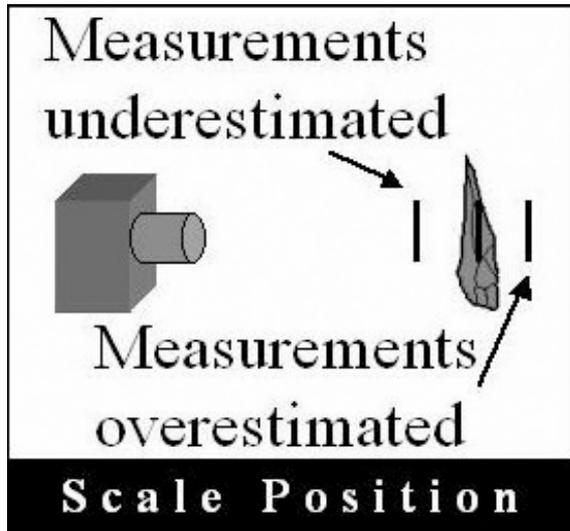


Fig. 6 Photogrammetry technique implemented during capture of images

Analysis of the edge was conducted using the image analysis program called ImageJ 4.0. Images were digitized using an Intuos Tablet at 2 to 4 times magnification.

Several techniques suggested by McPherron and Dibble (1999) were implemented during the capture of these images. In close range photogrammetry problems of lens distortion (parallax) can be subtle enough not to be readily noticed yet can cause dramatic differences in measurements.

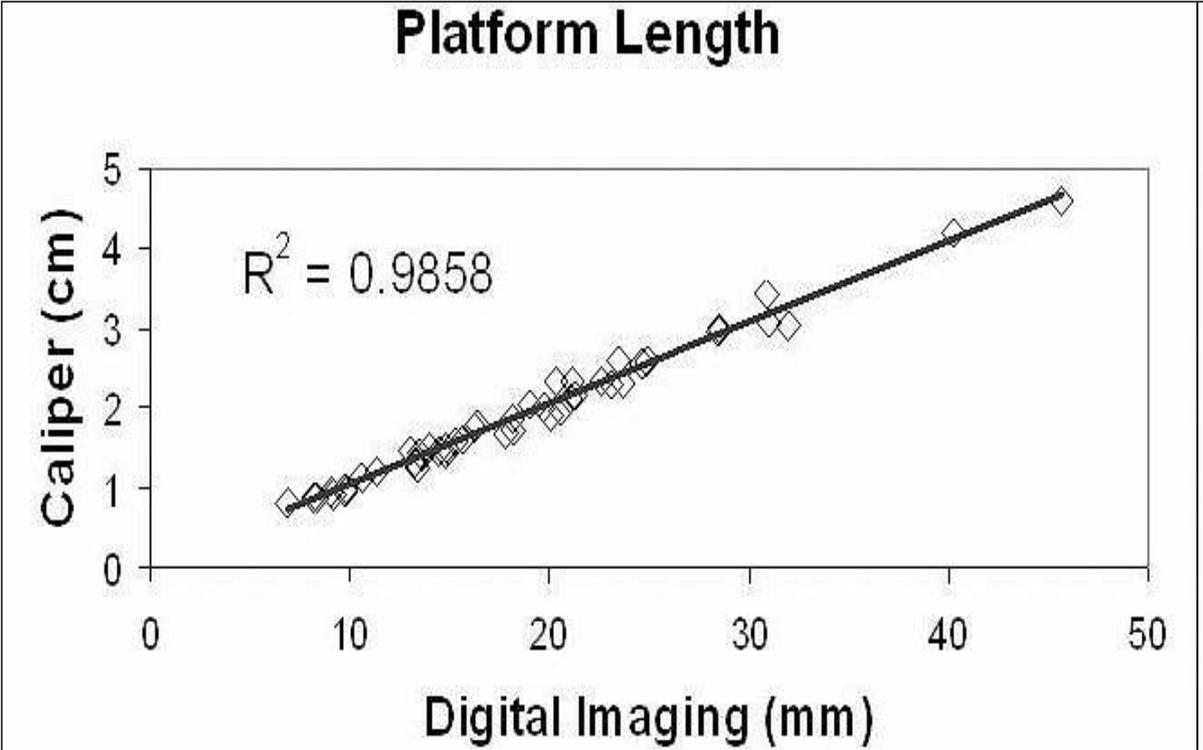
Parallax affects the edges of the image more drastically than the center of the image. To counter the affects of lens distortion, images of the artifacts were captured so that the artifact under analysis only comprised the very center of the image. This considerably reduces the effects of lens parallax. Another confounding factor in digital image photogrammetry is the use of a photographic scale as the reference point for all measurements.

The scale must be in the same plane as the objects being measured or else measurements will be consistently over- or underestimated. In our analysis we overcame this potential source of error by mounting the camera above the specimens and placing one end of a bubble level on the internal surface of the flake and the other end of the level on the reference scale (see figure 6).

To insure that these techniques are factoring out potential photogrammetric sources of error a reference disk that is 1 cm in diameter was periodically photographed and analyzed (as suggested in McPherron and Dibble 1999).

To further assess the accuracy and reliability of the digital imaging technique, measurements were also conducted using a digital caliper (Brown and Sharpe M700). Platform length (as described by Debenath and Dibble 1995) was measured with both techniques. The digital imaging technique is highly correlated to the caliper measurement ($r^2 = .985$, $p > .001$ see figure 7).

Fig. 7 High correlation on mesures of platform length by caliper and digital imaging.



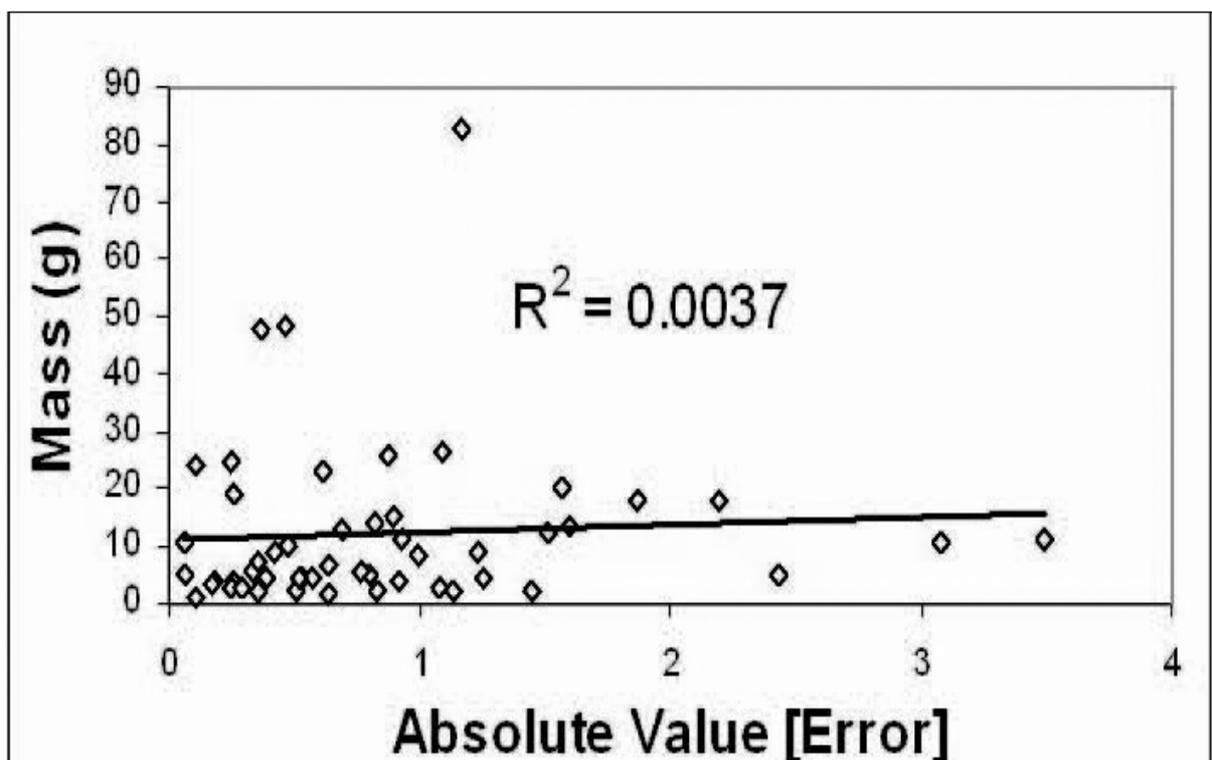
Although there are differences between the two measurement techniques, the error (i.e. Absolute Value [Platform Length (Digital Imaging) – Platform Length (Caliper)]) is not correlated to the mass of the piece (see figure 8). This is an important distinction because in digital imaging techniques the basis of measurements is pixels. If there is an error in the assignment of the reference scale to a specific number of pixels it will be too small to recognize on small objects. However, this error will be greatly magnified in large objects.

Results

Flake Utility

A comparison of flake utility measures between the KBS and Okote Member flake assemblages reveals significant time-transgressive technological change in the Koobi Fora Formation.

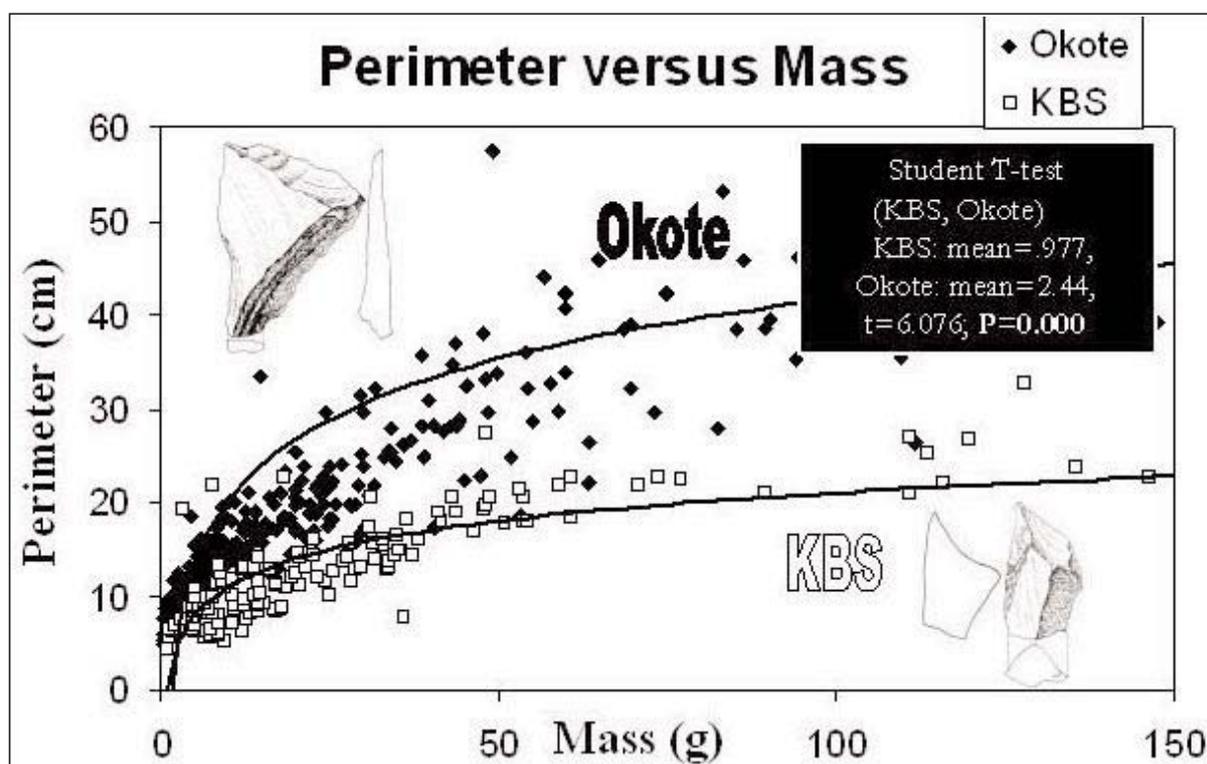
Fig. 8 Low correlation on measures on mass and absolute error



The Okote member flakes display a mean of 2.4 cm of edge per gram of mass, while the KBS member flakes display .977 cm of edge per gram of mass. A plot of mass and perimeter show the clear separation between these two technological systems (figure 9; Student's T-test $t=6.076$, $p<.001$).

Although this difference is compelling, there are complications in comparing two measures of size that increase at different rates (i.e. mass increases as a cube and perimeter increases as a square). In order to accurately represent the differences between Okote and KBS members and to separate the affects of flake size it is necessary to represent perimeter and mass values as a natural logarithm. Furthermore, in analyzing data that has a range greater than one order of magnitude (as perimeter and mass have in this analysis) a logarithmic scale is more appropriate. The resulting data set shows a more complete separation between the two technological patterns (figure 10).

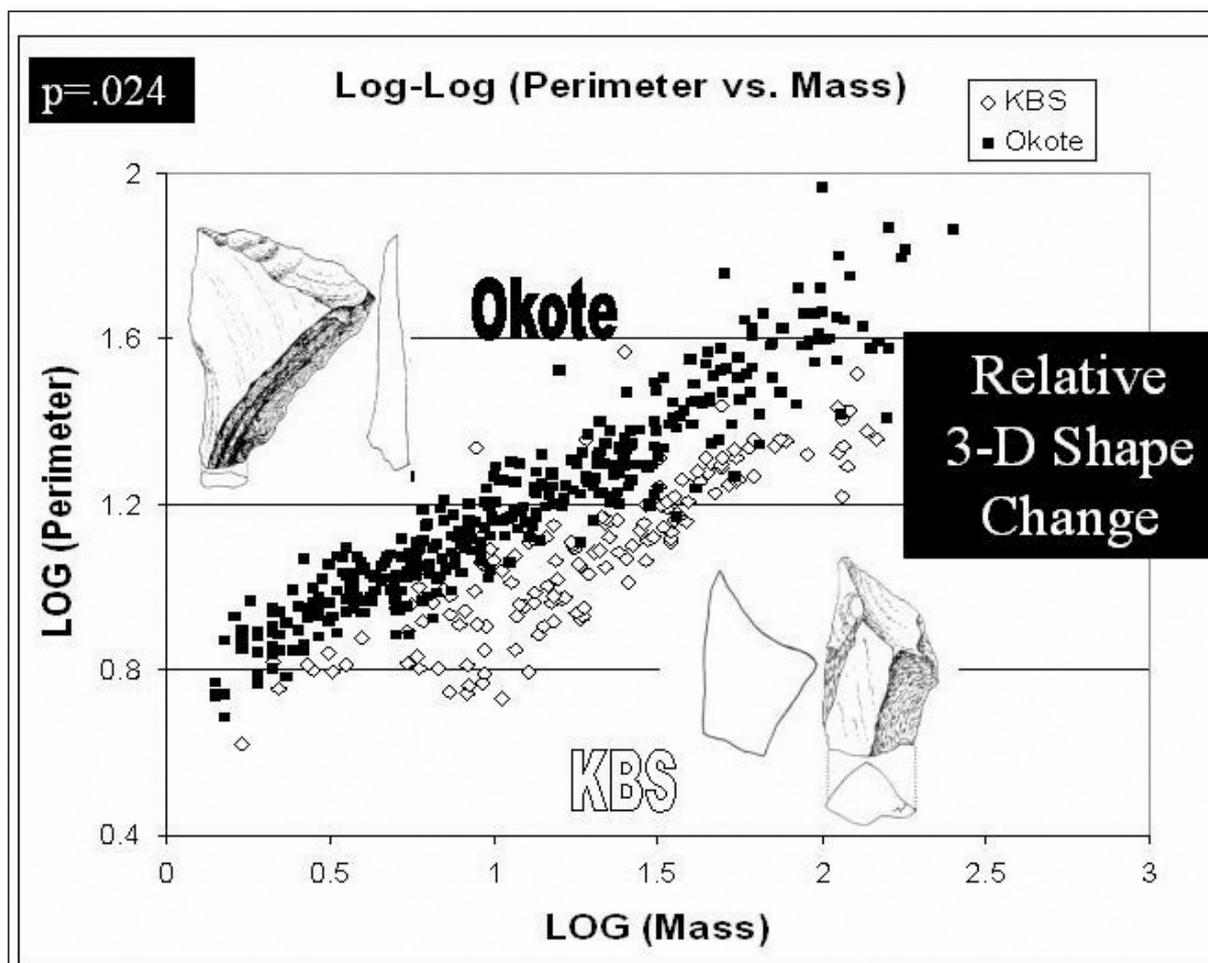
Fig. 9 Comparison perimeter versus mass in the flakes from KBS and Okote sites



To further emphasize the fact that the difference between these technological patterns is not merely an artifact of flake size and proportions, the average mass of flakes was plotted within different perimeter size categories. This shows that flakes of the same perimeter are consistently heavier in the KBS (figure 11; Student's T-test $t = 3.11$; $df = 4$; $p < .05$). The pattern displayed here shows that flake utility (perimeter/mass) is consistently lower in the KBS member as compared to the Okote Member.

This corroborates data presented by Roth and Dibble (1998) that as flake size increases not all dimensions must necessarily increase at the same rate (also see Kuhn 1994).

Fig. 10 Log Perimeter vs Mass and relative 3 D shape change observed on KBS and Okote flakes



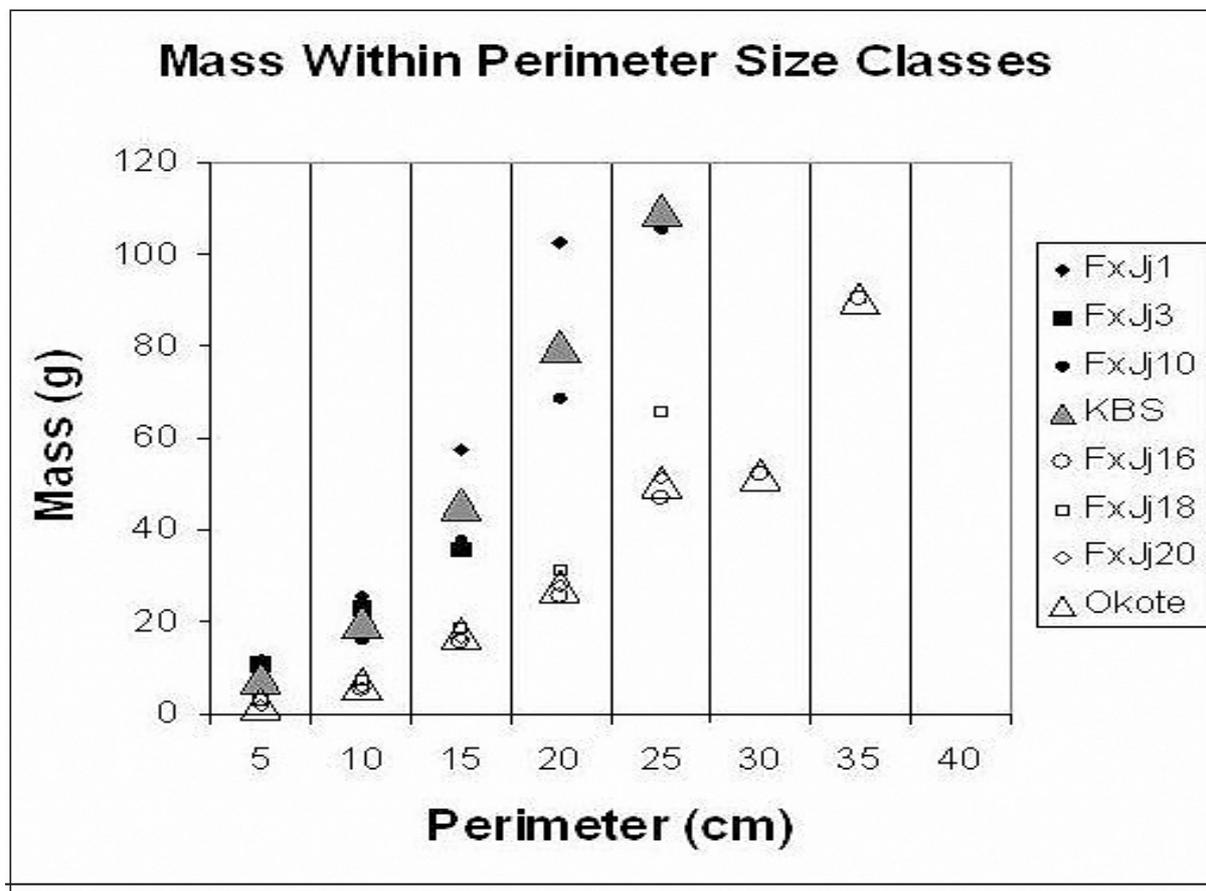


Fig. 11 Mass within Perimeter size classes in different archaeological Oldowan sites.

Core Reduction Strategies

This technological pattern is interesting because it suggests that hominids in the Okote Member were able to increase the utility of their technology by following a consistent pattern of increasing the perimeter of the flake while minimizing the impact on stone resources by keeping the overall mass (i.e. volume) of the flakes lower. However the actual impact of this technological strategy on hominid behavior lies in the implication of “flake utility” on core reduction strategies.

Numerous studies have suggested that core reduction strategies are often attempts to circumvent constraints on technological design (Boëda 1995; Bietti and Grimaldi 1991; Brantingham 2000).

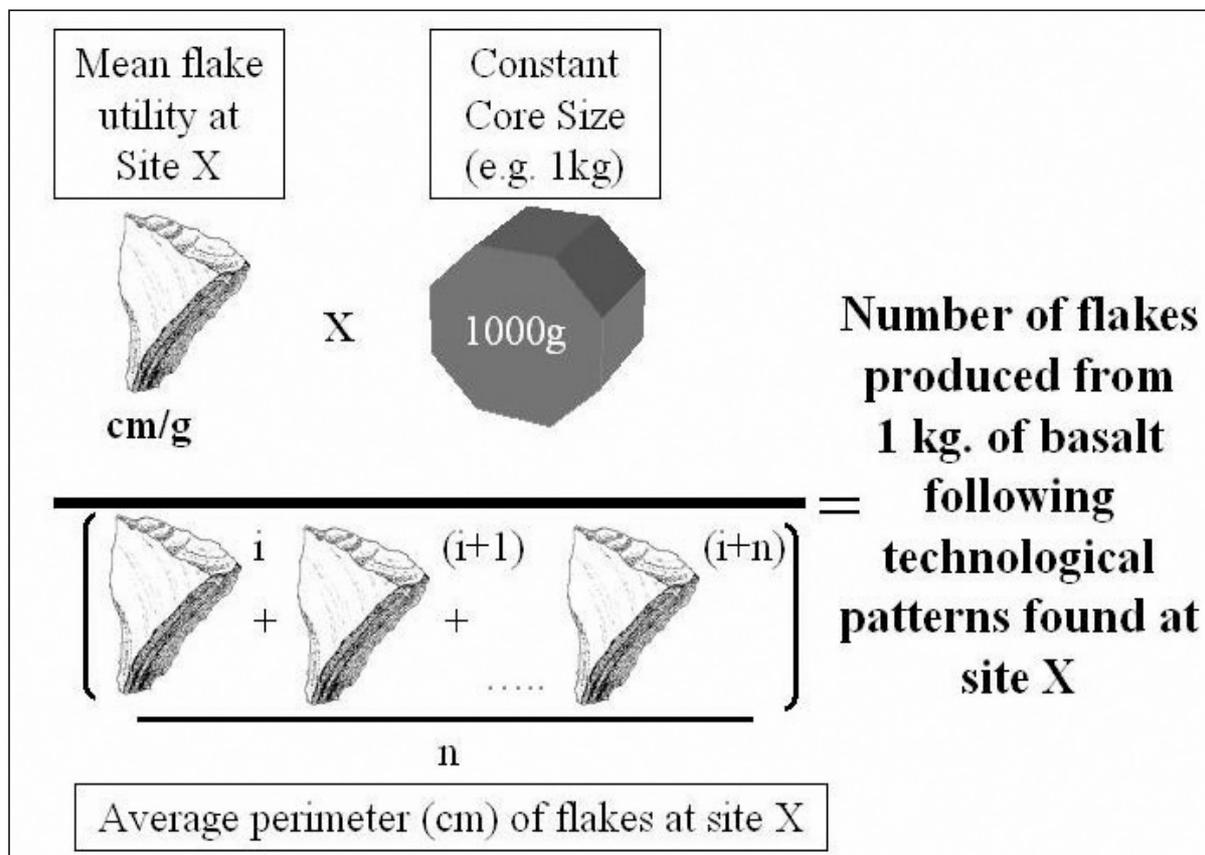


Fig. 12 Number of flakes produced from 1 kg of basalt.

It is possible that the “flake utility” variable is influenced by a core reduction strategy that attempts to maximize edge per volume of raw material. Since the flake utility measure incorporates aspects of both flake size and mass, a model can be derived that measures the number of flakes produced from a given mass (see figure 12). If mass is held constant (e.g. 1 kilogram core) it is possible to calculate the perimeter produced by following the KBS Industry pattern.

By dividing the total perimeter produced from 1 kilogram of raw material (Average “flake utility” value (cm/g) for a KBS site x 1000 g) by the average perimeter for whole flakes at the same site (i.e. the sum perimeter of all the whole flakes at a KBS site divided by the number of flakes at the site) it is possible to model the number of flakes produced from a 1 kilogram core.

KBS Member Sites		Okote Member Sites	
Site	# of flakes	Site	# of flakes
FxJj 1	3.33	FxJj 20Main	19.15
FxJj 3	3.62	FxJj 18GL	10.32
FxJj 10	6.79	FxJj 16	9.84

Table 1. Modeled Number of Flakes Produced from a 1 Kilogram Core.

Calculations of this flake production model show that technological strategies implemented during the Okote Member produced anywhere from double to six fold the number of flakes produced using technological patterns displayed in the KBS Member assemblages (see Table 1).

Conclusion

In this paper we have attempted to show that hominid behavioral patterns that have been described using land use patterns and typological characteristics can be further elucidated using metric analysis of attribute variables. We would emphasize that although the behavioral patterns that were under investigation in this study were initially identified through more conventional typological analysis, technological analyses that focus on metric data has the power to explain variability.

The present analysis not only presents plausible explanations for time transgressive behavioral patterns already described, but also provides further insights into variation within temporal units. While flake utility measures are absolutely higher in the Okote Member than the KBS Member significant variation within the KBS and Okote Member can be seen (e.g. FxJj 10 vs. FxJj 3 or FxJj20 vs. FxJj16). It is likely that these differences are associated landscape scale ecological differences, although more work is needed to explain this variation.

It is important to note that no aspect of this analysis suggests hominids in the KBS Member were incapable of implementing the strategies seen in the Okote Member. It is plausible that the ecosystem that KBS hominids lived in did not necessitate the development of such technological strategies.

Therefore this analysis does not directly impact the discussion of hominid abilities (see Chavaillion 1976; Piperno 1993; Kibunjia 1994; Roche 1989, 2000 vs. Semaw 2000, Semaw et. al 1997; also see Kimura 2002) but rather sheds light on the behavioral variability the that Oldowan comprises. Ecological pressures on technological design of hominid toolkits appear to work at very subtle levels. Perhaps the rather mundane nature of Oldowan variation that is the hallmark of the “technological stasis” model is purely the result of methodologies, which are incapable of isolating ecologically pertinent variables.

Further analyses are needed to test this hypothesis. We believe that finite methodologies, such as the digital imaging analysis described here, are the key to capturing the variation that reflects ecological variability. Analyses that attempt to deflate technological patterns to ordinal or nominal variables (e.g. Kimura 1999, 2002) are unlikely to address patterns of ecology and evolution.

The consistent implementation of a strategy that extracts more flakes from given volume of raw material is an adaptation that Isaac and Harris (1997:263) predicted would develop in the face of raw material scarcity.

Here we have shown that their morphological prediction is correct, although the impetus for this change is still uncertain. Research on Plio-Pleistocene technology has argued for substantial change in the ecology of hominids from the Plio-Pleistocene boundary to the early Pleistocene (Potts 1984, 1991, 1994; Rogers et al. 1994; Rogers 1997; Harris and Capaldo 1993).

Specific hypotheses predict that hominids were tethered to raw material sources early in the development of stone tool technology (Harris and Capaldo 1993; Rogers et al. 1994).

Potts (1991) has suggested that the ability to modify the environment in order to associate stone and faunal resources (i.e. raw material and carcasses with meat and marrow) was an adaptation even more significant than the appearance of stone tool technology.

The “flake utility” measure and the associated flake production model represents a mechanism for hominids to release any tethers from raw materials sources while at the same time reducing the risk of encountering faunal resources (meat and marrow) without adequate technological capabilities to access these resources (see figure 13).

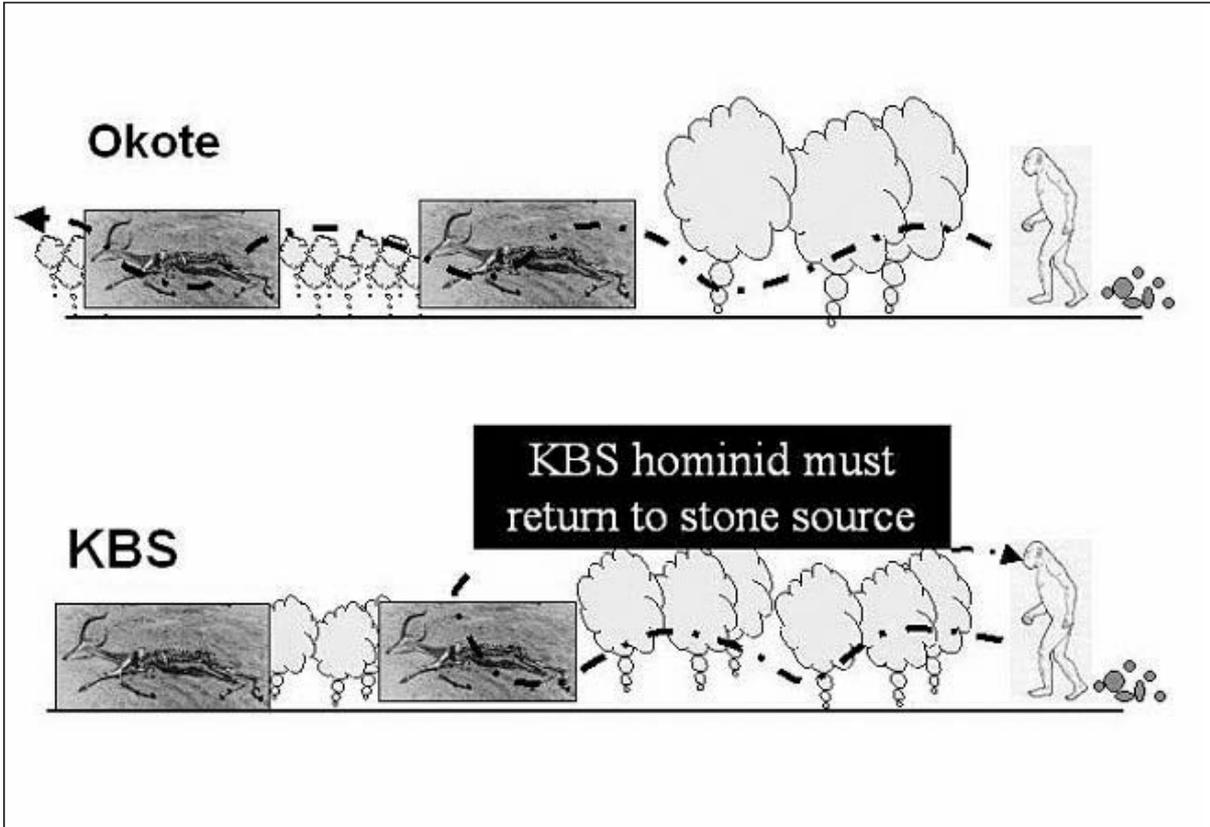


Fig. 13. Behavioural implications of the “flake utility” model.

The “flake utility” model suggests that hominids employed patterns that would afford them an adaptive advantage by either opening up areas of the landscape that were previously outside the boundaries of their raw material “tether” or by decreasing the probability of exhausting mobile stone resources (i.e. a transported core) when faunal resources are encountered.

At present it is difficult to tease apart these two different scenarios, although they are not necessarily dichotomous. We suggest that a continuation of these finite analyses coupled with a more rigorous metric approach to technological variation applied to sites within varying environmental settings will provide a better understanding of the nature of technological change.

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