METHODS FOR DETERMINING DIFFERENTIAL BEHAVIORS IN STONE TOOL PRODUCTION AND APPLICATION TO THE OLDOWAN OF OLDUVAI GORGE, TANZANIA AND KOOBI FORA, KENYA

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ABSTRACT OF THE DISSERTATION

Methods for Determining Differential Behaviors in Stone Tool Production and Application to the Oldowan of Olduvai Gorge, Tanzania and Koobi Fora, Kenya

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Traditional lithic artifact analyses have provided information regarding hominin ranging behaviors, raw material preferences, and the potential for functionality. However, there is currently no standard method for determining how hominins produced lithic artifacts. This dissertation research provides the first quantitative measure of flake production techniques and applies these measures to the Oldowan of Koobi Fora, Kenya and Olduvai Gorge, Tanzania. Four Oldowan production behaviors are identified and are used to define what has been called the “least effort approach” to flake production in the Oldowan. Behaviorally informative measurements are taken on whole flakes and size standardized using their geometric mean. In order to attribute each archaeological flake to a production behavior, large experimental assemblages are created using native raw materials from Koobi Fora and Olduvai Gorge (n = 3,651 flakes and 443 cores). Each experimentally produced flake has empirically known production behaviors associated with it. A multivariate classification algorithm is constructed to determine a classification tree of best fit for the experimental flakes such that each flake is assigned a particular production behavior. Archaeological flakes are assessed via this classification algorithm and then compared to the experimental expectations for distribution of production behaviors.

The application of Oldowan archaeological assemblages to this process demonstrates that the null hypothesis that a least effort manufacturing strategy was employed at Koobi Fora cannot be rejected, but this null hypothesis can be rejected for subsets of quartzite and basalt flakes at Olduvai Gorge. Hominins at both localities demonstrate an understanding of raw material economics, but at Olduvai Gorge these hominins demonstrate a consistent ability to produce flakes in a more efficient way than a least effort approach predicts. Hominins at Olduvai Gorge consistently transport quartzite flakes to the site locations, while they consistently transport basalt cores to the sites. Koobi Fora hominins also demonstrate the ability to transport raw materials, but do not produce flakes outside of least effort expectations. Due to these differences in stone tool production strategies and lithic transport behaviors, this research argues that distinct cultural differences between hominin populations are quantifiably evident as early as the Oldowan.

Dedication:

This dissertation is dedicated to my wife, Sarah, and to my parents, Joe and Valerie, and my brother, Alan, for their constant and unending support. Your love, encouragement, and sacrifice inspired this research.

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Chapter I: Introduction

I.A. Introducing Behavioral Lithic Analysis

The analysis of lithic artifacts has traditionally sought to elucidate the origins of technology (de Mortillet 1867) by using industrial models (Breuil 1913; Peyrony 1933) and formal typologies (Bordes 1950, 1961a, 1961b; Leakey 1971; Isaac and Harris 1997). Though functional (Binford and Binford 1966) and technological (Frison 1968; Jelinek 1976; Amick et al. 1988; Lenoir 1995; Shott 1996; Bradbury and Carr 1999) arguments have pointed out observer bias and subjectivity in typological systems, typological classification continues to dominate modern archaeology. Other research has attempted to classify stone tool manufacturing byproducts based on "interpretation-free" approaches (Sullivan and Rozen 1985); however, due to a lack of empirical evidence, such models have consistently met mixed reviews (Amick and Mauldin 1989; Ensor and Roemer 1989; Kuijt and Russell 1993; Shott 1994; Kuijt et al. 1995; Prentiss 1998; but see Sullivan 1987). Particularly strong research programs have demonstrated that typologies ineffectively identify behavioral differences in stone tool production in both the Early Stone Age (Schick 1987; Toth 1982, 1985, 1987) and the Middle Paleolithic (Dibble 1984, 1987).

Early Stone Age archaeologists studying Plio-Pleistocene artifacts have largely utilized typological systems (i.e. Leakey 1971) as their methodological tools for classification. Recent employment of *chaine operatoire* methodologies (Delagnes and Roche 2005) to West Turkana, Kenya artifacts from the site of Lokalalei 2C is a welcome change in analytical technique and has begun to demonstrate that variation and skill exists among Oldowan-producing hominins (Roche et al. 1999; Roche 2000), a suggestion that others have broadly acknowledged (Kyara 1999; Braun 2006). Isaac and Harris (1997) attempted to construct a technological system of classification based on whether the artifact in question is the product of flake removals (a Flaked Piece), a flake removal itself (a Detached Piece), or a percussive instrument (a Pounded Piece). Though such classification remedies some of the subjective issues surrounding formal typological terminology, the behavioral implications of this technological classification are limited. Toth (1982, 1985, 1987) demonstrated that the Oldowan was produced with a focus on flakes, the cores being byproducts of a reduction sequence. His replicative studies marked a new direction for Oldowan stone tool analysis in that they provided a known behavior (the replication experiments) by which to measure archaeological material. Toth (1985, 1987) developed a system called Technological Flake Categories that refers to the relative amount and placement of cortex on flakes to infer the intensity of reduction present at a given site. While other experimental research has utilized the Technological Flake Categories to further quantify the Oldowan "reduction sequence" (Braun et al. 2008), the potential problems associated with this methodology are twofold: 1) it has not been established that cortical amounts *necessarily* correlate to a least effort method of stone tool production, as is normally assumed for the Oldowan, and 2) this system of classification has limited utility in making meaningful technological comparisons between archaeological sites. However, Toth's research sets a foundation for the theoretical way that Oldowan assemblages are approached and thus serves as a stable platform for the research described in this dissertation.

However, despite the potential for further behavioral inferences between Oldowan hominins based on replication studies, few have been undertaken (Jones 1994; Kyara 1999; Tactikos 2005; Braun et al. 2008) and these are limited in their comparative value to other assemblages due their focus on a single locality. Other productive research has focused on raw material procurement strategies at Koobi Fora, Northern Kenya (Braun 2006), the reanalysis of artifacts for use-wear, including traces of pounding on anvils, at Olduvai Gorge (de la Torre and Mora 2005; Mora and de la Torre 2005), and qualitatively addressing the skill level of hominins in stone tool production (Kimura 1997, 1999, 2002; de la Torre 2004). Notably, with the exception of Tactikos (2005) and Braun et al. (2008), none of these Oldowan studies utilizes replication experiments and, rather than addressing issues concerning the lithic artifacts themselves, they address issues broadly surrounding stone tools such as their potential function, their provenance, and the reconstruction of core morphology. Though these avenues are certainly important to understanding hominin behaviors and have yielded significant and productive research, they leave questions concerning stone tool production behaviors unanswered. Those addressing the skill level of Oldowan-producing hominins (which is here interpreted to mean how the tools were created) leave several important questions unanswered: skill level relative to what expectation? Are some Oldowan hominins making tools differently than others? If so, what behaviors are different and what variables drive this variation in technological strategies? Are hominins in a given area practicing the same methods in stone tool manufacture or do methods vary across space? Addressing questions such as these helps to explain the potential adaptive roles of stone tools and, notably, the differential adaptive roles that stone tools may have played across paleolandscapes.

Methodology addressing such issues of relative production behavior, however, are acutely lacking for the Oldowan, as well as other time periods. Unfortunately, this lack of methodological development and analytical theory has produced an academic climate that treats lithic artifact analysis as necessary from "force of accumulated tradition…not for any higher analytical or theoretical goal" (Shott 2008:157). Shott's (2008) statement mirrors that of Sackett (1973:318), albeit 25 years later, who regretfully stated that a "monumental synthesis" of typological data is necessary to move lithic artifact analysis forward but that, at the time, there lacked the conceptual tools to undertake this necessary step. The conceptual tools Sackett desired are presently available in the form of high-powered statistics, 25 additional years of lithic analytical work, behavioral comparisons for Plio-Pleistocene hominins and Middle Paleolithic populations alike, and increased archaeological sample sizes. However, the "monumental synthesis" is still required and, for methodological and theoretical reasons, should begin with the earliest known stone tool technology: the Oldowan. In order to understand the progression of technological systems and production methods through time, it is logically necessary to understand the earliest technologies first and then move on to understand how these early technologies influenced later technologies. The Oldowan is, therefore, the logical starting point for understanding later complex production behaviors.

Though research has suggested that variation *may* exist within the Oldowan Industrial Complex (Delagnes and Roche 2005; Barsky 2009), none suggests why this variation exists, what this variation represents in terms of production strategies, and what impetus would drive this variation. Typological constraints continue to limit the questions and research goals of Early Stone Age lithic analysts. The ability of the archaeologist to identify and describe variation in lithic assemblages is, by definition, hampered by typologies. Instead of looking for variation, typologies necessarily group objects together in an attempt to limit the potential variation in assemblages. While this is often a methodological necessity to describe large bodies of data, typologies are potentially affected by research bias and are notoriously difficult to standardize between researchers (Binford and Binford 1966; Toth 1982; Dibble 1995; Bisson 2000).

The research outlined here defines a methodology that quantifies variation within archaeological assemblages. By basing measurements on behaviorally relevant, controllable aspects of flake morphology, variation within and between assemblages is statistically assessed. Replication experiments that model stone tool production behaviors in a controlled setting produce an assemblage of flakes with known associated production behaviors and are quantitatively classified via these behaviors by using a statistically determined classification algorithm. Archaeological lithic artifacts are then statistically correlated with the known replicated material in order to determine the presence, absence, and deviation of archaeological artifacts from experimental expectations. These archaeological artifacts are then classified via the classification algorithm to determine the relative presence of production behaviors within and between archaeological sites. This approach to the study of stone tools is called Behavioral Lithic Analysis (BLA).

Results of BLA analysis not only make archaeological flakes and assemblages directly and quantifiably comparable, they also provide concrete behavioral reconstructions for individual sites and archaeological localities. In this way, differential stone tool production behaviors are assessed. The analysis described here focuses on Oldowan stone tool technology as its foundation, but BLA methodology is broadly applicable to other time periods and site locations.

In order to understand the theoretical and methodological underpinnings of BLA development, it is first necessary to discuss 1) the typological origins of lithic analysis in the Early Stone Age and 2) the methodologies previously and currently utilized to reconstruct technological behaviors in the Early Stone Age.

I.B. Typology as an analytical tool in archaeology

Since its professional inception, the field of archaeology has largely borrowed its methodological principals and theoretical foundations from other disciplines (Binford 1972, 1983; Gardin 1980; Kimball 1987; Tomaskova 2005). Early French lithic analysts borrowed heavily from paleontological practices and the use of *fossil directeurs* to order and classify assemblages. The typologies that sprung from cultural (Peyrony 1933; Bordes 1950) and functional assumptions (Binford and Binford 1966) and applications of economic theory (Clark 1979) led to subjective classificatory systems and potentially misleading conclusions (Dunnell 1971; Sackett 1973; Watson 1973; Aldenderfer 1987a, 1987b; Clark 1987). These early European stone tool typologies focused heavily on the reconstruction of cultural groups.

The classification systems implemented to organize lithic artifacts are subjective at best and detrimental at worst. The subjectivity of classification in the sciences has long been recognized (e.g. Ford 1952; Dunnell 1971) and has more recently been subject to scrutiny in archaeology (for reviews see Dibble 1995; Bisson 2000). Early European archaeologists sought to classify stone tools using a system of hierarchical relationships, similar to the methods implemented using Linnaean taxonomy. This was accomplished by borrowing the concept of "fossil directors" from paleontology and applying it to specific stone tool "types" that were considered markers of certain past peoples (de Mortillet 1867). By the early twentieth century, archaeology in Europe began to flourish and typological systems were introduced that reorganized the previous Linnaean attempts of classification. Breuil (1913) organized industrial types, as opposed to individual fossil directors. By incorporating multiple types of stone tools with morphological similarities and equivalent complexities into related categories, Breuil used these industrial types to identify past groups of peoples. Other researchers questioned this "industrial" system of classification (Sackett 1991), not so much for its validity in philosophy, but for its accuracy in its attempts to differentiate cultural identities. Such debates were temporarily quieted with the advent of a formalized and detailed typology, introduced by Francois Bordes (1950, 1961a, 1965).

The so-called Bordesian Period (for a review, see Sackett 1991) differed from earlier periods of European archaeology in that it sought to quantify its typological definitions. Bordes wanted to demonstrate the presence of separate Paleolithic cultures by dividing lithic artifact assemblages into distinct types of cultural assemblages. These cultural groups became known as the Typical Mousterian, Quina-Type Mousterian, Denticulate Mousterian, Ferrassie, Mousterian of Acheulean Tradition A, and Mousterian of Acheulian Tradition B (Figure 1.1). In order to distinguish these groups archaeologically and demonstrate quantitatively that they exist, Bordes established a 63-

part typology that divided Middle Paleolithic (MP) lithic artifacts into discrete categories based on shape and location of retouch. Depending on the ratio of certain types of stone tools to others, Bordes claimed to have successfully identified MP cultures via the archaeological record. However, the quantified success of the Bordesian classification system rests on an accurate separation of similar stone tool types via a particular ratio.

The utility of the Bordesian typology became hotly contested by the mid-1960s. Binford and Binford (1966) countered the Bordesian typology with a non-cultural explanation for stone tool variation, known as the "Functional Hypothesis." The Functional Hypothesis states that MP stone tool variation can be attributed to seasonal changes and the necessity for different types of stone tools as determined by climatic and environmental variables. According to the Binford and Binford (1966) argument, archaeological assemblages would accumulate over time as groups used various sites during certain times of the year. As seasons changed, so would site occupation and thus artifact accumulations would reflect the season at which a particular site was occupied.

An alternate, technological school of thought arose in France in the late 1960s known as *chaine operatoire* (Brezillon 1968) but was not heavily utilized until the 1980s (Geneste 1985; Sellet 1993). The philosophy behind *chaine operatoire* seeks to incorporate a life history model to archaeological assemblages. Instead of analyzing materials as "end products" or as a static artifact, *chaine operatoire* asks questions of raw material procurement and transport, stone tool production and use, tool resharpening, recycling, and discard. More recently, *chaine operatoire* has included the analysis of production techniques associated with a wide range of technological industries. The Early Stone Age assemblages subject to these analyses derive from *in situ* assemblages with a

Figure 1.1:

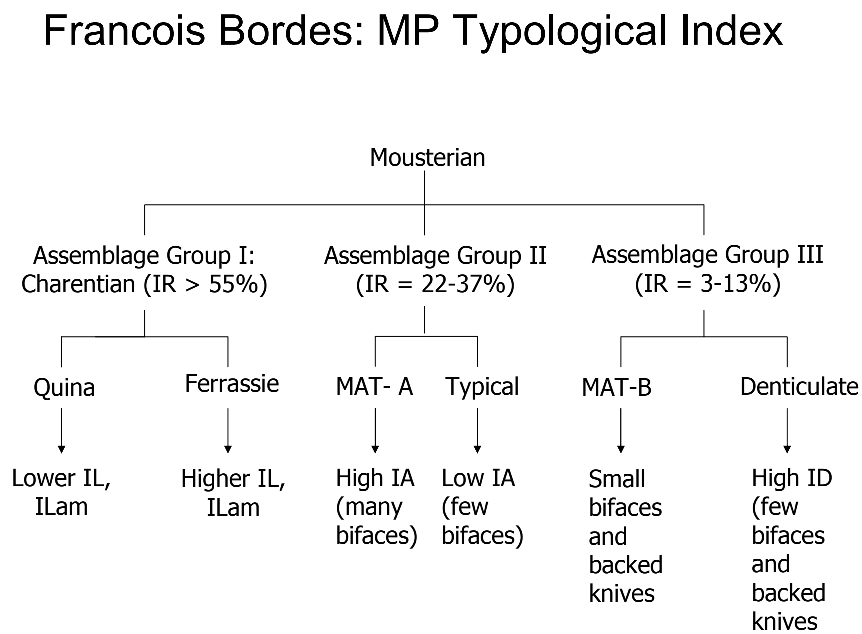


Figure 1.1: The Middle Paleolithic typology as established by F. Bordes (1951). The Mousterian was classified based on assemblage composition using specific indices. For instance, the relative presence of scrapers (*Index Racloir (IR))*, distinguishes which assemblage group an assemblage belongs to. Depending on other indices (Levallois Index (IL), Blade Index (ILam), Acheulean Index (IA), and Denticulate Index (ID)), cultural belonging for a particular assemblage was established.

high percentage of refits (Delagnes and Roche 2005). The information gleaned from such research is potentially valuable, providing unique insights into the specific behaviors of early hominins at the site investigated.

By the 1980s, some American archaeologists began using a methodology broadly similar to *chaine operatoire*. This "Cognitive Approach" to archaeology uses ethnographic data and/or middle range research to determine individual style and differences in production technique. Philosophically, the cognitive approach uses such dynamic links because of an underlying consideration that "material products cannot be understood apart from the processes involved in their creations" (Young and Bonnichsen 1984:5). Such an approach differs from traditional *chaine operatoire* literature in that the American focus is on replication and dynamic middle range theory whereas the European focus tends to be on static refits and landscape reconstruction.

I.B.1. European influence on Early Stone Age lithic analysis

Early European archaeologists and other scientists notoriously considered East Africa a backwater of human development. The discovery of ancient stone tools in South Africa and this Eurocentric bias led to an early shift in archaeological terminology. European archaeologists, for the most part, considered these discoveries to be the remnants of early European ideas diffusing and finally reaching southern Africa. Based on proposed morphological similarity, some African researchers followed suit with classificatory terms (Leakey 1935). South African archaeologists, however, argued for the antiquity of these artifacts, stating that they were older than European materials (Goodwin and Van Riet Lowe 1929). This European-African split in philosophy and morphology led to the naming of the African Early, Middle and Late Stone Ages as opposed to the European Lower, Middle and Upper Paleolithic.

Goodwin and Van Riet Lowe (1929) formally named and described these South African technologies as the Stellenbosch, Victoria West and Fauresmith industries. Classified from assemblages of river gravel with no obvious provenience, these industries were organized based on the apparent complexity of each respective technology such that the crude bifaces of the Stellenbosch preceded the side-struck, prepared flakes of the Victoria West Industry, which in turn, preceded the finely crafted, small bifaces of the Fauresmith. In modern terms, the Stellenbosch correlates with the Early Acheulian, the Victoria West to the terminal Acheulian, and the Fauresmith to the early Middle Stone Age (MSA). By 1947, a culture sequence for East Africa was formalized by the first Pan-African Congress on Prehistory. This sequence utilized the term *Chelles-Acheul* to describe the main culture of the African Early Stone Age, and claimed that it had evolved from two earlier cultures, the Kafuan and the Oldowan.

The work of Louis Leakey in East Africa was a major impetus for the establishment of a formalized culture sequence. L. Leakey followed a similar typological scheme as those outlined by European archaeologists. The original "Oldoway" technologies of Olduvai Gorge were thus utilized to classify their makers into distinct early human races (Leakey 1931, 1935). In retrospect, M. Leakey (1971:262) admitted that "there was a general tendency to follow the late Abbe Breuil in subdividing the Acheulean and indeed the majority of Stone Age lithic industries into a whole of evolutionary stages" and that this tendency led to the earlier Olduvai Gorge material being divided into "eleven stages of the Acheulean or 'Chelles-Acheul'".

Later, M.D. Leakey provided a more standardized typology than the earlier suggestions of Van Riet Lowe and L. Leakey. Following a Bordesian example, the Leakey typology divides tools into classes and subclasses and based on the relative ratios of these tool types, Leakey separates early stone tool industries (Leakey 1971). Beginning in the basal beds of Olduvai Gorge, Leakey identifies several types of heavy-duty tools including end and side (as well as unifacial and bifacial) choppers, discoids, polyhedrons, anvils and hammerstones. She contrasts these with light-duty tools, which are detached flakes and include "scrapers." All flakes that are unutilized are classed as debitage. Lastly, M.D. Leakey identifies manuports as unmodified raw material that had been moved to its location via deliberate hominin transport. Beginning in Lower Bed II, Developed Oldowan sites are identified via a change in the lithic types associated with them. Leakey (1971) subdivides the Developed Oldowan (DO) into types A, B and C, reminiscent of the Bordesian typological subdivision of the Mousterian into distinctive cultural groups. The DO-A group consists of typical Oldowan tools but also includes an increase in spheroidal forms and light duty tools, including scrapers and *outils ecailles* (for discussion see Jones (1994)). By the Middle and Upper portions of Bed II, the DO-B group appears and is defined based on the ratio of bifaces to the rest of the assemblage; namely, if the site has fewer than 40 percent bifaces, it is classified as DO-B whereas if it has more than 40 percent, it is considered Acheulian. Though Leakey classifies some assemblages as DO-C groups, she never defines this term properly and therefore attribution to this category was much more subjective (Gowlett 1988).

A similar evolution of cultural sequences occurred at the Kenyan site of Koobi Fora. Initial analysis of 1.9 Ma stone tools from the KBS member of the Koobi Fora

Formation described the artifacts in terms of the typology associated with the Olduvai Gorge material (Leakey 1970). However, further examination showed potential differences, mainly based on the small size of the exhausted cores, and the Koobi Fora stone tools were named, as a variant of the Oldowan, the KBS Industry (Isaac, 1976) after a site discovered by Kay Behrensmeyer. Further excavation of the Okote and Chari geological members uncovered both a Developed Oldowan variant and potential Acheulian sites. The Karai Industry, the Koobi Fora Developed Oldowan variant, is defined by a *fossil directeur*: the Karari scraper. Initially described by Harris and Isaac (1976) and further defined by Harris (1978), the Karari scraper is a unifacial core made on either a large flake blank or a flat-topped cobble in which flakes have been removed around the perimeter, leaving acute angles on all sides of the flat platform (Harris 1978). Importantly, Isaac and Harris recognized the shortcomings of stone tool cultural affiliation and note that "the setting up of these defined archaeological taxa for the classification of the archaeological material from the Koobi Fora Formation is not intended to denote the existence of culturally or ethnically distinct entities" (Isaac and Harris 1978:75).

The pioneering work of G. Isaac began the transition of moving East African typologies away from cultural constraints and toward a more behavioral evaluation. Though similar typologies were originally used by Isaac, the meaning of these types were not tied to untested cultural conclusions, but rather to landscape usage and changes in hominin behavior through time (Isaac and Harris 1978). In fact, Isaac and Harris (1978:65) recognized the importance of the contextual information of stone tools over their typological importance, an important move in establishing landscape archaeology and in investigating not only large sites, but also the "scatter between the patches" (Isaac and Harris 1975). Instead of establishing a typology of technological information, Isaac and Harris (1978) established a contextual typology to characterize different site formations and interpretations. These site types range from large stone assemblages with little associated bone (type A) and stone tools associated with a single animal skeleton (type B), to sites with a large number of both stone tools and faunal remains (type C). These distributions, Isaac and Harris (1978) argue, can produce insightful behavioral conclusions of stone tool production sites (type A), butchery sites (type B), or "home-base" sites (type C). Other sites might include very low-density assemblages of stone tools that are not associated with other material (type D); these "scatter" sites are potentially important for defining hominin ranging patterns and landscape usage behaviors. Such site typologies are the foundation for further behavioral inference including theories of hominin landscape usage (Isaac 1984; Binford 1984; Potts 1991).

By the 1980s lithic artifact analysis had evolved into a technological assessment of stone tools; research included attention to replication and the processes associated with the manufacture of these lithic implements. The European application of technological analysis by Dibble (1981 1987) was matched by the East African application by Toth (1982, 1985, 1987). Not satisfied with the cultural typology of M. Leakey or the site typology of Isaac and Harris, Toth sought to classify tools based on technological features associated with the order in which flakes were removed (the reduction sequence (Frison 1968; Jelinek 1976)). Toth's dissertation (1982) established a set of reduction sequences associated with Koobi Fora KBS industry artifacts, each sequence based on the original size and shape of the cobble procured for the experiments. By identifying relative proportions of cortex on the dorsal surface and the platform, and combinations thereof, Toth (1985) was able to establish his own technological “types.” The presence of platform and dorsal cortex is interpreted to mean that early stages of reduction occurred at that location and the presence of non-cortical platform and dorsal flakes means that later stages of reduction occurred and/or cores were more severely flaked than at sites with high percentages of cortical flakes. This model of reduction allowed for a broad interpretation as to what hominin technological behaviors were associated with particular sites and whether cores and flakes were introduced or removed from a site (Toth 1982, 1985, 1987).

I.C. Current Early Stone Age research

Though the terminology of the Leakey and Van Riet Lowe typologies is still in use, just as the Bordesian typological terms are still used to describe European archaeological assemblages, over the last twenty years, research has begun to move in new directions. The application of quantitative use-wear studies, more specific chaine operatoire techniques, and landscape archaeological approaches have added to the knowledge base of lithic technology. The following sections will highlight current approaches to lithic artifact analysis at key East African archaeological sites so as to gain interpretive insight into what conclusions are valid, what are not, and where, logically, lithic artifact analysis should go to successfully address modern archaeological questions and develop new testable hypotheses.

I.C.1. East African archaeological localities

Olduvai Gorge has remained a hotbed of archaeological research since the excavations of M.D. Leakey, with significant research being conducted to reconstruct hominin behaviors over this paleolandscape. Whether in terms of ecology (Lewis 1997), stone tool production (Jones 1994; Kyara 1999; Tactikos 2005; Diez-Martin et al. 2011) and use (Kyara 1999; Mora and de la Torre 2005; de la Torre and Mora 2005; Tactikos 2005) and raw material usage (Kimura, 1997, 1999; Tactikos, 2005; Blumenschine et al., 2008), or dietary reconstruction (Sponheimer and Lee-Thorp 1999; Van der Merwe et al. 2008), Olduvai Gorge provides a unique setting for early hominin research. Underlying this research is the landscape approach to archaeology, outlined by Blumenschine and Peters (1998). The landscape approach looks broadly at a single horizon and archaeologically documents how hominin behaviors vary across that landscape given ecological differences across that geographic space. The exposures and relative simplicity of the Olduvai geological beds allow for this detailed work to be done and to accurately reconstruct large portions of the paleolandscape.

Raw material procurement and production strategies are also relatively simple at Olduvai since the raw materials available to early *Homo* populations are still visible and available on the modern landscape (Hay 1976). Recent lithic artifact research has utilized the broad spatial reconstructions of previous studies to provide evidence for differential use of the paleolandscape in terms of stone tool production (Kimura 1997, 1999, 2002; Tactikos 2005; Blumenschine et al. 2008).

Tactikos (2005) utilized Blumenschine and Peters' (1998) landscape methodology to reconstruct paleohabitat use based on stone tool prevalence. Using a mixture of typologies (Leakey 1971; Tactikos 2005) to answer several behavioral questions regarding Oldowan hominins, the question of most significance to this paper concerns the relative homogeneity of the Oldowan Industrial Complex across a single paleolandscape such as Olduvai Gorge. Since the Oldowan of Olduvai Gorge is considered the type assemblage for the entire Oldowan Industrial Complex (Clark 1966), Tactikos rightly seeks to justify this assessment. Using original Leakey type sites and those excavated by OLAPP over the course of a decade, Tactikos (2005) divides sites based on ecological factors in order to determine if the same activities were taking place (a cultural explanation) or if different activities were occurring on different parts of the landscape (an ecological explanation). She demonstrates that assemblage variability increases based on landscape association, but overall assemblage composition reasserts that each site typologically belongs within the Oldowan Industrial Complex.

Others have attempted to reconstruct the functional utility of various Oldowan artifact forms. Mora and de la Torre (2005) reanalyze the "pounded material" classified by Leakey (1971) as anvils and hammerstones and also material originally classified as cores (such as polyhedrons and spheroids). Based on the absence of scars showing negative bulbs of percussion, Mora and de la Torre (2005) conclude that many polyhedral forms classified by Leakey are actually natural forms without human modification. Similarly, they argue that subspheroidal forms are not a rare occurrence naturally and that many spheroidal ridges show evidence for battery. Perhaps then, hominins preferentially chose naturally rounded forms as hammerstones and simply battered down their natural edges into spheroidal shapes. These conclusions add to previous studies that suggest many of the manuports purported to be carried into a site via human means, are actually ecofacts that naturally occur in these locations (de la Torre and Mora 2005).

The functional utility of various stone artifacts can best be inferred via experimental methods of production and use. Schick and Toth (1993) performed many experimental tasks with stone tools including cracking nuts, digging for tubers, woodworking, hideworking, and butchery (including skinning, defleshing and bone cracking) on several animals including an elephant. Though use-wear traces can be detected on glassy materials such as chert, the majority of early East African materials are produced on stone that is too hard and coarse to see such wear patterns. More recently, Toth and Schick (2006) utilized actualisitic experiments in order to assess the cognitive prerequisites for stone tool production by looking at both chimp behaviors and modern knapping skill via arm motions and brain activity. This is a new advent in middle range research, in that we may be able to infer actual cognitive behavior (albeit broadly) based on our own behaviors when producing stone tools. For instance, Stout et al. (2006) discovered that the same parts of the brain are utilized in producing Oldowan and Acheulian stone tools, but these areas are more heavily utilized in the Acheulian, likely due to the symmetric qualities and multiple stage of thinning (including platform preparation) included in their manufacture.

Lake Turkana in Northern Kenya offers deposits rich in archaeological material from a range of dates beginning around 2.0 Ma on the East side of Lake Turkana and even earlier on the West side of Lake Turkana. The site of Lokalalei is located on the west side of Lake Turkana and is important for two reasons: the lithic assemblage is extremely well-preserved and it is dated to 2.34 Ma. The site complex is divided into two sites, LA1 and LA2C (Roche et al. 1999, but see Brown and Gothogo 2002). LA1 has produced the earliest evidence of the genus *Homo* in the Lake Turkana Basin (Pratt et al. 2005), while LA2C produced the earliest archaeological traces in the basin (Roche et al. 1999; Delagnes and Roche, 2005). The early age of the site provides a unique insight into the behaviors of these stone tool-producing hominins. Research into the stone tool manufacture present at the site suggests that the associated hominin producers were not novices at tool production (Kibunjia 1994; Roche et al. 1999). In addition, Delagnes and Roche (2005) note that the assemblage is so complete that a significant proportion of the stone tools were able to be refit. These refits provide a concrete glimpse into the production techniques of early hominins and quantifiable evidence for complexity of behavior. The use of *chaine operatoire* in this sense allows for a holistic reconstruction of hominin behavior; not only can definitive conclusions be placed on ranging behavior based on raw material sourcing, but on-site production activities can be reconstructed based on the refitted material. This reconstruction affirms the forethought and significant production abilities of these early hominins, as was originally suggested by the 2.5 Ma Gona artifacts (Semaw et al. 1997, 2005; Semaw 2006). The presence of nearly exhausted cores displaying many flake scars and even platform preparation, suggests that early hominin producers were aware of the predictable nature of conchoidal fracture mechanics and could consistently produce stone tools given an acceptable platform.

Though not actively seeking reassessment of stone tool technology, Braun (2006) has utilized chemical techniques of tracing basaltic material from Koobi Fora, East Lake Turkana to reconstruct procurement strategies of KBS hominins and thus place the KBS stone tool industry in an ecological context. Braun (2006) identified two basaltic forms from Koobi Fora: Gombe and Assile basalt. KBS producing hominins demonstrate little preference for one form of basalt over the other but generally use Gombe basalt in higher quantities due to its distribution over the East Turkana landscape; Gombe basalt was easier to procure.

The Omo deposits from Southern Ethiopia, namely the Shungura formation, have produced the oldest lithic artifact assemblages found to date. Pushing hominin technology back to nearly the 2.5 Ma mark with Gona (Semaw et al. 1997, 2005; Semaw 2006), and others at 2.35 Ma in Tuff E of Member E (Chavaillon 1976), it is surprising that little attention has been paid to these early assemblages. In fact, the only re-evaluation of these artifacts was that of de la Torre (2004). Reviewing the work of Chavaillon in the 1970s, de la Torre found that Member E sites, including Omo 71 and Omo 84, could not be linked to hominin behavior as the stone tools excavated from these sites showed no evidence of human modification.

However, Member F sites display substantial human modification (de la Torre 2004). As has been displayed at Gona (Semaw et al. 2005; Semaw 2006), the Omo (de la Torre 2004), West Turkana (Delagnes and Roche 2005) and potentially at Hata Member sites of the Bouri Formation (de Heinzelin et al. 1999), early hominins show refined skill in their stone tool production abilities. This skill level exceeds what is expected for the earliest stone tool producers and leaves archaeologists wondering if there might be a technological strategy that precedes the Oldowan and, if so, begs the question of what this “Pre Oldowan” stone tool technology might look like.

The site of Kanjera, located along Lake Victoria in Western Kenya, became controversial after L. Leakey found anatomically modern human fossils in the early

1930s (Leakey 1935). In recent years, the geological history and paleoecology (Behrensmeyer et al. 1995; Ditchfield et al. 1999) have been re-evaluated and the Leakey modern human fossils re-assessed (Plummer and Potts 1995). Kanjera is unique in that it is more than 2.0 Ma and, unlike other contemporaneous sites, has stone tools and fauna in associated context (Plummer et al. 1999). Paleoenvironmental data based on carbon isotopic evidence suggests that this is also the first definitive site in which early hominins were utilizing open savanna habitat (Plummer et al. 1999). Despite this interplay of hominin behavioral evidence and paleoecological data, no complete assemblage description or analysis was published prior to Braun (2006) and even this is a broad analysis aimed at landscape reconstruction. More recently, the lithic artifact assemblage from Kanjera South has been used to infer hominin raw material preference based on quality (Braun et al. 2009). Preferential behavior and the import distances associated with them (up to 10 km) suggest that Oldowan hominin behavior is more complex than what is normally associated with these early tool users (Braun et al. 2009). However, no technological discussion has begun on the Kanjera material. With the associated fauna and detailed geological mapping, understanding production behaviors would allow for more complex conclusions of hominin-landscape interaction, differential use of the landscape, technological change over time, and comparisons of all of these points with many other sites in East, South and North Africa.

I.C.2. Analytical techniques

Recent research has begun to apply unique analytical methodologies to address archaeological questions. Application of biological taxonomic techniques, such as cladistic analysis, offers a new way to view old questions.

Lycett (2009) offers a refreshing evaluation of the technological relatedness of the Victoria West Industry of South Africa and the Levallois tradition of the Middle Stone Age and Middle Paleolithic. Since its early discovery and description, the Victoria West has been considered a "proto-Levallois" industry, or a precursor to the prepared core techniques seen in Levallois flake production (Van Riet Lowe 1945; Kuman 2001). These conclusions are based on descriptive properties of flake scars and core forms and have a broad impact on the interpretations surrounding the evolution of technological behavior and influence in Africa, as well as African industrial relatedness to European Middle Paleolithic Levallois technologies. Instead of using qualitative methods of analysis, Lycett (2009) employs a phylogenetic approach to lithic analysis in which Levallois and Victoria West core forms are quantitatively assessed based on detailed morphological criteria and evaluated cladistically in order to establish a phylogenetic relationship. Lycett (2009) uses this method in a novel way, building on the work of O'Brien et al. (2001) and Shott (2008). The construction of operational taxonomic units based on a variety of morphological character traits, methods borrowed from paleontology, allows Lycett (2009) to convincingly demonstrate that morphological similarities between Victoria West and Levallois core forms is founded in a convergent process and that therefore the Victoria West should not be an assumed proto-Levallois Industry.

A similar problem in assessing lithic artifact production behaviors stems from the inherently destructive process of producing stone tools; the archaeologist is unaware what the original core form looked like and must make inferences based on flakes present and scar counts (Kimura 1997, 1999; but see Braun et al. 2005), as discussed relative to flake recovery rates. However, for Middle and Upper Paleolithic assemblages that contain re-sharpened tools, computer models can utilize statistical analyses of edge angles and the relative intensity of retouched edges to infer the original form of the tool prior to re-sharpening (Iovita 2009). Though the conclusions of this research are aimed at disentangling morphology and technology from functional systematics, the potential is there for broad application of this study to earlier technologies and more varied core forms.

Eren et al. (2008) discusses a particularly long-held assumption that Upper Paleolithic blade technologies are more "efficient" than Middle Paleolithic "scraper" technologies (Bar-Yosef and Kuhn 1999). Replication experiments showed the potential for scraper technologies to yield a greater amount of usable edge than blades when resharpening is considered (Eren et al. 2008). Blades, though possessing a long cutting edge, are relatively thin and resharpening often leads to breakage; scrapers, though being relatively short and round, have the material properties that allow them multiple sharpening events (as suggested by Dibble 1987; but see Hiscock and Clarkson 2009). Eren et al. (2008) demonstrate the consistent utility that experimental stone tool replication offers to lithic analysis and also specifically addresses problems of inferential assumption that plague the archaeological sciences.

Modeling of archaeological processes of procurement, production and disposal as well as possible land-use patterns help archaeologists pose feasible and testable hypotheses. These models can also provide a means of questioning accepted logic and conclusions regarding hominin behavior. Brantingham (2003) models raw material procurement, transport and discard using a neutral model. Neutral models (Kimura 1983) assume adaptive neutrality of all factors so that behaviors can be targeted, but each behavior has equal weight in occurring and has equal adaptive outcomes. In his model, Brantingham (2003) produces a digital hominin that ranges over a landscape that has predetermined "raw material sources." The conclusions demonstrate that archaeologists cannot discount a neutral model of procurement and discard among Oldowan hominins. Such theoretical models help construct the philosophical boundaries of archaeological inference and provide a measure by which future hypotheses might be constructed and tested.

I.D. Darwinian Archaeology

Early archaeologists studying pottery, such as W.F. Petrie (1899), noticed that ceramic styles had "genealogies" that would branch through time from a parental line to two new lines of stylistic variation. Furthermore, Petrie (1899) noted that two lines of pottery could also combine to form a new stylistic line. Though other early archaeologists found similar patterns among archaeological material (Kidder 1915), no explanatory device was in place to suggest why these changes should be chronological (Kroeber 1916). Colton and Hargrave (1937) explicitly used evolutionary terms to describe the relationship between material objects, referring to pottery features as "derived" and "ancestral."

The application of evolutionary principles to nonliving material culture has since been a continued area of debate. Common arguments against cultural evolution include the idea that culture is reticulate, like a braided stream channel branching and coming back together, such that cultural evolutionary lines can never be accurately reconstructed archaeologically (Steward 1941); oppositely, Ford (1962) viewed phylogenies to be anagenetic, progressing linearly without diversification, a call back to early cultural typologies (i.e. Morgan 1877). As one critic pointedly stated, "phylogenetic relationships do not exist between inanimate objects" (Brew 1946:53).

Recent objections to cultural evolutionary theory present similar skeptical undertones. The argument that artifacts do not carry phylogenetic information because they do not breed has been a common criticism of cultural evolution (Mayr 1982; Gould 1996; Bamforth 2002). It seems that this criticism stems from a philosophical difference between cultural evolutionists and their critics: to critics, the material artifacts of any animal cannot be the subject of Darwinian selection because there are not genetic components that can be inherited. To cultural evolutionists, the fact that biologists commonly consider material artifacts such as birds' nests (see O'Brien and Lyman 2003a) as part of the animal's phenotype leads to the logical question: why not consider stone tools or pottery as similar extensions of the human phenotype? O'Brien and Lyman (2003a:99) state clearly that "products of technology are not simply adaptive reflections but rather active components of the adaptive process." Just as with other aspects of phenotype, selection can act on technology and other aspects of material culture that affect the fitness of the producer; those able to produce and/or have the capacity to learn how to produce such objects may have higher survival and reproduction than their counterparts. If artifacts are considered nonsomatic aspects of the phenotype, then changes in their morphology may correlate to changes in their effect on the fitness of the producer.

This conclusion assumes functional aspects of material culture. "Function" usually implies some form of efficiency or utility, which in turn implies the potential for selection. Since its recent inception (Dunnell 1978; Dunnel and Wenke 1980; Rindos 1980), the argument of Darwinian (or evolutionary) archaeology has been met with debate over whether material culture can be considered "functional" and if so, where the line should be drawn between "function" and "style." Style usually implies an aesthetic value and has traditionally been considered neutral relative to selection (Schiffer 1995; Schiffer and Skibo 1997). However, even stylistic variation can be considered subject to selection depending on the value of that style within a specific social system (Brantingham 2007). For O'Brien and Lyman (2000:180), the debate is a moot point because "trait variation and inheritance, but not fitness differences, are required for evolutionary change to occur; differences in fitness are required only for evolution via natural selection." Such arguments have also been made in studies of sexual selection in which selectively neutral phenotypic traits can be selectively advantageous or disadvantageous in Fisherian runaway processes (Fisher 1930; Andersson 1994), but this argument can equally be made for phenotypic variation randomly affected by drift factors. Similarly, as Brantingham (2007) theoretically models, stylistic variation may become functional when that style suggests group inclusion or status of any kind and is reproduced regularly.

Thus artifacts can theoretically be considered phenotypic extensions of human behavior, whether functionally or stylistically, and explicit hypotheses can test their subjectivity to selection. How, then, do the equivalents of "mutations" and "adaptations" arise within the material culture paradigm? In other words, how is variation added to material culture products and how are these variants both maintained and altered through time?

Transmission theory (or dual-inheritance theory) (Cavalli-Sforza and Feldman 1981; Boyd and Richerson 1985; Schiffer 1995; Shennan 2002; O'Brien and Lyman 2003b; Mace et al. 2005; Richerson and Boyd 2005) serves to explain how random and directed variation in human-produced objects ranging from artifacts, pottery, textiles, and basketry (Tehrani and Collard 2002; Jordan and Shennan 2003; Eerkens and Bettinger 2008; O'Brien et al. 2008; Shott 2008) to transcriptions of manuscripts (Spencer et al. 2004) arises and is maintained. Models of transmission are crucial to the theoretical model of Darwinian archaeology because without them, the model "suffers the fatal flaw of lacking the theory of processes by which adaptations arise" (Shott 2008:150).

Unlike biological inheritance, which is vertically restricted in that genetic material is only passed on from parent to offspring, cultural transmission can function in multiple, simultaneous directions (Eerkens and Bettinger 2008; O'Brien et al. 2008). For instance, cultural material can be transmitted between peers (horizontal transmission) and can also be transmitted vertically from a younger generation to an older generation (Boyd and Richerson 1985; Richerson and Boyd 2005). Aspects of material cultural can also diffuse from one group of people to another (Bettinger and Eerkens 1997, 1999; O'Brien and Lyman 2000; Richerson and Boyd 2005). Just as rates of mutation and fidelity of inheritance can be measured and assessed in biological cases, rates of production error and stylistic change and preference can be archaeologically identified over time (Bettinger and Eerkens1999; O'Brien and Lyman 2000; O'Brien et al. 2001; Brantingham 2007; Buchanan and Collard 2007). Transmission data, in turn, can identify patterns of exchange, migration, group identity, and group belonging.

I.E. Developing Behavioral Lithic Analysis (BLA)

The development of BLA is as much philosophical as it is theoretical. Archaeological analytical techniques require a method by which to directly and statistically compare lithic assemblages. Further, this technique must be behaviorally informative.

The typological roots of Early Stone Age lithic analysis has branched into a diverse array of methodological strategies all aimed at describing aspects of early human behavior. Ecological reconstruction and raw material preference provide evidence for hominin landscape utilization; experimental functional studies and faunal analytical techniques provide insights into what activities hominins may have been participating in; landscape approaches suggest how these activities were distributed across ancient landscapes. However, there is one methodological assumption of these approaches: Oldowan technology is more or less uniform. If "variation" is identified within an archaeological assemblage, there is currently no methodological way of comparing this supposed variation with any other assemblages or of defining this variation in a technological way. Variation is commonly attributed to differences in raw materials or vaguely described as varying due to functional differences across the landscape. These explanations are assumptions that have not been explicitly tested.

The development of BLA fills this methodological gap in lithic analysis. By bridging static archaeological lithic artifacts with dynamic experimental programs, quantitative models are constructed to classify archaeological materials in terms of discrete behaviors used to create them. Archaeological materials can then be assessed in terms of these production behaviors (either at the individual artifact or assemblage level) and artifacts from different archaeological sites can be directly and statistically compared in terms of the production behaviors utilized to create them.

Further, the application of Darwinian archaeological theory to Oldowan technology is a necessary step forward for archaeological understanding of both technological and cultural origins. Though potentially more inflammatory due to its classification of early hominin culture based on technological differences (but for primate application, see (overview) Perry 2006; (chimpanzees) Whiten, et al. 1999, 2005; Lycett et al. 2007; (orangutans) van Schaik et al. 2003), Darwinian archaeology can formally model *why* the Oldowan has variation, instead of the simple fact that it does (as seen in Barsky 2009). Because “any evolutionary account of transmission must be built around…models of the mechanisms that introduce variants into a population” (Shott 2005:34), so too must Oldowan variation be accounted for.

Many have concluded that difference in raw material accounts for significant Oldowan variation (Toth 1982; Asfaw et al. 1992; Kibjunjia 1994; Roche et al. 1999; Roche 2000; Braun 2006; Barsky 2009). Quantifying whether raw material accounts for variation or not, however, has proven difficult (Brantingham et al. 2000). Analysis of the behaviors associated with Oldowan tool production can provide a statistical assessment of raw material constraints on Oldowan variation. If a particular behavior yields a basalt flake within a certain morphological range, as demonstrated by experimental reproductions, the same behavior can be performed on other raw materials and the morphological signatures compared. In this way, each behavior can be directly compared based on morphological signatures relative to the raw material on which the flake was produced. Thus if two sites are compared, one with basalt flakes and one with quartz flakes, each can be measured on a statistical curve that is relevant to the raw material in question. Under traditional typologies, these sites may be considered highly different (or uniform), but with behavioral analysis, they become directly comparable and can be analyzed in terms of *how* they are different (or alike), independent of raw material constraints.

To explain transmission modes among Oldowan producing hominins, variation in stone tool morphology over time and space relative to the behaviors needed to produce them must first be assessed. Depending on the level of variation, Oldowan technology may demonstrate a long period of technological stasis over a broad area of production or it may demonstrate a long period of technological divergence in which variation is either temporally dependent, geographically dependent, or both. The combination of environmental reconstructions, stone tool morphologies, limitations of raw material resources, and composition of archaeological assemblages can be used in a Darwinian approach to assess differential behaviors of hominins across space and time.

For instance, the broad use of stone tools among Oldowan-producing hominin populations and the long technological stasis normally attributed to Oldowan technology has never fully been explained. How is such behavior maintained across broad geographic space? Why are technological changes through time apparently the same over these geographic areas? Darwinian explanations of these relationships can provide a concise analysis of evolutionary relationships among the earliest material culture left by human ancestors. These methods can potentially be widely applied, thus making archaeological sites broadly comparable and technological change over time feasibly quantified.

Chapter II: Methodology

Behavioral Lithic Analysis (BLA) is divided into three methodological stages of development in that it:

1) quantifies morphological variation using archaeological assemblages,

2) explains this variation in terms of production behaviors using controlled replication experiments, and

3) statistically compares these production behaviors across archaeological sites and localities to explain variation in production behaviors across archaeological landscapes.

BLA serves as a standardized way of comparing archaeological assemblages, given that morphological variation exists and controlled experimental assemblages can be produced on raw materials native to the archaeological site(s) in question.

Each of the three steps listed above is presented in detail in this chapter. The first step of BLA identifies whether variation exists among and/or between archaeological assemblages. The presence of such morphological variation warrants further research into the other stages of BLA methodology, namely to explain that variation in terms of specific production behaviors.

II.A. Identifying variation archaeologically

The goal of BLA, as outlined above, is to quantify how stone tools are created and statistically describe archaeological assemblages in terms of these production behaviors. To statistically identify different production behaviors there necessarily need to be different production behaviors. In other words, if no statistical variation exists in the morphologies of flakes from an archaeological assemblage (or between archaeological assemblages), then teasing out different production behaviors has no statistical basis. If, however, morphological variation is identified, it is possible for this variation to be defined in terms of production behaviors.

The first step of BLA is therefore to identify whether morphological variation exists among archaeological assemblages. This section describes how this variation is identified in terms of 1) variable selection, 2) size standardization, and 3) statistical tests.

II.A.1. Variable selection

The way in which lithic artifacts are measured impacts their behavioral relevance; if measurements are not behaviorally informative, results based on those measurements will not yield information related to behavior. By "behavior", this research is referring to how stone tools are actually produced, or *production behaviors*. Identifying discrete production behaviors is described in detail later in this chapter (section *II.B.4*). Once behaviorally relevant variables are selected, archaeological materials are analyzed using these variables to assess whether morphological variation is, in fact, present between sites and localities. Variation can, therefore, be identified archaeologically without knowing exactly what that variation might mean. For instance, if archaeological materials are found to vary between sites as a function of flakes' length, it is known that at one site flakes are relatively longer and at another site flakes are relatively shorter, but it is still unknown what difference(s) in actual production behaviors was the cause of this variation in the length dimension.

Many aspects of flake morphology are potentially controllable by the producer of that flake. It has been demonstrated that aspects of platform dimension, for instance, are indicative of other aspects of flake morphology (i.e. Pelcin 1997). Flintknappers have an inherent understanding of what platform morphology should look like for successful removal of a given flake. Moreover, they have a firm understanding of what the flake itself will look like based on the distribution of mass across the core, the position of the platform relative to this mass, the strength of the strike, the material of the hammerstone, the angle of the core, and many other behavioral variables. This inherent understanding is due to the physical principles that underlie the fracture mechanics of microcrystalline and cryptocrytalline raw materials.

II.A.2. Fracture mechanics

The physical principles that explain the predictable pattern in which rocks fracture are integral to understanding lithic analytical methods. Early stone tool makers understood aspects of these principles and applied them in complex ways. Modern studies have attempted to quantify how stone breaks, in what circumstances these variables differ, and how these variables change depending on the type and quality of rock being intentionally fractured.

Lithic fracture mechanics applies specifically to raw materials that are micro or cryptocrystalline, homogenous (free of impurities), isotropic (uniform composition in all directions), brittle, and elastic (Whittaker 1994). Tangential force applied to the surface of such a raw material via a hammerstone (or any specific source) will produce a conical wave of force known as a Hertzian cone. Early analysts recognized the compressions rings emanating from the bulb of percussion and thought it looked similar to the concentric swirls of a conch shell; thus the name "conchoidal fracture" has been applied to describe the fundamental fracture form in stone tool production. Under ideal conditions, a round hammerstone is used to tangentially strike the smooth surface of a core (or nucleus). The force applied travels equally in all directions forming a cone of force with a consistent angle of 136 degrees (Speth 1972; Cotterell and Kamminga 1987; Whittaker 1994; Andrefsky 1998; Odell 2003). If this force is applied to the center of a large core, the force may be entirely absorbed by the mass of the core. With no exit points, no flakes will be removed. If, however, the striking area (platform) is near an acute edge of the core and is struck with enough force, part of the Hertzian cone will travel into the core and part will travel to an exit point at the edge of the core. This will produce a recognizable flake with all of the attributes normally given a man-made artifact.

The amount of applied force is critical to the removal of a successful flake. Too little force and an unsuccessful Hertzian cone has been created within the core that may cause unintended fracture during successive hammer stone strikes; too much force and the core may break causing damage or loss of the core and/or tool being produced. Further finesse is needed to remove flakes of an intended shape and size. Flake terminations (the shape of the distal end of the flake as it breaks off of the core) determine the success of a particular biface, for instance, and experimental studies have suggested that the proportion of stepped terminations in a given assemblages might inform the archaeologist of the presence of novice flintknapper activity in prehistoric times.

It is important, however, to realize that conchoidal fracture is not the only force at work in stone tool production. Bending and compression initiations also occur under circumstances other than (but also including) hard hammer percussion (Cotterell and Kamminga 1987). For instance, when hammerstones break the resulting flakes often lack the definition of the bulb of percussion expected with conchoidal fracture. This is due to the bending fracture that initiates the flake removal. Instead of merely breaking off the core due to applied force as in conchoidal fracture, the successive blows involved in removing a hammerstone flake from a rounded surface force a flake to "bend" off of the core (a hammer stone in this case) and thus does not possess the attributes normally associated with lithic artifacts (Cotterell and Kamminga 1979). Similarly, compression flaking occurs due to microscopic wedging of sand grains or grain-sized fragments of the parent material that have been dislodged during unsuccessful blows and forced into small cracks on the surface of the core. Although often produced during bipolar flaking activities, normal hard-hammer percussion can also produce compression flakes. Compression flakes (also known as "wedging" flakes) may have similar features to conchoidal flakes, but their shape is less predictable due to the multiple blows necessary to remove them (Cotterell and Kamminga 1987).

Lithic fracture follows predictable patterns other than those dealing directly with percussive force. Areas of large mass tend to be removed first due to how force is dispersed into the core. Thus if a platform is directly over a ridge (a natural ridge or one produced from a previous flake scar), the flake will tend to follow that ridge until termination is reached. Similarly, if an area of low mass relative to the rest of the core is struck, it is likely that the core will break due to the applied force traveling to an area of high mass.

II.A.3. Variable definitions

The variables measured for BLA are all aspects of flake morphology that are *potentially* controllable. This is not to say that all aspects are, in fact, controlled at any given time, especially in the Oldowan. However, one goal of BLA methodology is to make assemblages belonging to different geographic areas and temporal periods directly comparable. Therefore, all aspects of flake morphology that might be controlled are measured and assessed for variation.

Eleven measurements are taken for each flake (Figure 2.1) to an accuracy of 0.01 millimeters using Mitutoyo CD 200mm digital calipers. Each measurement is defined below. Table 2.1 offers a quick definition guide to each measurement.

Technological length

The length of the flake is defined as the distance between the point of percussion (where the core was struck with the hammerstone) and the distal margin of the flake such that the axis of measurement is perpendicular to the plane of the flake's platform. Length is not, therefore, necessarily the longest axis of the flake; rather, length is a replicable measurement dependent on the point of percussion. The stone tool producer can control aspects of length by following areas of relatively high mass, such as a ridge produced from a previous flake scar (Cotterell and Kamminga 1987). This control, one can imagine, is readily apparent in blade technologies

Technological width

The width measurement is taken following the length measurement, as the technological length of the flake determines where the width measurement is taken. The length of the flake is divided by two and this distance is measured down from the point of percussion along the same axis as length. The point on the flake that is measured to be one half the technological length is a marker for the width measurement. Technological width is measured perpendicular to the axis of technological length and is measured across the flake at one half the technological length. Similarly to length, the stone tool producer can potentially use mass distribution across the core (such as a previously produced flake scar or natural distributions of mass on an unmodified cobble), as well as the angle of force, to constrain the width of a given flake (see Cotterell and Kamminga 1987:693 for a discussion of stiffness-controlled flaking).

Thickness

The thickness measurement is taken at the intersection of the technological length and width measurements, but in the third dimension, perpendicular to both the

Figure 2.1a:

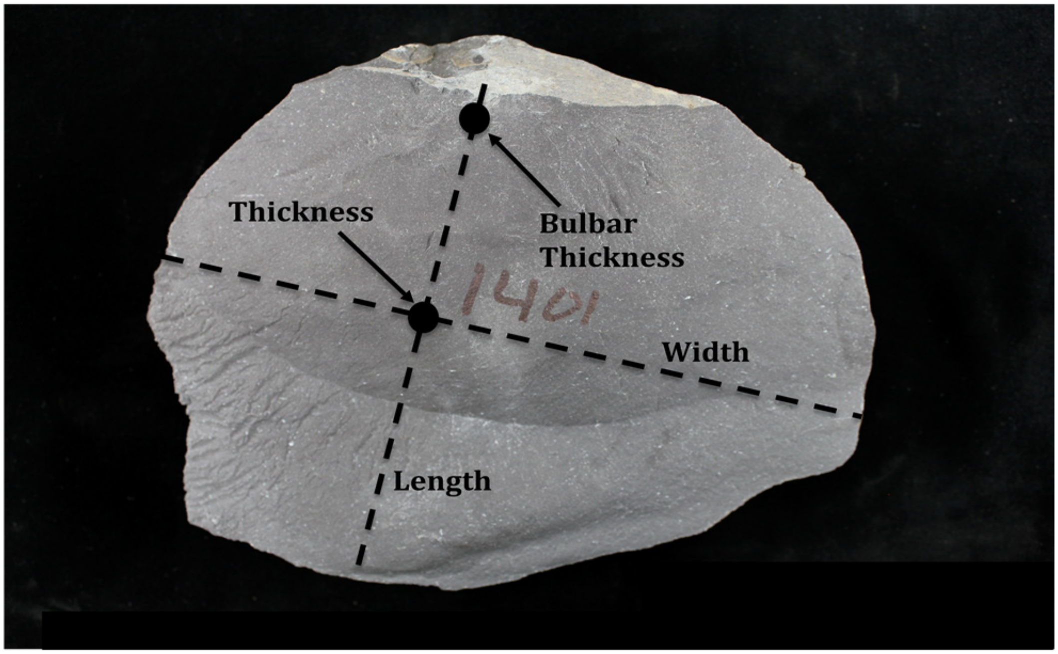


Figure 2.1b:

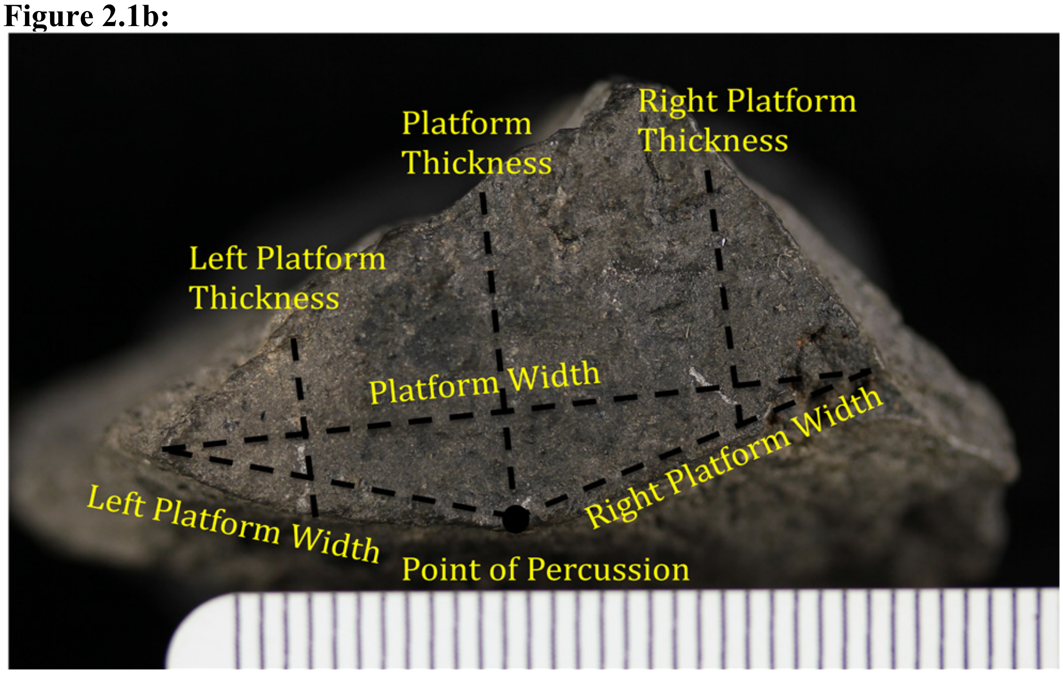


Figure 2.1: a) Ventral measurements taken on all whole flakes and b) Platform measurements taken on all whole flakes; see text and Table 2.1 for measurement definitions.

Table 2.1: Measurements taken on whole flakes and corresponding definitions

Measurement	Definition
Length	Technological axis measured perpendicularly to the point of percussion, taken on the ventral side
Width	Perpendicular to length, measured at ½ length measurement, taken on the ventral side
Thickness	Measured in the third dimension at the point where width and length intersect
Bulbar Thickness	Measured in the same dimension as thickness but from the point of percussion
Platform Width	Measured from left lateral margin of the platform to the right lateral margin of the platform; measured along the same axis as width
Left Platform Width	Measured on the same axis as flake width but from the point of percussion to the furthest left margin of the platform
Right Platform Width	Measured on the same axis as flake width but from the point of percussion to the furthest right margin of the platform
Platform Thickness	Measured perpendicular to platform width and taken from the point of percussion to the furthest dorsal margin of the platform
Left Platform Thickness	Platform thickness measured at 1/5 the platform width
Right Platform Thickness	Platform thickness measured at 4/5 the platform width
Maximum Dimension	The longest dimension of the flake, taken on the ventral side
Platform Cortex	The percentage of the striking platform surface with cortex present
Dorsal Cortex	The percentage of the dorsal surface with cortex present

technological length and width measurements. This measurement demonstrates the absolute thickness of a given flake at the technological center of that flake.

Bulbar thickness

The bulbar thickness measurement is taken in the same way as the thickness measurement, but is taken directly at the point of percussion, perpendicular to the length and width planes already established. Flake thickness, platform thickness (see below), and bulbar thickness provide a measure of how mass is differentially distributed across a given flake.

Platform width

Platform morphology has been demonstrated as particularly informative in terms of fracture mechanics and control in the flaking process (Dibble and Pelcin 1995; Pelcin 1996; Dibble 1997; Davis and Shea 1998, but see Pelcin 1998 and Dibble 1998; Shott et al. 2000; Clarkson and Hiscock 2011; Rezek et al. 2011). Due to its relative importance, this research gives particular focus to platform dimensions for the purpose of calculating platform area.

Platform width is measured from one lateral extreme of the flake's platform to the other lateral extreme of the platform. This measurement is taken along the same axis as that of the technological width measurement previously described.

Left platform width

The left platform width measurement is taken from the point of percussion, just above the bulb of percussion at the proximal end of the ventral surface, to the most lateral point of the platform toward the left. This most lateral point was determined with the platform width measurement. This measurement is taken when the analyst is holding the flake with the ventral face facing him/her and the platform is upright (as depicted in Figure 2.1b).

Right platform width

The right platform width measurement is taken from the point of percussion, just above the bulb of percussion at the proximal end of the ventral surface, to the most lateral point of the platform toward the right. This most lateral point was determined with the platform width measurement. This measurement is taken when the analyst is holding the flake with the ventral face facing him/her and the platform is upright (as depicted in Figure 2.1b).

Platform thickness

Platform thickness is measured from the point of percussion to the distal margin of the platform, such that the measurement is perpendicular to that of the platform width measurement. Platform thickness has been the subject of debate concerning its potential utility in predicting flake size based on controlled experimental settings and experimental flintknapping (Dibble and Pelcin 1995; Pelcin 1996, 1998; Dibble 1998; Davis and Shea 1998; Shott et al. 2000).

Left platform thickness

To assess how platform thickness varies across the platform, platform thickness is measured in multiple locations. The left platform thickness measurement is determined via the platform width measurement. Once platform width is measured, it is divided by five and left platform thickness is taken at 1/5 the total platform width as measured from the lateral extreme of the left side of the platform. It is measured along the same axis as platform thickness. The flake is viewed such that the ventral side is closest to the analyst (see Figure 2.1b).

Right platform thickness

The right platform thickness measurement is determined via the platform width measurement. Once platform width is measured, it is divided by five and right platform thickness is taken at 1/5 the total platform width as measured from the lateral extreme of the right side of the platform. It is measured along the same axis as platform thickness. The flake is viewed such that the ventral side is closest to the analyst (see Figure 2.1b).

Maximum dimension

Maximum dimension is measured as the greatest distance across the ventral face along any axis. Contours along a core's surface often provide the stone tool producer with a guide for the direction that the fracture line will follow. Depending on mass distribution and skill in production, the stone tool producer can predict the longest axis of a given flake.

Platform area

The six platform variables described above are combined to estimate platform area. Platform Area has traditionally been calculated as platform width multiplied by platform thickness (Dibble and Pelcin 1995). This simple calculation, however, assumes a rectangular platform shape and thus may overestimate or underestimate true platform area (Shott et al. 2000).

For comparison of archaeological assemblages using the variable defined above, multivariate analyses (like Multivariate Analysis Of Variation (MANOVA)) require that variables be independent. To determine if measurements covary, covariance coefficients were calculated between each of the eleven variables. Not surprisingly given their similarity, platform measurements are not statistically independent (Table 2.2). A measure of platform area produces a composite of these measured platform variables that can be used for statistical purposes with the other, previously described measurements. The methodology presented here requires only the use of digital calipers and thus is a mobile means of calculating platform area. This is particularly useful for measuring platform area on a large assemblage of flakes and is a reliable, quick alternative to photographic analysis of platform area.

Platform area is calculated using simple geometry. The platform measurements taken for each flake are depicted in Figure 2.1b and in an idealized illustration in Figure 2.2a and 2.2b. The triangle formed (Triangle A) from the left platform thickness measurement (the base of the triangle) and *h* (the height of the triangle, which is 1/5 the total platform width) is calculated using the basic formula for calculating triangle area (*E1*) in which *b* is the base of the triangle and *h* is the height of the triangle:

Table 2.2: Covariation coefficients for platform measurements taken on all whole flakes

Variable	PW	LPW	RPW	PT	LPT	RPT
PW	1.0					
LPW	**0.89**	1.0				
RPW	**0.89**	0.62	1.0			
PT	0.68	0.60	**0.81**	1.0		
LPT	0.64	0.51	0.62	**0.81**	1.0	
RPT	0.61	0.57	0.53	**0.83**	0.69	1.0

(E1) $$A = 0.5bh$$

The triangle formed (Triangle B) on the right lateral side of the platform is similarly calculated using right platform thickness (b) and h (see Figure 2.2a).

To approximate the remaining area between triangles A and B, the areas of triangles C and D are calculated. However, as Figure 2.2b demonstrates, simply calculating the area of triangles C and D underestimates the total platform area. Thus the basic triangular area equation, *E1*, is an insufficient approximation for triangles C and D. To better estimate the actual areas of the platform above and below the platform width dimension and between the left and right platform thicknesses, equation *E2* is used.

(E2) $$A = xbh$$

In *E2*, the base (b) of triangles C and D is Middle Platform Thickness (MPW), which is simply 3/5 of the total platform width. The height (h) of triangles C and D are Bottom Platform Thickness (BPT) and Upper Platform Thickness (UPT), respectfully. The coefficient (x) corrects for the underestimation of area by *E1*. To determine BPT, UPT, and x, the following steps are taken.

To calculate the height of triangle C (BPT), Heron's Law is used (Figure 2.2c). In Heron's Law, if all three sides of a triangle are known, the following formula (*E3*) calculates the area (A) of the triangle, where s is the semi-perimeter of the triangle.

(E3) $$A = \sqrt{s(s-a)(s-b)(s-c)}$$

Figure 2.2a:

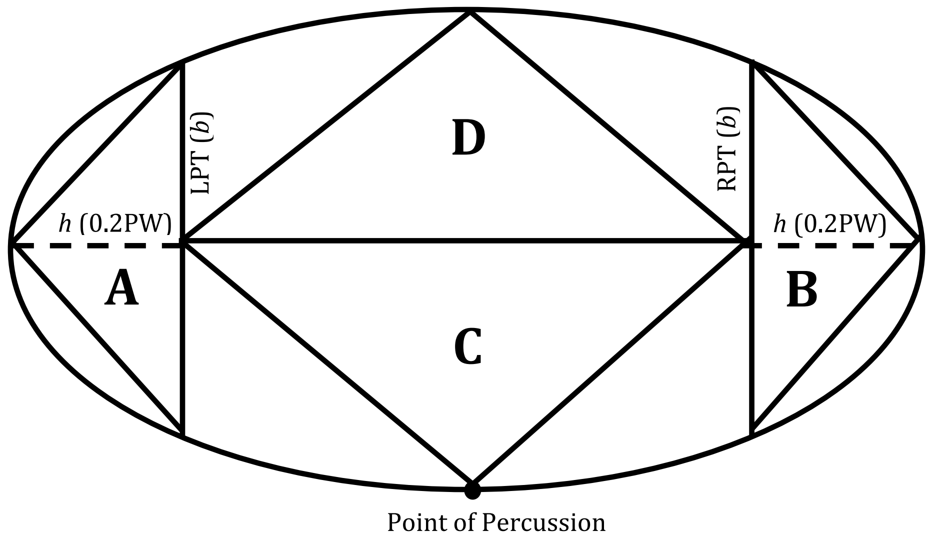


Figure 2.2b:

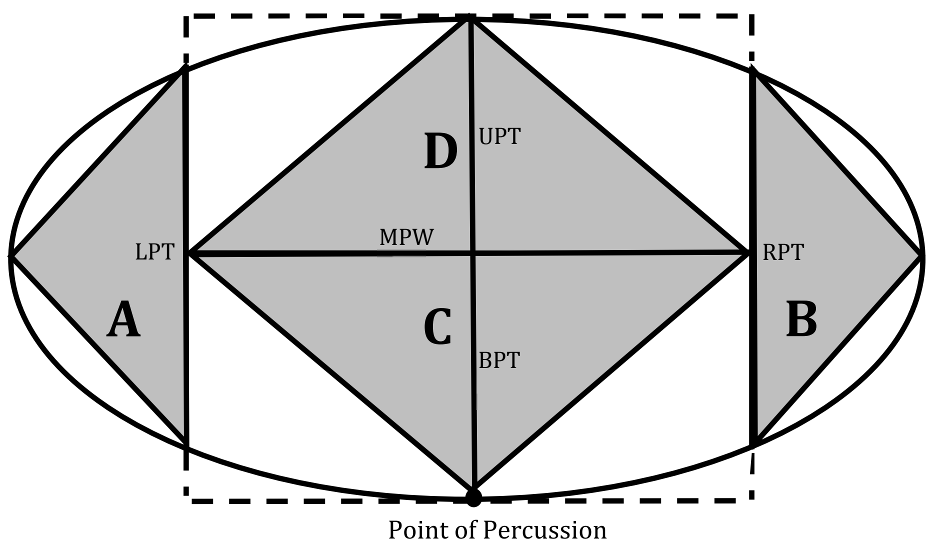


Figure 2.2c:

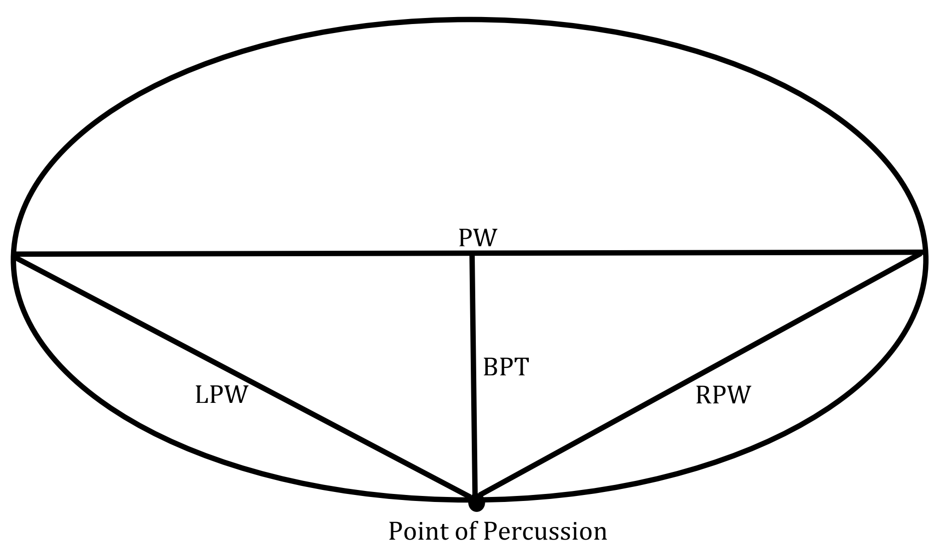


Figure 2.2: a) Each platform is divided into four triangles. Triangles A and B show the variables for base (*b*) and height (*h*), used in calculating their areas. b) Simply calculating the areas of Triangles C and D leaves a large portion of the platform area out and thus underestimates total platform area. c) In order to determine the actual areas of Triangles C and D, their respective heights must first be determined. PW, LPW, and RPW are used in Heron's Law to calculate the area of the triangle depicted here. This area is then used to calculate the height of that triangle, which is also the height of Triangle C. Subtracting BPT from PT will provide the height of Triangle D (UPT).

The area of this larger triangle (seen in Figure 2.2c) is not itself useful for calculating total platform area. This is because the lateral portions of this triangle include parts of triangles A and B, which have already been estimated. Including this larger triangle would therefore overestimate the total area of the platform. Instead of using the area of this triangle to calculate total platform area, it is used to calculate the triangle height (BPT) of triangle C by solving *E1* for *h* (see *E4*). Upper Platform Thickness (UPT), which is the height of triangle D, is calculated by subtracting BPT from PT.

(E4) $$h = \frac{2A}{b}$$

To calculate the coefficient, *x*, three idealized versions of platforms are used to establish expected coefficients given the relative measurements of PT, LPT, and RPT (Figure 2.3). Based on these expectations, a linear equation is derived to model any actual measurements on archaeological flakes.

The first idealized version is a scenario in which PT = LPT = RPT. In this scenario, using equation *E1* would omit the light gray platform areas. To more accurately estimate the areas of triangles C and D, the formula below is used:

(E5) $$A = 1.0bh$$

This is simply the product of (length x width), which is the total area of the rectangles depicted in Figure 2.3a. In this case, the coefficient (*x*) used for the area equation is 1.0.

The next idealized scenario (Figure 2.3b) is when PT = 0.5LPT =0.5RPT. In this scenario, using formula *E6* is appropriate and is a close approximation of platform area when added to the areas of triangles A and B. In this case, the coefficient (*x*) used for the area equation is 1.5.

(E6) $$A = 1.5bh$$

The final idealized scenario (Figure 2.3c) is when PT = 2LPT = 2RPT. In this case, the formula calculating area of a rectangle (A=BH) overestimates the upper and lower areas of the platform, but the formula calculating area of a triangle (*E1*) underestimates the upper and lower areas of the platform. However, using a coefficient (*x*) of 0.75 (*E6*) approximates platform area well, as seen in Figure 2.3c.

(E7) $$A = 0.75bh$$

Of course, actual flake platforms will have any combination of relative platform thicknesses. Using the idealized scenarios described above, the average of the LPT and the RPT was calculated, and then the ratio between PT and this average was determined for each scenario using an arbitrary, unitless value of “10” as the standard (Table 2.3). Each of these idealized scenarios has a known coefficient used to calculate area. The ratio between PT and the average Left and Right Platform Thickness is plotted against the

Figure 2.3a: PT = LPT; PT = RPT
(E5): Area = 1.0bh

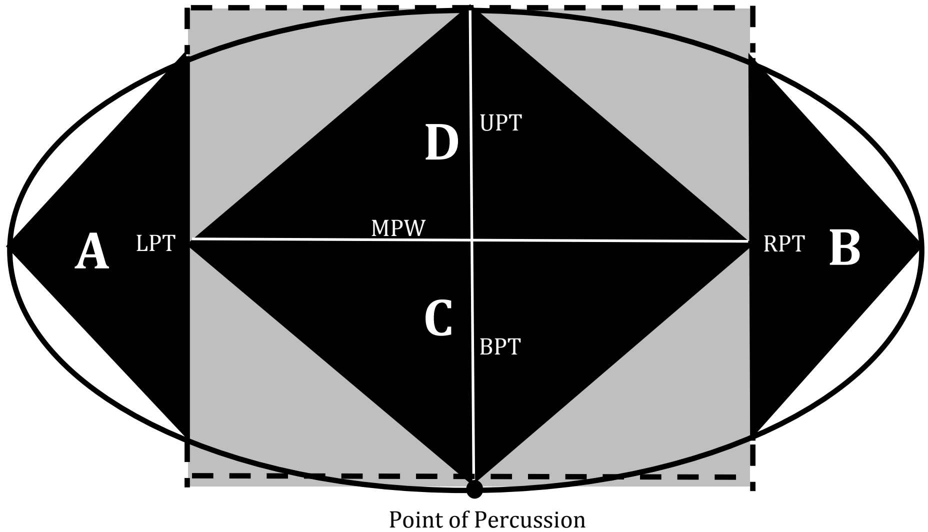


Figure 2.3b: PT = 0.5LPT; PT = 0.5RPT
(E6): Area = 1.5bh

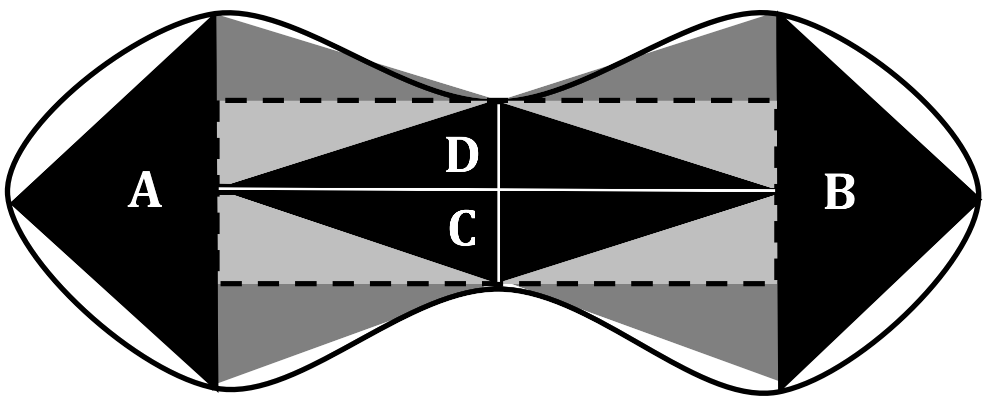


Figure 2.3c: PT = 2LPT; PT= 2RPT
(E7): Area = 0.75bh

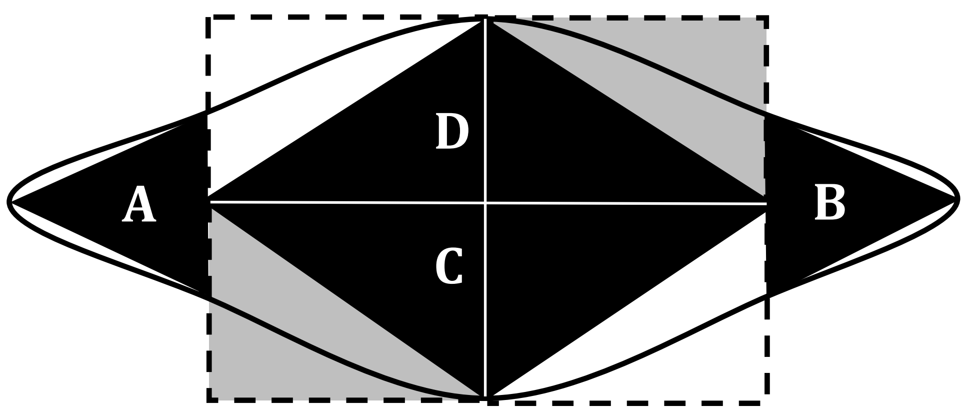


Figure 2.3: The figures above demonstrate platform area calculations for three idealized scenarios. a) The platform thickness, left platform thickness, and right platform thickness are all equal. In this case the coefficient used to calculate the area of Triangles C and D would be 1.0. b) The platform thickness is exactly half of the left and right platform thicknesses. In this case the coefficient used to calculate the area of Triangles C and D would be 1.5. c) The platform thickness is exactly twice the size of left and right platform thickness. In this case the coefficient used to calculate the area of Triangles C and D would be 0.75. Of course, platform dimensions rarely fit such parameters. The theoretical scenarios presented here (and in arbitrary units in Table 2.3) provide a means to construct a general equation to model any platform based on the relative platform thicknesses.

Table 2.3: Idealized relationship between platform thickness values and the coefficient used to calculate the areas represented by triangles C and D in Figure 2.3

PT	LPT	RPT	X*	X/PT	Coefficient
10	10	10	10	1.0	1.0
5	10	10	10	2.0	1.5
20	10	10	10	0.5	0.75

* X = Average of LPT and RPT (LPT+RPT/2)

Figure 2.4:

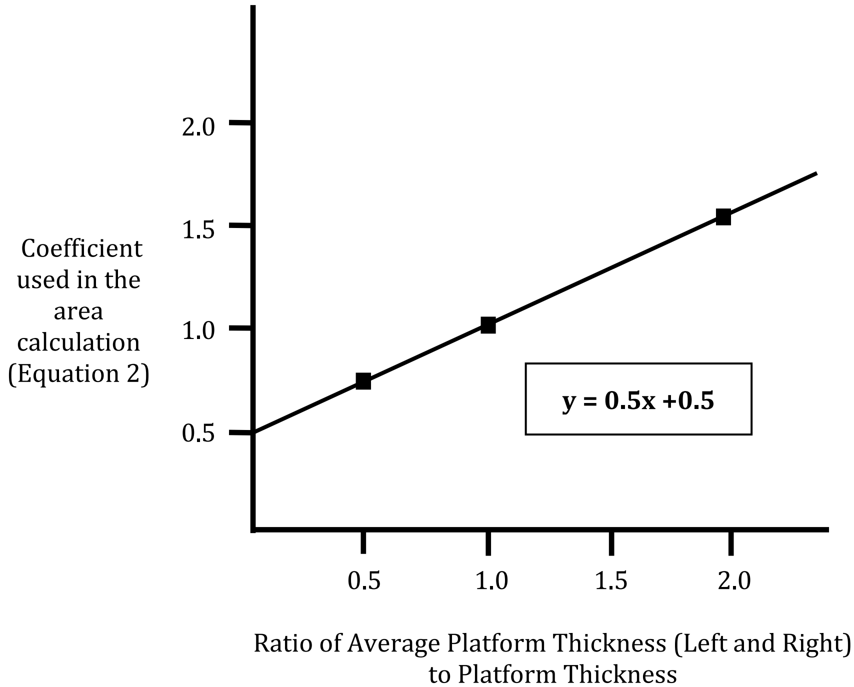


Figure 2.4: The points plotted here demonstrate the relationship between variable platform thicknesses and the coefficient that best estimates area given that relationship. The plotted points are derived from the idealized scenarios in Figure 2.3 and the hypothetical values in the last two columns in Table 2.3.

idealized coefficient in Figure 2.4. This linear relationship can be described through the linear formula (*E8*):

$$\text{(E8)} \qquad y = 0.5x + 0.5$$

The value of *y* is the ratio between PT and Left and Right Platform thickness and is thus empirically known via measurements. The dependent variable is the coefficient, *x*, which is calculated and then used as the coefficient in the original equation, *E2,* to calculate the area of triangles C and D. For triangle C, MPW is *b* and BPT is *h*; for triangle D, MPW is *b*, and UPT is *h*.

For each flake, the coefficient for the area formula was calculated to produce area approximations for triangles C and D. These areas were added to the areas calculated for triangles A and B to get a value for Total Platform Area (PA).

The accuracy of this estimation of platform area was tested using digital software. Digital photographs were taken of the platforms of a random sample of 40 replicated flakes, produced on Koobi Fora basalt. Platforms varied in terms of shape, size, and cortical covering. A Benchmark photographic stand ensured stable lighting and clear photographs taken with a Canon EOS T2i digital camera. A metric scale was used for each photograph and was placed at the same focal height as the platform (+/- 1.0 mm) to ensure that issues of parallax would not affect scaling (McPherron and Dibble 1999; Braun and Harris 2003). Images were imported into the computer program ImageJ Version 1.45s (Rasband 2007) for analysis. Each platform was digitally outlined, thus providing an empirical assessment of actual platform area. These measures of platform

Figure 2.5: Test of accuracy for the equation *E2*, calculating Platform Area

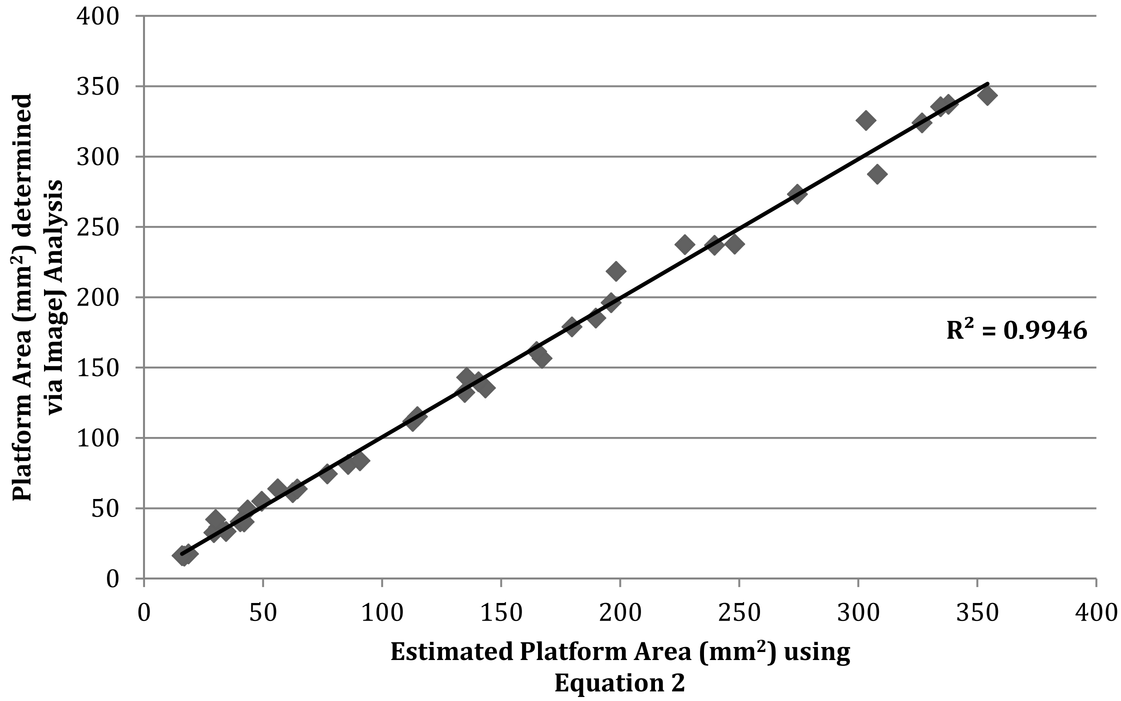


Figure 2.5: Empirically derived values for Platform Area were determined via ImageJ and were plotted against estimated Platform Area values determined via the derived equation, *E2*. Results show significantly correlated results ($r^2 = 0.9946$).

area were plotted against the platform area estimated that was calculating by using *E2* and the methods outlined above. Figure 2.5 demonstrates that actual and estimated platform areas are highly correlated ($r^2 = 0.9946$). This relationship is statistically significant, demonstrating that no difference exists between the two samples (Mann-Whitney U-Test, $p=0.98$ for $\alpha = 0.01$).

Equation *E2*, as derived from the idealized platforms depicted in Figure 2.3, thus provides an accurate measure of platform area. This technique provides an efficient and mobile method of calculating platform area for this and future studies.

II.A.4. Size standardizing measurements

Identical production behaviors can potentially produce flakes of very different sizes. Imagine flaking a large cobble: the first step to identifying an appropriate platform is to find an acute angle near the edge of that cobble. Using only this criterion to produce a flake, a flintknapper could remove a relatively large flake from a large cobble. Using the same criterion to produce a flake from a relatively small cobble, the same flintknapper might produce a relatively small flake. The behavior related to the production of both flakes is identical, yet the flakes are morphologically distinct based on size. Based on this basic fact, all measurements of flakes are size standardized to remove size-dependent bias from statistical analyses. In this way, flakes are analyzed only based on relative *shape*, not size.

Traditional size standardization techniques in lithic analysis have relied on using measurements assumed to approximate size to standardize all variables (i.e. Wynn and Tierson 1990). However, using measures such as length, maximum dimension, or weight, to size standardize has been criticized in evolutionary biology due to constraints of the sample size, deviations from normal distributions within assemblages, and consistency in fitting lines of regression (Aiello 1992; Falsetti et al. 1993; Martin 1993). To avoid such problems, flakes are size standardized using a geometric mean (see Lycett et al. 2006).

The geometric mean "is the *n*th root of the product of all *n* variables" in which size standardizing occurs on a specimen-by-specimen basis (Lycett et al. 2006:854). In other words, to size standardize each measurement using a geometric mean, each of the six variables measured for a given flake (length, width, thickness, maximum dimension, platform area, and bulbar thickness) are first multiplied together to produce a composite of all variables. Each measurement for that flake is then divided by the sixth root of this composite number. Taking the sixth root of the multiplied value creates a one-dimensional value that is then used to standardize each of the other individual variables. Platform area (PA), it should be noted, is a two-dimensional variable (its units are in mm^2). Before geometric mean is calculated, the square root of PA is first determined so as to produce a measure comparable in units (*mm*) to all other measurements. Flakes are standardized on a specimen-by-specimen basis so that they can be directly compared based solely on shape criteria. The effectiveness of using geometric mean, as opposed to the more traditional weight standard is demonstrated in Figure 2.6.

II.A.5. Statistical tests

The size-standardized variables measured for each flake are used to run a Multivariate Analysis of Variation (MANOVA) in the statistical program MATLAB

Figure 2.6:

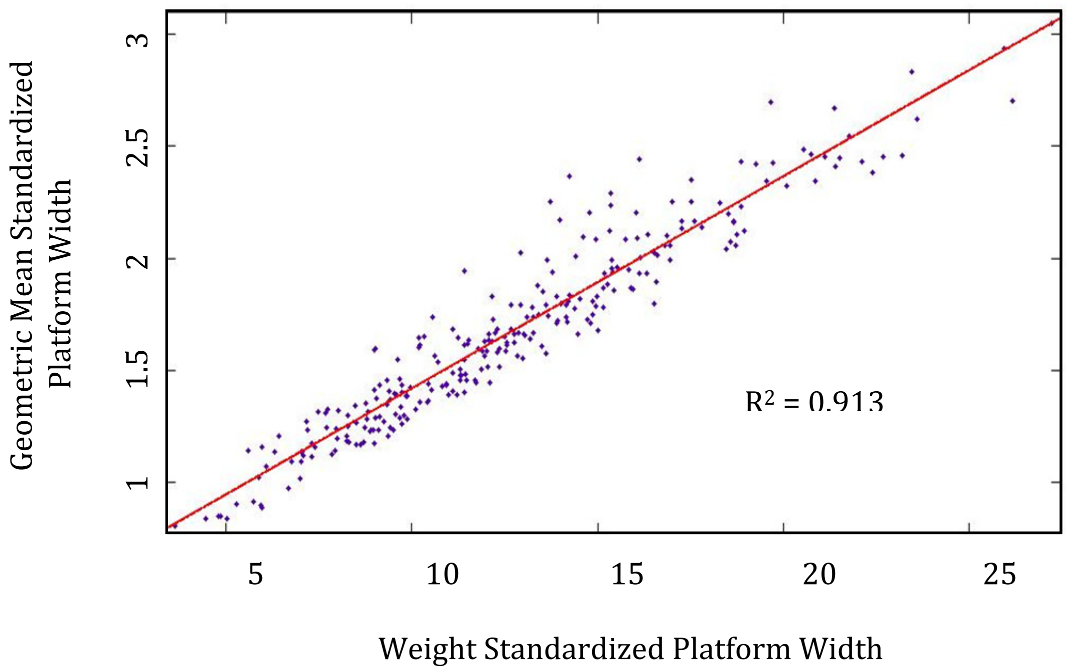


Figure 2.6: This graph compares size standardization methods. With the X-axis, platform width has been standardized using the traditional measure of weight; the Y-axis has been standardized via geometric mean as discussed in the text.

(version 2012a). Flakes are grouped as assemblages and statistically assessed relative to other assemblages. Assemblages can, therefore, be classified differently. A group of sites from one locality can be tested against one another to assess variation within a locality. Alternatively, these sites might be grouped together to make a regional assemblage so that this regional assemblage can be statistically tested for variation relative to another regional assemblage.

The null hypothesis for all assemblage comparisons is that there is no difference between them. If MANOVA tests validate this null hypothesis (show no statistical difference between assemblages), then there is little need to address differential production behaviors. If, however, this null hypothesis is invalidated (MANOVA tests successfully demonstrate statistical morphological variation between assemblages), this identified variation needs to be explained in terms of behavior. If stone tools look different, *how* are they different, and most importantly, *why* are they different? Significant MANOVA results do not necessarily indicate dramatic differences in production strategies, but could represent different ratios of similar behaviors at different sites. Thus these statistical results only provide a broad analysis that warrants further investigation.

II.B. Experimental explanation of archaeological variation

To address the behavioral implications of variation among archaeological assemblages, BLA utilizes experimental methods. The second stage of BLA development requires stone tool replication experiments utilizing raw materials native to the archaeological site(s) in question under controlled experimental settings.

Experimental stone tool production has a long history as an archaeological tool. The term “flintknapping” refers to the production of stone tools generally, such that modern day enthusiasts are called “flintknappers.” This contrasts with the scientific concept of “replication,” which refers to controlled methods that seek to accurately model archaeological phenomena. Francois Bordes was a renowned stone tool producer and used the information he gained through their reproduction to bolster his archaeological arguments. Don Crabtree is considered the father of American flintknapping and published widely on the methodologies, terminology, and utility of replication as a tool in archaeology (Crabtree 1970, 1972). Experimental replication as an analytical tool gained momentum by the early 1980s in Early Stone Age contexts (Toth 1982, 1985, 1987), North American archaeological settings (Callahan 1979; Magne and Pokotylo 1981; Patterson and Sollberger 1978; Patterson, 1982; Amick et al. 1988; Ahler 1989a, 1989b; Mauldin and Amick 1989), and in terms of defining fracture mechanics (Dibble and Whittaker 1981; Cotterell and Kamminga 1987).

Research related to replication analyses seeks to produce flakes with as much control as possible to *model* production behaviors utilized by earlier human populations. This is not to say that replication studies are exact replicas (or that analysts assume them to be exact replicas) of archaeological material; rather, replicated materials represent assemblages with known sets of controlled conditions surrounding their manufacture. Replicated assemblages, therefore, allow for the experimental creation of *expectations* for archaeological material given a certain set of conditions. Using these assemblages allows for hypothesis construction and testing, but is not meant to serve as a direct analogue to archaeological artifacts.

The second stage of BLA development is meant to construct an experimental model to explain the morphological variation identified in archaeological assemblages from the first step of BLA. The following section describes the necessary controlled elements for these replication experiments and defines the theoretical and methodological parameters placed on the replication experiments themselves.

II.B.1. Raw material selection

Raw materials fracture in different ways depending on, among other factors, their relative density, hardness, brittleness, crystalline qualities, and homogeneity. For instance, the volcanic glass obsidian will fracture very easily and produce an extremely sharp edge while fine-grained volcanic basalts are generally quite difficult to fracture because they are far harder and denser. Raw material selection for replication experiments is, therefore, of utmost importance. For BLA, raw materials should be the same raw materials utilized by the archaeological population in question. In this way replication experiments model the actual fracture mechanics that the population in question faced when production stone tools and the replicator will be faced with similar fracture planes and potential production problems.

II.B.2. Sample size

Many replication experiments have been conducted, but with few exceptions (see Toth 1982) the experimental sample size is quite small (Braun et al. 2008; Diez-Martin et al. 2011). Small experimental sample sizes are problematic when the results are applied archaeologically for several reasons. First, even when using a single raw material, internal quality of that raw material can differ significantly from one cobble to another and this will affect how that cobble fractures. Second, variation in initial cobble size can affect the morphologies of flakes that result from reduction of that cobble. Third, variation in the initial cobble shape can dramatically affect how flakes are removed from that core and in the morphology of the resulting flakes. Fourth, variation in hammerstone size and material may or may not play a role in determining the resulting flake morphologies. Each of these aspects of experimental reduction must be statistically addressed in order to determine the efficacy of experimental methods to model archaeological behaviors.

Reduction experiments should, therefore, include an extremely large sample size of reduced cores in order to produce an assemblage large enough to statistically assess the natural variation produced from core shape, core size, variation in raw material quality, and hammerstone variation. Previous replicative research has limited experiments to approximately 30 cobbles. The research presented in this dissertation included the systematic reduction of 443 cobbles (360 usable cobbles), from three different raw materials to yield 3651 total detached pieces. This project is the largest experimentally produced stone tool assemblage to ever be undertaken. The expectations for archaeological assemblages are, therefore, the most statistically robust in the archaeological literature.

II.B.3. Hammerstone selection

BLA requires that hammerstone selection is empirically determined through archaeological assemblage composition. Based on the material and weight of excavated hammerstones, stone with equivalent weight and raw material are selected from the landscape in question (if available). Multiple hammerstones are utilized during reduction experiments. Hammerstones are varied around the mean weight of the archaeological sample and should include hammers that are near the mean weight, near one standard deviation above the mean, and near one standard deviation below the mean. For research conducted in this study, hammers near two standard deviations above the mean were also utilized to demonstrate conclusively whether hammer weight statistically affects resulting flake morphologies of these particular raw materials.

II.B.4. Identifying production behaviors in the Oldowan Industry

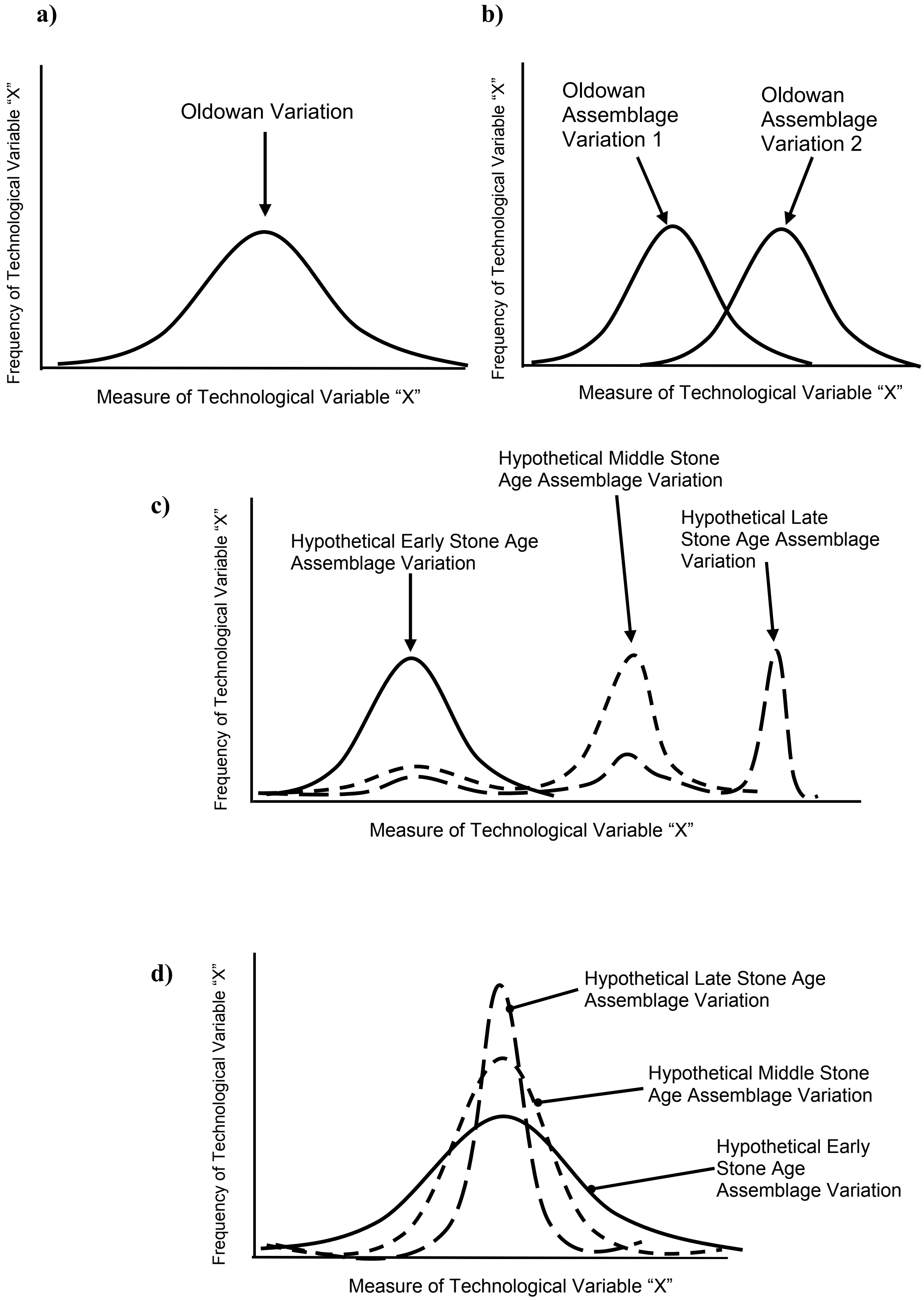
Methodologically, BLA has thus far been described quite generally. This is because BLA is meant to be widely applicable to archaeological assemblages. However, it is necessary to fully explain the theoretical and methodological reasons why this study applies BLA to the Oldowan Industry of East Africa. The following subsections outline why the Oldowan is methodologically a necessary starting point for BLA development and then describes how replication experiments are conducted and how individual production behaviors are identified and defined within the Oldowan.

II.B.4.a Necessity of beginning with the Oldowan

Quantifying production behaviors necessitates being able to identify specific production behaviors. As technological prowess increases through time over human evolutionary history, control of stone tool production also increases and production behaviors necessarily become more complex. Ideally, suites of production behaviors associated with different technologies through time will be identified and quantified. Accomplishing such a feat, however, requires understanding how technological production behaviors change through time. Beginning with the earliest identified technology, the Oldowan, therefore, is the most logical choice. By quantifying Oldowan behaviors, deviation from expected Oldowan behaviors might theoretically be identified in the Developed Oldowan and Acheulean, leading to a fruitful dialogue of technological change based on statistically identified production behaviors through time and across space.

The Oldowan also presents potential analytical problems. Oldowan production patterns have traditionally been considered simple and expedient in nature (Leakey 1971; Kimura 1999, 2001; Kyara 1999; Tactikos 2005). Even though evidence presented in this study demonstrates differential production patterns within Oldowan technology and therefore more advanced production skills that previously thought, the Oldowan, by definition, is the most primitive technology as of yet identified. This means that a large range of variation in flake morphologies is expected since technological prowess was not as advanced as later times. This range of variation might be thought of as a distribution curve for a given technological variable called *variable X* (Figure 2.7a). For the Oldowan, this distribution is predicted to be fairly wide and thus identification of any particular behavior is statistically difficult. However, as technological ability becomes more refined through time (Figures 2.7c and 2.7d), the distribution of *variable X* is predicted to become narrower such that a particular value of that variable becomes a predictor for a certain behavior (or behaviors). The problem with the Oldowan, then, is

Figure 2.7:


a)
Oldowan Variation
Frequency of Technological Variable “X”
Measure of Technological Variable “X”
b)
Oldowan Assemblage Variation 1
Oldowan Assemblage Variation 2
Frequency of Technological Variable “X”
Measure of Technological Variable “X”
c)
Hypothetical Early Stone Age Assemblage Variation
Hypothetical Middle Stone Age Assemblage Variation
Hypothetical Late Stone Age Assemblage Variation
Frequency of Technological Variable “X”
Measure of Technological Variable “X”
d)
Hypothetical Late Stone Age Assemblage Variation
Hypothetical Middle Stone Age Assemblage Variation
Hypothetical Early Stone Age Assemblage Variation
Frequency of Technological Variable “X”
Measure of Technological Variable “X”

that variation might be so broad that statistically identifying individual behaviors is difficult. However, if the suite of variables already defined can tease apart this wide distribution of variation within the Oldowan, then: 1) at a minimum, statistical parameters can be placed on individual flake morphologies to determine the likelihood of behavioral belonging or 2) in a best case scenario, flake morphologies successfully identify individual production behaviors to a statistically significant level. It is hypothesized that within the Oldowan, categorical placement will include higher rates of misclassification than later technologies, given the broad variation in morphology represented by Oldowan production techniques. Oldowan assemblages could, however, separate more cleanly than predicted (Figure 2.7b) and demonstrate that either the behaviors utilized to produce lithic implements was different or that the behaviors utilized to produce lithic implements are not as expected.

The Oldowan provides a platform from which to establish evidence for how hominin populations initially produced stone tools. From this foundation further analysis can quantitatively demonstrate how production strategies deviate from this initial strategy and begin to explain what adaptive strategies these deviations were fulfilling; in other words, the evolutionary history of stone tool production can be expressed objectively and quantitatively.

II.B.4.b Least effort approach to stone tool manufacture

Viewing the Oldowan as a simplistic technology has led to body of experimental literature that models stone tool manufacture during this time period through a "least effort approach" to manufacture (see Bunn et al. 1980; Isaac et al. 1981; Toth 1982;

Kimura 1999; Kyara 1999; Delagnes and Roche 2005; Tactikos 2005; Braun et al. 2008). The least effort model assumes that stone tools were being produced using the easiest platform at a given time; forethought to core shape and form is not considered under the least effort approach. After each flake removal, the least effort approach would be to reassess the platforms available on the core and select the one that is most acceptable for flake production.

BLA for the Oldowan assumes a least effort approach during experimental replications. Each flake removal follows what is considered the most effective platform at a given time. Using this approach there is no distinct "reduction sequence" for any given core. Rather, flakes are removed as independent behavioral events, each dependent on the core morphology at the time of its creation. Each flake removal, however, has a particular production behavior associated with its manufacture. All conclusions in this report are relative to this least effort approach to flake manufacture.

II.B.4.c. Defining Oldowan production behaviors

BLA uses production behaviors to define how stone tools were manufactured. "Production" refers to the actual manufacture of the flake in question; "behavior" refers to the combination of the *cognitive understanding* necessary to produce flakes in a particular way and the *ability* to successfully remove the intended flake.

Four production behaviors were experimentally identified via a pilot study for this research (Reti, 2009) that explain the behavioral suite behind how all Oldowan core forms could have been manufactured. The following defines each of these behaviors.

Oldowan Behavior A (OBA):

To intentionally produce a flake via hardhammer percussion, one primary piece of knowledge concerning fracture mechanics is cognitively necessary: an acute angle at the edge of the rock is needed for successful flake production. Conchoidal fracture requires that the force that is put into a particular rock via percussive action exits that rock; the point of entry of the force is the point of percussion, while the point of exit of the force is the distal termination of the flake. If one strikes a cobble along an obtuse-angled edge, or in the center of that piece of material, it much more difficult to produce a predictable flake (if at all). Oldowan Behavior A (OBA) is a flake that has been produced by striking anywhere on an unmodified surface that forms an acute angle along the edge of that cobble (Figure 2.8).

Oldowan Behavior B (OBB)

Using a least effort model for flake production, once a flake has been produced using OBA the stone tool producer reevaluates the core and finds the next-most desirable platform to produce the next flake. This platform might be an unmodified portion of the core that is unrelated to the initial flake removal, in which case the resulting behavior would still be OBA. As discussed in the fracture mechanics section of this chapter, predictability of flake production increases when a platform is placed above the ridge produced from a previous flake removal. Cognitively understanding this aspect of fracture mechanics results in Oldowan Behavior B (OBB). The platform utilized for OBB is adjacent to a previously utilized cortical platform that produced another flake. The ridges on either side of this flake scar produce areas of relatively higher mass and also provide directionality for the force of another hammerstone strike to follow (Figure 2.9). Removal of several flakes in the manner produces a "unifacial chopper," using the Leakey typology.

Oldowan Behavior C (OBC)

Following either an OBA or OBB flaking event (or any combination thereof), the stone tool producer may begin to bifacially flake the core. Bifacial flaking requires that the core be flipped over such that a flake scar produced from previous flake removals becomes the platform for the next flake. Utilizing a cortical platform requires more force to produce a successful flake, and thus often results in more unpredictable flaking events. This is because cortex, especially if it is relatively thick, dampens the hammerstone blow and thus absorbs some of the force being transferred into the core. Utilizing a non-cortical surface removes this dampening effect. Oldowan Behavior C (OBC) requires an understanding by the stone tool producer that a non-cortical surface is beneficial to flake production (Figure 2.10). Removal of OBA, OBB, and OBC flakes from the same edge of a core produces a core form that the Leakey typology refers to as a "bifacial chopper."

Oldowan Behavior D (OBD)

Following either an OBA, OBB, or OBC flaking event (or any combination thereof), an Oldowan stone tool producer may realize that flaking around the perimeter of the core produces not only usable flakes, but also produces acceptable platforms for further flake removals. The combination of OBA, OBB, and OBC flakes produces a bifacially flaked core, or as M.D. Leakey would have typologically called it, a bifacial chopper. This kind of bifacial flaking removes flakes directly toward the midline of the core (Figure 2.11a). Flaking limited to this kind of bifacial flake removal will result in a relatively blocky and thick core that becomes difficult to flake (Figure 2.11b).

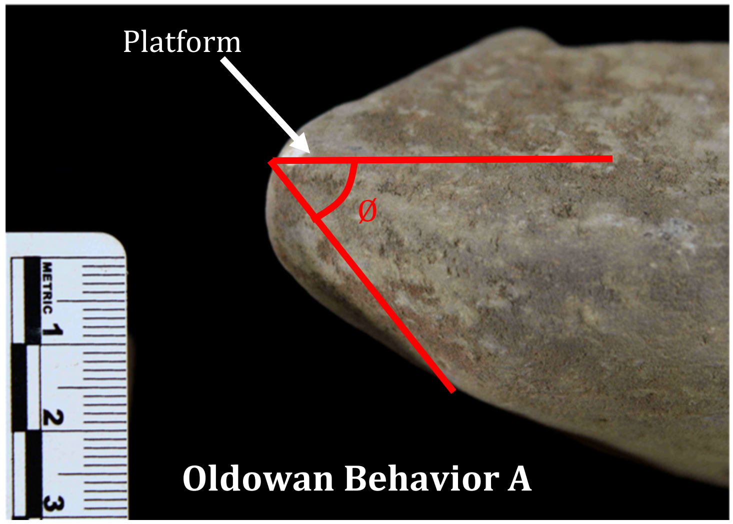
Instead of focusing the direction of the hammerstone strike directly toward the midline of the core, as with OBB and OBC flaking events, Oldowan producing hominins were cognitively aware and capable of directing the force of their hammerstone blows at an angle that propagated flakes around the perimeter of the core (Figure 2.12a). This behavior of directing flake removals around the core's perimeter designates Oldowan Behavior D (OBD). On most occasions, OBD flake production behavior produces an acceptable new platform on the flake scar created (Figure 2.12b). Several flakes removed in succession produces a characteristic "zig-zag" edge along the core that is particularly diagnostic of discoids (using the Leakey typology).

If the most efficient platform is available on a surface that produces a flake going in a direction other than the two bifacial directions already established on a core, the resulting core form is referred to as a "polyhedron" under the Leakey typology. However, no new behavior is necessary to produce this core form. Rather, if a cobble is rather thick and/or blocky to begin with, it seems that an OBB or an OBC behavior, directed in a new direction, is responsible for polyhedron production.

Each of these behaviors builds upon the cognitive understanding of the other behaviors and demonstrates a clear understanding of fracture mechanics and an ability on the part of the Oldowan hominin responsible to actualize his/her intention. It is important

Figure 2.8:

a)



b)

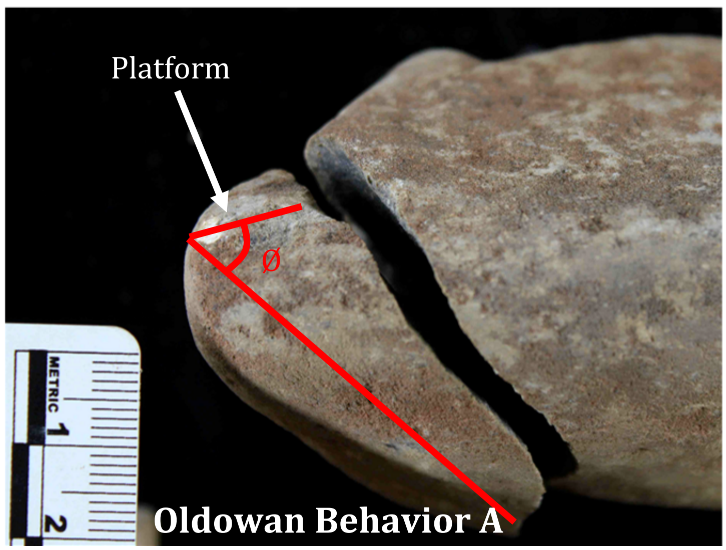
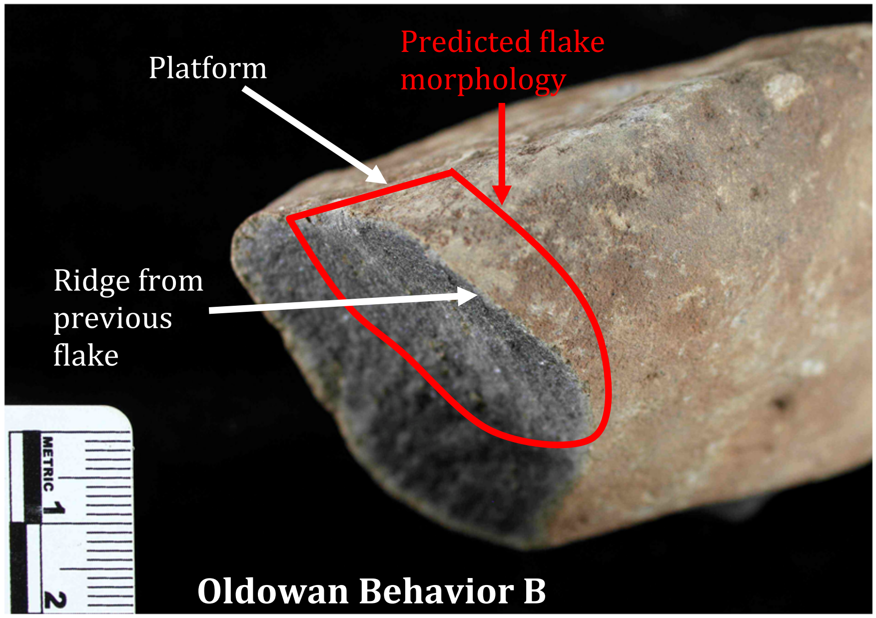


Figure 2.8: In (a) an unmodified cobble of Koobi Fora basalt is shown. The primary behavior (or Oldowan Behavior A (OBA)) necessary for regular flake production on the part of hominins is the realization that striking the platform must rest on an acute edge of a cobble. Once this behavior is realized, flakes can be regularly produced (b). While OBA flakes are necessarily the first flake removed from a cobble, they do not *necessarily* denote lack of reduction. OBA flakes can also be removed when other available platforms are lost. This same cobble of KBS basalt is used to demonstrate Oldowan Behavior B, Oldowan Behavior C, and Oldowan Behavior D, in succession. Given the least effort approach to flake manufacture, however, the succession of flakes can be in any order and can change at any time given the morphology of a given core and the results of attempted flake removals.

Figure 2.9:

a)



b)

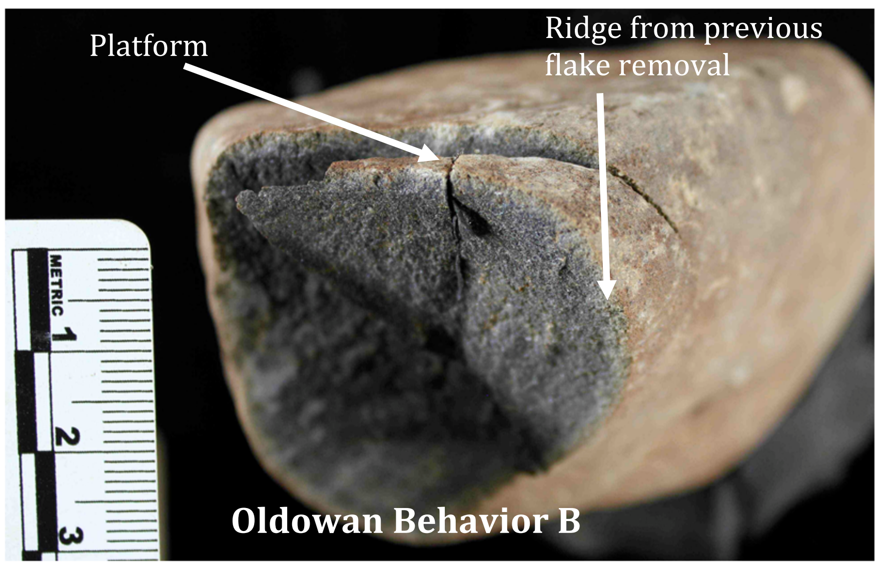
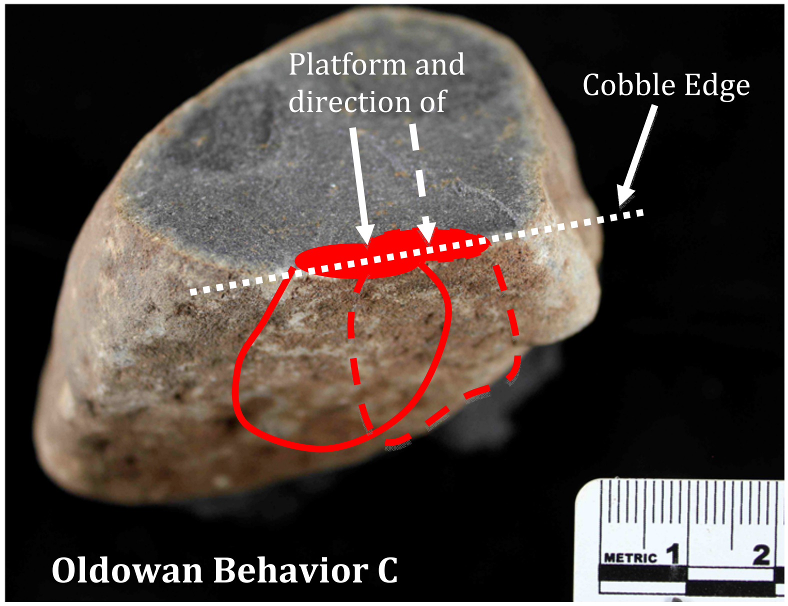


Figure 2.9: Here, Oldowan Behavior B (OBB) is defined. In (a), the flake scar produced by the OBA flake removed in Figure 2.8 can be easily seen. Another cortical, acute edge serves as the next platform for OBB. In addition to realizing that an acute edge is necessary for flake production, OBB flakes make the realization that placement of a platform above a ridge produced from a previous flake removal (and pointed out in 2.9a) produced a flake with a more predictable morphology since conchoidal fracture follows areas of higher mass (the ridged area). In (b), the resulting flake can be seen following that ridge down its dorsal side.

Figure 2.10:

a)

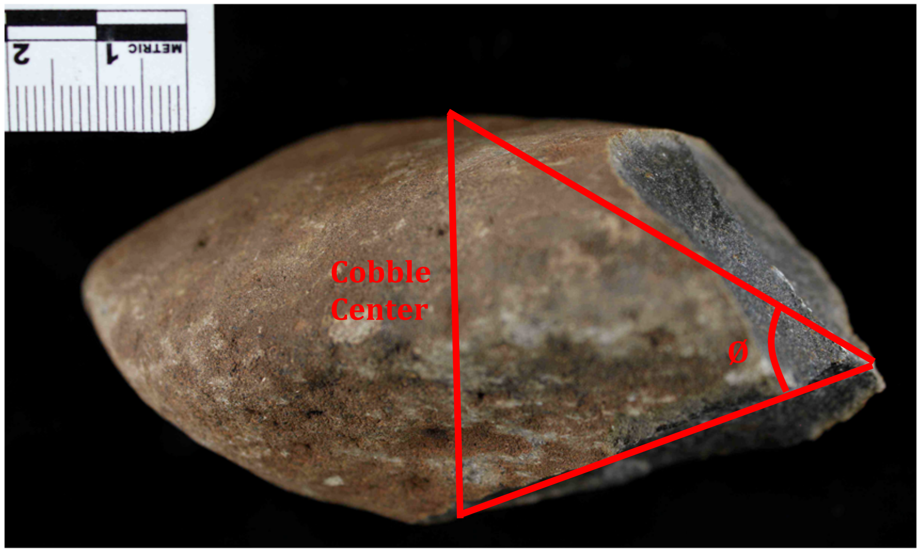


b)

Figure 2.10: Defining Oldowan Behavior C (OBC): Using the flake scars produced via one or more OBA and OBB flake removals, the behavior that distinguishes OBC flake production is the non-cortical platform and the direction of the force utilized to create that flake. In (a), a dotted white line is added and labeled “cobble edge” in order to clearly denoted the edge utilized for flake production. Note that the direction of force utilized to create these flakes is roughly perpendicular to this edge such that flake are removed directly toward the center of the cobble. This will be contrasted with Oldowan Behavior D in Figure 2.12. In (b), it is demonstrated how a series of OBC flakes might be removed along a single edge.

Figure 2.11:

a)



b)

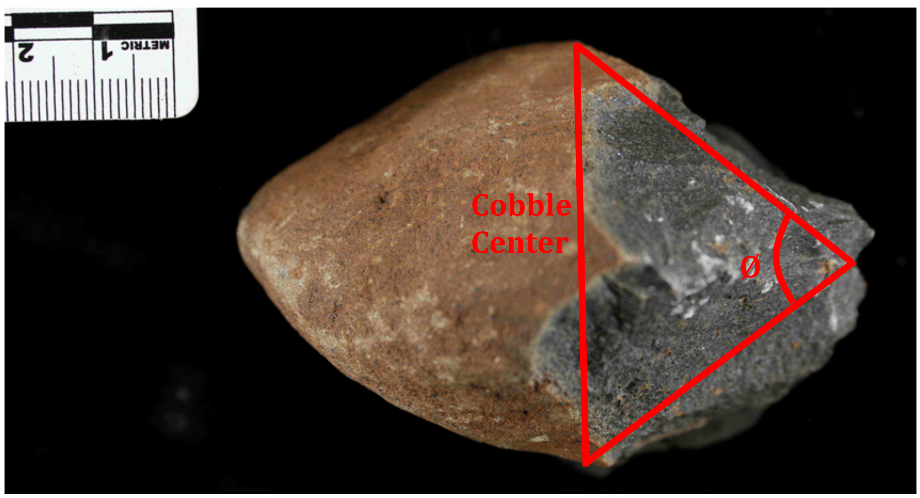
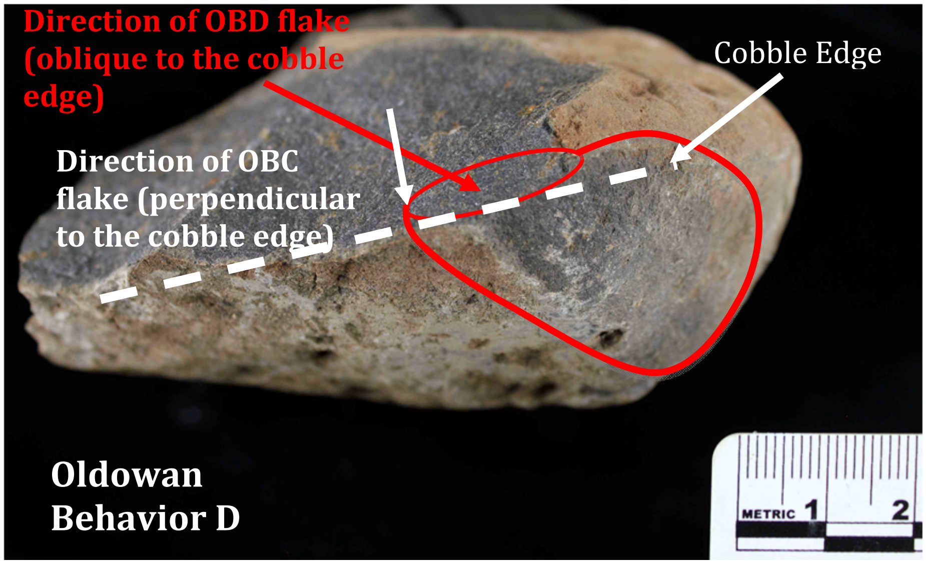


Figure 2.11: Here the directionality of flaking in the bifacial OBC flake progression is shown. If OBC flakes are produced following the removal of one or more OBA and/or OBB flakes, as is Figure 2.10, a core form that M.D. Leakey would call a "bifacial chopper" is formed (as seen in "a" above). As more OBC flakes are removed in succession, the bifacial flaking toward the center of the core (perpendicular to the cobble's edge) produces a thick core with increasingly obtuse platform angles (as seen in "b" above). Hominins avoided such problems of flake production by changing the angle that they struck relative to the cobble's edge, resulting in Oldowan Behavior D (OBD, found in Figure 2.12).

Figure 2.12:

a)



b)

Figure 2.12: Production of Oldowan Behavior D (OBD) flakes. When contrasted with Figure 2.11 (OBC flake production), OBD flake production is defined primarily by the direction of the force to produce the flake. In (a), the direction of force to produce an OBC flake is shown in white while the direction of force to produce an OBD flake is shown in red. OBC flakes are defined by the direction of force being nearly perpendicular with the cobble edge (shown as a dashed white line) whereas OBD flakes are produced using an oblique angle to that same cobble edge. The resulting flakes are more invasive and produce a scar that travels around the perimeter of the flake. In contrast, OBC flakes do not remove the perimeter and therefore make the cobble thicker and more difficult to flake (see Figure 2.11). (b) shows that an OBD flake removal and demonstrates that OBD flakes tend to produce new platforms for further flake production. A series of OBD flakes results in a core form that M.D. Leakey calls a "discoid."

to remember, however, that using a least effort approach to flake production, no single behavior necessitates that another behavior follows; behaviors are utilized only based on what platforms are available. That being said, it takes a firm understanding of fracture mechanics to weigh and consistently understand whether a cortical or non-cortical platform is more efficient to produce a flake; to decide if a less acute platform over a ridge is more likely to produce a usable flake versus a platform with a better angle but that is not associated with a ridge. Most importantly, a least effort approach necessarily means that no “reduction sequence” can be applied to the Oldowan. Each core will yield a different set of behaviors and could change depending on the success or failure of other flake removal attempts.

II.B.5. Flake production experiments

For BLA to effectively differentiate morphological traits between these production behaviors, data must be procured with careful experimental control. Every effort is taken to gather all relevant data during replication experiments. The methodology surrounding these experimental replications is described in the following subsections.

II.B.5.a. Experimental setting

Replication experiments are conducted over a canvas floor cover so that every fragment of debris is accounted for during stone tool production. Stone tool production was conducted such that the stone tool producer (J. Reti) was in an upright, seated posture. Experiments were conducted using freehand, hard hammer percussion; the core was held in the left hand and the hammer in the right hand. The left elbow was kept firmly on the left thigh so that the left arm was anchored during percussion. The hammerstone was held loosely, roughly in the manner of a baseball, such that the wrist remained loose during the hammer strike. The wrist produces the majority of the force that is transferred into the core by turning just before the moment of the strike.

Adjacent to the stone tool producer, catalog sheets were available for recording elements of each flake production event as the experiment unfolds. The criteria recorded is described below.

II.B.5.b. Hammerstone selection and use

Each hammerstone was selected based on its morphology and weight as compared to the available archaeological sample of hammerstones. Once a hammerstone was selected, its weight was recorded and entered into an Excel spreadsheet such that it is correlated with each flake produced through its use. Each hammerstone was utilized for 50 replication experiments (50 cores) or until it broke, whichever came first. The surface of each utilized hammerstones was photographed using a Canon Rebel T2i, 18 MP digital camera with either a Canon EF-S 60mm macro lens or a Canon EFS 18-55mm lens, depending on the size and surface morphology of the hammerstone. Photography methodology is described in section *II.B.6.* Photographs were recorded prior to hammerstone use and taken again after each course of ten cores was reduced, or when the hammerstone broke.

II.B.5.c. Core selection

Each cobble was measured in three dimensions: maximum length, width, and thickness. Maximum length is measured at the longest axis of the cobble. Width is measured as the longest axis perpendicular to the axis determined for maximum length. Thickness is measured as the maximum thickness in the dimension that is perpendicular to both the length and the width axes. Each cobble was also weighed to the nearest 0.1 gram using a digital scale. The core was then photographed on three sides: the upper surface, the lower surface, and the profile. Taking these measurements and photographs permanently records the initial morphology of the core prior to reduction and thus provides a potential measure of whether or not initial core morphology affects resulting flake morphologies.

II.B.5.d. Replication experiments

After a hammerstone was selected, weighed, and photographed and a cobble was selected, measured, weighed, and photographed, replication experiments began. The core was thoroughly assessed to determine potential acceptable locations for the first platform. Acceptable platform location was determined for this primary flake solely by the availability of a proper angle at the edge of the core, as described in the methodology surrounding identification of OBA (section *II.B.4.c*). Flake removal began at this platform. After primary flake removal, a data recordation sheet (Table 2.4) was utilized to record the catalog number of that flake, the number of hammerstone strikes necessary to remove that flake, the production behavior utilized to create that flake, and the completeness of the flake.

Table 2.4: Data recording sheet used during replication experiments

Catalog Number	Number of Strikes	Behavior Used	Flake Completeness

First, catalog numbers were determined based on the placement of that replication experiment. For instance, the first cobble to be reduced has a catalog number of "1." The first flake removed from this cobble has the catalog number "101." The second flake removed has the catalog number "102" and so forth. The two-hundredth core reduced has a catalog number of "200" and the first flake to be removed from that core has the catalog number "20001."

Next, the number of hammerstone strikes needed to remove each flake was recorded. Since hammerstone size is being considered a potentially important variable in flake production, the hypothesis that the number of strikes associated with each flake removal impacts the morphology of that flake is also being tested. Recording number of hammerstone strikes also provides a measure of how the surface of the hammerstone changes over its use life.

The production behavior (OBA, OBB, OBC, or OBD) associated with each flake removal was also recorded for each cataloged flake. This is perhaps the most important piece of information for this study because it links a particular flake with a particular behavior and thus, a particular morphology with a particular production event.

Finally, the completeness of the removed flake was recorded. A flake is considered "whole" if the entire platform and perimeter of that flake is intact and unbroken. A flake is considered "split" if the platform of that flake is broken in any way but the rest of the flake is complete. A flake is considered "snapped" in the platform is complete but any other portion of the flake is broken. A flake is considered "split and snapped" if the platform is broken *and* any portion of the rest of the flake is broken. Finally, a broken piece of the core may be considered a "cobble fragment" if it fractured along an impurity or broke without being struck directly. These portions of the core are cataloged with all of the information described above, but are not considered as part of the behavioral analysis.

If two complete flakes are removed with a single strike, the more external flake (further toward the dorsal side) was labeled as "a" and the more internal flake labeled as "b." In this way, two flakes may share the same catalog number (such as 1205), but the more external flake is labeled as "1205a" and the more internal flake labeled as "1205b."

No "angular fragments" are cataloged because each flake produced is pieced back together so that it is in a "whole" state for measurement purposes. At the conclusion of all replication experiments, debris that is unassociated with any particular flake removal is collected from the canvas floor cover and placed in a sample bag together, labeled as "debitage" from that particular reduction experiment.

Following experimental production, each flake is placed in a sample bag that is labeled with the information concerning what raw material the flake is, the catalog number, the behavior associated with the production of that flake, and the completeness of that flake, along with an individual tag inside the bag with the same information.

Flakes were removed from each core, utilizing the least effort approach to flake manufacture that was previously described (section *II.B.4.b.*) until the core was determined as "exhausted." An exhausted core was determined via one of two criteria: 1) no acceptable platforms remain for flake production or 2) no acceptable platform exists given the hammerstone in use. In the majority of cases, acceptably angled platforms remained at the end of a reduction experiment, but the size of the hammerstone and the skill required to produce further flakes was such that the core was determined to be exhausted.

If a core was determined to have significant impurities or fracture planes that prevented it from fracturing conchoidally, that cobble was removed from the sample.

The information recorded for each flake removed means that each core can be theoretically reconstructed back to its original form; each behavior and the decisions going into each flake removal can be reconstructed based on the whole reduction experiment being recorded.

II.B.5.e. Measuring replicated flakes

Each replicated flake was measured following production in the same dimensions described in section *II.A.3*. Only whole flakes were measured because each of the variables measured is complete in whole flakes. Any flake with missing measurements was excluded from analysis. Split, snapped, and split and snapped flakes were included only if all pieces were present and could accurately be pieced back together so as to form a whole flake. No cobble fragments were measured.

Mitutoyo CD 200mm digital calipers were used to accurately measure all experimentally produced flakes to the nearest 0.01 millimeter. These calipers were digitally connected via a Mitutoyo cable to a Toshiba Netbook computer. This cable allows for direct input of digitally measured values into an Excel spreadsheet and thus is an efficient and accurate method for measuring and inputting spreadsheet data.

II.B.6. Photographing experimental materials

For hammerstone and cobble photographs, as well as archaeological photographs and selected photographs of replicated flakes, a Canon EOS Rebel T2i SLR camera with an 18.0 megapixel capacity was used. Two lens options were available for use depending on the size, detail, and topography of the surface being photographed. The first is a Canon EF-S 60mm macro lens that was used for close ups of surfaces and for particularly small artifacts. The second is a Canon EF-S 18-55mm lens that was used for general photographs or broader surfaces with multiple topographic levels that needed to be in focus.

A Benchmark Copymate II camera stand was used to standardize the position and lighting of all photography. This camera stand utilizes two fluorescent lights along either side of the stand. The fluorescent lighting uniformly lights the stand's photographic surface. Black velvet was utilized as a background to all photographs so that details of the lithic materials could be easily identified. A level was used to ensure that both the camera and the stand were level before photographing began. A photographic scale was also used. This scale was carefully placed within the same focal plane as the lithic surface being photographed. Thin (~1.0 mm) wooden squares were stacked so as to bring the photographic scale to the correct height so that there was no distortion in the scale of the surface being photographed due to paralax.

II.B.7. Statistical analysis of experimental materials

Several multivariate analyses are used to assess if morphological differences successfully separate production behaviors and if so, what morphological features

Figure 2.13:

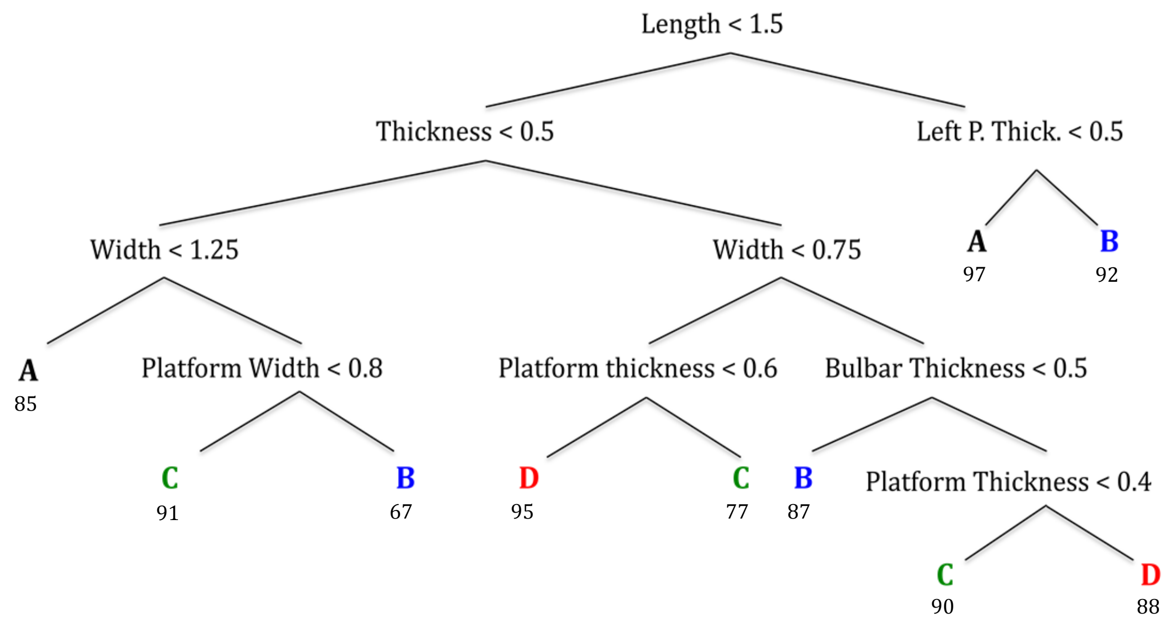


Figure 2.13: This represents a short, idealized classification tree. Beginning at the top, if a particular flake has a size-standardized length less that 1.5 (units are arbitrary after size standardization), classification moves to the left, if larger than 1.5, classification moves to the right. The algorithm that derives this classification tree takes all variation of the data input into account. This allows for each classification made to have a misclassification error rate associated with (the small numbers under each behavioral classification designate the percentage chance of the classification being correct).

separate these behavioral groups. As discussed, each replicated flake is associated with the behavior utilized to produce it. MANOVA tests (in MATLAB 2012a) are used to determine how well separated individual behaviors are within a given raw material assemblage. It is expected that a significant overlap will occur between behaviors in the Oldowan, but that individual flakes will still be classifiable via the construction of a classification algorithm.

To construct this classification algorithm based on the morphological differences between flakes produced via different production behaviors, a phenetic tree is produced. Graphically, tree functions better demonstrate what variables are driving the morphological variation of individual flakes relative to their associated behaviors as compared to a formal discriminant function plot. Instead of building amalgamations of variables that best separate groups (discriminant functions) and defining sets of axes based on these variable combinations, tree functions use the individual variables to hierarchically classify observations based on which variables successfully divide these observations into their constituent groups.

Importantly, tree functions can be quantitatively addressed in terms of misclassification rates and can also be used to calculate the probability of an individual flake as belonging to a particular production behavior. Figure 2.13 is an idealized example of such a tree function. In this example, note that the variables closer to the top are responsible for larger differentiation among flake morphologies and those variables closer to the bottom more specifically designate behavioral classification. Based on the hypothetical data utilized to construct Figure 2.13, each terminal node (behavioral classification) has a probability associated with it. This number, under each classificatory behavior, demonstrates the relative probability of its being correct for an individual flake classified as that behavior via the particular morphological markers that led to that behavioral conclusion. Each flake, in reality, will have four classification values associated, one for the probability that belongs to each production behavior category. Each node has a variable and value associated with it. The value is the size-standardized value that is statistically determined to best discriminate between production behaviors.

Misclassification rates can also be calculated for a given population in a tree function. For a sample size of 4,000 flakes, for instance, 3,500 flakes can be used to "train," or construct, the classification tree function. These randomly selected 3,500 flakes build a classification algorithm for future flakes with unknown behavioral affiliation. The remaining 500 flakes from the original sample size (which also have known behaviors associated with each) are then tested against the algorithm constructed by the initial 3,500 flakes. Analytically, it can be determined how many of these 500 flakes are correctly classified via the algorithm and how many are incorrectly classified, thus calculating an expected misclassification rate. This misclassification rate will become important later when archaeological materials with unknown behavioral affiliations are classified via the experimentally trained tree function.

II.B.7.a. Other statistical tests

Other questions will also be addressed that are independent of the behaviors utilized for flake production. For instance, initial cobble size may be an indicator of the number of flakes removed. Previous research has suggested that larger cobbles may produce more flakes than smaller cobbles and a large sample size of cores and resulting flakes can test this via a Mann-Whitney U-Test that uses core size (small, medium, or large as determined by distribution around the mean) and number of resulting flakes. A Mann-Whitney U-Test is most appropriate in this situation due to the nonparametric nature of the data.

Similarly, initial core shape may prove to be an indicator of resulting flake morphology. MANOVA tests that use core morphology variables to classify cores into different groups can test these core morphologies against the flakes that result from these cores and thus potentially assess whether, for instance, oblong and flat cores produce different distributions of production behaviors relative to thick and short cores. While initial cobbles size may affect the number of potential flakes that are removed (Toth 1997; Braun et al. 2008), cores collected for this research all fall within the range of cobbles recovered archaeologically and that are predicted to have been available to Oldowan producing hominins at Koobi Fora in the river channels near these KBS sites.

Relationships between hammerstone size and flake morphology will also be established. Do hammerstones of different sizes produce flakes of differing morphologies? MANOVA tests might also help to determine if this might be the case. Depending on the results, Principle Component Analysis (PCA) might also help to visually represent how these flakes differ morphologically.

The number of strikes required to produce a flake may also result in differential morphologies. A similar MANOVA test can help establish whether there is a statistical relationship between number of strikes and morphology or, at a minimum, if there is a relationship between number of strikes and the completeness of the resulting flake.

Lastly, the large sample size of flakes produced experimentally will establish expectations for the average number of flakes a given raw material type can be expected to yield. This measure provides a baseline for archaeological expectations given the number of cores and flakes present at a given site.

II.C. Archaeological application of the experimental model

The third stage of BLA methodological development uses the behavioral classification model created via experimental means to classify archaeological material into behaviorally relevant categories. For application to the Oldowan, the first step in this process is to establish the relationship between the experimental approach to flake production and the archaeological materials. In other words, does the archaeological material statistically look like the replicated material?

II.C.1. Establishing the least effort approach

The first step in applying the experimental model to archaeological lithic artifacts is to statistically establish the relationship between the reduction method used in the experimental setting and the morphologies of archaeological materials. As was discussed in section *II.B.4.b*, the least effort approach is the model that previous research has used to describe Oldowan stone tool production. The null hypothesis that is tested here is that there is no statistical difference between flakes replicated using a least effort approach to production and archaeological flakes. If the null hypothesis is validated, then the least effort approach can be considered a valid explanation for Oldowan stone tool production. In this case, archaeological artifacts are classified via the experimentally derived algorithm. If the null hypothesis is invalidated, at least a portion of the archaeological material was produced using a reductive approach other than the least effort approach. An invalidated null hypothesis necessitates further statistical examination to define which archaeological artifacts fit within expectations for a least effort approach and which artifacts do not fit within that expected variation. For those artifacts that fit within expected variation, as established via the reduction experiments, the experimentally derived classification algorithm is used to assess which behaviors are represented. For those artifacts that do not fit within expected variation, a PCA is used to determine which morphological aspects differentiate these flakes from the flakes fitting experimental expectations.

II.C.2. Archaeological site analysis

Classifying archaeological material into discrete behavioral units allows for assemblages to be directly compared in terms of those behavioral units. The classification tree defined via experimental means is used to classify each archaeological lithic artifact with a corresponding behavior. Each archaeological site is then analyzed in terms of the behaviors present and/or absent. Further, these sites are compared in terms of what behaviors were utilized to produce the stone tools at each site. Sites within a single locality can be directly compared and sites between localities (or different localities as whole assemblages) can also be directly compared.

Comparison and site analysis may also yield interesting behavioral information in terms of the variation in the presence and/or absence of least effort methods of flake production. For flakes that are not statistically analogous to least effort approaches, other analyses must be used to determine their behavioral relevance. Divergence from a least effort approach may be indicative of divergence of overall stone tool production behaviors. The presence of such divergence from expectations of production, as well as ways in which such a divergence might be explained, such as differential adaptive responses, cultural divergence, and functional responses, will be discussed in Chapter 5.

II.C.2.a. Other questions for site analysis

Analysis of individual sites and direct comparison between sites and localities are dependent on more information that purely the production behaviors present or absent at those locations. Environmental reconstruction, distance to raw materials, raw material use, evidence of flora and fauna, and site information from landscape approaches to archaeological research will all contribute to discussions of why stone tool assemblages may appear similar or look dramatically different.

Further, the large replicated sample associated with BLA experimental methodology provides a quantitative assessment of expectations for archaeological assemblages. This is especially relevant in terms of calculating expected ratios of flakes to core size and determining if flakes or cores were imported to the site or whether flakes and cores may have been artificially removed from a site.

Chapter III: Archaeological Localities and Samples

To establish a robust BLA model for a given technological period or system, selection of archaeological sites and raw material samples are of significant importance. Localities should fit the following criteria:

1) to establish a BLA model of a technology, the archaeological sample size of lithic artifacts should be relatively large, and
2) the raw materials utilized to produce archaeological lithic artifacts should be available in large enough quantities to procure for experimental replication.

The Oldowan is a logical place to begin the process of statistically defining stone tool production behaviors (see section *II.B.4.a*). Olduvai Gorge, Tanzania and Koobi Fora, Kenya are prominent archaeological localities that have yielded large archaeological Oldowan assemblages. Further, both Olduvai Gorge and Koobi Fora have raw materials that were utilized by Oldowan producing hominins available on the modern landscape. The well-documented geologic histories and multiple attempts to typologically classify these stone tools make these archaeological localities ideal for BLA development.

Most importantly, despite the decades of research at Olduvai Gorge and Koobi Fora, no research program has compared the assemblages of these localities in a technological way. The research presented here represents the first comprehensive comparison of lithic materials between Olduvai Gorge and Koobi Fora.

III.A. Olduvai Gorge, Northern Tanzania

Olduvai Gorge is appropriate for BLA investigation of Oldowan technology due to the large assemblages previously (and continuously) excavated, the prominence of the site in Oldowan literature, the presence of available raw materials, and the paleoenvironmental information available for Oldowan archaeological sites. Of particular importance to the research presented here are the conclusions determined via the landscape approach to archaeology implemented at Olduvai Gorge over the last two decades, as outlined by Blumenschine and Peters (1998) (see section *I.C.1*).

Archaeological sites at Olduvai Gorge that are attributed to Oldowan technology are from the geological formations known as Bed I and Lower Bed II. Large Oldowan assemblages were excavated and described by M. Leakey (1971). The original typology described in the 1971 monograph of Leakey's excavations divided lithic materials into "heavy duty" and "light duty" versions, with heavy duty tools being core tools and light duty tools being utilized flake tools. Other flake material was considered "debitage." More recently, the Olduvai Landscape and Paleoanthropology Project (OLAPP) has expanded the scope of excavated areas within Olduvai Gorge. The landscape approach to archaeological investigation carried out (and outlined in Peters and Blumenschine 1995; Blumenschine and Peters 1998) provides a unique glimpse into hominin behaviors across the paleoenvironmental landscape during Lower Bed II times.

Blumenschine and Peters (1994, 1998) modeled specific predictions for hominin activity across the Olduvai Gorge landscape during Lower Bed II based on environmental reconstructions. Predictions outlined include hominin utilization of canopied areas where potential for hominin-carnivore interaction is lower and where carcass acquisition and consumption is less conspicuous and therefore safer. These predictions, along with the more recent paleoenvironmental and archaeological conclusions based on OLAPP research, are pertinent to the research presented here; with such specific reconstructions, behaviors related to stone tools and stone tool production might be hypothesized, tested, and quantitatively addressed given a BLA approach to technology.

The following sections detail the geological research at Olduvai Gorge relevant to this study, the raw materials utilized by hominins and for experimental BLA replication, and the archaeological sites studied for the research presented here.

III.A.1. Geological history of Bed I and Bed II, Olduvai Gorge, Tanzania

The geological formation at Olduvai Gorge is layered with tuffaceous statigraphic layers that make archaeological sites particularly easy to date (Hay 1976), with the oldest dates going back to about 1.8 million years ago. The continuity of stratigraphic exposures also makes Olduvai Gorge a primary example of the utility of landscape approaches to archaeology (Peters and Blumenschine, 1995; Blumenschine and Peters 1998). Landscape archaeological methods provide a means of reconstructing more complete scenarios of hominin behavior. Instead of making broad behavioral conclusions based on a single site location, studying the same stratigraphic unit across a large landscape allows for reconstruction of a breadth of behaviors, and potentially for differential behaviors across that paleolandscape. Geological research begun by R. Hay (1976) have very accurately traced the paleoenvironments and ecosystems associated with Olduvai Gorge (Figure 3.1).

The present condition of Olduvai Gorge, in which there is the main gorge, the side gorge, and the river bed traveling down the bottom of this fluvial system, was not always present. Figure 3.1 shows that during Upper Bed I and Lower Bed II times, a perennial lake that fluctuated in size was present at Olduvai. The edge of this paleolake served at a prominent location for hominin congregation and many of the sites discussed in this research sit adjacent to this resource. However, this paleolake was saline and alkaline and therefore not potable for hominin populations. Fluvial systems feeding the lake ran roughly from east to west down from the volcanic highlands to the east of Olduvai. These fluvial systems brought not only fresh water to the lakeshore environments, but also carried raw material resources. Recent geological research has clearly demonstrated that the transgression and regression of Paleo-lake Olduvai also produced unconformities at site locations like FLK was valid (Blumenschine et al. 2012).

The long history of archaeological investigation at Olduvai Gorge has produced a robust collection of stone tools from across that ancient landscape. Notably, these stone tools were produced on raw materials that are still visible and available on the modern landscape. During the Oldowan at Olduvai Gorge, which correlates to Bed I and Lowermost Bed II sites, Oldowan producing hominins were using primarily basaltic raw materials and quartzite. The basalts were produced in the volcanic highlands to the east of Olduvai Gorge and transported to the paleolake primarily via fluvial channels.

Figure 3.1:

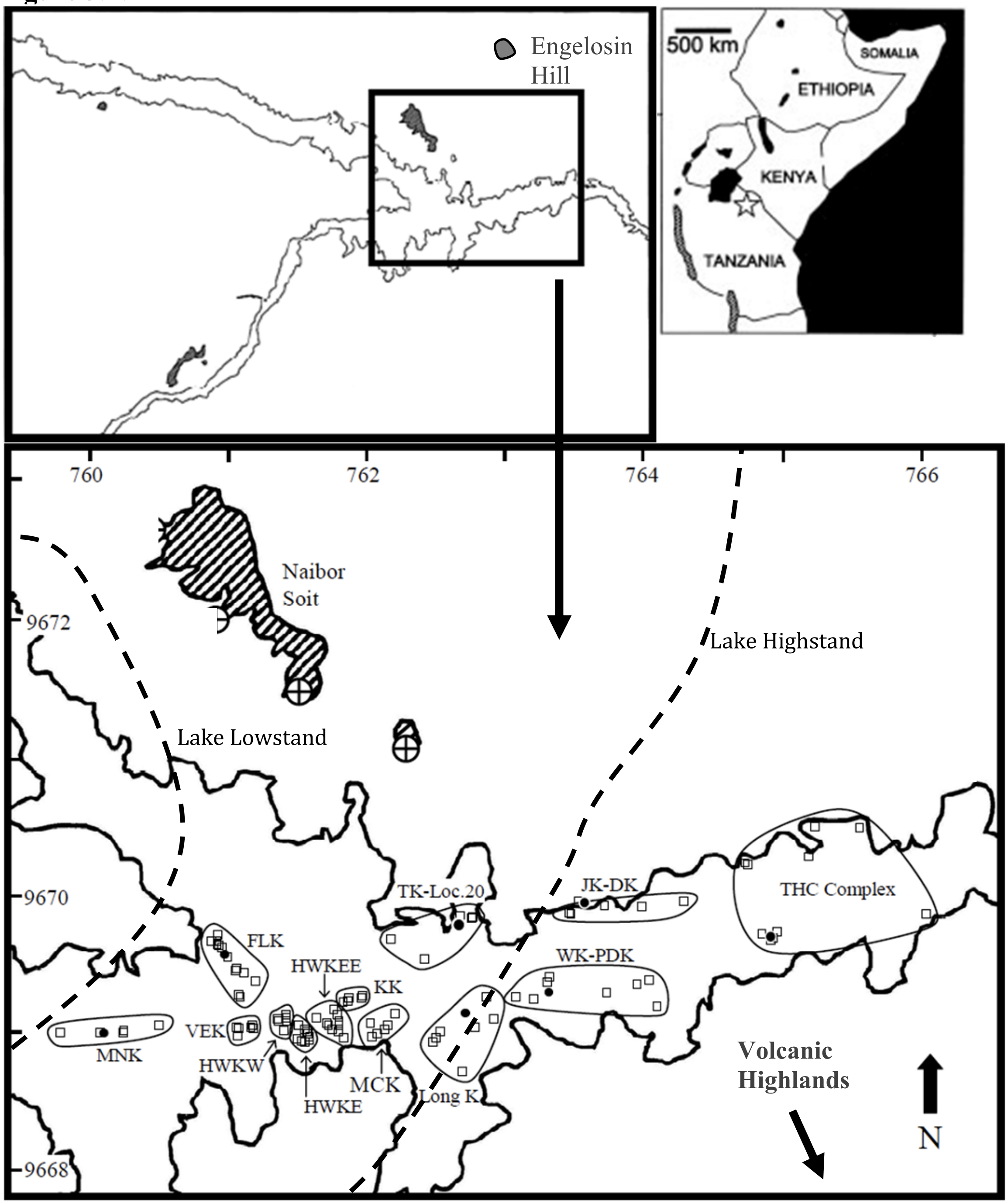


Figure 3.1: Map of Olduvai Gorge, Tanzania, with emphasis on site locations and raw material sources. Naibor Soit, labeled in the lower map, is the source of quartzite from Olduvai Gorge. Modern exposure of basement basalts occur at locality KK and cobbles of basalt are available for procurement in the adjacent river bed. Basalt cobbles such as these are eroded from the volcanic highlands to the East of Olduvai Gorge. Engelosin Hill, far to the North, is an outcrop of phonolite. (Map adapted from Blumenchine et al. 2003:1218, Blumenschine et al. 2008:78, and Blumenschine et al. 2012).

Quartzite was available via the large exposure to the north of Olduvai Gorge known as Naibor Soit (see Figure 3.1 for raw material source locations).

Geological reconstructions of the Olduvai paleolandscape during the transition from Bed I to Bed II have revealed specific information regarding the immediate environments surrounding archaeological sites from Olduvai Gorge. In general, sites cluster around the eastern side of the paleo-lake that perennially existed on the ancient landscape (Blumenschine et al. 2008). The environments of these sites demonstrate proximity to fresh water sources (Ashley et al. 2010; Dominguez-Rodrigo et al. 2010; Albert and Bamford 2012) and, generally, are proximal or adjacent to areas showing woody vegetation (Blumenschine and Peters 1998). These immediate environments are discussed below (section *III.A.3.*).

III.A.2. Raw materials from Olduvai Gorge, Tanzania

III.A.2.a. Basalt

During the Oldowan, two dominant materials were used to produce lithic implements. The first is volcanic basalt. At Olduvai Gorge, a large basaltic layer underlies the entirety of Bed I; this thick basaltic bedding outcrops at the locality known as KK (Figure 3.2). Hominins were not likely collecting basalt for stone tool production at such outcrops, however, due to the quality of the basalt at these locations and the large, thick beds in which they outcrop. More likely is that Oldowan producing hominins were collecting basalts in the streams and channels that were flowing from the volcanic highlands to the east. The cobbles of basalt were fluvially transported from these volcanic highlands to the areas surrounding the paleolake at Olduvai were naturally worn, smaller in size, and generally more acceptable for stone tool production.

Oldowan producing hominins utilized two kinds of basalt: fine-grained basalt and vesicular basalt. Fine-grained basalt is readily available in the modern Olduvai Gorge and was collected by the author from the riverbed adjacent to the KK (Figure 3.2) location for the experimental portion of this research. Fine-grained basalt (Figure 3.3a) ranges from micro- to macro-crystalline. It is often difficult to determine the quality of this basalt from visually assessing the cobble; it is not until the cobble is broken that the quality can be ascertained. The conchoidal potential of Olduvai fine-grained basalt, therefore, varies. If a cobble is angular and homogenous, regular flakes can be removed and these flakes have a sharp edge. If a cobble is rounded or more spherical in shape, often it cannot be broken via a basalt hammerstone. Selecting acceptable cobbles for experimental replication proved difficult. Upon examination of the first cobbles selected from the KK locality, the author noticed that fine cracks and impurities were visible with the naked eye. Cobbles with such impurities break unpredictably along these lines of impurity, often resulting in a broken cobble following only one or two strikes. Following inspection of all collected cobbles, it was noted that the majority suffered from these cracks and impurities. During a second collecting event at KK, each cobble was inspected before being selected. Selection was based on visual assessment to screen any cobbles with cracks or visible impurities. Upon experimentation, however, some cobbles of every raw material variety in this study were unusable. Cobbles with such impurities were discarded and replaced in the sample with other, more acceptable, cobbles.

Figure 3.2:

Figure 3.2: The locality of KK at Olduvai Gorge from the view of the modern Olduvai Gorge river channel. This locality is one where the basalt bedding underlying Olduvai Gorge outcrops. The modern river channel also carries basalts from the volcanic highlands to the east and southeast of Olduvai Gorge. Such transport of basalt cobbles is the same as the transport method during hominin occupation times. For this study, basalt cobbles of both fine-grained and vesiculated types were procured from the surrounding river channel area, including hammerstone procurement of both basalt and river-rounded quartzite.

Figure 3.3:

a)

b)

Figure 3.3: Examples of (a) fine grained basalt (core number 350) and (b) vesicular basalt (core number 375) from Olduvai Gorge, Tanzania.

The second variety of Olduvai basalt is vesicular basalt (Figure 3.3b). Vesicular basalt is porous and has many visible inclusions and abnormalities. Despite these visible imperfections, hominins produced a vast number of identifiable flakes on this material. Vesicular basalt was collected in the riverbed adjacent to the KK locality within the Olduvai Gorge riverbed. Thus through fluvial transport, both fine-grained and vesiculated forms of basalt are found in the same geographic areas. This has potential implications for assessing hominin raw material preference. Vesiculated basalt appears to be a poor choice for stone tool production; it is brittle, the porosity should make predictability of flake propagation difficult, and it is often blocky in its cobble form. However, (and surprisingly), this vesicular basalt fractures fairly consistently and produces a relatively sharp edge. Flakes and cores of vesicular basalt are abundant in the archaeological record from Olduvai Gorge, thus it seems that hominins valued the relative ease of producing flakes from vesicular basalt versus the much harder-to-fracture fine-grained variety.

III.A.2.b. Quartzite

The second raw material type that appears in high frequency in the Oldowan of Olduvai Gorge is quartzite. Quartzite outcrops at the large inselberg called Naibor Soit (Figure 3.1). Naibor Soit is the closest source to Oldowan archaeological sites and is the assumed raw material source for the quartzite utilized at these locations (Blumenschine et al. 2008). Naibor Soit quartzite is tabular, meaning that it outcrops in thick laminated layers at the top of Olongoidjo Ridge at the main Naibor Soit source and at the top of Engitati Hill, just to the southeast of the main source. The quartzite eroding from

Engitati Hill tends to be degraded and poor examples of the type of raw material utilized by Olduvai hominins to make stone tools. Eroded cobbles on the slopes of Olongoidjo Ridge were assessed for suitability and collected (Figure 3.4). Suitable quartzite cobbles ranged in size from several hundred grams to approximately two kilograms, had acceptable angular platforms available, and were of suitable quality to the naked eye. The quality of collected quartzite cobbles varied, however, since archaeological artifacts vary in the type of quartzite on which they are made.

In general, experimental reproductions demonstrated that quartzite is difficult to predict and produce flakes on. Extremely fine-grained (sand-grain sized) shatter results from every hammer strike and this shatter is quite sharp. Flakes often split or snap during production and undetectable impurities in the cobbles become problems during flake production. Many cobble fragments resulted from quartzite cobbles breaking in unpredictable ways due to impurities and fracture planes that followed large crystalline structures within the quartzite. The material itself ranges from sandy, large crystals that produce a large amount of debitage (Figure 3.5a) to fine-grained quartzite that breaks in predictable, conchoidal patterns (Figure 3.5b). In either case, significant care must be taken during the knapping process to avoid injury.

III.A.2.c. Hammerstone procurement

Hammerstones were carefully selected from the Olduvai river channel near the KK locality (Figure 3.2). Archaeological samples of hammerstones demonstrate that hominins were utilizing both rounded cobbles of basalt and quartzite. Naturally rounded cobbles of both of these materials were therefore collected for use as hammerstones

(Figure 3.6a and 3.6b). As previously described (section *II.B.3.*), specific hammerstone selection during experimental replication was determined statistically by the distribution of hammerstone weights from the archaeological record.

III.A.3. Oldowan sites from Olduvai Gorge, Tanzania

This research measured all whole flakes excavated from Oldowan time periods at the sites of DK, FLK, FLK-N, HWK-E, and HWK-W.

DK is a Bed I assemblage that is located at the confluence of the paleo lake present in the Olduvai Basin and a fluvial channel running from East to West from the volcanic highlands (Hay 1976). DK is a fluvial margin site, with some potential for fluvial disturbance. Unlike other Olduvai Gorge sites included in this study, DK is in the general vicinity of basalt cobbles and further toward the volcanic highlands to the east, where basalt is originating. Hominins, therefore, were likely to have less cost in procuring basaltic raw materials at DK.

FLK is a lake margin site (McHenry 2009, 2012) with evidence of edaphic grasslands present just prior to the large volcanic deposition of Tuff IF (which caps Bed I and divides Bed I and Bed II) (Bamford et al. 2008; Bamford 2012). However, during most of Bed I there appear to be cycling periods of marshlands and rooted layers of vegetation (Bamford 2012). This cyclic environmental patterning may have predictive implications for hominin presence and activity. The FLK site complex includes the site of FLK-*Zinj*, the famous site in which M. Leakey discovered the first hominin found at Olduvai Gorge, *Zinjanthropus boisei,* which later became known as *Australopithecus*

Figure 3.4:

Figure 3.4: This photograph was taken on the Eastern slope of Naibor Soit. Note the abundance of quartzite cobbles scattered across the sloping landscape. The Naibor Soit source is large and quartzite could have been procured anywhere along this outcrop. Quartzite blocks erode from the tabular exposures of quartzite at the top of Naibor Soit and move down the slopes. There are many different sized nodules of different quality along these slopes. Many, but not all, of these nodules follow the tabular nature of the exposure and therefore have relatively flat tops and bottoms with steep, blocky sides.

Figure 3.5:

a)

b)

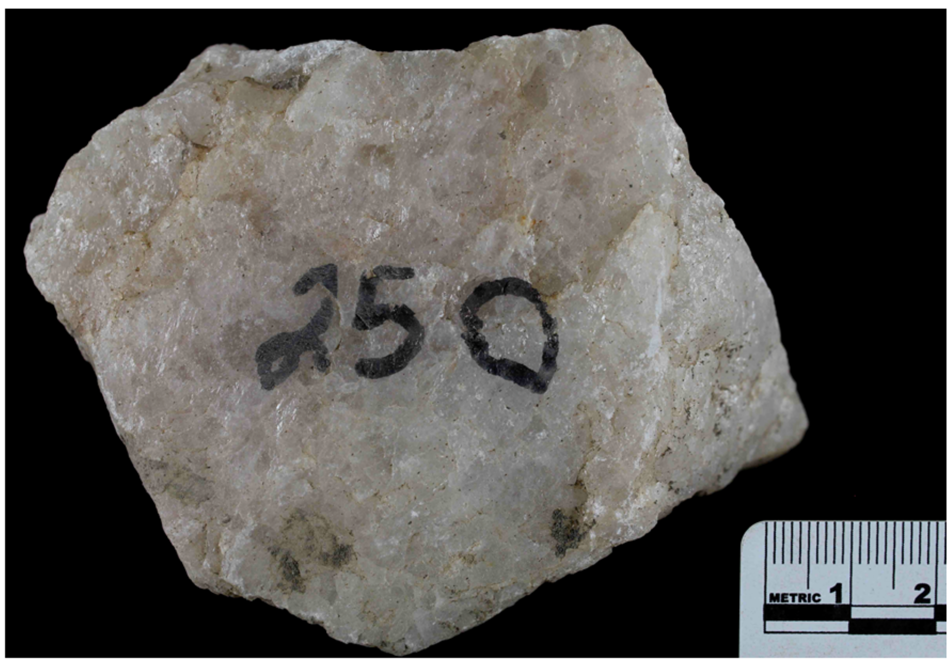
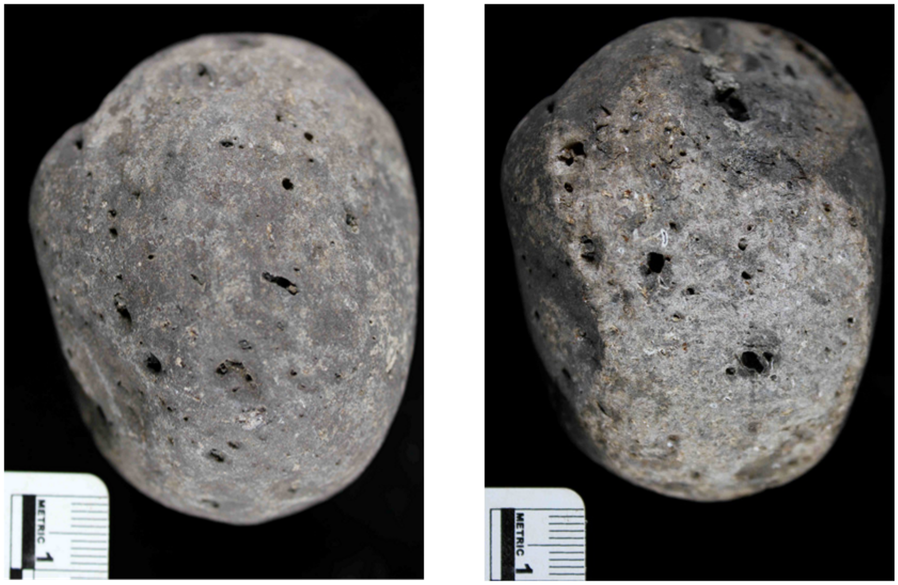


Figure 3.5: Examples of (a) large crystal ("sandy") quartzite (core number 267) and (b) fine-grained quartzite (core number 250) from Olduvai Gorge, Tanzania.

Figure 3.6:

a)



b)

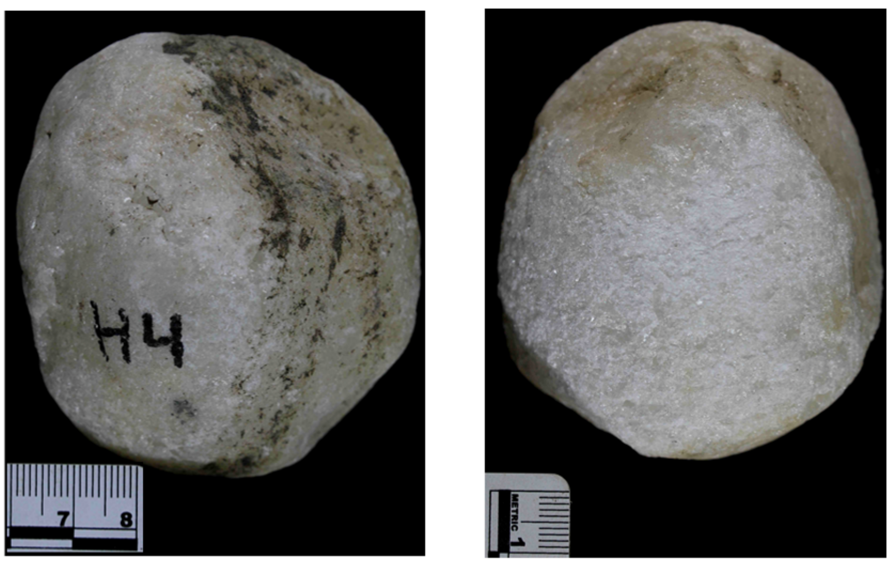


Figure 3.6: Examples of experimental hammerstones from Olduvai Gorge. 3.6a shows a basalt hammerstone (H7) unmodified (left) and after reducing 50 cobbles (right). 3.6b shows a quartzite hammerstone (H4) unmodified (left) and after reducing 50 cobbles of quartzite (right).

boisei. Significant archaeological and geological investigation has focused on reconstructing the environments of the FLK site complex, including FLK 22. These sites are located within a peninsula setting with a fresh water spring during later Bed I (Ashley et al. 2010; Dominguez-Rodrigo et al. 2010; Albert and Bamford 2012). This area of fresh water caused marshy conditions but was immediately adjacent to more closed vegetation (Copeland 2007; Barboni et al. 2010) with open habitats in areas surrounding the peninsula. Following deposition of Tuff IF, environmental conditions were variable (Stollenhofen et al. 2008) until later in Lower Bed II when there is more vegetation in the area and hominin activity resumes (Blumenschine et al. 2008). More specifically, the peninsula can be divided into three distinct habitats: 1) a river channel, 2) the peninsula itself, and 3) a freshwater wetland (Blumenschine et al. 2012). The presence of both hominin butchery marks and crocodile toothmarks suggest that hominins took advantage of crocodile kills. Close proximity of closed canopy woodlands, immediately adjacent to wetland environments, likely attracted both large carnivores and hominins. This made for both a safe (canopied) and unsafe (carnivore presence) environment, but this environment was lucrative in terms of the potential for feeding opportunities (Blumenschine et al. 2012). Although Leakey (1971) described the archaeological localities as being "living floors" or home bases for hominins, Blumenschine et al. (2012) argue that the proximity and competition of the carnivore guild precludes this conclusion. Instead, the area was likely utilized regularly, but represents food processing only. Artifacts studied for this report from FLK-N come from Levels 1/2 and Level 3.

HWK-E is a lake margin site, but grassland environments were dominant in Bed I below Tuff IF (Bamford et al. 2008; Albert and Bamford 2011). However, after Tuff IF deposition, vegetation increases and demonstrates evidence of sedge growth in the upper reworked section of Tuff IF (Albert and Bamford 2011). Stratigraphic levels 1 and 2 are used for this analysis due to their affiliation with the Oldowan and their unique position at the very end of the Oldowan sequence (and where, according to M.D. Leakey's definition, the "Developed Oldowan A" begins.

III.B. Koobi Fora, Northern Kenya

The Northern Kenyan archaeological locality of Koobi Fora, Kenya represents another primary location for Oldowan research based on the number and provenience of available Oldowan archaeological material. Similarly to Olduvai Gorge, the geological placement of Koobi Fora within the East African volcanic rift allows for relatively easy dating of archaeological sites. The geology of the Koobi Fora Formation has been linked to other geological formations in Ethiopia to the north (Cerling 1979; Cerling and Brown 1982). This makes Koobi Fora a good candidate for potential site comparisons based on the known ages of sites and the direct correlation of these sites with other early human sites in more distant locations.

Like Olduvai Gorge, raw materials utilized by Oldowan producing hominins at Koobi Fora are still available on the modern landscape. Some materials are exposed in fluvial contexts and others are available in large exposures in the far eastern part of the Lake Turkana Basin (Figure 3.7). Unlike Olduvai Gorge, however, Koobi Fora hominins relied primarily on basalts to produce lithic implements. Basalt accounts for approximately 95% of the stone tools produced during the Oldowan of Koobi Fora (known locally as the KBS Industry).

III.B.1. Geological history of Koobi Fora

Sites at Koobi Fora during the period associated with Oldowan lithic production cluster around reliable water sources (Rogers et al. 1994). Geologically, the Turkana Basin has fluctuated between the existence of a perennial lake and braided river channels running the length of the basin (Brown and Feibel 1991; Feibel and Brown 1993; Rogers et al., 1994; Lepre et al 2007). Further, drainage channels from the volcanic eastern basin margin fed the central basin (Quinn et al. 2007), bringing basaltic raw materials in the process (Figure 3.8). This research includes measurements of all whole flakes excavated from Oldowan time periods at the sites of FxJj 1, FxJj 3, FxJj 4, FxJj 10, and FxJj 11.

III.B.2. Raw materials from Koobi Fora

III.B.2.a. Basalt

The basalts available in the areas adjacent to the modern Lake Turkana are derived from the volcanic basin margin that defines the Eastern extent of the Lake Turkana Basin (see Figure 3.9). The dissertation research of D. Braun (2006) chemically defined the basaltic types that are present in the Lake Turkana Basin. The two basalt types, known as Gombe basalt and Asille basalt, are both found at KBS sites. Gombe basalts were utilized by hominins marginally more than Asille basalts, but Braun determined that this preference was largely due to Gombe basalt's presence near archaeological sites rather than a definite preference for one basaltic type versus the other.

Figure 3.7:

Figure 3.7: The basin margin basalt exposure at Koobi Fora is pictured here. The location is at a higher elevation that the sites in the Turkana Basin several kilometers to the west. However, geologically it seems that exposures such as these were linked to the hominin environments via river and stream channels. Such channels would have transported cobbles such as these to an area proximal to the water sources to which Koobi Fora Oldowan producing hominins were tethered. These hominins had access to these materials in the form of river gravel beds. Cobbles and hammerstones were collected from this locality.

Figure 3.8:

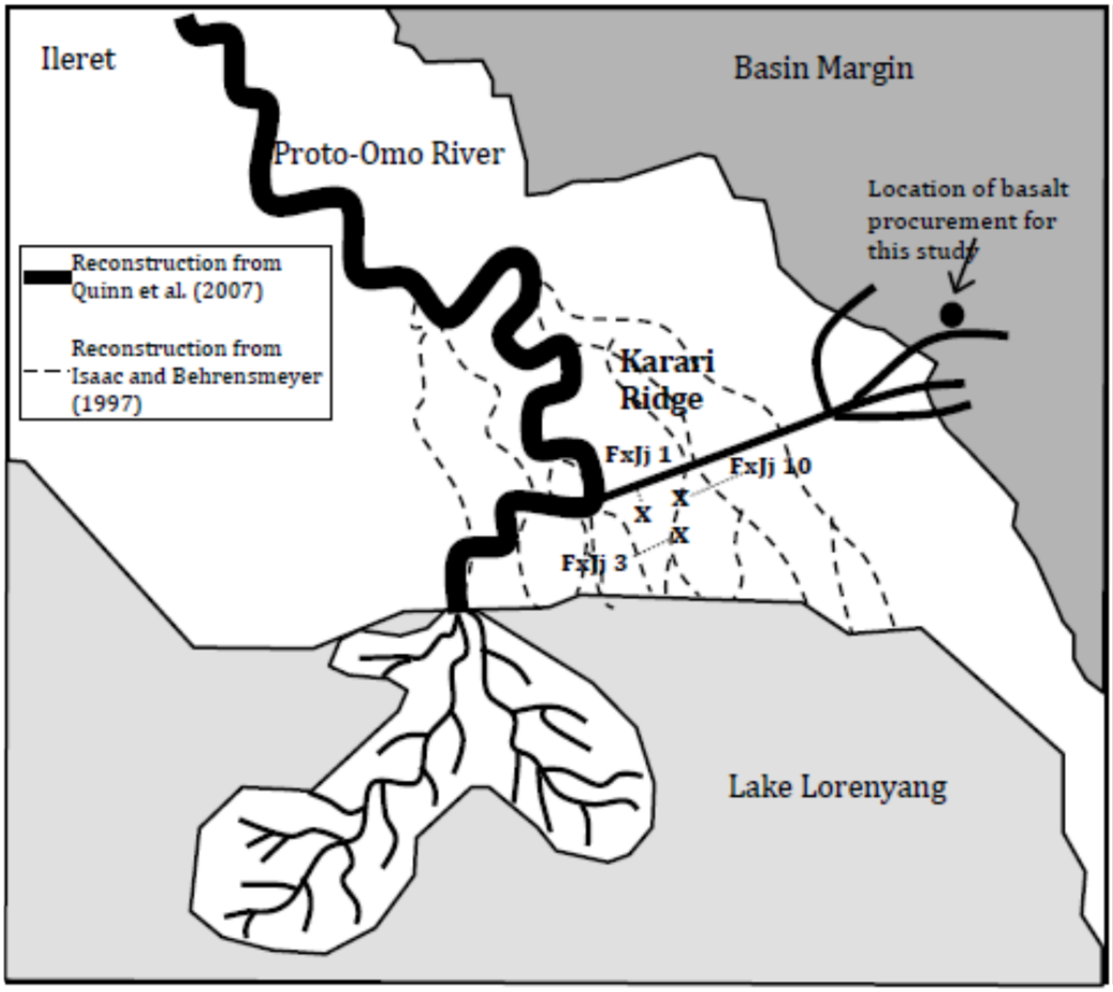


Figure 3.8: The paleogeography at Koobi Fora circa 1.9-1.8 mya (during KBS formation). Though different interpretations of the Lake Lorenyang (see Brown and Feibel 1991; Feibel and Brown 1993) basin have been put forward, the interpretations are similar. During this time, the Paleo Omo River drained into the basin from the northeast. According to Isaac and Behrensmeyer (1997), this river splays into an alluvial delta as it approaches the lake shore. Quinn et al. (2007) sees a similar effect, though occurring at different points and at different specific times in lake transgression and regression (see also Rogers et al. 1994). KBS sites (FxJj 1, 3, and 10) are located in these alluvial deposits, suggested deltaic environments for these lower energy flows stemming from the Paleo Omo River. Basalt resources were transported from the higher elevation basin margin environments to the east of the basin. Both the Paleo Omo River and other fluvial drainages from the basin margin would have transported cobbles of basalt to within 1-3 kilometers of the KBS sites.

Basalt was procured along the basin margin to the east of the Karari Ridge in the Koobi Fora region. This outcrop of basalt (Figure 3.7) is at a higher elevation than the archaeological sites approximately 10 km to the west and southwest along the Karari Ridge and is exposed at the surface, as Figure 3.7 demonstrates. The basalt is naturally weathered but fractures fairly consistently and mirrors the materials utilized by Koobi Fora hominins producing the KBS industry. Cobbles such as these were likely fluvially carried from these higher elevation basin margin regions to lower lying areas that were either adjacent to the paleolake present within the Turkana Basin or adjacent to more significant riverine systems possessing tree cover and fresh water to hominin populations. The availability of basalt cobbles sufficient enough to produce stone tools during KBS times is contentious (Toth 1997; Braun 2006). Toth (1997) suggests that hominins procured raw materials and transported them at least several kilometers to KBS sites. Braun (2006) suggest that cobbles may have been available in settings quite close to the KBS sites.

Basalt cobbles of varying sizes are available at this modern basin margin outcrop. The author selected cobbles based on their size and physical appearance. Cobbles of a size equivalent of those excavated archaeologically were collected (ranging from approximately 300g to approximately 2kg). Basalt cobbles vary from rounded and spherical to angular and flat; a representative sample of these shapes and sizes were collected such that 200 replication experiments might be performed.

Koobi Fora basalt fractures conchoidally and ranges from fairly fine-grained forms (Figure 3.9) to more brittle forms with internal impurities. Upon experimentation, if cobbles were found to be internally inconsistent such that they fractured unexpectedly,

Figure 3.9:

Figure 3.9: Example of a standard basalt cobble from Koobi Fora (Catalog number 100).

they were discarded from the sample and replaced with examples that fractured consistently.

III.B.2.b. Hammerstone procurement

Basalt is the hardest material available on the Koobi Fora landscape. As such, hammerstones necessary to consistently break basalt cobbles must be quite hard themselves. Basalt hammerstones were procured from the same basin margin outcrop (Figures 3.10). Naturally round cobbles of basalt were collected for experimental use based on their size relative to archaeological hammerstones housed at the National Museums of Kenya, Nairobi.

III.B.3. KBS sites from Koobi Fora, Kenya

This research measured all whole flakes excavated from Oldowan time periods at the sites of FxJj 1, FxJj 3, FxJj 4, and FxJj 10. FxJj 11, an Okote Member site, is also included as an outlier to test for potential temporal differences in technology within the Lake Turkana Basin.

FxJj 1 is located in Area 105 at Koobi Fora. During the time of hominin occupation of FxJj 1, the perennial lake that intermittently filled the paleo-Turkana basin was consistently retreating to the west. The location of FxJj 1, therefore, appears to be "on the upstream part of the delta where it merged with a fluvial floodplain" (Harris and Isaac 1997:80). The position of FxJj 1 within Area 105 places the site approximately 12-15 kilometers from the basin margin hills. However, a series of braided streams likely

Figure 3.10:

a)

b)

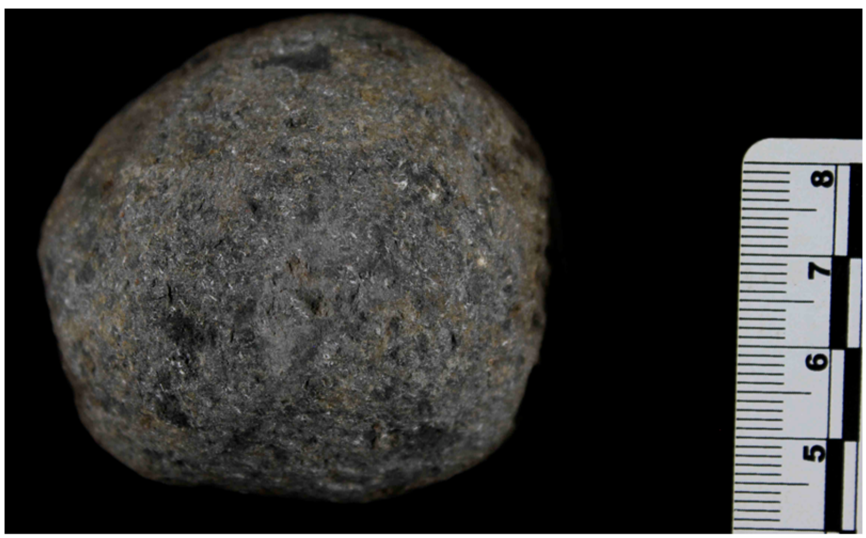


Figure 3.10: Experimental basalt hammerstone (H3) from Koobi Fora. 3.10a shows the unmodified hammerstone. 3.10b shows the hammerstone after reducing 50 Koobi Fora basalt cobbles.

carried basalt materials to the vicinity of the site (Quinn et al. 2007). The archaeological materials at FxJj 1 have been traditionally viewed as relatively *in situ*. Although the depositional environment of the site sits on top of a fluvial channel, it appears that the channel was no longer active during hominin occupation. Fine grained silts overlying the channel suggest that artifacts are undisturbed (Harris and Isaac 1997:84).

FxJj 3 (also known as the "Hippo and Artifact Site") lies is a similar depositional environment as FxJj 1 (Harris and Isaac 1997:84). Though the integrity of the site was initially circumspect due to the vertical distribution of artifacts (20-40cm through the site), it later became apparent that this distribution was due to post-depositional factors such as sediment cracking. This is readily apparent when considering the fact that flake and core refits were found within the assemblage. However, the relatively small assemblage and association with hippo bones suggest a relatively brief occupation event at this site (Harris and Isaac 1997:97-98).

FxJj 4, another KBS site in Area 105, is included in the sample of measured sites to represent a small accumulation of flakes with unknown stratigraphic origin. FxJj 4 is a surface scatter site and is thus another test of BLA sensitivity in determining behavioral information about even the smallest accumulation of flakes. Implications for BLA and site comparisons will be discussed in detail in Chapter 5.

FxJj 10 lies at the border of Area 105 and Area 118, but the depositional environment is somewhat similar to those of FxJj 1 and FxJj 3. FxJj 10 represents a proximal floodplain environment in which the deposits encasing the artifacts accumulated during periodic stands of low energy, high water in a bar or riverbank setting (Harris and

Isaac 1997). However, other interpretations suggest that FxJj 10 was farther from the main axis of the Proto-Omo river (see Figure 3.8) and, in fact, was in a much drier environment. This interpretation is based primarily on the presence of xerophilic fauna (Braun 2006). There is mixed evidence for site integrity in that no artifact refits were recovered, but microdebitage is present. The presence of microdebitage indicates that winnowing is minimal and thus it seems that the site is in primary context.

FxJj 11 is an Okote Member site and is thus an outlier to this sample. The archaeological assemblage from FxJj 11, however, is reminiscent of KBS technology and stands out against other Karari Industry archaeological sites in the size and density of the artifact assemblage. The stratigraphic level of FxJj 11 places the site in an orange tuffaceous material that immediately underlies the Okote Member (Rogers 1997) and thus makes FxJj 11 older than the other Karari Industry sites. Its floodplain paleoenvironmental setting also makes FxJj 11 reminiscent of KBS sites. Thus an affiliation closer to the KBS makes FxJj 11 an excellent site with which to test the sensitivity of the BLA methodology and also to determine if any significant difference between KBS and Okote member sites might be expected.

Chapter IV: Results

IV.A. Determining variation in archaeological materials

The first analytical step to determining if variation exists within and between Oldowan assemblages is to statistically compare those assemblages. Koobi Fora KBS assemblages and Olduvai Gorge Oldowan assemblages demonstrate significant *intra*basinal differences. Further, there are significant morphological differences between assemblages at Koobi Fora and Olduvai, suggesting *inter*basinal variation as well. The sections below provide details for these results. Taken together, these broad results demonstrate that further research is warranted to define the morphological differences in terms of specific behaviors related to Oldowan production patterns.

IV.A.1. Archaeological sample size

All whole flakes were measured from Oldowan assemblages at Koobi Fora and at Olduvai Gorge. For Olduvai Gorge, the original assemblages excavated by M.D. and L.S.B. Leakey, which are housed at the National Museums of Kenya, Nairobi were measured, as well as materials excavated by the Olduvai Landscape And Paleoanthropology Project (OLAPP) that are housed at the National Natural History Museum of Tanzania, Arusha. For Koobi Fora, all available KBS assemblages were measured. The sample sizes for each site and total flake counts is found in Table 4.1.

Sites with relatively large sample sizes (FxJj 10, FxJj 11, DK, and FLK), as well as sites with low sample sizes (FxJj 3, FxJj 4, and HWK W) were specifically selected to test the range and sensitivity of the BLA methodological process.

Table 4.1: Sample sizes for archaeological localities, by site and totals

Locality	Site	Number of measured whole flakes
Koobi Fora	FxJj 1	34
Koobi Fora	FxJj 3	9
Koobi Fora	FxJj 4	3
Koobi Fora	FxJj 10	60
Koobi Fora	FxJj 11	54
Koobi Fora	**TOTAL**	**160**
Olduvai	DK	171
Olduvai	FLK	84
Olduvai	FLK N	54
Olduvai	HWK E	27
Olduvai	HWK W	4
Olduvai	**TOTAL**	**340**
Combined	**TOTAL**	**500**

IV.A.2. Variation within Koobi Fora assemblages

Flake assemblages from each measured site were analyzed against one another using a Multivariate Analysis of Variation (MANOVA). Results demonstrate that KBS assemblages from each site cannot be assumed to be part of the same continuum of variation (Table 4.2a). A d=1 value demonstrates that the null hypothesis that each assemblage represents a subsample from a larger population can be rejected at a statistically significant level, though the relationship could be linear.

To assess where variation specifically exists, each site was analyzed against each other site (Table 4.3). Based on Table 4.3, the site that is driving this difference is FxJj 4. FxJj 4 was included in the sample to test the efficacy of BLA methodology on a site with a low sample size (N=3 whole flakes). The significant results, therefore, should be viewed with skepticism. Without the significant results driven by FxJj 4, the KBS appears relatively uniform is morphology based on this broad statistical test. Further analyses help to illuminate the KBS morphological uniformity in section *IV.C.*, when experimental results are applied to archaeological sites.

IV.A.3. Variation within Olduvai Gorge assemblages

Identical statistical tests as those described in section *IV.A.2.* were run to analyze broad variation within Olduvai Gorge assemblage (Table 4.2b) and then specifically between Olduvai Gorge sites (Table 4.4). Results demonstrate that the null hypothesis that each assemblage represents a subsample from a larger population can be rejected at a statistically significant level.

Table 4.2a: MANOVA results for intersite variation at Koobi Fora

Variables	d	p
Koobi Fora Oldowan Sites	1	0.002

*KBS flake platform area measured using BPT=UPT

Table 4.2b: MANOVA results for intersite variation at Olduvai Gorge

Variables	d	p
Olduvai Gorge Oldowan Sites	1	0.007

Table 4.2c: MANOVA results for Olduvai Gorge vs. Koobi Fora archaeological materials (all alphas = 0.05 for given d value)

Variables	d	p
Koobi Fora vs. Olduvai Gorge	1	<0.01

Table 4.3: Site-by-site MANOVA analysis of Koobi Fora KBS sites to determine if intra-basinal assemblage variation exists (significant alpha levels = 0.05 for d=1)

Sites	FxJj 10	FxJj 11	FxJj 1	FxJj 3	FxJj 4
FxJj 10	1.0				
FxJj 11	0.39	1.0			
FxJj 1	0.95	0.28	1.0		
FxJj 3	0.77	0.34	0.56	1.0	
FxJj 4	**0.002**	**0.004**	**0.008**	**0.03**	1.0

Table 4.4: Site-by-site MANOVA analysis of Olduvai Gorge Oldowan sites to determine if intra-basinal assemblage variation exists (significant alpha levels = 0.05 for d=1)

Sites	DK	FLK	FLKN	HWKE	HWKW
DK	1.0				
FLK	0.06	1.0			
FLKN	**0.02**	0.49	1.0		
HWKE	0.18	**<0.01**	**<0.01**	1.0	
HWKW	0.75	0.83	0.61	0.63	1.0

IV.A.4. Variation between Koobi Fora and Olduvai Gorge

To establish whether variation broadly exists between Koobi Fora and Olduvai Gorge, a MANOVA test was run between assemblages using the size standardized data points. Results demonstrate that there are broad assemblage differences between the archaeological localities (Table 4.2c). The statistical differences between assemblages at Olduvai Gorge and between Olduvai Gorge and Koobi Fora could be due to raw material differences and differential fracture behaviors of those raw materials. These issues will be addressed in section *IV.C.*

The results of sections *IV.A.2., IV.A.3., and IV.A.4.* provide statistical reasons for pursuing further investigation into what this assemblage-level variation means in terms of production behaviors. Further, the readily apparent variation between sites at Olduvai Gorge seems to contrast with the seemingly uniform distribution of flake morphologies in the KBS of Koobi Fora.

IV.B. Establishing experimental expectations – reduction experiments

Previously published literature has assumed a "least effort approach" to stone tool manufacture in the Oldowan (see section *II.B.4.b*). The controlled experiments undertaken for this research test this assumption by creating a large sample size of replicated flakes produced under least effort suppositions. The large sample size of replicated flakes discussed in this section serves as an experimental model that empirically establishes morphological expectations for Oldowan lithic implements produced through least effort means.

IV.B.1. Experimental sample size

The methodology outlined in section *II.B.* was implemented to reduce a total of 443 cobbles (360 of usable material) into 3,651 detached pieces. Each resulting detached piece has 1) an empirically known production behavior associated with it, 2) its relative position in the reductive process of a core recorded, and 3) a core of known original morphology. Further, the number of strikes necessary to remove a given flake is also empirically measured, as is the morphology and weight of the hammerstone used to create that flake. Only detached pieces with complete morphology were measured and included in the sample for this study (total N=2,828). The total number of experimentally produced whole flakes and cores is shown in Table 4.5. Each flake was size standardized using the geometric mean method outlined in Chapter 2. Isometric expectations are met (ex: for Koobi Fora basalt, standardized length was plotted against measured length: r^2 = 0.70, equation: y = 0.41x + 0.27).

IV.B.2. Constructing the classification algorithm

Each of the flakes in the experimentally produced assemblage seen in Table 4.5 has one of the Oldowan production behaviors (defined in section *II.B.4.c*) empirically associated with it. The size-standardized measurements for each flake (section *II.A.3.*) were utilized in MATLAB (v.2012a) to construct a classification algorithm using the *classregtree* function. This classification algorithm is a set of "if-then" statements that classify the objects in question into their constituent units based on the measurements provided.

Table 4.5: Experimental sample size: cores and total flakes by raw material

Site	Material	Type	Total	Measureable (N)
Koobi Fora	Basalt	Core	224	168
Olduvai	Basalt	Core	107	100
Olduvai	Quartzite	Core	112	92
Total Cores	**Combined**	**Core**	**443**	**360**
Koobi Fora	Basalt	Flakes	1893	1611
Olduvai	Basalt	Flakes	798	597
Olduvai	Quartzite	Flakes	960	620
Total Flakes	**Combined**	**Flakes**	**3651**	**2828**

Each raw material was separately utilized to construct an algorithm specifically reflecting the variation of that material. Because all raw materials have the same set of classification outcomes (OBA, OBB, OBC, or OBD), they become directly comparable in terms of these production behavior. In other words, flakes from different raw materials become directly comparable; this serves to quantitatively demonstrate if and how differences in raw materials affect the outcome of Oldowan flakes morphology and to what extent raw material differences can be used to explain morphological and behavioral variation within the Oldowan. Thus the first diagnostic feature utilized for behavior classification is raw material.

IV.B.3. Misclassification rate calculation: assemblage level vs. individual artifact

After the classification algorithm was constructed, its efficacy was assessed at two levels: the assemble level and the individual artifact level. At the assemblage level, this research utilized a substitution method for misclassification diagnostics. The *classregtree* function was programmed to randomly divide the experimental sample into ten subsamples and test the accuracy of the constructed algorithm against these subsamples at different levels of classification tree "pruning." Pruning refers to the process of removing nodes from a given tree to reduce its complexity. By substituting random samples and determining misclassification rates at different levels of pruning, the smallest tree with the highest rates of correct classification was determined. This tree is described as being the most "efficient."

The probability of any individual artifact being correctly classified was also determined. At the end of any classification tree branch is a final classification value (in the case of this research, this represents a production behavior). Some branches yield flakes with high probabilities of being correctly classified; other branches extend down paths in which two or more production behaviors share significant morphological overlap. These branches will yield lower probabilities of correct classification.

Either way, using a classification algorithm allows the researcher to assign probabilities to the behavioral classifications of these assemblages or individual artifacts. In the case of the Oldowan, significant morphological overlap was hypothesized, whereas as technological prowess increases through time (i.e. Middle Paleolithic and Upper Paleolithic), it is hypothesized that morphological distinction will also increase (please revisit Figure 2.7 in section *II.B.4.a*). Therefore for the Oldowan, as with all other technologies, it is useful to have knowledge of the likelihood of correct classification at different levels of analysis.

At the assemblage level, misclassification rates vary between raw materials. As expected, given the highly variable morphology of flakes produced through the least effort approach, assemblage level misclassification is relatively high (Figure 4.1). This misclassification rate, however, is mediated by the effect of assigning probabilities of classification correctness to individual artifacts (Table 4.6). For instance, if a KBS flake has a morphological signature such that it is classified as an Oldowan Behavior D flake, in the third position (labeled as D^3 in Table 4.6; see Figure 4.2 for all behaviors), it may appear that there is only a 68% chance that that particular flake is classified correctly. However, there is a 0.00% chance that the flake is an OBA flake, a 4% chance that the flake belongs to the OBB category, and a 28% that the flake could be an OBC flake. Thus the misclassification information yields interesting and useful information, mainly

Figure 4.1a: Misclassification rates for experimental KBS assemblage

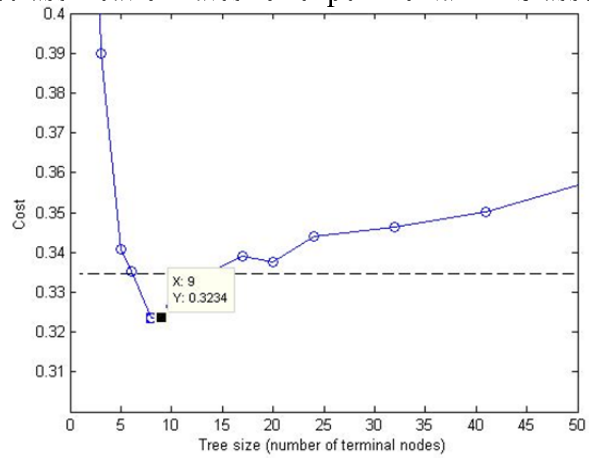


Figure 4.1b: Misclassification rates for experimental Olduvai Basalt assemblage

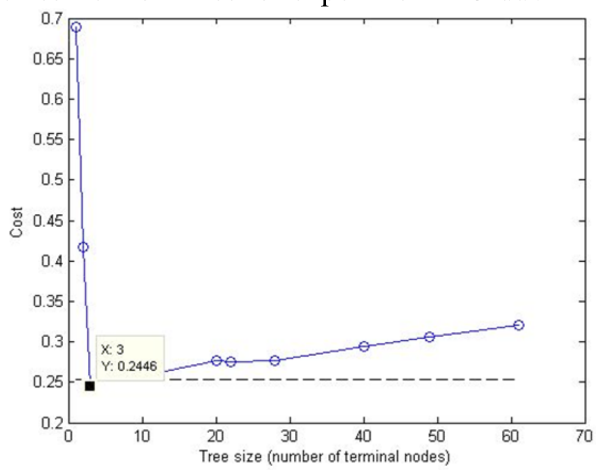


Figure 4.1c: Misclassification rates for experimental Olduvai Quartzite assemblage

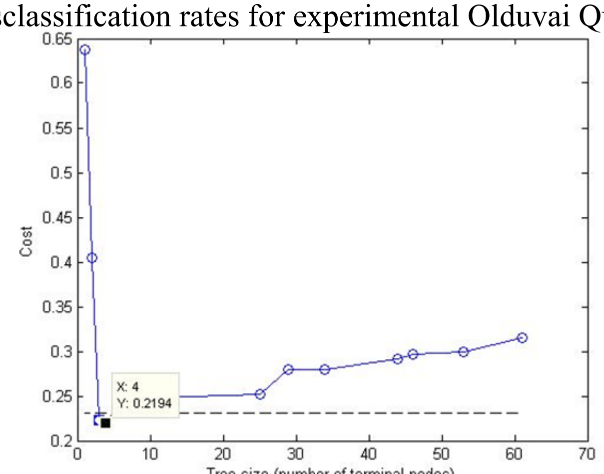


Figure 4.1: Each misclassification graph is constructed via random substitution of samples with empirically known classes into the trained algorithm. The X value represents the number of terminal nodes (ends of branches). The smallest value of X for the smallest misclassification value of Y is considered the most economical tree.

Table 4.6: Probability of correct classification for individual flakes (see Figure 4.2)

Classified Behavior	Raw Material	Probability A (%)	Probability B (%)	Probability C (%)	Probability D (%)
A^1	Koobi Fora Basalt	**87.40**	8.88	0.94	2.80
A^2	Olduvai Quartzite	**84.00**	11.50	3.21	1.28
A^3	Olduvai Basalt	**87.60**	7.75	1.55	3.10
B^1	Koobi Fora Basalt	7.69	**87.80**	1.75	2.80
B^2	Olduvai Quartzite	8.50	**87.60**	1.77	1.77
B^3	Olduvai Basalt	5.11	**90.30**	2.27	2.27
C^1	Koobi Fora Basalt	8.20	5.74	**52.50**	33.60
C^2	Koobi Fora Basalt	1.80	3.60	**57.70**	36.90
C^3	Koobi Fora Basalt	1.61	2.02	**62.10**	34.30
C^4	Koobi Fora Basalt	0.80	3.20	**80.00**	16.00
C^5	Olduvai Quartzite	0.86	3.88	**65.90**	29.30
C^6	Olduvai Basalt	0.00	0.00	**85.70**	14.30
C^7	Olduvai Basalt	0.00	3.55	**74.50**	22.00
D^1	Koobi Fora Basalt	0.00	1.54	38.50	**60.00**
D^2	Koobi Fora Basalt	1.69	3.13	31.80	**63.40**
D^3	Koobi Fora Basalt	0.00	4.00	28.00	**68.00**
D^4	Olduvai Basalt	16.70	0.00	0.00	**83.30**
D^5	Olduvai Basalt	0.81	0.81	41.50	**56.90**

that in this case, OBC and OBD flakes share a similar morphological pattern in the KBS, but that there is little to no chance of confusing this flake with an OBA or OBB flake.Further, by limiting the classification to OBD (likely) or OBC (possible), the analysis at a broader level can still say something significant about assemblage-level differences and the likelihood that a given archaeological assemblage fits the expectations of the experimental model (this will be demonstrated in section *IV.C.2.* and section *IV.C.3.*).

IV.B.4. Classification of production behaviors

Using the classification algorithm constructed from the measurements and classifications of the experimentally produced Oldowan assemblages, a final classification tree was constructed (Figure 4.2). The number of terminal nodes per raw material was statistically determined to be the most economical via the methodology described for Figure 4.1. Each terminal node in Figure 4.2 has an Oldowan behavioral classification associated with it (OBA, OBB, OBC, or OBD). Each behavior also has a superscripted number associated with it. This behavior-number combination can be referenced in Table 4.6 to determine the probability of a given classification for any given flake.

Figure 4.2 is an elegant example of how the experimental model of BLA methodology can be used. It is simple, straightforward, statistically bound, and behaviorally informative at both the assemblage and individual artifact level. Since the terminal classifications are based on physical behaviors in stone tool production, behavior becomes strictly defined and can be directly compared across the archaeological sites

Figure 4.2:

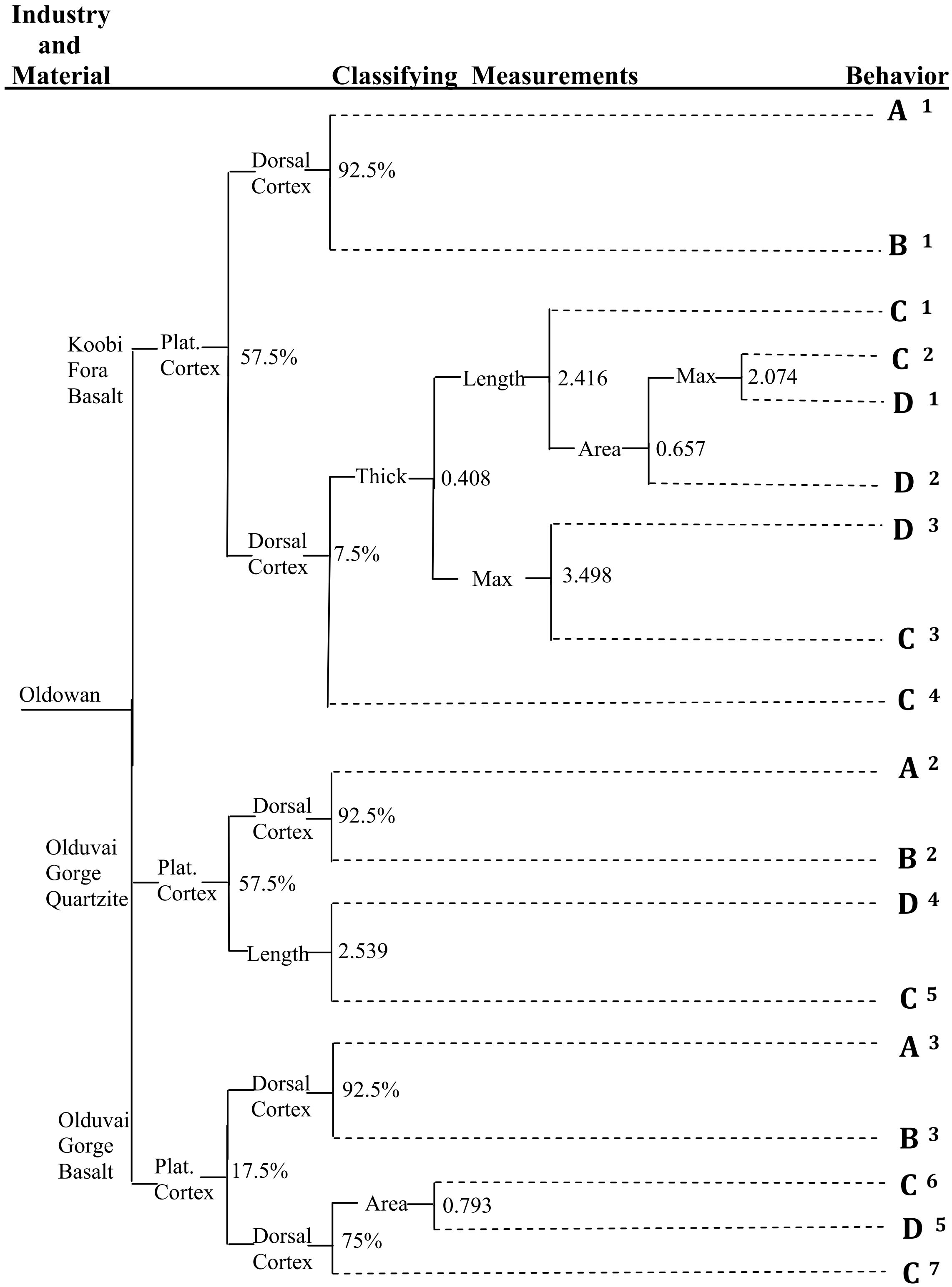

Industry and Material
Classifying Measurements
Behavior
Oldowan
Koobi Fora Basalt
Plat. Cortex
57.5%
Dorsal Cortex
92.5%
A 1
B 1
Dorsal Cortex
7.5%
Thick
0.408
Length
2.416
C 1
Area
0.657
Max
2.074
C 2
D 1
D 2
Max
3.498
D 3
C 3
C 4
Olduvai Gorge Quartzite
Plat. Cortex
57.5%
Dorsal Cortex
92.5%
A 2
B 2
Length
2.539
D 4
C 5
Olduvai Gorge Basalt
Plat. Cortex
17.5%
Dorsal Cortex
92.5%
A 3
B 3
Dorsal Cortex
75%
Area
0.793
C 6
D 5
C 7

Figure 4.2: This master classification tree represents a composite image of the classification algorithms for the three raw materials studied in this report. Beginning with the Oldowan as a general industry, the classification system narrows until a terminal node is reached and a production behavior category is determined. At each branching event, if the value for the flake in question is larger than the number at that particular node, then one moves up that branch to the next node; if the value for the flake in question is smaller than the number at that particular node, then one moves down that branch to the next node. Each terminal node with a behavioral classification has a corresponding superscripted number associated with it. This represents one of several ways by which that production behavior might have been reached. Each letter and superscript has a correlate in Table 4.6 that provides statistical information as to the probability of that classification being correct.

studied (and compared directly to future archaeological excavations from Koobi Fora KBS sites and Olduvai Gorge Oldowan sites). Thus an OBA flake produced on Koobi Fora basalt is directly comparable to an OBA flake produced on Olduvai Quartzite; an assemblage of Oldowan flakes from DK becomes behaviorally comparable to an assemblage of Oldowan flakes from FxJj 10; the entire Oldowan assemblage from Olduvai Gorge becomes behaviorally comparable to the entire KBS assemblage from Koobi Fora.

Another way to visually represent how the classification algorithm is separating flakes based on relative morphology is to view the variation in terms of principal components. Using a principal component analysis allows for significant variation to be viewed as composite variables that represent different elements of variation on a single axis. More importantly, using principal components to view this variation allows for a graphical representation of how groups are broadly different and how they are similar (based on where they overlap). For instance, experimental KBS flakes were analyzed in a three-dimensional principal components analysis in Figure 4.3. Oldowan Behaviors A and B separate out, given the variation accounted for by principal components 1, 3, and 4; Oldowan behaviors C and D are not as easy to separate out. This fact correlates with the relative likelihoods of classification success as predicted by the classification algorithm in Table 4.6. This pattern continues with Olduvai Gorge Basalt (Figure 4.4) and Olduvai Gorge Quartzite (Figure 4.5).

The point of the BLA experimental model is to produce an assemblage with empirically known characteristics so as to establish a baseline expectation of variation for archaeological assemblages. While such a large experimental sample provides more data

Figure 4.3:

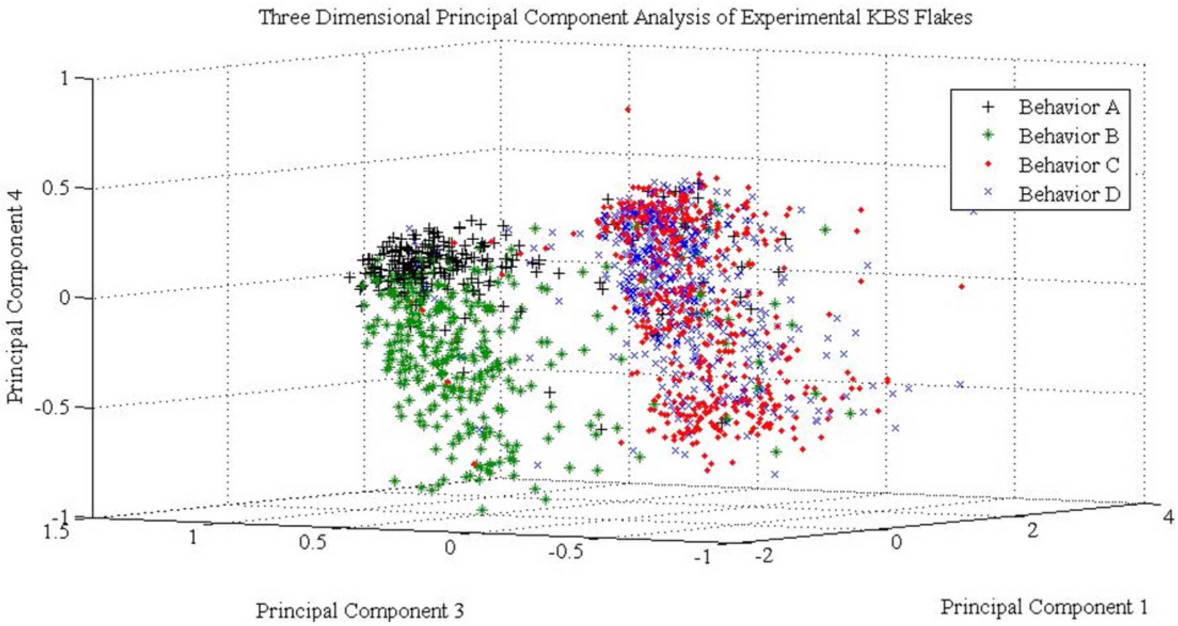


Figure 4.3: PCA distribution of KBS production behaviors as classified via Figure 4.2. On the left, note that OBA and OBB behaviors overlap, but separate from one another. OBC and OBD flakes, on the right, overlap more than OBA and OBB, but separate morphologically from them. The misclassification rates in Table 4.6 demonstrate these relationships as well. The first four principal components (PC1, PC3, and PC4 pictured here for clarity of separation) account for 92.32% of the assemblage variation.

Figure 4.4:

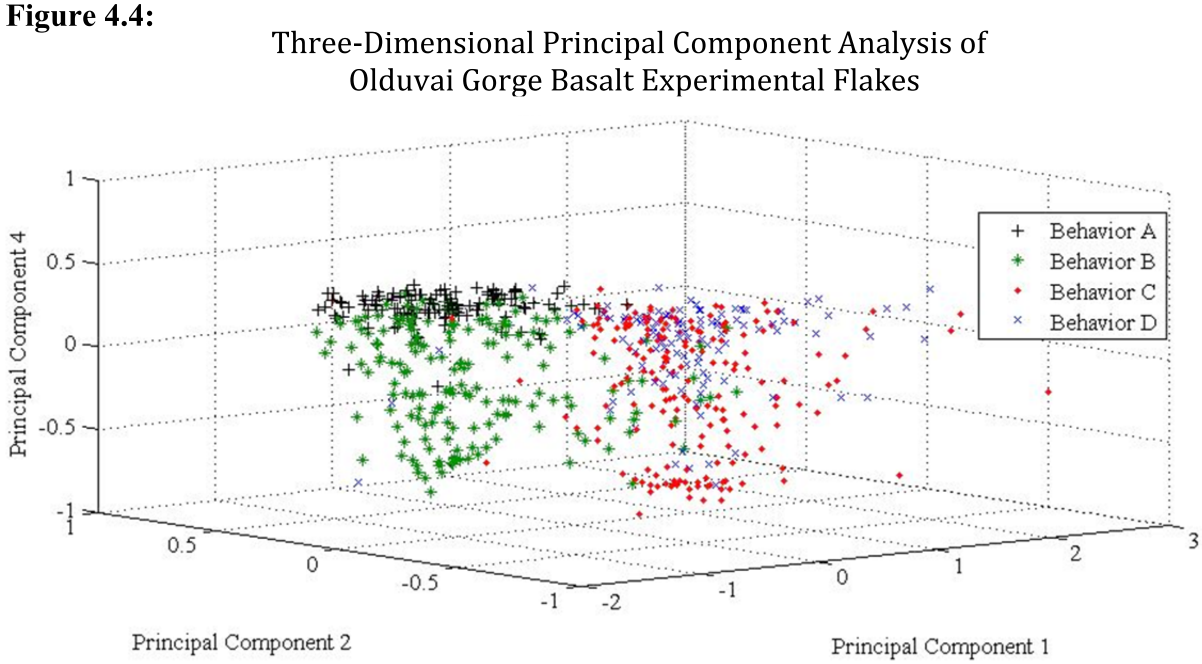


Figure 4.4: PCA distribution of Olduvai Gorge production behaviors for basalt as classified via Figure 4.2. On the left, note that OBA and OBB behaviors overlap, but separate from one another. OBC and OBD flakes, on the right, overlap more than OBA and OBB, but separate morphologically from them. The misclassification rates in Table 4.6 demonstrate these relationships as well. The first four principal components (PC1, PC2, and PC4 pictured here for clarity of separation) account for 91.99% of the assemblage variation.

Figure 4.5:

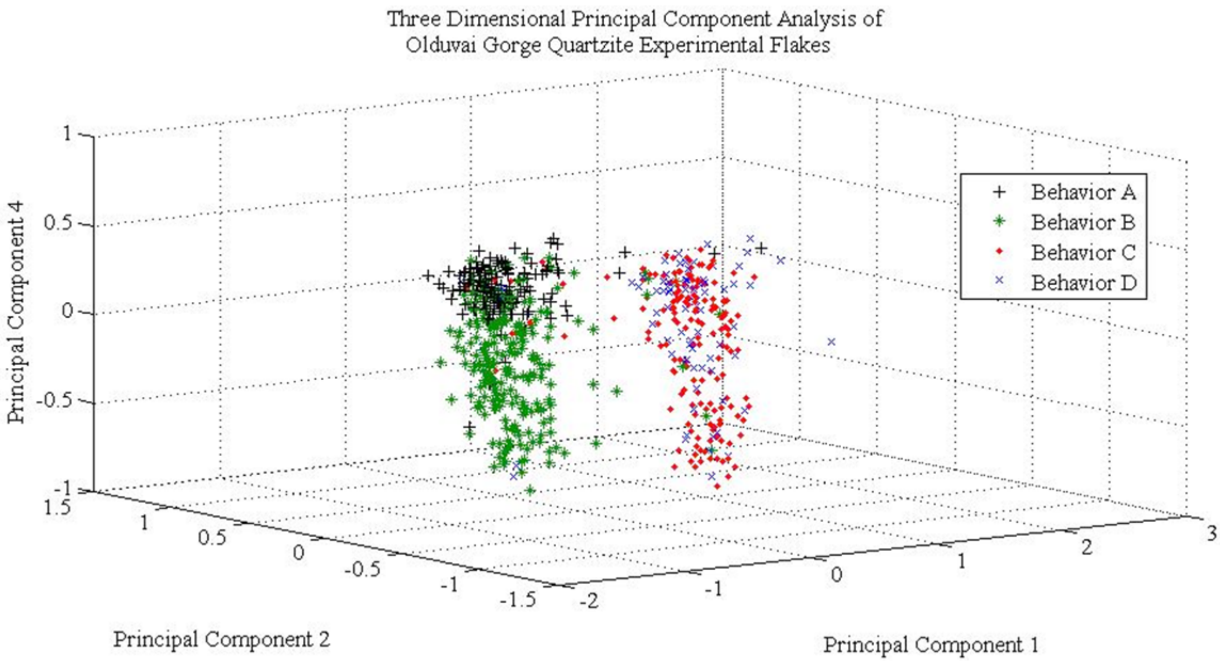


Figure 4.5: PCA distribution of Olduvai Gorge production behaviors for quartzite as classified via Figure 4.2. On the left, note that OBA and OBB behaviors overlap, but separate from one another. OBC and OBD flakes, on the right, overlap more than OBA and OBB, but separate morphologically from them. The misclassification rates in Table 4.6 demonstrate these relationships as well.The first four principal components (PC1, PC2, and PC4 pictured here for clarity of separation) account for 90.61% of the assemblage variation.

than just production behaviors (see section *IV.B.5.*, below), the most useful aspect of BLA is the classification of flakes into production behaviors via the classification tree in Figure 4.2. After 360 reduction experiments for a total of 2,828 complete, measurable flakes, Figure 4.6 shows the average distribution of Oldowan behaviors given a least effort approach to their manufacture. Based on this experimental model it is expected, therefore, that archaeological sites representing the complete reductive process will have similar distributions of classified flakes (see section *IV.C.*). Significant deviance from this expectation would indicate site disturbance, incomplete reductive processes, or selective removal/addition of flakes to a site.

IV.B.5. Experimental assemblage characteristics

Archaeological artifacts are notoriously difficult to infer behavior from because they are static remnants of an otherwise dynamic process; stone tools were actively made, but when they are found, they are inert. Descriptive characteristics of the experimentally produced assemblage are useful because they contribute to reconstructing that dynamic character to the stone tool production process. This research records every detail of each flake's production, including hammerstone size, original core morphology, the production behavior used to create it, the number of strikes necessary to remove it, the order in which each flake was removed, and the integrity of the resulting flake.

This section will analyze these various components of the reductive process so as to determine how a core is reduced on average, and what the resulting assemblage is expected to look like. This information is particularly useful to establish baseline expectations for archaeological assemblage composition.

Figure 4.6:

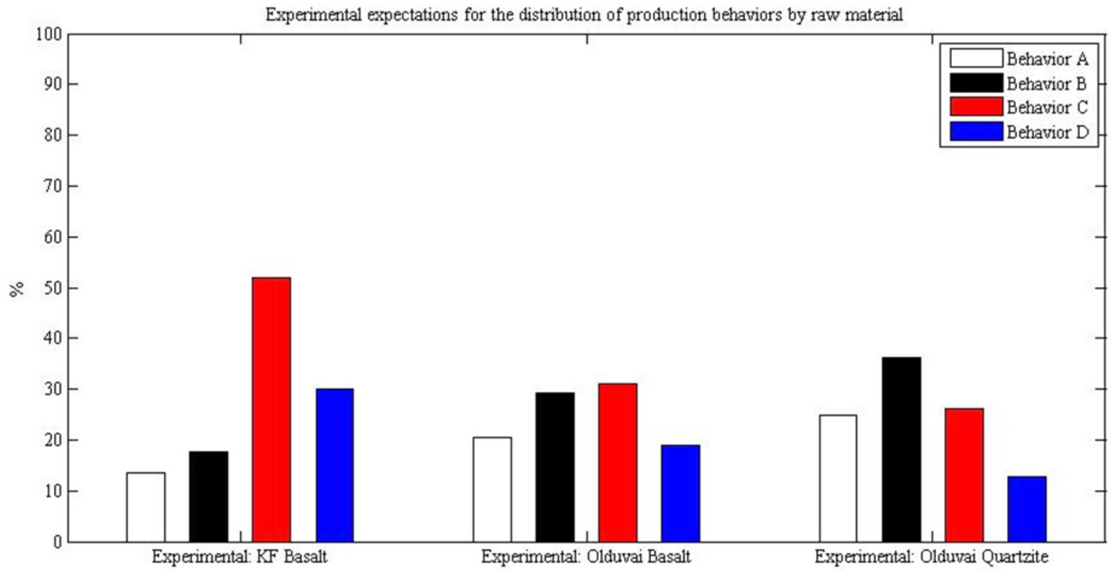


Figure 4.6: For each raw material considered in this study, this represents the final assemblage composition in terms of production behaviors for a least effort approach to stone tool production. This model provides a valuable rubric by which to judge archaeological assemblages.

IV.B.5.a. Average number of flakes per core

Another way to view Figure 4.6 is to break down each raw material into an average number of flakes per core and then to further break this down into the average number of individual production behavior events per core. Table 4.7 shows the average number of flakes per core per raw material and the average number of production behaviors per core per raw material. The differential distribution of core productivity (how many overall flakes per core there are) as well as the distribution of production behaviors yields both important behavioral information about Oldowan producing hominins and important information regarding raw material constraints and potential selectivity on the part of the hominin (see Chapter 5).

IV.B.5.b. Flake and core assemblage composition

Many flakes break during production. A broken flake yields a shorter cutting edge than its complete counterpart and thus is potentially less effective for utilitarian tasks. The ability for a material to break in a predictable manner includes being able to produce relatively complete flakes. To assess each raw material in terms of its ability to yield whole flakes, each experimental assemblage was broken down into its constituent components by percentage of the total assemblage population (whole flakes, split flakes, snapped flakes, split and snapped flakes, and cobble fragments) (Figure 4.7).

It is readily apparent that all three raw materials yield a high amount of whole flakes, but both Koobi Fora basalt and Olduvai Gorge basalt yield a higher proportion of whole flakes than Olduvai Gorge quartzite. Olduvai Gorge quartzite is quite brittle and will often break in abnormal, unpredictable ways. This likely accounts for the variable

Table 4.7: Average number of flakes removed per core and number of production behaviors for a given raw material

Raw Material	Avg. # Flakes Per Core	OBA	OBB	OBC	OBD
KF Basalt	11.27	1.39	1.82	5.36	3.09
Olduvai Basalt	8.67	1.33	1.90	2.02	1.23
Olduvai Quartzite	9.60	1.54	2.25	1.62	0.79

Figure 4.7:

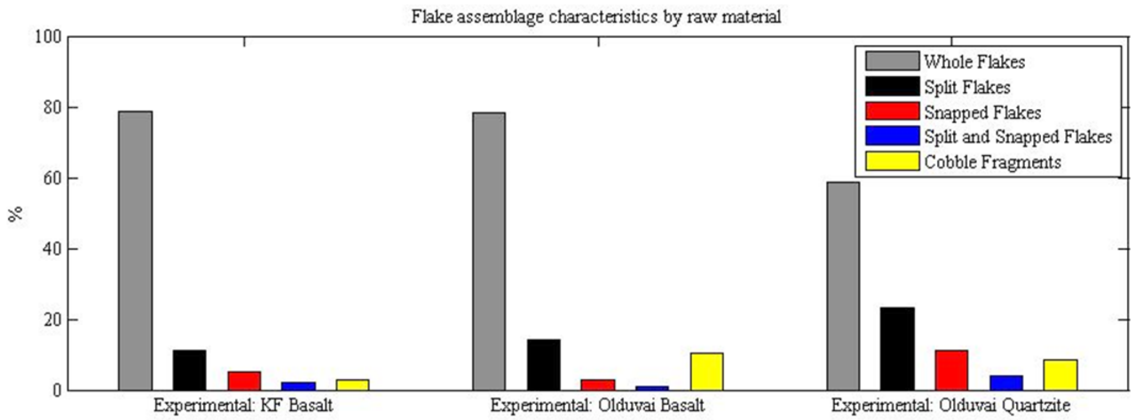


Figure 4.7: A total breakdown of flake types and their prevalence per raw material. (KF: N = 1893; Olduvai Basalt: N=798; Olduvai Quartzite: N=960)

breakage of whole flakes. However, Olduvai Gorge quartzite was used to a great extent by Oldowan producing hominins, who had to travel a distance to procure it. Such time investment and energy in procurement suggests an advantage to using this material.

Despite the careful selection process of acceptable cobbles of raw material from Olduvai Gorge and Koobi Fora (see sections *III.A.2* and *III.B.2.*), some cobbles had impurities and were unfit for predictable flake manufacture. These cobbles were labeled as "poor raw material" and set aside. Because the same selection method was used for all cobbles, it is prudent to establish an expectation for what percentage of available raw materials on the landscape are insufficient for stone tool production. Given the large sample size of cobbles and the rigorous process by which they were selected, Figure 4.8 provides a baseline expectation for raw material quality at the sites from which materials were collected. The results demonstrate that despite yielding the highest proportion of broken flakes (and thus the lowest proportion of whole flakes), Olduvai Gorge quartzite is a predictably high quality raw material in terms of its lack of internal inconsistencies and abnormalities.

IV.B.5.c. Hammerstone influence on the reductive process

No Oldowan experimental study has determined the effects of hammerstone size and material on resulting flake morphology. To make certain that experimentally produced assemblages of flakes were not morphologically skewed due to hammerstone selection, and to test if there are, in fact, any hammerstone effects, hammerstones of different sizes and raw materials were utilized.

Figure 4.8:

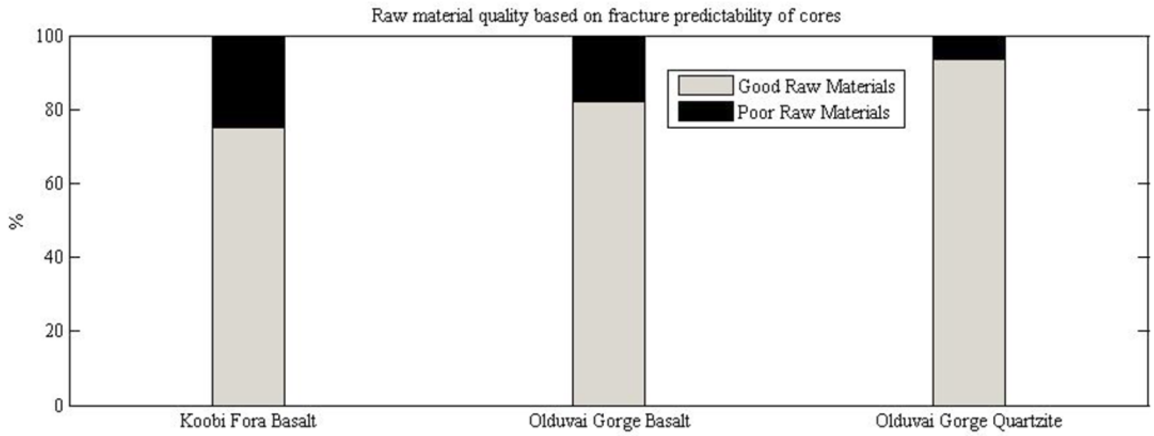


Figure 4.8: The relative percentages of appropriate and poor raw materials for each raw material type tested by this research. Koobi Fora basalt has the highest rate of inclusions and impurities, followed by Olduvai Gorge basalt. Olduvai Gorge quartzite, despite being brittle, was acceptable for flake production 93.5% of the time (only 7 cobbles out of 107 were found inappropriate for flaking).

For Koobi Fora reduction experiments, four hammerstones were utilized, all of KBS basaltic material. Raw material was kept constant because no hammerstone has been excavated from KBS deposits that was any material other than basalt. Therefore, it is a safe inference that KBS hominins were utilizing basalt as their hammerstone material, just as they were utilizing basalt as their raw material for flake manufacture. Hammerstones were selected based on the excavated assemblages of archaeological hammerstones from the KBS at Koobi Fora (Table 4.8). One hammerstone (H3) was near the archaeological mean for weight, one (H1) was approximately one standard deviation above the archaeological mean for weight, and two were approximately one standard deviation below the archaeological mean for weight (H2 and H10). As Table 4.8 indicates, the sample size of flakes produced by these hammerstones is nearly equivalent across the three weight categories (when weight category assemblages are combined).

No clear morphological distinction is apparent between flakes produced from differently sized hammerstones at Koobi Fora (Figure 4.9). However, even if morphological differentiation at the individual artifact level cannot be determined, there may be assemblage level differences based on hammerstone attributes. To determine if this is the case, the relative frequency of production behaviors for each hammerstone size was compared. A Kruskal-Wallis test was run ($p=0.51$), followed by a Tukey's post-hoc test for multiple comparisons. No significant results were produced for either hammerstone size or for hammerstone material ($p=0.66$) (Table 4.9), suggesting that behavioral differences in assemblages cannot be attributed to variation in hammerstone characteristics in the Oldowan.

Figure 4.9:

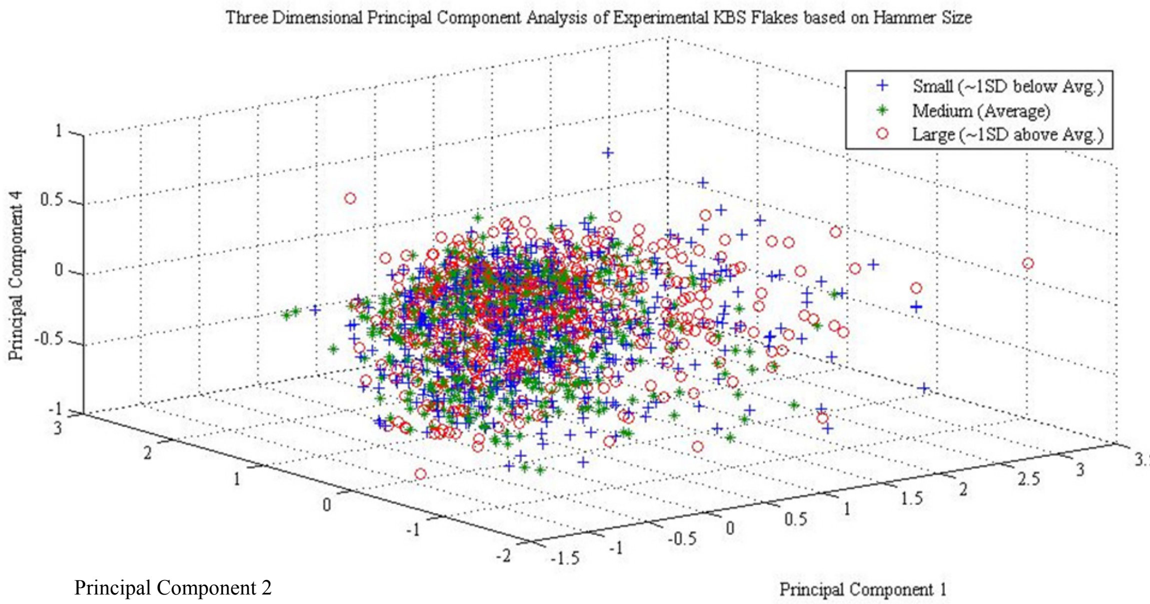


Figure 4.9: This principal component analysis demonstrates that hammerstone size is not a strong determinant of resulting flake morphology. The first four principal components (PC1, PC2, and PC4 pictured here for clarity of separation) account for 92.32% of the assemblage variation.

Table 4.8: Experimental hammerstones and flake assemblage sizes for each

Hammer CAT#	Hammer Material	Core Material	Weight (g)	Size Class	Assemblage Size (N)
H1	KF BAS	KF BAS	647	Large	561
H2	KF BAS	KF BAS	315	Small	488
H10	KF BAS	KF BAS	348	Small	119
H3	KF BAS	KF BAS	471	Medium	443
H4	OLD QTZ	OLD QTZ	625	Large	331
H5	OLD BAS	OLD QTZ	576	Large	75
H6	OLD BAS	OLD QTZ	464	Medium	214
H7	OLD BAS	OLD BAS	438	Medium	351
H9	OLD QTZ	OLD BAS	659	Large	239

Table 4.9: Tukey's post-hoc results testing for assemblage level differences in relative proportions of production behaviors based on hammerstone size and raw material

Group Comparison	Material	Lower confidence interval	Difference in group means	Upper confidence interval
Small vs. Medium	KFBAS	-3.09	2.88	8.84
Small vs. Large	KFBAS	-5.09	0.88	6.84
Medium vs. Large	KFBAS	-7.96	-2.00	3.96
Effect of material	OLDBAS vs. OLDQTZ	2.62	0.75	4.12

IV.B.5.d. Core shape and influence on the reductive process

The initial shape of the core utilized to produce flakes could influence the morphology of the resulting flakes and/or the relative proportion of production behaviors represented in a given assemblage (Toth 1982). To address this analytical concern, each core was quantitatively classified into a general shape category (Figure 4.10) based on a combination of shape predictors and cobble edge morphology (Table 4.10). Cobble edge morphology was determined empirically prior to cobble reduction and preserved through photographic evidence.

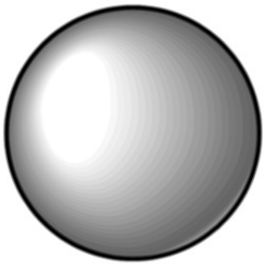
Two different tests are pertinent to the question of how initial cobble morphology influences the resulting flakes. First, we can ask if cobbles of a particular morphology are more productive in terms of absolute number of flakes produced. Second, we can ask if there are assemblage level differences such that cores with a particular initial morphology produce variable proportions of Oldowan production behaviors. Results to these questions will help interpret potential variation in archaeological assemblage in behaviorally informative ways.

To address the first question, data was organized to reflect the total number of flakes (whole, split, snapped, and split and snapped, but excluding cobble fragments) for each cobble reduction. Cobble reductions were then organized by the shape classification of their initial cobble. A Kruskal-Wallis test was then run to compare whether the number of flakes produced from a given core was related to the initial cobble morphology of that core. Tests were run separately on each raw material (Table 4.11). Tukey's post hoc test for multiple comparisons was run to assess the differences between individual

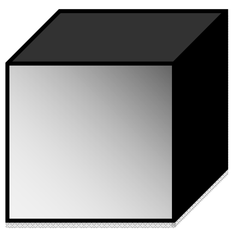
Figure 4.10: Core Shape Classification Categories:

Idealized (profile view): | *Examples (profile view):*

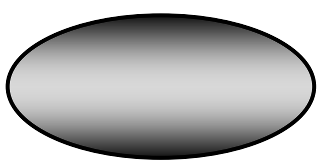
Category 1: "Rounded"



Category 2: "Blocky"



Category 3: "Discoidal"



Category 4: "Oblong"

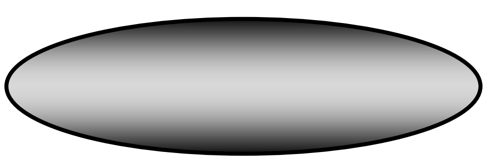


Table 4.10: Core morphological classification criteria

Category	Length:Width Ratio	Thickness:Length Ratio	Cobble Edge Morphology
1	<1.5	>0.65	Rounded edges
2	<1.5	>0.65	Blocky/Angular edges
3	<1.5	<0.65	No distinction
4	>1.5	<0.65	No distinction

Table 4.11: Kruskal-Wallis and Tukey's post hoc test for multiple comparisons results testing whether cores of different initial morphological classification tend to differentially yield more or fewer total flakes (significant results are in bold)

Kruskal-Wallis Results:

Site	Material	p
Koobi Fora	Basalt	**<0.01**
Olduvai Gorge	Basalt	0.26
Olduvai Gorge	Quartzite	0.24

Tukey's Results:

Group Comparison	Material	Lower confidence interval	Difference in group means	Upper confidence interval
1 vs. 2	**KFBAS**	**-82.30**	**-43.75**	**-5.21**
1 vs. 3	**KFBAS**	**-67.51**	**-38.32**	**-9.14**
1 vs. 4	**KFBAS**	**-101.55**	**-61.89**	**-22.24**
2 vs. 3	KFBAS	-24.94	5.43	35.80
2 vs. 4	KFBAS	-58.68	-18.14	22.39
3 vs. 4	KFBAS	-55.33	-23.57	8.19
1 vs. 2	OLDBAS	-65.45	-26.48	12.50
1 vs. 3	OLDBAS	-43.36	-17.83	7.70
1 vs. 4	OLDBAS	-46.80	-14.38	18.05
2 vs. 3	OLDBAS	-23.02	8.64	40.30
2 vs. 4	OLDBAS	-25.34	12.10	49.54
3 vs. 4	OLDBAS	-19.67	3.46	26.59
1 vs. 2	OLDQTZ	-17.69	25.17	68.03
1 vs. 3	OLDQTZ	-27.13	11.01	49.14
1 vs. 4	OLDQTZ	-39.28	3.58	46.44
2 vs. 3	OLDQTZ	-37.31	-14.16	8.99
2 vs. 4	OLDQTZ	-51.89	-21.58	8.72
3 vs. 4	OLDQTZ	-30.57	-7.42	15.72

groups. Significant results are represented in bold text. Total sample sizes for each core shape classification per raw material can be found in Table 4.12.

Results demonstrate that the null hypothesis that there is no difference in total number of flakes produced by a given core cannot be rejected for Olduvai Gorge basalt and quartzite. In other words, as long as there is an initial acute angle from which to begin the reduction process (a methodological consideration this research used in selecting a core), initial core shape does not influence the total number of flakes produced from a given core. The one exception is that KBS basalt cores with a morphological classification of 1 produce significantly fewer flakes than any other morphological classification.

The spherical shape associated with Class 1 cores are particularly difficult to flake successfully, so this result is not surprising. What is more surprising is that this trend does not continue into Olduvai Gorge raw materials.

Though results demonstrate, somewhat surprisingly, that no broader trend exists for cobbles with a greater preponderance of acute edges to yield absolutely more flakes, this does not mean that assemblage level differences do not exist. For instance, a thicker core may not yield platforms conducive to discoidal (OBD) flaking. Thus, it may be that cores with a classification of 1 or 2 yield fewer OBD flakes than do cores with classifications of 3 or 4. The relative proportion of production behaviors, as well as the sample sizes of cores with a given morphological classification can be found in Table 4.12.

Table 4.12: Proportion of classification behaviors relative to the initial core morphology classification

Core Material	Core Shape Class.	Core Sample Size	Behavior A (%)	Behavior B (%)	Behavior C (%)	Behavior D(%)
KF BAS	1	22	19.67	11.48	36.07	32.79
KF BAS	2	20	12.96	20.37	41.20	25.46
KF BAS	3	108	14.89	19.85	32.73	32.54
KF BAS	4	18	11.11	17.33	34.22	37.33
OLD BAS	1	5	19.23	11.54	57.69	11.54
OLD BAS	2	2	12.50	27.50	35.00	7.50
OLD BAS	3	69	20.99	31.69	28.69	18.63
OLD BAS	4	10	23.44	20.31	35.94	20.31
OLD QTZ	1	4	18.75	43.75	18.75	18.75
OLD QTZ	2	12	33.33	33.33	24.24	9.09
OLD QTZ	3	72	25.17	37.75	23.60	13.48
OLD QTZ	4	12	18.18	27.27	45.45	9.09

Table 4.13: Kruskal-Wallis and Tukey's post hoc test for multiple comparisons results testing whether cores of different initial core morphologies (groups are core classification numbers) produce assemblage of flakes with relatively different proportions of Oldowan production behaviors; bold print indicates significant results.

Kruskal-Wallis Results:

Site	Material	p
Koobi Fora	Basalt	0.26
Olduvai Gorge	Basalt	0.01
Olduvai Gorge	Quartzite	0.01

Tukey's Results:

Group Comparison	Material	Lower confidence interval	Difference in group means	Upper confidence interval
1 vs. 2	KFBAS	-10.02	-1.38	7.27
1 vs. 3	KFBAS	-14.52	-5.88	2.77
1 vs. 4	KFBAS	-13.39	-4.75	3.89
2 vs. 3	KFBAS	-13.14	-4.50	4.14
2 vs. 4	KFBAS	-12.02	-3.38	5.27
3 vs. 4	KFBAS	-7.52	1.13	9.77
1 vs. 2	OLDBAS	-10.25	-1.63	7.00
1 vs. 3	**OLDBAS**	**-18.87**	**-10.25**	**-1.63**
1 vs. 4	OLDBAS	-13.75	-5.13	3.5
2 vs. 3	OLDBAS	-17.25	-8.63	0.00
2 vs. 4	OLDBAS	-12.12	-3.50	5.12
3 vs. 4	OLDBAS	-3.50	5.13	13.75
1 vs. 2	OLDQTZ	-12.95	-4.38	4.2
1 vs. 3	**OLDQTZ**	**-19.57**	**-11.00**	**-2.43**
1 vs. 4	OLDQTZ	-13.20	-4.63	3.95
2 vs. 3	OLDQTZ	-15.20	-6.63	1.95
2 vs. 4	OLDQTZ	-8.82	-0.25	8.32
3 vs. 4	OLDQTZ	-2.20	6.38	14.95

To test whether assemblage level differences exists, in terms of production behavior prevalence, a Kruskal-Wallis test was utilized (like in Table 4.9) to compare relative proportions of Oldowan production behaviors relative to the morphological classification of the cores from which those flakes come (Table 4.13). The sample demonstrates that with the least effort approach to flake production, initial core morphology does not play a significant role in the relative proportion of production behaviors that are utilized during cobble reduction for Koobi Fora basalt (Kruskal-Wallis $p = 0.26$). However, there is a significant difference in the proportion of production behaviors due to initial cobble morphology for Olduvai Gorge basalt ($p = 0.012$) and for Olduvai Gorge quartzite ($p = 0.011$). Tukey's post-hoc tests for multiple comparisons corroborates the Kruskal-Wallis conclusions and suggests that spherical cores (category 1) significantly differ from discoidal cores (category 3) (Table 4.13).

IV.C. Archaeological application of the experimental model

The experimental model and results that were described in the previous section establish a foundation for Oldowan behavioral analysis. By experimentally producing assemblages of flakes on indigenous East African raw materials, each with empirically known and recorded sets of behaviors, an empirically complete assemblage of Oldowan flakes was created. These results provide the first quantitative measure for behavioral variation in the Oldowan.

This section applies the experimental model established in section *IV.B.* to Oldowan archaeological assemblages from Koobi Fora, Kenya and Olduvai Gorge, Tanzania.

IV.C.1. Establishing the least effort approach

The limited previous research that has produced experimental Oldowan assemblages has assumed a "least effort approach" to the production of Oldowan flakes (see section *II.B.4.b*). Though this research has had impactful results, no one has questioned and/or tested the validity of the least effort model. A direct test of the least effort model is necessary if experimental research programs in the Oldowan are to be undertaken in the future and also to accept the validity of previous research results.

To determine if the least effort model can be applied to Oldowan assemblages, the total assemblage variation of the experimental model was first calculated (Table 4.14). Table 4.14 reflects the mean, standard deviation, and range (two standard deviation upper and lower limits) for each measurement, on each raw material. Given the large sample size of experimentally produced flakes, the wide variation of core morphologies reduced to yield these flakes, and the variable hammerstones utilized for their production, the resulting experimental assemblage provides a model for the expected range of Oldowan flake morphologies for Koobi Fora and Olduvai Gorge. With this assumption in mind, if flakes excavated from archaeological sites fall within the morphological parameters established by the experimental model, then the null hypothesis of the least effort approach cannot be rejected; if archaeological flakes fall outside of the morphological parameters established by the experimental mode, then the least effort approach null hypothesis is rejected and another explanation must be considered.

Archaeological distributions (Table 4.15) were compared with experimental expectations (Table 4.14). Archaeological flakes falling outside of experimental expectations (+/- 2 standard deviations from experimental means) were removed from the

Table 4.14: Distribution of assemblage variation for each measurement and raw material for experimentally produced flakes (SL: Size-Standardized Length; SW: Size-Standardized Width; ST: Size- Standardized Thickness; SMAX: Size-Standardized Maximum Dimension; SBT: Size-Standardized Bulbar Thickness; SAREA: Size-Standardized Area)

Site	Material	Measurement	2SD Below	Mean	2SD Above	SD
Koobi Fora	Basalt	SL	0.841	1.911	2.980	0.535
Olduvai	Basalt	SL	0.802	1.672	2.542	0.435
Olduvai	Quartzite	SL	0.864	1.689	2.513	0.412
Koobi Fora	Basalt	SW	0.983	1.953	2.924	0.485
Olduvai	Basalt	SW	1.084	1.940	2.796	0.428
Olduvai	Quartzite	SW	0.755	1.456	2.157	0.350
Koobi Fora	Basalt	ST	0.235	0.476	0.717	0.121
Olduvai	Basalt	ST	0.244	0.482	0.721	0.119
Olduvai	Quartzite	ST	0.138	0.441	0.744	0.152
Koobi Fora	Basalt	SMAX	1.634	2.643	3.652	0.504
Olduvai	Basalt	SMAX	1.628	2.489	3.349	0.430
Olduvai	Quartzite	SMAX	1.599	2.352	3.106	0.377
Koobi Fora	Basalt	SBT	0.144	0.431	0.718	0.144
Olduvai	Basalt	SBT	0.156	0.451	0.747	0.148
Olduvai	Quartzite	SBT	0.233	0.493	0.753	0.130
Koobi Fora	Basalt	SAREA	0.379	0.685	0.992	0.153
Olduvai	Basalt	SAREA	0.355	0.563	0.771	0.104
Olduvai	Quartzite	SAREA	0.399	0.677	0.955	0.139

Table 4.15: Distribution of variation within each measurement for each raw material for archaeological flakes (SL: Size-Standardized Length; SW: Size-Standardized Width; ST: Size- Standardized Thickness; SMAX: Size-Standardized Maximum Dimension; SBT: Size-Standardized Bulbar Thickness; SAREA: Size-Standardized Area)

Site	Material	Measurement	2SD Below	Mean	2SD Above	SD
Koobi Fora	Basalt	SL	0.784	1.944	3.103	0.580
Olduvai	Basalt	SL	0.974	1.849	2.723	0.437
Olduvai	Quartzite	SL	1.045	1.851	2.657	0.403
Koobi Fora	Basalt	SW	1.055	1.828	2.601	0.387
Olduvai	Basalt	SW	1.030	1.744	2.458	0.357
Olduvai	Quartzite	SW	1.044	1.704	2.365	0.330
Koobi Fora	Basalt	ST	0.285	0.533	0.781	0.124
Olduvai	Basalt	ST	0.326	0.570	0.815	0.122
Olduvai	Quartzite	ST	0.301	0.561	0.821	0.130
Koobi Fora	Basalt	SMAX	1.468	2.528	3.589	0.530
Olduvai	Basalt	SMAX	1.571	2.385	3.198	0.407
Olduvai	Quartzite	SMAX	1.601	2.352	3.103	0.375
Koobi Fora	Basalt	SBT	0.158	0.458	0.757	0.150
Olduvai	Basalt	SBT	0.215	0.476	0.737	0.130
Olduvai	Quartzite	SBT	0.226	0.482	0.738	0.128
Koobi Fora	Basalt	SAREA	0.234	0.573	0.912	0.170
Olduvai	Basalt	SAREA	0.305	0.557	0.809	0.126
Olduvai	Quartzite	SAREA	0.344	0.572	0.800	0.114

archaeological sample representing flakes falling within least effort expectations. A total of 125 archaeological flakes out of 500 (or 25%) fall outside the expected range of variation.

The fact that a significant portion of the archaeological assemblages from both Koobi Fora and Olduvai Gorge fall outside of the expected range for flake morphological variation given a least effort approach to flake manufacture is suggestive that hominins were producing flakes using methods other than least effort manufacture, at least 25 percent of the time. However, these archaeological flakes must also statistically separate from the rest of the archaeological assemblage in order to demonstrate clear separation from one continuous distribution of variation. If flakes predicted to be outside of least effort variation by the distribution of the experimental assemblage do not deviate from the archaeological assemblage, these flakes cannot be assumed to be "different" than that assemblage. These results warrants further analysis of exactly how (and if) these flakes vary from least effort expectations.

IV.C.2. Olduvai Gorge: production behaviors site-by-site

The flakes from Olduvai Gorge that fall within the range of least effort production strategies were classified, flake-by-flake, into production behavior categories based on the classification algorithm in Figure 4.2. The results presented here separate the classifications by site and by raw material, both for clarity and to stress the potential differences in production strategies based on raw material. The results for Olduvai Gorge basalt are presented in Figure 4.11a and the results for Olduvai Gorge quartzite are presented in Figure 4.11b.

Figure 4.11a:

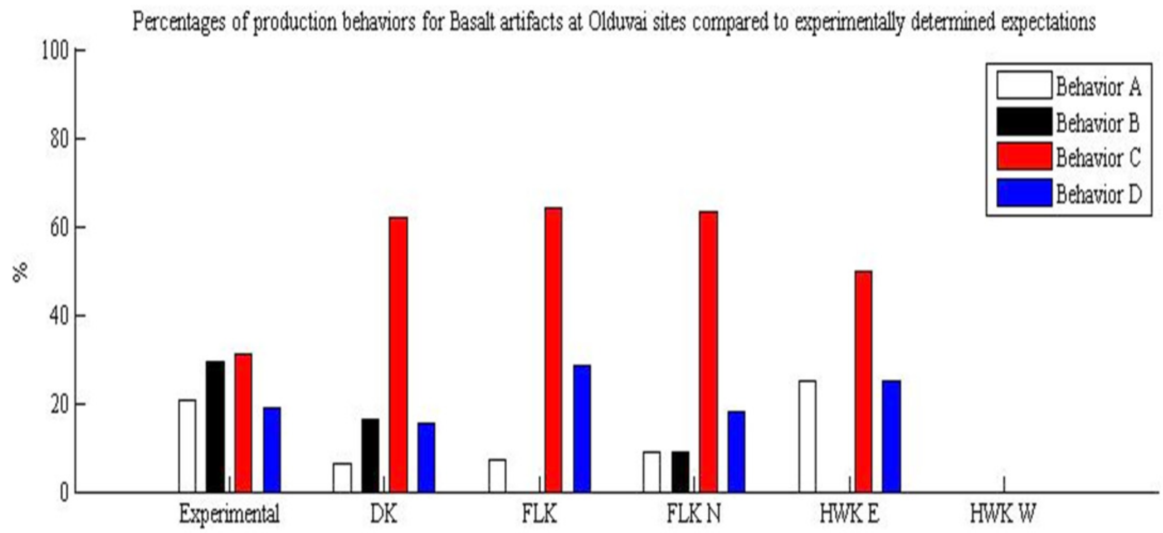


Figure 4.11b:

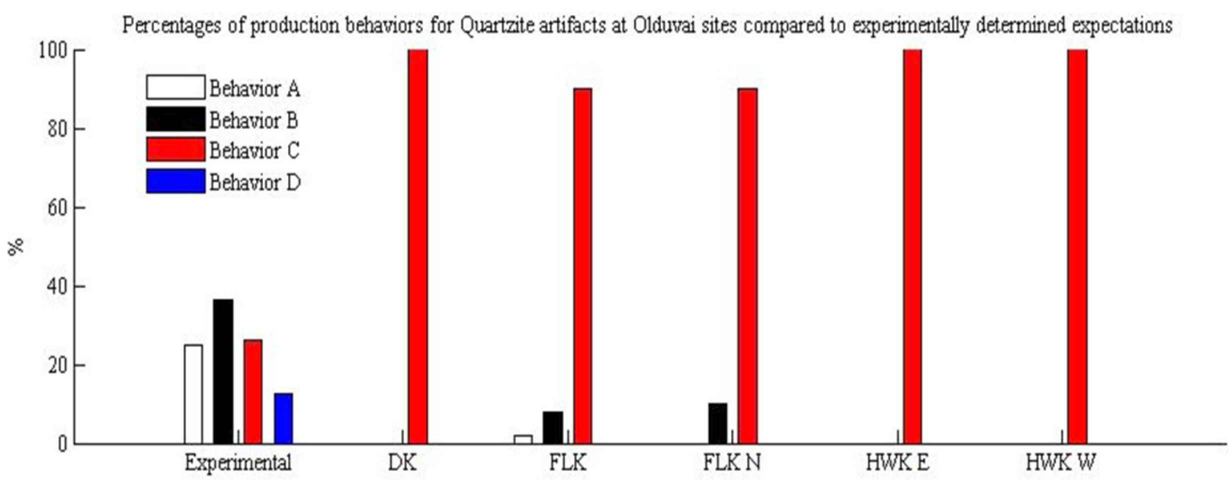


Figure 4.11: The first column in each chart (labeled "experimental") represents the average distribution of production behaviors as determined by experimental stone tool production. The remaining columns represent the actual distributions of production behaviors present at archaeological sites, as classified via the classification algorithm in Figure 4.2. See Figures 4.12 and 4.13 for results that take the misclassification rates (Table 4.6) into account for production behavior distributions. Chi-square results for 4.11a: (Expected OBC and OBD vs. FLK/FLKN/HWKE OBC and OBD: chi-square = 1.16, df = 3, p = 0.76; Expected vs. DK: Yates' chi-square = 8.58, df = 1, Yates' p = <0.01; OBA and OBB values are lower than expected for behaviorally inferred reasons and thus not expected to be uncovered on-site). Chi-square results for 4.11b: (Expected vs. combined sites: chi-square = 177.01, df = 3, p = 0).

The first distribution depicted on each graph in Figure 4.11 represents the experimentally determined expectation for a complete assemblage, given the least effort approach (see Figure 4.6 for experimental expectations for each raw material side-by-side). While Figure 4.11a shows an increase in OBC flakes for Olduvai sites when compared to the expectation, the overall pattern is similar to the expected distribution pattern, with most behaviors present at all sites (with the exception of HWK-W which only has Olduvai quartzite present). Figure 4.11b, however, is strikingly different than the expectation. OBC flakes dominate the quartzite assemblages with OBA, OBB, and OBD flakes being nearly absent from all sites.

Figure 4.11 simplifies the potential range of flakes present at a given site. It will be remembered that Table 4.6 (section *IV.B.3.*) details the expected misclassification rates for each terminal classification. Thus the archaeological flakes that were classified to produce Figures 4.11a and 4.11b each have a misclassification statistic attached its classification. It is informative to apply these misclassification rates at the assemblage level to assess the potential differences in assemblage characteristics at the potential misclassification extremes. To make this assessment, flakes were organized based on their terminal classification, as determined by Figure 4.2 (for instance A^1 or D^3). As an example, if 50 Olduvai basalt flakes were initially classified as C^5 flakes, it would be fair to assume that 22% of these flakes could be misclassified and should actually be classified as OBD flakes. Thus at one extreme, 11 flakes (50*0.22 = 11) could be OBD flakes, which would mean that 39 flakes would actually be OBC flakes, attributable to the

Figure 4.12a:

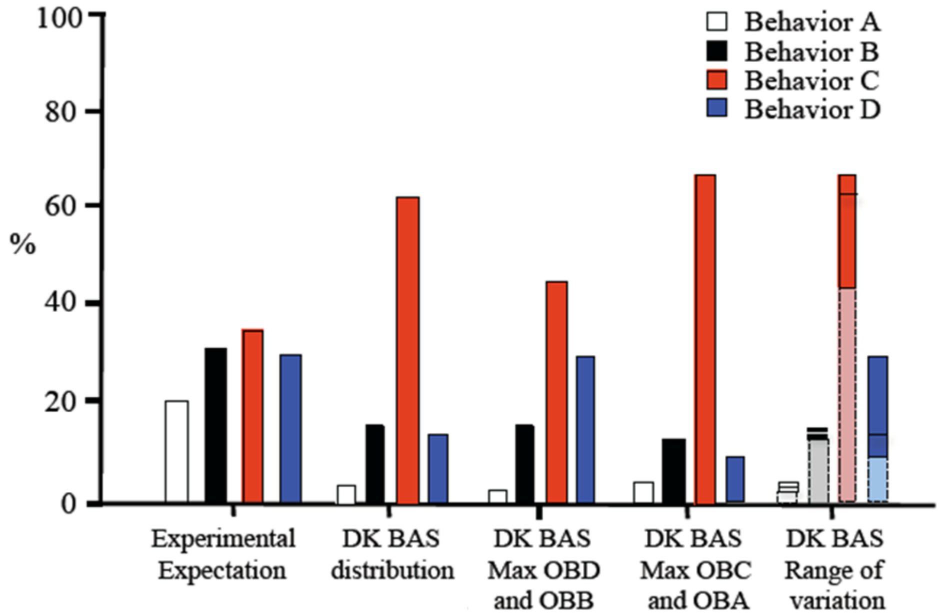


Figure 4.12b:

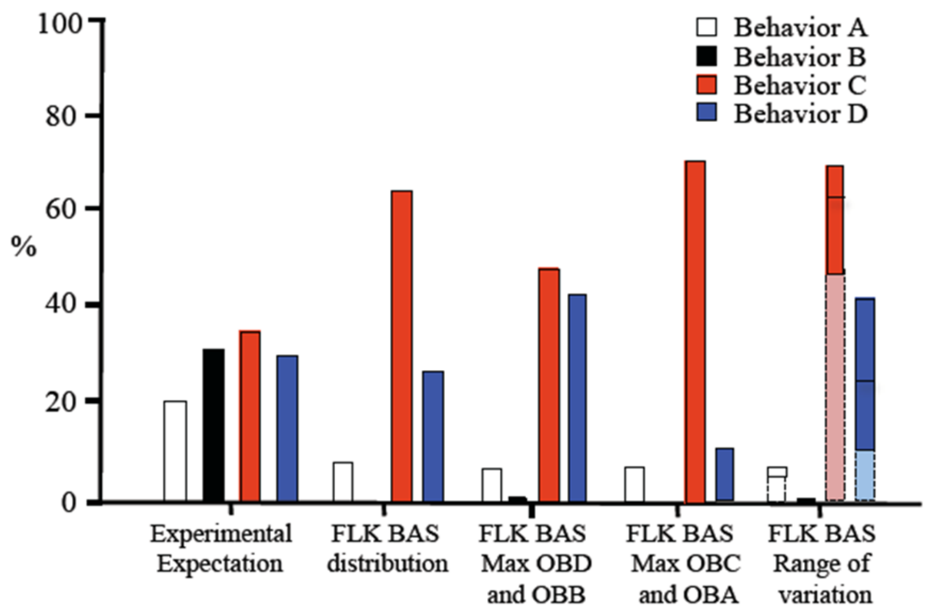


Figure 4.12c:

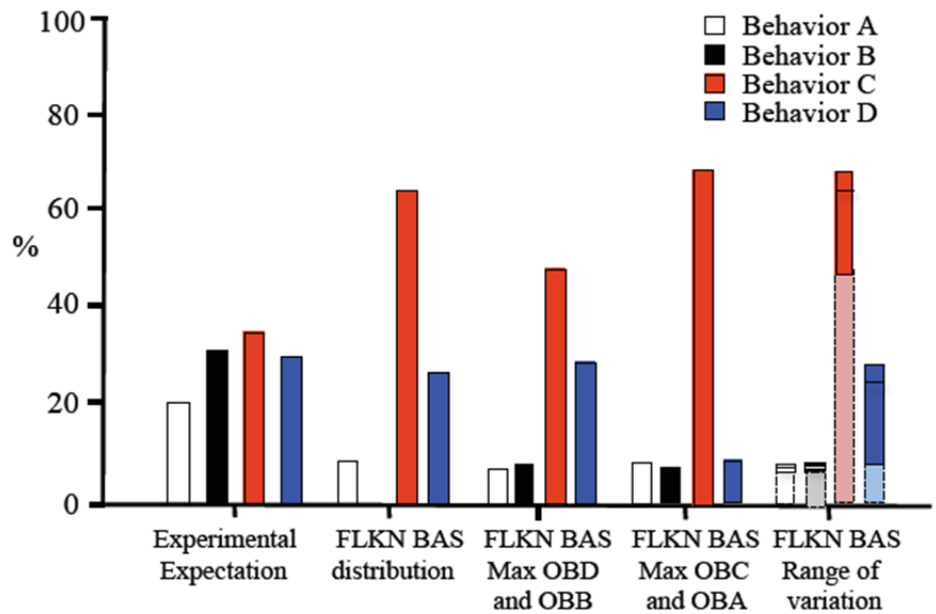


Figure 4.12d:

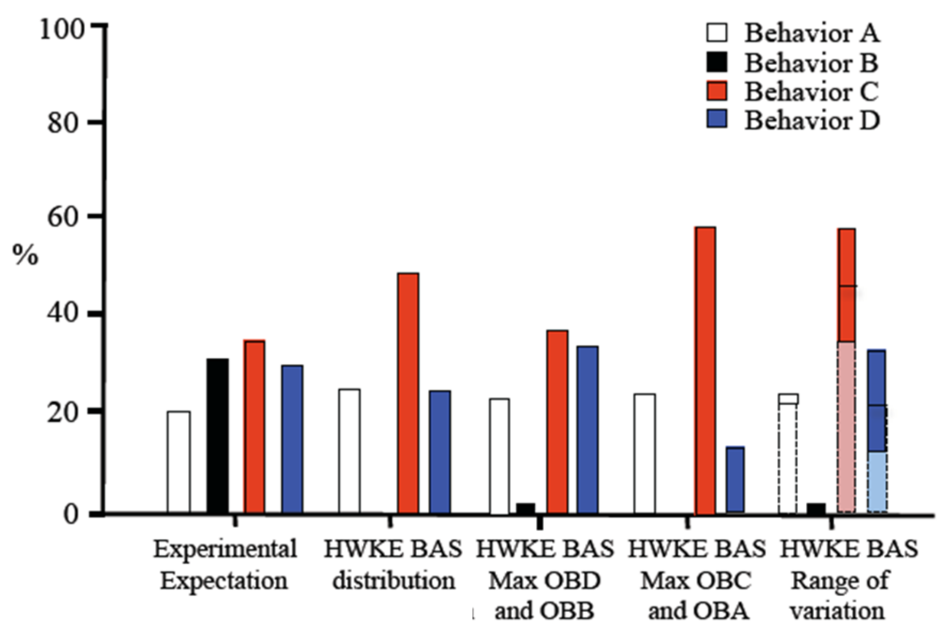


Figure 4.12: Each figure represents one site at Olduvai Gorge and the raw material basalt (a: DK; b: FLK; c: FLK-N; d: HWK-E). The first distribution ("Experimental Expectation") represents the distribution of behaviors empirically determined from the controlled experimental replications. If all of the flakes produced at a site were produced in a least effort manner and were still present at the site when it was excavated, the archaeological distribution is expected to be similar to that of the experimental distribution. The second distribution is classified via the classification algorithm in Figure 4.2. However, each flake classified via this algorithm has a misclassification statistic associated with it (Table 4.6). Therefore, the third distribution ("Max OBD and OBB") and the fourth distribution ("Max OBC and OBA") demonstrate the potential extremes of the archaeological distribution. Finally, the last distribution ("Range of Variation") combines the second, third, and fourth distributions into one easily readable chart. For each bar on the graph, the dark colors represent the potential range of representation for that production behavior, given the potential misclassifications outlined in Table 4.6. The lower margin of the colored boxes represents the lower extreme, while the upper margin represents the upper extreme. The line inside the colored box represents the actual value, given classification via Figure 4.2. If no line is present in the colored box, then either the upper or lower extreme is the actual classified value (this can be referenced against the second distribution on the graph).

Figure 4.13a:

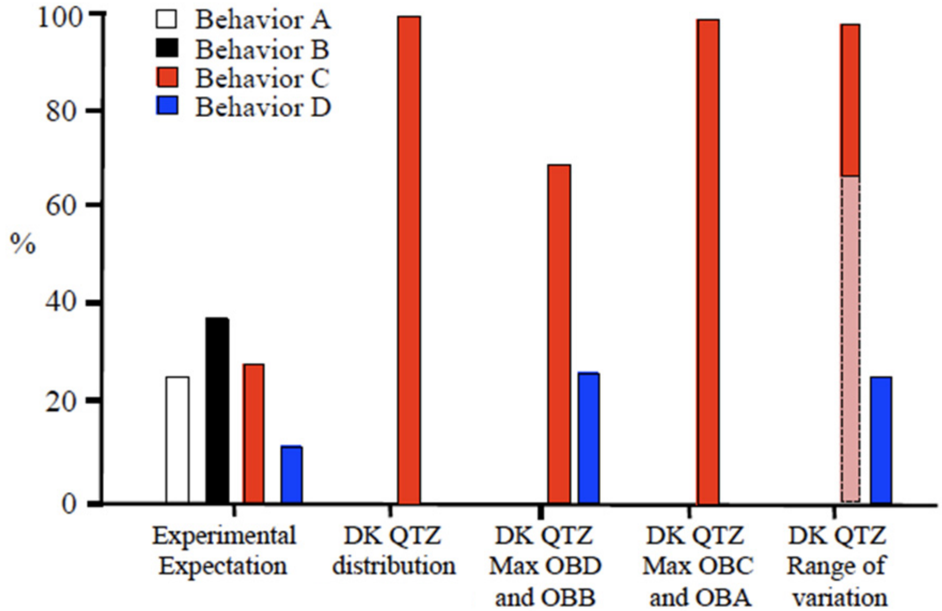


Figure 4.13b:

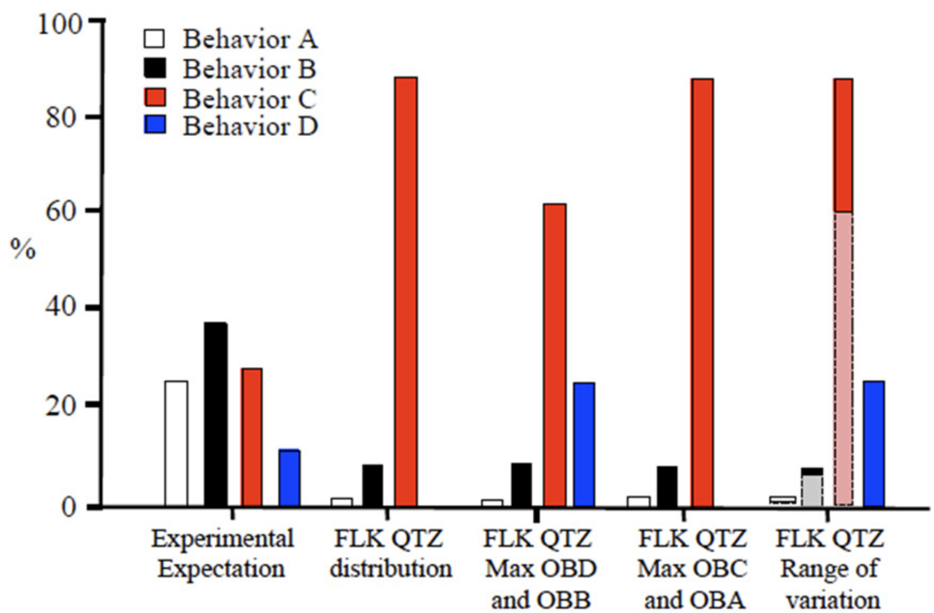


Figure 4.13c:

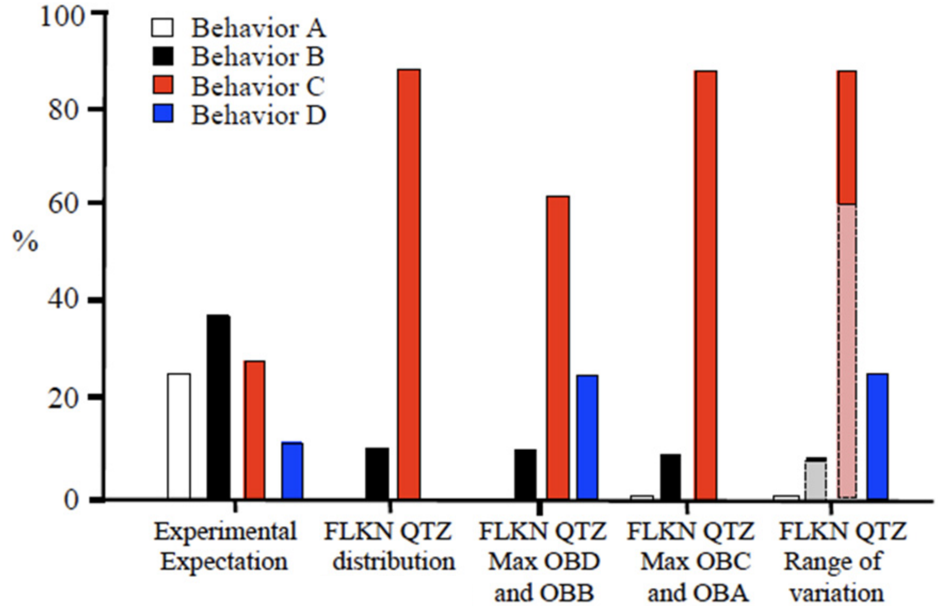


Figure 4.13d:

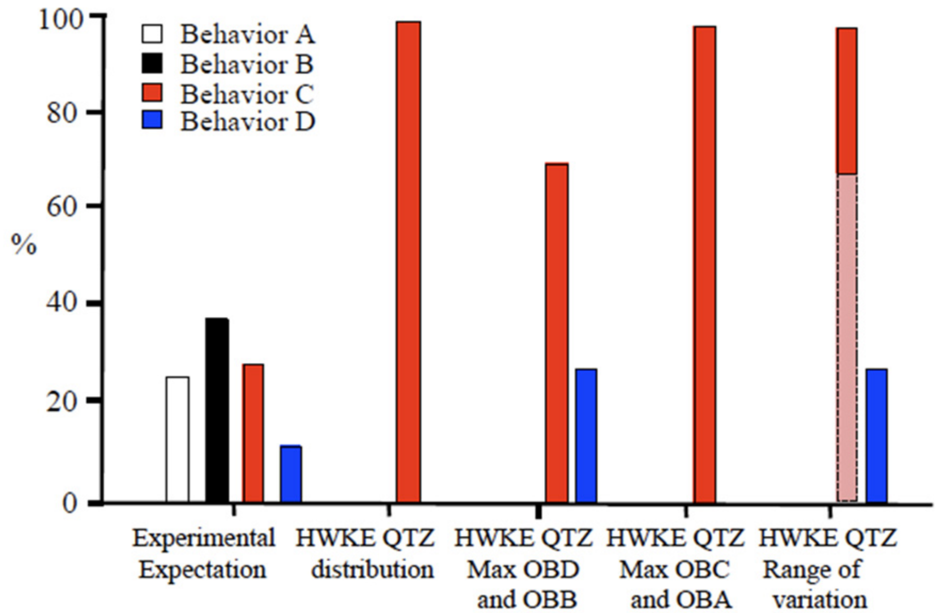


Figure 4.13e:

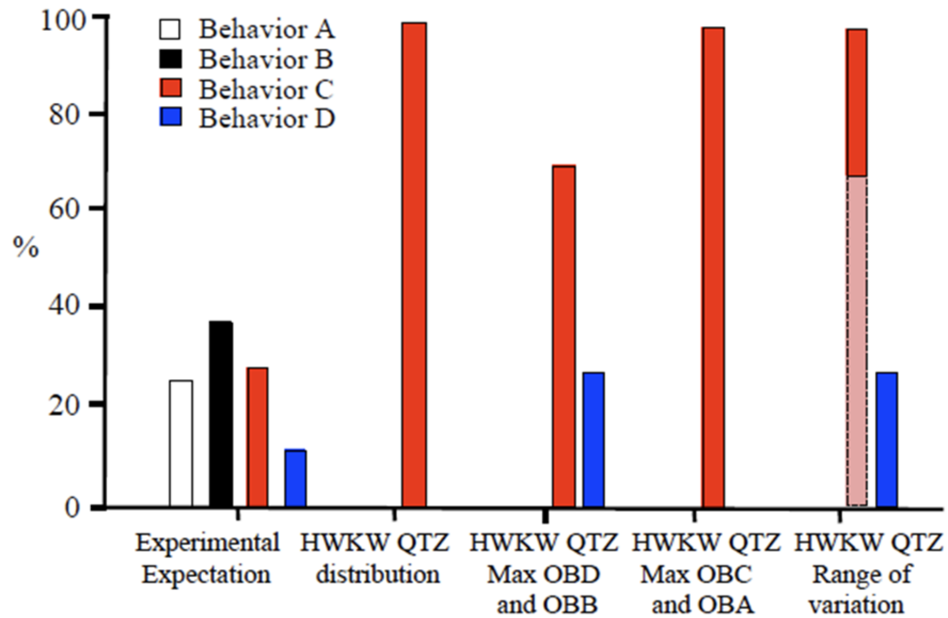


Figure 4.13: Each figure represents one site at Olduvai Gorge and the raw material quartzite (a: DK; b: FLK; c: FLK-N; d: HWK-E; e: HWK-W). The first distribution ("Experimental Expectation") represents the distribution of behaviors empirically determined from the controlled experimental replications. If all of the flakes produced at a site were produced in a least effort manner and were still present at the site when it was excavated, the archaeological distribution is expected to be similar to that of the experimental distribution. The second distribution is classified via the classification algorithm in Figure 4.2. However, each flake classified via this algorithm has a misclassification statistic associated with it (Table 4.6). Therefore, the third distribution ("Max OBD and OBB") and the fourth distribution ("Max OBC and OBA") demonstrate the potential extremes of the archaeological distribution. Finally, the last distribution ("Range of Variation") combines the second, third, and fourth distributions into one easily readable chart. For each bar on the graph, the dark colors represent the potential range of representation for that production behavior, given the potential misclassifications outlined in Table 4.6. The lower margin of the colored boxes represents the lower extreme, while the upper margin represents the upper extreme. The line inside the colored box represents the actual value, given classification via Figure 4.2. If no line is present in the colored box, then either the upper or lower extreme is the actual classified value (this can be referenced against the second distribution on the graph).

C^5 position (50-11=39). At this extreme, the 11 misclassified OBD flakes would be added to the OBD assemblage from that site and the relative percentage of OBD flakes in the assemblage would be recalculated; similarly, those 11 misclassified OBD flakes would be removed from the OBC assemblage form that site and the relative percentage of the OBC flakes in the assemblage would be recalculated. Each assemblage was reassessed in this fashion to establish the possible extremes of production behavior prevalence per site. For these calculations, the alpha level was set at p=0.05, such that if a particular behavioral classification had less than a 5% chance of misclassification into another behavior, that recalculation was not made.

The results from these assessments of potential misclassification are organized site-by-site for clarity. Figure 4.12a-d show the distributions for Olduvai Gorge basalt assemblages. Figure 4.13a-e show the distributions for Olduvai Gorge quartzite. Detailed behavioral assessments of these distributions are discussed in section *V.A.1*.

IV.C.3. Koobi Fora: production behaviors site-by-site

Koobi Fora KBS sites were analyzed in exactly the same way as described in the previous section (section *IV.C.3*). The classifications of each KBS site based on the classification tree in Figure 4.2 is shown in Figure 4.14. Each site is then re-analyzed based on the possible misclassified flakes as outlined in Table 4.6. The possible distributions of production behaviors based on the calculated misclassification rates is shown in Figure 4.15a-e. The potential behavioral significance of these distributions will be discussed in Chapter 5 (section *V.A.2*).

Figure 4.14:

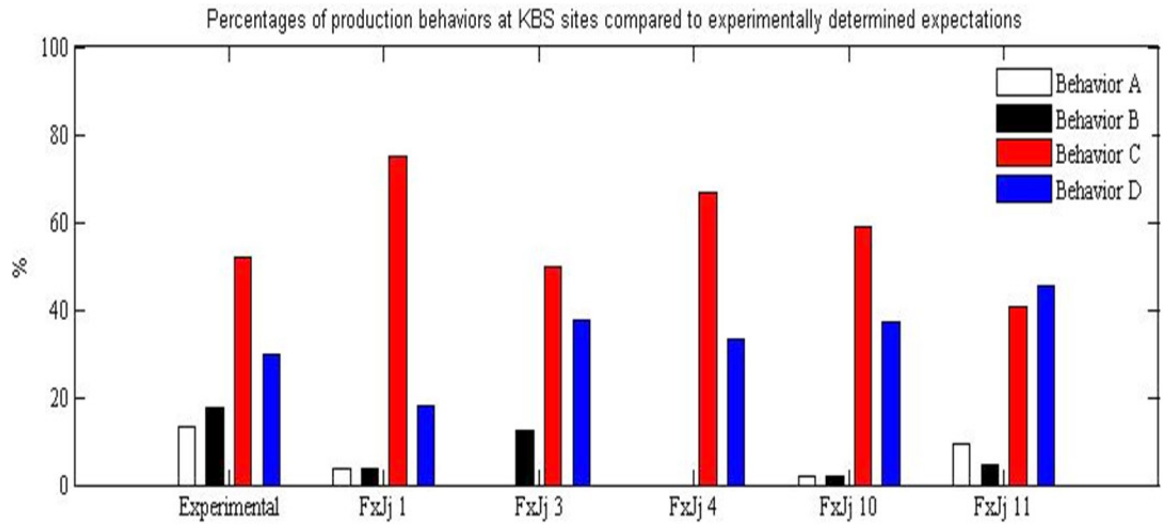


Figure 4.14: The first column in each chart (labeled "experimental") represents the average distribution of production behaviors as determined by experimental stone tool production. The remaining columns represent the actual distributions of production behaviors present at archaeological sites, as classified via the classification algorithm in Figure 4.2. See Figure 4.15 for results that take misclassification rates (Table 4.6) into account for production behavior distributions. Chi-square results: Chi-square for OBC and OBD of expected and all sites, Yates' chi-square = 3.546, df = 1, Yates' p = 0.06. Yates' chi-squre and p values were conservatively utilized due to the single degree of freedom. Only OBC and OBD behaviors were compared to the expected due to the behaviorally inferred reasons for their absence on-site. Only FxJj 1 was individually significantly different from expectations (Yates' chi-square = 7.56, df = 1, Yates' p = <0.01), all other sites were not significantly different (Yates' p values range from 0.26-0.96).

Figure 4.15a:

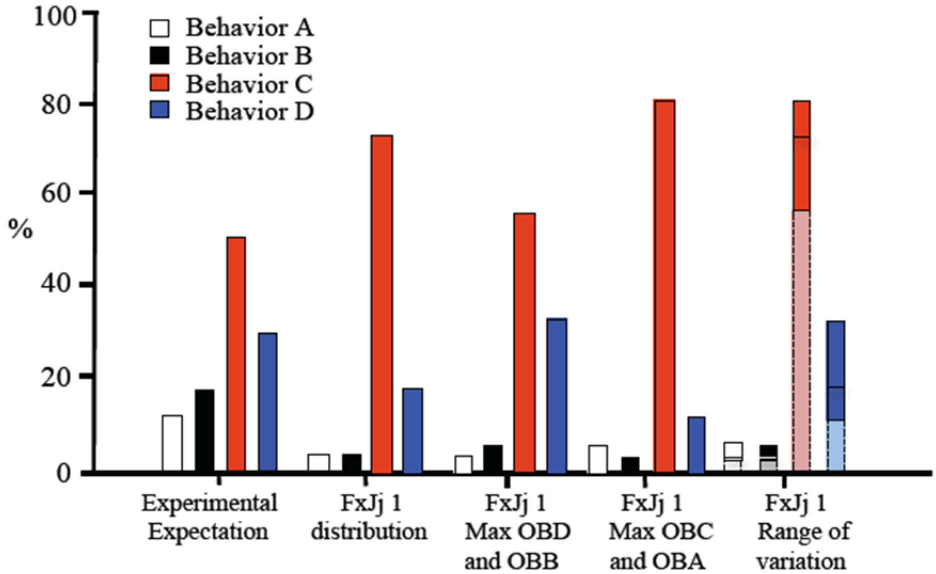


Figure 4.15b:

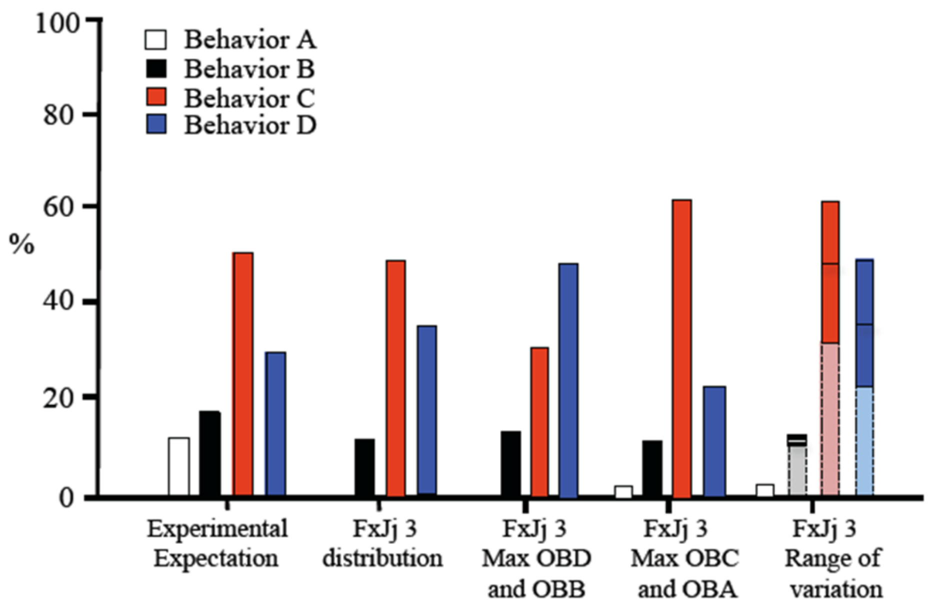


Figure 4.15c:

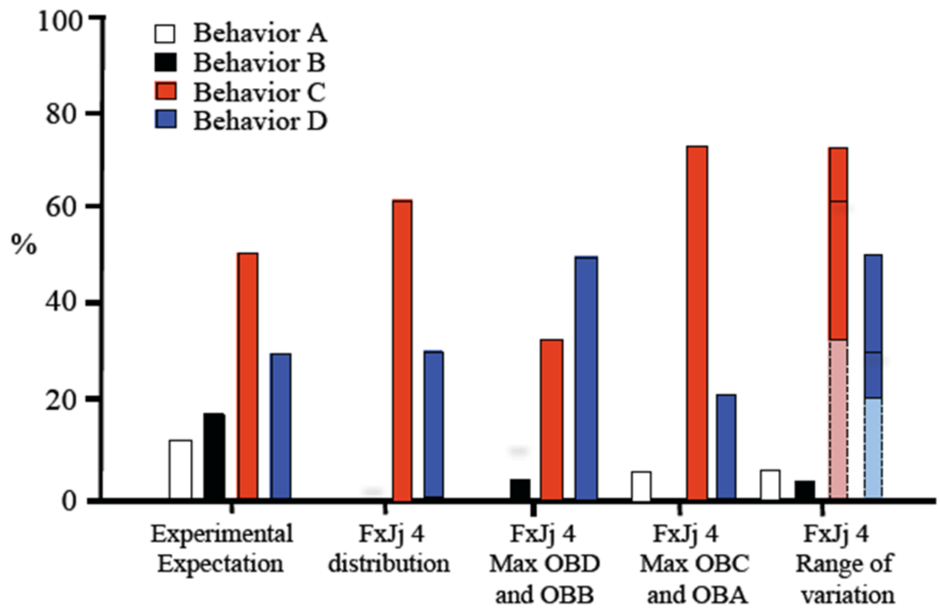


Figure 4.15d:

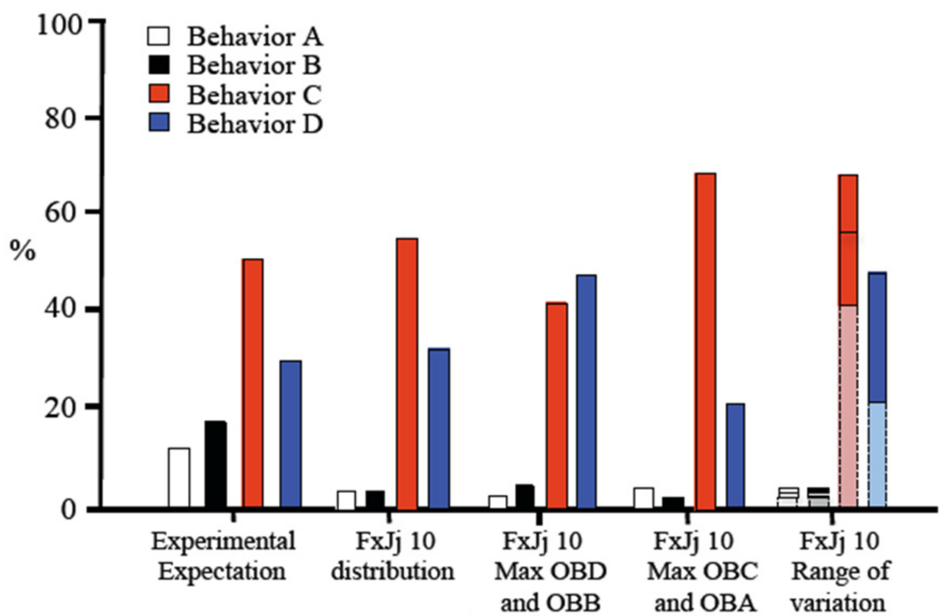


Figure 4.15e:

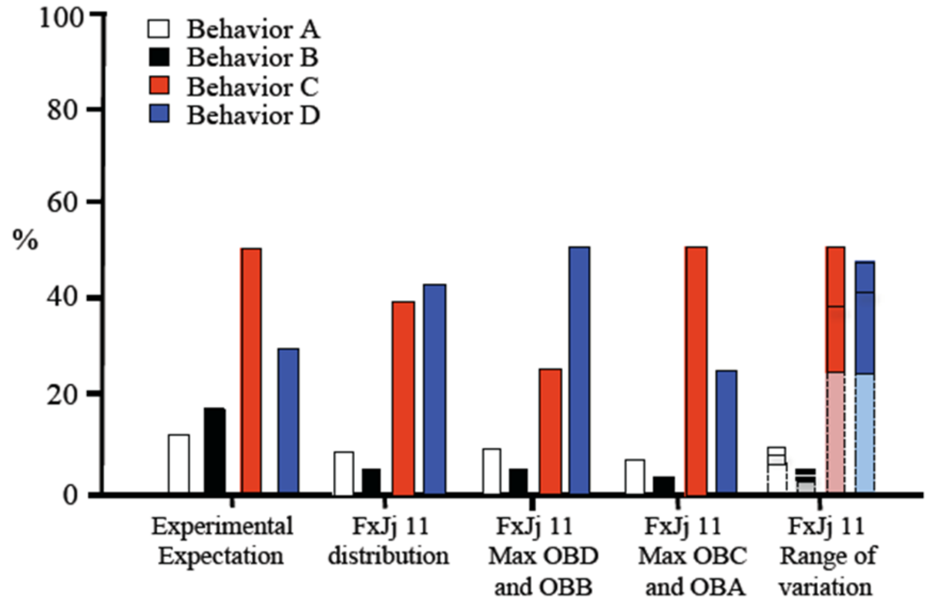


Figure 4.15: Each figure represents one site at Koobi Fora (a: FxJj 1; b: FxJj 3; c: FxJj 4; d: FxJj 10; e: FxJj 11). The first distribution ("Experimental Expectation") represents the distribution of behaviors empirically determined from the controlled experimental replications. If all of the flakes produced at a site were produced in a least effort manner and were still present at the site when it was excavated, the archaeological distribution is expected to be similar to that of the experimental distribution. The second distribution is classified via the classification algorithm in Figure 4.2. However, each flake classified via this algorithm has a misclassification statistic associated with it (Table 4.6). Therefore, the third distribution ("Max OBD and OBB") and the fourth distribution ("Max OBC and OBA") demonstrate the potential extremes of the archaeological distribution. Finally, the last distribution ("Range of Variation") combines the second, third, and fourth distributions into one easily readable chart. For each bar on the graph, the dark colors represent the potential range of representation for that production behavior, given the potential misclassifications outlined in Table 4.6. The lower margin of the colored boxes represents the lower extreme, while the upper margin represents the upper extreme. The line inside the colored box represents the actual value, given classification via Figure 4.2. If no line is present in the colored box, then either the upper or lower extreme is the actual classified value (this can be referenced against the second distribution on the graph).

IV.C.4. Analysis of flakes outside of experimental expectation: alternate production behaviors

Not all archaeological flakes fall within experimental expectations (section *IV.C.1.*). If flakes fall outside of the extremely broad variation established by this experimental research, they might have been produced utilizing production strategies other than a least effort strategy. However, this assumption is not valid if the archaeological flakes outside of experimental expectations are not significantly different than the respective assemblages that they are from. In other words, a single flake with a morphological difference is not statistically informative when trying to determine behavioral patterns among Oldowan-producing hominins; assemblage level differences, on the other hand, are extremely informative in determining such broad behavioral patterns.

To test for assemblage level variation between archaeological flakes falling within experimental expectations and archaeological flakes outside of expectations, archaeological assemblages were organized into each respective group (within expected variation and outside of expected variation). Each measurement for within range assemblages was statistically tested against the same measurement in outside of range assemblages using a Mann-Whitney U-Test. To visualize what the results mean, a schematic diagram was created to show what an "average" archaeological flake looks like. Using the size-standardized units, average values for length, width, thickness, maximum dimension, bulbar thickness, and platform area were calculated and used to create composite images of, for example, what an average KBS flake looks like from the within-experimental-range assemblage and from the outside-experimental-range assemblage (Figure 4.16). Size standardized units were converted directly to "inches" to provide a scale for relative morphological difference. On average, KBS flakes falling outside of experimental expectations appear to be larger, but statistically speaking, there are no significant results between the within range and outside of range assemblages (*p* values are labeled in Figure 4.16). This result suggests that none of the KBS flakes, at the assemblage level, can be considered statistically different from experimental expectations for least effort approach production strategies. Rather, KBS flakes represent one continuum of variation

Olduvai Gorge, on the other hand, demonstrates significant differences at the assemblage level when looking at basalt and quartzite independently. For this reason, differences between the within-range archaeological flakes and the outside-of-range archaeological flakes were analyzed on a site-by-site basis. By analyzing the basalt assemblage and quartzite assemblage at DK, for instance, statistical confidence can be placed on each measurement to determine exactly how outside-of-expected-range flakes differ from within-expected-range flakes. Results provide useful information in determining how production strategies may have differed from a least effort approach, and ultimately, inform as to if and how hominins from Koobi Fora differed technologically from hominins at Olduvai Gorge, and if Olduvai Gorge hominins differed among themselves over space, or through time. Analyses for Olduvai Gorge utilize the same schematic images that were presented for Koobi Fora in Figure 4.16. Results are shown for basalt and quartzite for DK (Figure 4.17), FLK (Figure 4.18), FLK-N (Figure 4.19), and HWK-E (Figure 4.20).

Figure 4.16: KBS Basalt

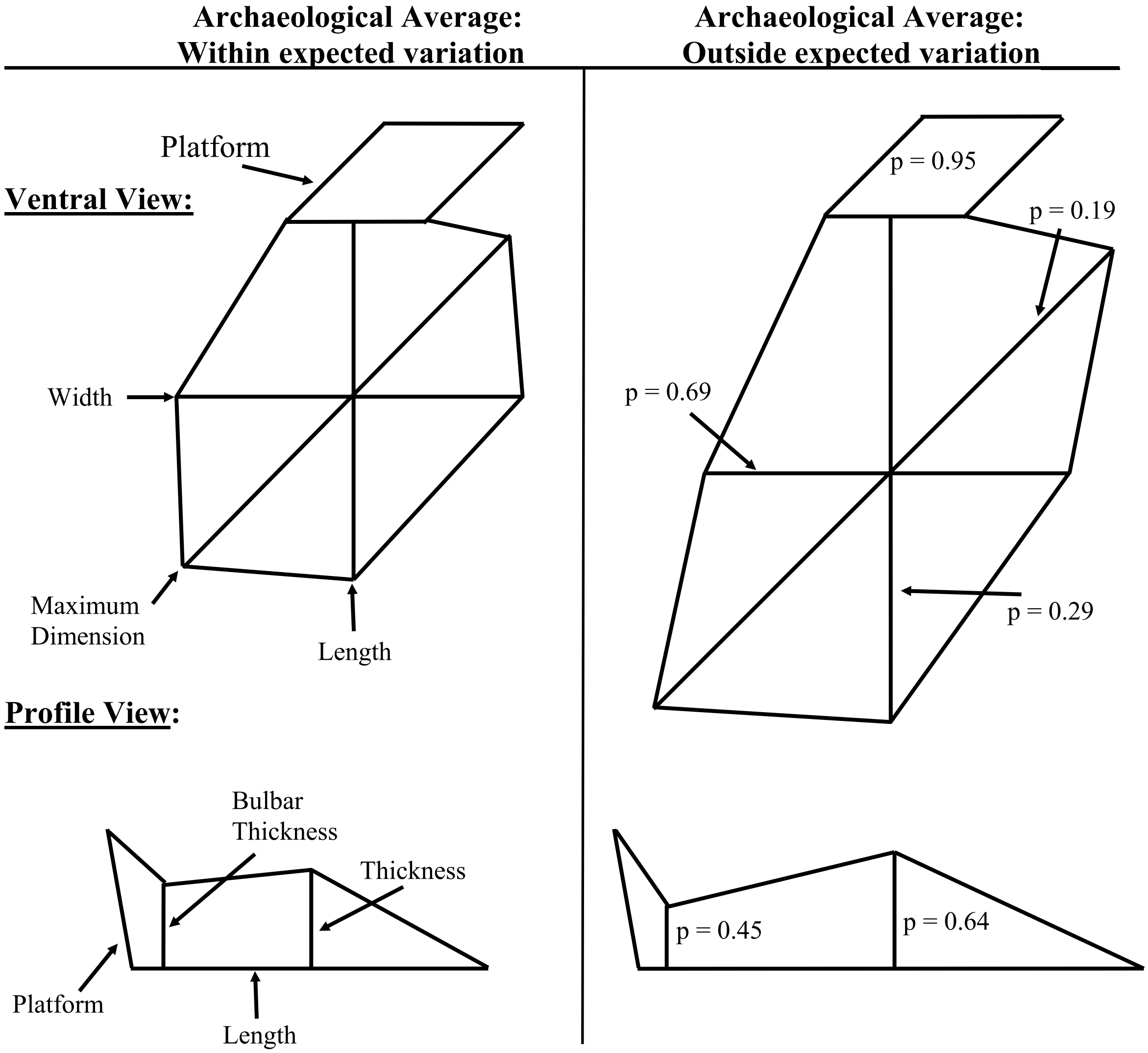


Figure 4.16: These images represent idealized, schematic drawings of average measurements for KBS archaeological flakes. The first column shows the ventral and profile views of the average KBS flakes that fall within experimentally expected variation. The second column shows the ventral and profile views of the average KBS flakes that fall outside of experimentally expected variation. For consistency and ease of comparison, the maximum dimension was placed at a 45 degree angle from the length measurement. All measurements are still size standardized, but are translated into “inch” units, such that if the average size-standardized length measurement is 1.0, this becomes 1.0 inch in this image. Similarly, average platform area is depicted as a square, such that platform width and thickness are equal and both are the square root of average platform area. No significant differences exist within or between any KBS sites when comparing the assemblages that fall outside of experimental expectation and those that fall within experimental expectation. No flakes can, therefore, can be statistically determined as being different from least effort approach flakes; they fall along a continuum of variation.

Figure 4.17: Olduvai Gorge assemblages from the site of DK

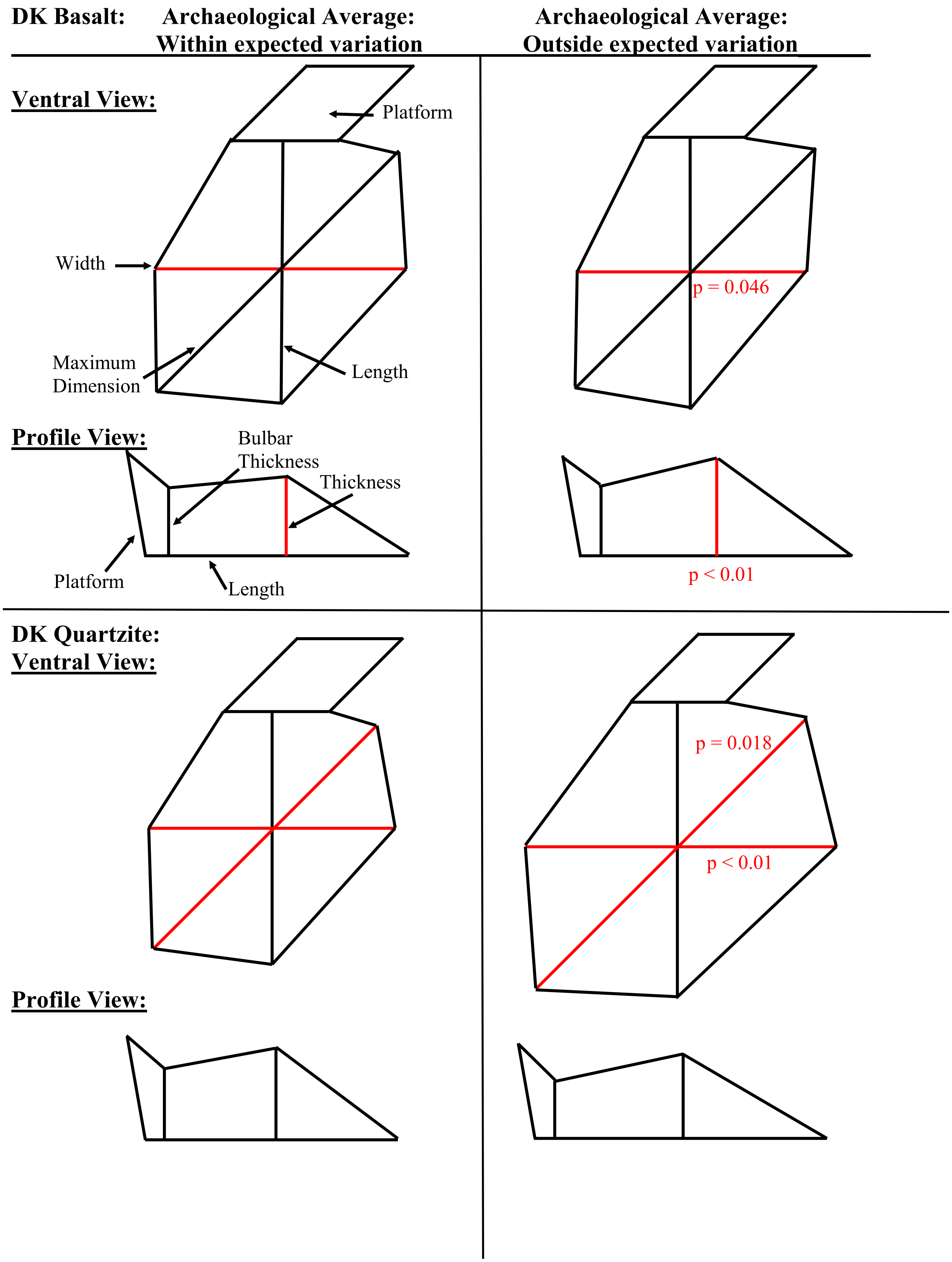


Figure 4.17: These images represent idealized, schematic drawings of average measurements for Olduvai Gorge archaeological flakes from the site of DK, both basalt and quartzite. The first column shows the ventral and profile views of the average DK flakes that fall within experimentally expected variation. The second column shows the ventral and profile views of the average DK flakes that fall outside of experimentally expected variation. For consistency and ease of comparison, the maximum dimension was placed at a 45 degree angle from the length measurement. All measurements are still size standardized, but are translated into "inch" units, such that if the average size-standardized length measurement is 1.0, this becomes 1.0 inch in this image. Similarly, average platform area is depicted as a square, such that platform width and thickness are equal and both are the square root of average platform area. Significant differences between outside-of-range and within-range assemblages are drawn in red.

Figure 4.18: Olduvai Gorge assemblages from the site of FLK

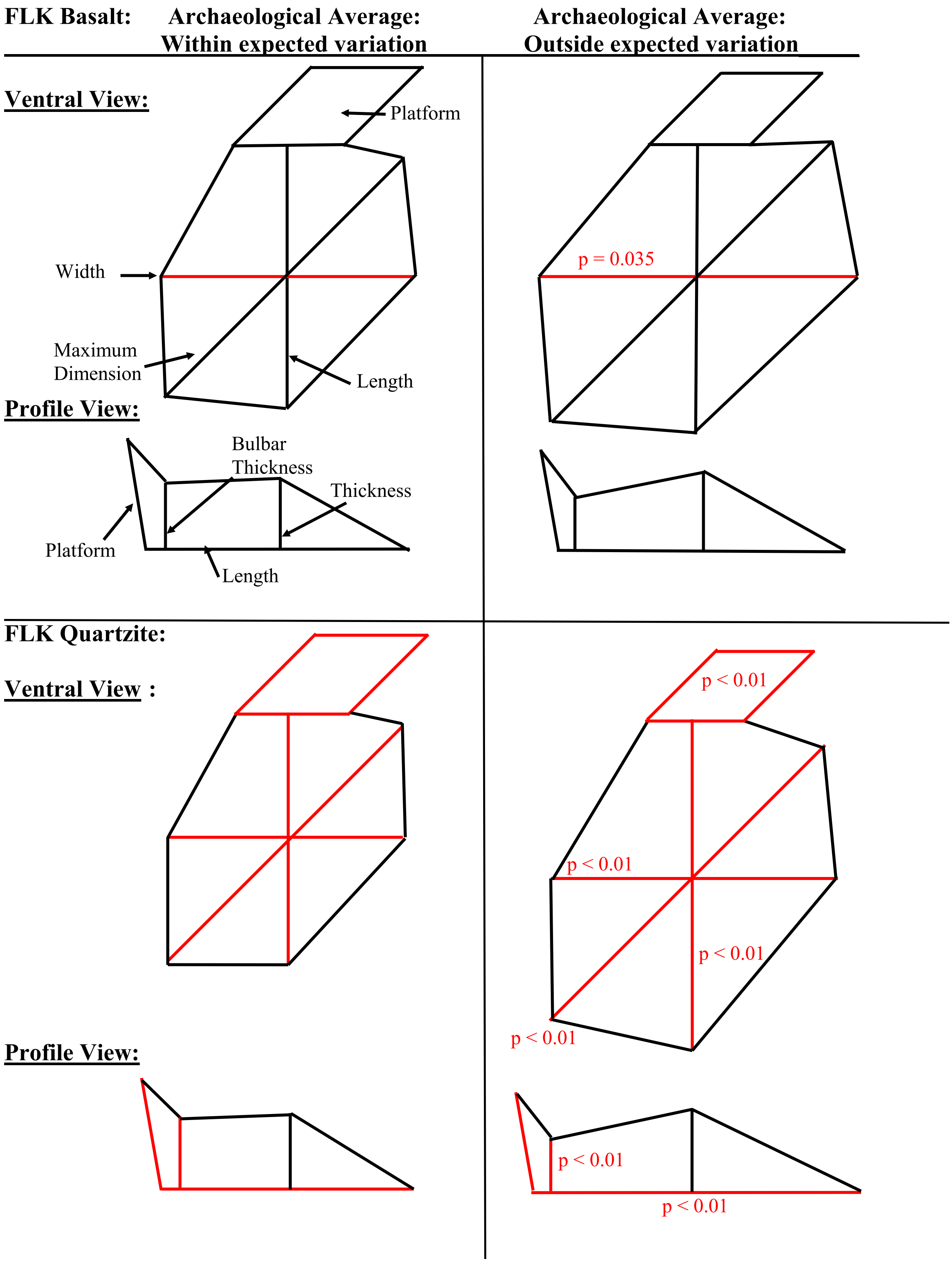


Figure 4.18: These images represent idealized, schematic drawings of average measurements for Olduvai Gorge archaeological flakes from the site of FLK, both basalt and quartzite. The first column shows the ventral and profile views of the average FLK flakes that fall within experimentally expected variation. The second column shows the ventral and profile views of the average FLK flakes that fall outside of experimentally expected variation. For consistency and ease of comparison, the maximum dimension was placed at a 45 degree angle from the length measurement. All measurements are still size standardized, but are translated into "inch" units, such that if the average size-standardized length measurement is 1.0, this becomes 1.0 inch in this image. Similarly, average platform area is depicted as a square, such that platform width and thickness are equal and both are the square root of average platform area. Significant differences between outside-of-range and within-range assemblages are drawn in red.

Figure 4.19: Olduvai Gorge assemblages from the site of FLK-North

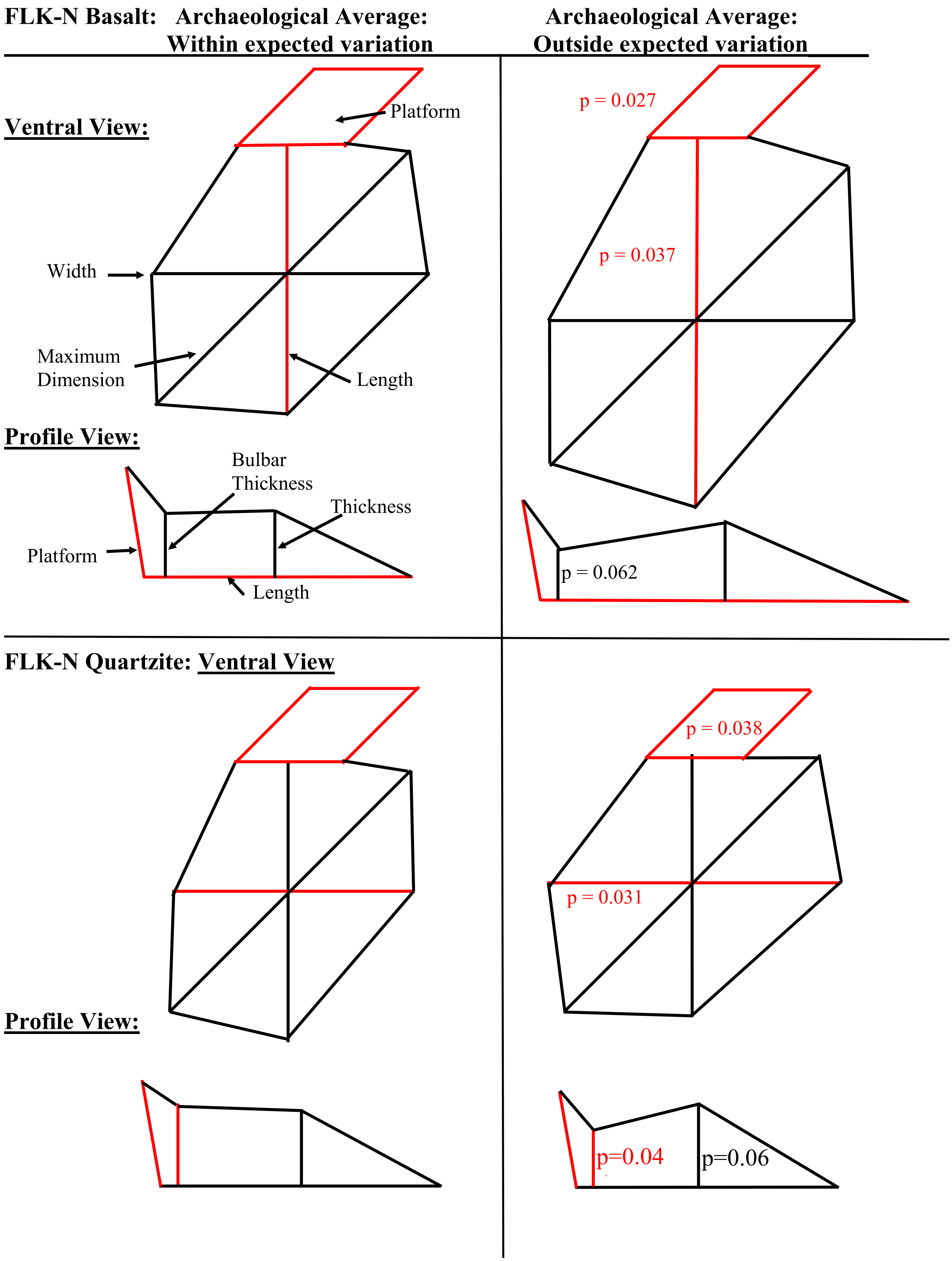


Figure 4.19: These images represent idealized, schematic drawings of average measurements for Olduvai Gorge archaeological flakes from the site of FLK-N, both basalt and quartzite. The first column shows the ventral and profile views of the average FLK-N flakes that fall within experimentally expected variation. The second column shows the ventral and profile views of the average FLK-N flakes that fall outside of experimentally expected variation. For consistency and ease of comparison, the maximum dimension was placed at a 45 degree angle from the length measurement. All measurements are still size standardized, but are translated into "inch" units, such that if the average size-standardized length measurement is 1.0, this becomes 1.0 inch in this image. Similarly, average platform area is depicted as a square, such that platform width and thickness are equal and both are the square root of average platform area. Significant differences between outside-of-range and within-range assemblages are drawn in red.

Figure 4.20: Olduvai Gorge assemblages from HWK-East

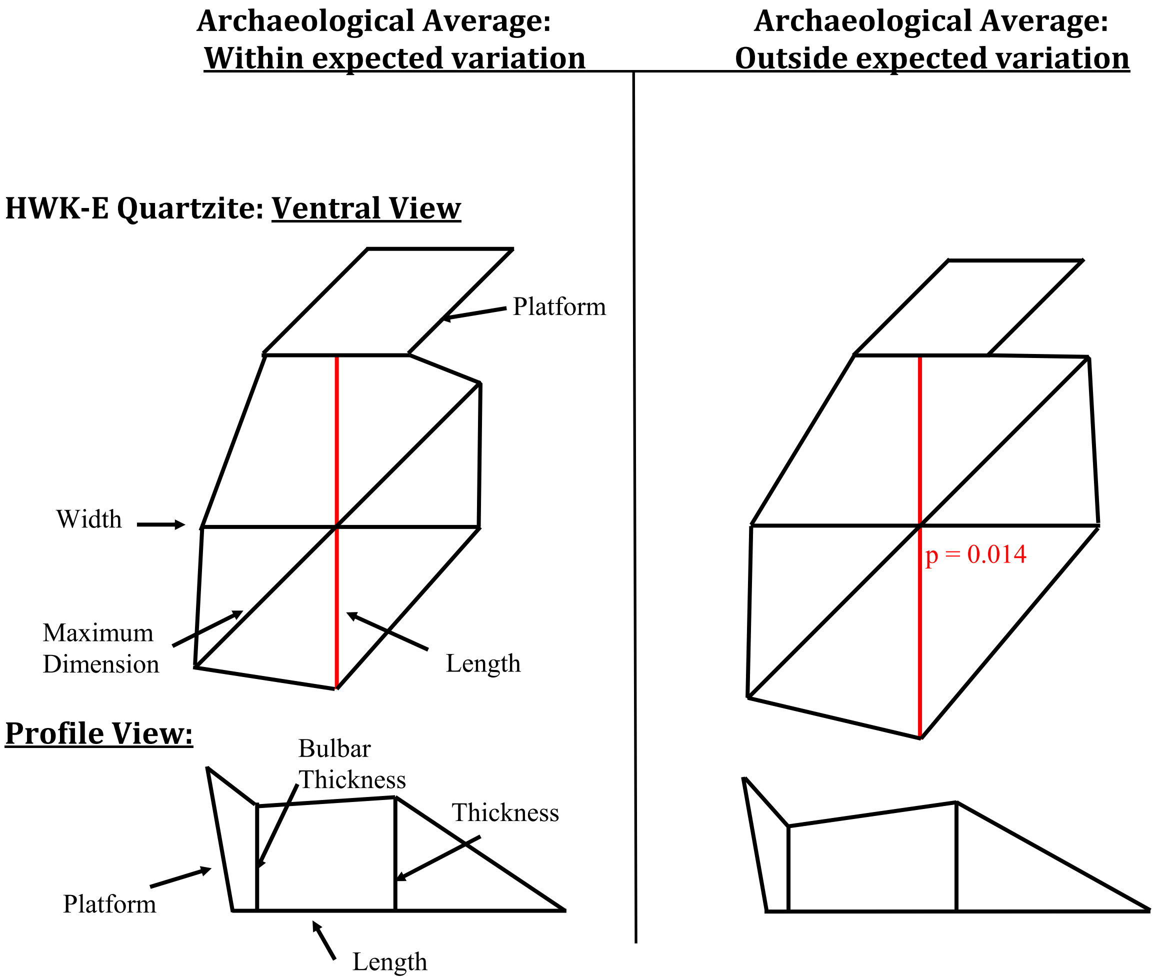


Figure 4.20: These images represent idealized, schematic drawings of average measurements for Olduvai Gorge archaeological quartzite flakes from the site of HWK-E. Only quartzite flakes are shown because the sample size of basalt flakes falling outside of expectation was too small for statistical significance (N=2). The first column shows the ventral and profile views of the average HWK-E flakes that fall within experimentally expected variation. The second column shows the ventral and profile views of the average HWK-E flakes that fall outside of experimentally expected variation. For consistency and ease of comparison, the maximum dimension was placed at a 45 degree angle from the length measurement. All measurements are still size standardized, but are translated into "inch" units, such that if the average size-standardized length measurement is 1.0, this becomes 1.0 inch in this image. Similarly, average platform area is depicted as a square, such that platform width and thickness are equal and both are the square root of average platform area. Significant differences between outside-of-range and within-range assemblages are drawn in red.

Basalt at DK that falls outside of experimental expectations tends to be thinner and thicker than their counterparts falling within experimental expectation (Figure 4.17). Conversely, quartz at DK that falls outside of experimental expectations tends to be relatively larger than those flakes falling within experimental expectations. This means that while the basalt is relatively thinner and thicker, the quartzite tends have an increased relative size while maintaining an equivalent thinness.

Basalt at FLK (Figure 4.18) follows a pattern more closely resembling the quartz at DK in that flakes falling outside of expectation tend to be wider than flakes produced until least effort expectations. While this width increases, and therefore increases the size of the perimeter of the flake, the platform area and thickness measures are maintained. Quartzite falling outside of experimental expectations shows a striking assemblage-level difference compared to flakes falling within experimental expectations. Length, width, and maximum dimension are all significantly larger (relatively), while platform area and bulbar thickness are reduced relative to other archaeological quartz flakes from FLK. This means that for this subset of flakes, there is an increased relative size in every ventral dimension, but a reduction in size of the platform necessary to produce this large flake and no increase in the thickness necessary to produce this large flake.

Basalt flakes falling outside of experimental expectation FLK-N (Figure 4.19) show a larger-than-expected length and reduction in the expected platform area, while maintaining (and almost reducing, see p value for bulbar thickness) relative thickness measures. Similarly, the quartzite flakes from FLK-N that fall outside of experimental expectations show an overall increase to the relative width, while reducing the platform area and bulbar thickness. For both raw materials, this means that a larger perimeter is being created per unit of raw material.

Figure 4.20 indicates that quartzite flakes from HWK-E that fall outside of experimental expectations are only relatively longer than flakes within experimental expectations. This suggests that longer flakes were being consistently produced while preserving the same relative proportions otherwise.

The implications that these results have for behavioral differences among Oldowan producing hominin production strategies at Olduvai Gorge are discussed site-by-site and in detail in Chapter 5 (secton *V.A.1.*). Similarly, the potential for behavioral differences between Oldowan producing hominins at Koobi Fora and Oldowan producing hominins at Olduvai Gorge will be discussed in detail in the following chapter.

Chapter V: Discussion

This chapter is divided into two main sections. The first addresses the specific archaeological results described in Chapter 4 in a behaviorally informative way. The second addresses the implications that BLA methodology has at a broader level, including assumptions of the BLA model, further hypothesis testing, and adaptive explanations for the results.

V.A. Implications for Oldowan behavioral reconstruction

The following sections provide analytical details and discussion about the possible behavioral conclusions of each archaeological site studied in this research. Each site will be analyzed in several ways. First, the relative proportions of production behaviors present at each site will be directly compared to the experimental expectation. Deviation from this expectation produces various new, testable hypotheses about site use, raw material transport, and stone tool preferences. However, these conclusions must be considered relative to the potential for misclassification (see Figures 4.12, 4.13, and 4.15) and the morphological similarity and deviation from experimental expectations (Figures 4.16-4.20). Discussion will, therefore, first focus on the likelihood that assemblage-level distributions of production behaviors for a site fit a least effort production strategy. Next, an overall assessment of hominin technological behavior at each site will be discussed. This assessment includes site location, proximity to raw material resources, and evidence for raw material transport and is discussed through the lens of the production behaviors and assemblage characteristics identified in this research.

V.A.1. Olduvai Gorge site analysis

Each Olduvai Gorge site must be analyzed in terms of both raw materials utilized in this study: basalt and quartzite. Discussion of each site, therefore, will first focus on basalt and then focus on quartzite.

V.A.1.a. DK

DK Basalt

Based on experimentally established expectations of Olduvai Gorge basalt assemblages, it is expected that given a least effort approach production strategy, flake assemblages will be slightly dominated by OBC flakes, followed by nearly equivalent numbers of OBB and OBD flakes, while OBA flakes will be the least numerous (Figure 4.12a, "experimental expectation"). Figure 4.12a provides a graphical representation of the expected range of behavioral classification given the misclassification rates calculated in the construction of the classification algorithm (Table 4.6). While in every misclassification scenario for DK the proportion of OBC flakes is higher than expected, the *relative* proportions of behaviors falls within expected variation (OBC is highest, followed by nearly equivalent numbers of OBB and OBD, and the lowest numbers of OBA).

The archaeological core assemblage from DK, as defined by Leakey (1971), contains a total of 106 cores, 97 produced on basalt. The total *debitage* from DK (for all sites in this analysis this is liberally calculated as being inclusive of whole flakes and broken flakes, but exclusive of core fragments) includes 506 basalt flakes. Based on the experimental data in Table 4.7, if every basalt core was reduced using a least effort approach strategy and was reduced until the core was relatively exhausted of usable platforms, it would be expected that approximately 841 basalt flakes would have been produced (97 cores x 8.67 flakes/core = 841 flakes). There is a discrepancy, therefore, between expected flake counts and the archaeological flake counts. Only 60.2% of the expected number of basalt flakes was recovered (Table 5.1).

There are several explanations that could potentially account for this discrepancy. First, if DK was the site where flakes were being produced, hominins could have selected some flakes and carried these flakes away from the production site for use elsewhere. Second, if DK was not the site where flakes were being produced, hominins could have carried cores that were partially reduced elsewhere into the site, in which case it is not expected that the expected number of flakes would be higher than the actual number of flakes produced on site. Third, hominins could have stopped flake production prior to a core's exhaustion.

The first is a possibility, but is particularly hard to address. If hominins were selectively transporting basalt flakes away from DK and to another location, it would be assumed that another contemporaneous archaeological site would show more basalt flakes than expected given the number of cores present. The location of DK is such that basalt cobbles were available for hominin use in close proximity to the site (see Hay 1976:52). This ease of raw material procurement at DK suggests that the second scenario, that cores were reduced elsewhere and then brought into the site, is not a likely scenario. It is not an expected behavior that heavy raw materials would be transported if they were not needed at a given location.

This argument informs the third scenario as well. Economic expectations for raw material use suggest that individuals will not give particular value to a raw material that is easy to obtain; as raw materials become more difficult to obtain, more economically advantageous usage of that material is expected to increase (Clark 1979; Blumenschine et al. 2008; demonstrated in the Early Stone Age by Harris (1978) and Isaac (1986)). Therefore, the third option is the most reasonable explanation for the discrepancy between the expected number of basalt flakes, given the number of cores present, and the actual number of flakes present at the site. Said another way, there was not an economic reason for Oldowan producing hominins at DK to reduce basalt cobbles to the point of exhaustion. Instead, because basalt was readily available, hominins likely discarded cobbles while they still had available platforms, especially if the quality of a cobble was less than desirable. Rather than the expected average of 8.67 flakes per basalt core (Table 4.7), it appears that at DK, hominins were removing an average of 5.2 flakes per core.

This economic explanation for DK flake counts is reinforced by several lines of evidence: 1) deviation from flakes with morphologies suggestive of least effort approach production (Figure 4.16), 2) the relative proportions of production behaviors present at DK (Figure 4.12a), and 3) the relative numbers of core types as described by M.D. Leakey (1971:39).

For the first line of evidence, results from DK indicate that the archaeological basalt assemblage is unique compared to all other Olduvai Gorge sites. Figure 4.17 demonstrates how flakes that fall outside of experimental expectations given a least effort approach to flake manufacture deviate from those expectations in terms of relative morphology. All other flakes that fall outside of this range of variation show trends toward being a more efficient use of raw material, as will be discussed as each site is discussed in this chapter. More efficient use of raw material includes increasing the perimeter of the flake by making wider and longer flakes (presumably more cutting edge) while simultaneously reducing the amount of raw material required to make that flake (reduction in platform size, bulbar thickness, and thickness). DK basalt flakes falling outside of expected variation demonstrate the exact opposite trend. Figure 4.17 clearly shows that these flakes only significantly vary from expectations in the dimensions of width and thickness. In both cases, flakes are made thicker and less wide than expectations predict. In other words, these flakes show a *decrease* in perimeter and an *increase* in raw material used to produce the flake, which is economically quite inefficient.

By revisiting Figure 4.12a, the second line of evidence is apparent in that all of the misclassification scenarios have a higher-than-expected percentage of OBC flakes in the assemblage. As was explained in Chapter 2, a series of OBC flakes leads to a core form that M.D. Leakey would call a "bifacial chopper." Flaking bifacially allows for flakes to be produced with relatively less energy and more precision given the non-cortical platforms utilized for their production. However, experimental data presented here suggest that OBD flakes tend to be more invasive than OBC flakes and thus more regularly produce new platforms. OBC flakes, as described earlier in Chapter 2 (section *II.B.4.c.*) tend to limit the total number of flakes that can be removed from a core due to the fact that a core becomes thicker as bifacial flakes approach the center of that core (Figure 2.11). Since initial cobble shape in Olduvai basalt does not significantly affect the relative proportions of behaviors per assemblage given a least effort approach to manufacture (Table 4.14), an archaeological dominance of OBC flakes demonstrates an approach to manufacture that is not concerned with gaining many flakes or with efficiently flaking a core to exhaustion.

Third, the quartz examples of cores at DK show more invasive flaking than basalt flakes and prompted M.D. Leakey to comment that they "…are remarkable for the refinement of workmanship" (1971:31). Core types like "side choppers," "end choppers," and "two-edged choppers" in which flaking is minimal, are produced entirely on poor quality basalts, while quartz core forms tend to be more heavily reduced (see Leakey 1971:24-39 for assemblage descriptions).

This combination of corroborating evidence indicates the strength of an economic hypothesis for raw material usage at DK:

1) basalt cobbles were available with less transport cost than other Oldowan sites,

2) basalt cores were not reduced to exhaustion,

2) basalt cores were not reduced efficiently in term of behaviors used to reduce them, and

3) the flakes that were produced were economically inefficient (thin and thick).

DK Quartzite

Based on experimentally established expectations of Olduvai Gorge quartzite assemblages, it is expected that given a least effort approach production strategy, flake assemblages will be slightly dominated by OBB flakes, followed by nearly equal numbers of OBC and OBA flakes, while OBD flakes will be the least numerous (Figure

4.13a, "experimental expectation"). The reason for the difference between Olduvai basalt behavioral expectations (Figure 4.12) and Olduvai quartzite behavioral expectations is primarily due to the fracture qualities and relative core shapes of the two raw materials. While basalt is found mainly as angular and river-rounded cobbles, the Naibor Soit quartzite outcrops in a tabular formation and breaks, primarily, into blocky pieces with square edges that were utilized for flake production. The result is that flakes tend to be invasive for the basalt cobbles, which leads to the natural formation of new platforms. For quartzite, however, the squared edges and crystalline nature of the material leads to square-edged and side-struck flakes that do not leave an invasive flake scar. Leakey (1971:37) notes the fact that at DK, "…*all* the quartz flakes…are divergent; that is, splayed outwards from the striking platform" (emphasis mine). In other words, all quartzite flakes show side-struck features due to the lack of available natural or produced areas of high mass to follow during flake manufacture. Due to this lack of invasive flaking, the flake scar lacks on appropriate platform angle and is thus difficult to use as a new platform (OBC bifacial flaking). This results in a longer series of OBA and OBB flakes.

Figure 4.13a demonstrates a dramatic difference from the experimental expectation. In all scenarios of misclassification, OBC flakes dominate the assemblage (and likely represent 100% of the recovered flakes). This represents a significant difference in how quartzite is being treated at DK when compared with basalt. While the null hypothesis that Olduvai basalt was being reduced in a least effort manner cannot be rejected, given the distribution of production behaviors for quartzite, this null hypothesis is in question for the quartzite assemblage from DK. Since these archaeological quartzite

OBC flakes morphologically fall within least effort experimental expectations, they cannot be ruled out as being produced via least effort manufacture strategies. However, the lack of any other production behaviors is highly unusual and suggests a notable difference in the way that Oldowan producing hominins at DK were treating quartzite as compared to basalt.

Several explanations could account for why the DK quartzite assemblage is dominated by OBC flakes. First, hominins could have preferred OBC flakes and selectively transported them into the site. Second, hominins could have initially reduced quartzite cobbles elsewhere (leaving OBA and OBB flakes behind) and brought in cores that were prepared to be flaked in a bifacial manner. Third, OBA and OBB flakes could have selectively been transported away from the site.

To establish the likelihood of each of these scenarios, it is pertinent to address the number of quartzite cores and flakes actually found at DK. From M.D. Leakey's monograph (1971), DK only has nine excavated quartz cores. Based on experimental expectations of exhausted cores (Table 4.7), it is expected that nine quartz cores would yield a total of 86.4 flakes**.** However, a total of 233 quartzite flakes and broken flakes were recovered from DK. This represents an increase of 270% from the experimentally established expectations of the number of flakes per core. This is a striking departure from the pattern formed with the DK basalt, in which only 60.2% of the expected basalt flakes are present. An overabundance of quartzite flakes suggests that either flakes were brought into the site from elsewhere (but not the cores that those flakes were produced from), or that quartzite cores were removed from DK, while the flakes were left behind. If quartzite cores were reduced on-site at DK, it is unlikely that only OBC flakes would be produced, unless cores were specifically shaped elsewhere (an unlikely hypothesis for Oldowan stone tool production and one that certainly deviates from least effort expectations). Similarly, it is unlikely that all OBA, OBB, and OBD flakes would be removed from the site. This combined evidence suggests that quartzite cores were not being reduced, or were only minimally reduced, at DK. Rather, OBC flakes were being transported into the site after being produced elsewhere.

Oldowan producing hominins may have preferred quartzite for tasks requiring a durable cutting edge (Tactikos 2005), but acquiring quartzite was costly for hominin populations. Such functional explanations for quartzite utilization will require further experimental evidence, but research such as that of Tactikos (2005) does suggest that quartzite may have had a functional advantage in terms of its sharpness and durability. However, quartzite shatters easily, which would be potentially dangerous if flakes were utilized to procure meat resources for consumption. Quartzite outcrops at the Naibor Soit inselberg at Olduvai Gorge (Figures 3.2 and 3.4), a static resource that would require physical transport from Naibor Soit to the sites in question. Blumenschine et al. (2008) apply an exponential decay model to Olduvai Oldowan quartzite artifacts and determine that, as a general trend, quartzite artifacts become less common and smaller as the distance increases from the raw material source. However, they also find that this trend is mediated by ecological factors and the environments in which sites were located (as predicted in Blumenschine and Peters 1998). Quartzite can, therefore, be considered a costly material for stone tool producing hominins at Olduvai Gorge. It is predicted based on raw material economics that costly materials will be utilized more efficiently as the distance to the source location increases.

Results from Figure 4.17 corroborate this economic interpretation. While Blumenschine et al. (2008) demonstrates that the *absolute* maximum dimension of quartzite artifacts decreases as distance to Naibor Soit increases, results presented here (Figure 4.17) demonstrate that *relative* maximum dimension and width of flakes actually increases at DK. For quartzite flakes that fall outside of expected least effort variation, hominins were able to consistently create flakes that had a relatively larger perimeter (increased maximum dimension and width) while preserving the same platform dimensions and relative thickness. This demonstrates an economically efficient use of raw material and directly opposes the way that basalt was being treated at the same locality. For quartzite at DK, it is concluded that:

1) the majority of quartzite flakes were produced elsewhere and transported into the site,
2) a minimal number of quartzite cores were transported to the site and may or may not have been reduced on site, and
3) a subset of quartz flakes were produced using strategies that are more efficient in terms of raw material conservation than expected under a least effort approach to flake manufacture.

At DK, Oldowan producing hominins were assessing the costs of their resources and exploiting them in an economically efficient way. Basalt was available in large quantities in the immediate vicinity of the site. This abundance of material and low cost of transport led to inefficient flake production (Figure 4.17) and incomplete cobble reduction (Leakey 1971). Quartzite, on the other hand, was costly to procure and required transport of 2.58-4.12 kilometers (Blumenschine et al. 2008:80). Based on the dominance of OBC quartzite flakes (Figure 4.13a) and lack of quartzite cores at DK (Leakey 1971; Blumenschine et al. 2008), it appears that instead of transporting heavy cobbles to DK, hominins likely carried OBC flakes, produced elsewhere, with them across the landscape.

V.A.1.b. FLK-N

FLK-N Basalt

The FLK-N (levels 1-3) basalt assemblage presents a similar trend in production behaviors as DK. Figure 4.12c demonstrates that OBC flake proportion is higher than expected, with OBD flake proportions at nearly the expected level for least effort production strategies and OBA flakes less than expected. Unlike DK, OBB flakes are not present given initial classification, but may be present as a small proportion of the assemblage based on misclassification assumptions. With the exception of the lower-than-expected proportion of OBB flakes, FLK-N classification follows a similar trend as the experimentally predicted production behaviors utilized through a least effort approach to flake manufacture.

The archaeological core assemblage from FLK-N (levels 1-3) excavated by Leakey (1971), contains a total of 104 cores, 95 produced on basalt. Based on the experimental data in Table 4.7, if every basalt core was reduced using a least effort approach strategy and was reduced until the core was relatively exhausted of usable platforms, it would be expected that approximately 824 basalt flakes would have been produced. The total number of whole flakes and broken flakes from FLK-N, however, only totals 173 basalt flakes. There is a discrepancy, therefore, between expected flake counts and the archaeological flake counts. Only 21% of the expected number of basalt flakes was recovered (Table 5.1). This trend of fewer basalt flakes than expected is present in both DK and FLK-N and suggests that hominins were treating basalt in a unique way.

At DK, hominins were not efficiently utilizing basalt due to the low cost of its procurement at that site location. Based on Hay's (1976:52) geologic account, it seems that basalt may have come from within one kilometer from these sites. However, no direct evidence for river gravels of substantive size has been uncovered to demonstrate this assumption. With this in mind, analysis of potential raw material transport costs must take variable raw material transport distances into account. Alternately, basalt sources may have been quite close since recent geological evidence suggests that a basalt high was exposed at the FLK site complex during lower Bed II times (Blumenschine *pers. com.*). Transport costs for basalt, therefore, may range from being far less than Naibor Soit quartzite, to equivalent to Naibor Soit quartzite, but there is always some cost associated with basalt procurement at these sites.

Compared to the reasonable 5.2 flakes per core that DK hominins were averaging, at FLK-N, there is a low average of only 1.8 flakes per core. As has been widely described, including by M.D. Leakey herself (1971:71-80), the basalt cores at FLK-N (levels 1-3) are predominantly choppers and are bifacially reduced. Bifacial flaking necessarily implies a minimum of two flake removals, and usually more. Thus an average of 1.8 flakes per core is not a valid assumption for FLK-N if the entire reduced assemblage was present on site.

This discrepancy between expected number of flakes and the actual number of basalt flakes could be attributed to one or more factors: 1) cores that were reduced elsewhere could have been carried into the site and/or 2) flakes that were produced at FLK-N could have been selectively carried away from the site. Leakey observed that in many Bed I sites, with the exception of DK, the low amount of basalt debitage is suggestive of core ("tool" to M.D. Leakey) manufacture elsewhere, "presumably at the sources of raw material" (1971:262-263).

Both the core assemblages from FLK-N and the proportions of production behaviors found there (Figure 4.12c) corroborate the idea that core manufacture began elsewhere and continued at FLK-N. The majority of the cores (82.9%) are what Leakey would classify as "choppers," and the majority of these choppers are bifacially flaked. It is fair to assume that the majority of flakes removed from these bifacial choppers would be behaviorally classified as OBC flakes. The predominance of OBC flakes in the FLK-N basalt flake assemblage, as demonstrated in Figure 4.12c, supports the idea that basalt cores were reduced to a bifacial form elsewhere (presumably at the nearby stream channel that transported basalt cobbles from the volcanic basin margin), transported to FLK-N, and reduced further on-site using an OBC approach to flaking due to the platforms available.

FLK-N production behaviors on basalt deviate in another way from those discussed at DK. At DK, basalt flakes that morphologically vary compared to the least-effort experimental assumptions show an extremely inefficient flake production strategy in which flakes are thicker and thinner than expected. At FLK-N, however, basalt flakes show an increased efficiency in manufacture (Figure 4.19). A subset of basalt flakes were being produced in a manner more efficient than the least effort production strategy predicts. These flakes show significantly smaller platforms but a significant increase in the length of the flake and a nearly significant reduction in bulbar thickness. Thus Oldowan producing hominins were able to regularly create basalt flakes that increased cutting edge (longer flakes) while reducing the amount of raw material required to produce the platform. Efficient use of raw material is suggestive of transport costs associated with the raw material and may, therefore, corroborate an hypothesis for higher transport costs of basalt and a correspondingly increased distance from FLK-N and the source of basaltic cobbles. Cores that were transported into the site were transported there with available platforms and thus were ready to be utilized in terms of creating flakes, but these flakes were produced in an economically efficient way.

FLK-N Quartzite

The distribution of production behaviors for quartzite at FLK-N is very similar to DK and all other Olduvai Oldowan sites: OBC flakes dominate the assemblage and thus deviate from the least effort approach expectations quite dramatically (Figure 4.13c). FLK-N resembles DK in most ways, including more quartzite flakes than expected given the number recovered from the site (total quartzite cores = 9; expected number of flakes = 86; actual number of flakes = 672; percentage difference = 781.4% more quartzite flakes than expected). Further, quartzite flakes from FLK-N that deviate from least effort morphological expectations show efficient usage of raw material in that they have significantly smaller platforms, increased cutting edge due to an increase in width, and utilize less material due to a decreased bulbar thickness (Figure 4.19).

The behavioral explanation for this economic utilization of quartzite, the large number of quartzite flakes, and the few quartzite cores recovered is the same as that from DK. The transport distance from Naibor Soit is still greater than two kilometers and thus represents a significant cost to hominins procuring this material. Non-cortical OBC flakes appear to have been produced elsewhere (presumably near or at Naibor Soit) and then selectively transported to FLK-N. A subset of these OBC flakes was produced with greater efficiency than least effort predictions.

V.A.1.c. HWK-E

HWK-E Basalt

HWK-E basalt flakes are highly underrepresented. While 58 basalt cores were uncovered from HWK-E (resulting in an expectation of approximately 503 flakes), only 32 basalt flakes were excavated. The recovery of only 6.4% of the expected assemblage follows the trend established by DK and FLK-N, but to a more severe degree. Similarly, the proportion of production behaviors follows a similar trend (Figure 4.12d). The majority of the assemblage is OBC flakes, followed by an equivalent number OBD and OBA flakes. These ratios are close to those established by experimental reductions and thus represent corroboration of least effort manufacture assumptions. However, as with DK and FLK-N, OBB flakes are significantly underrepresented (in this case, missing entirely).

HWK-E offers a potential explanation for why OBB flakes are conspicuously missing from Olduvai Oldowan sites. Some cores excavated from HWK-E have only two flakes removed from them. These cores are still bifacially flaked and show one flake removed from one surface (and OBA flake) and then a second flake removed from the opposite side, using the OBA flake scar as a platform (producing an OBC flake). This obvious and simple reconstruction was even noted by M.D. Leakey (1971:89) who states that "[the choppers] include some simple specimens in which only two flakes have been removed from the working edge, one from either side." In most experimental cases, though not all, an OBB flake was the simplest platform following removal of an OBA flake. With the consistent lack of OBB flakes at these Oldowan sites in addition to these minimally reduced cores at HWK-E, however, it appears that Oldowan producing hominins at Olduvai Gorge may have imposed platforms on OBA flake scars so as to take advantage of their noncortical surface, thus bypassing OBB flake production and focusing more on OBC flake production. Imposing platforms (striking for a technological purpose, rather than simply striking a spot where a flake can easily be removed) represents a departure from assumptions of a least effort approach to flake manufacture.

HWK-E, similar to FLK-N, is a lake margin site lying along the eastern edge of the lake that filled the Olduvai basin during Bed I and Lower Bed II times. Specifically, HWK-E sits at the lowest level of Bed II, on top of the marker Tuff IF. Paleoenvironmental indications show that HWK-E represents a time following lake regression in which vegetation had returned to the eastern lake margin (Albert and Bamford 2011). It is likely that both grazing/browsing fauna and hominins moved into the Paleolake Olduvai basin during these periods of vegetation (Peters and Blumenschine 1995; Blumenschine et al. 2011). HWK-E is also within one kilometer of a paleostream channel that would have transported basaltic clasts from the north side of the Sadiman volcano (Hay 1976), but the specific location of basalt procurement is difficult to determine. Thus transport costs of basalt, similar to FLK-N, must be analyzed as a variable range, from low to quite high. But why the dramatic discrepancy between the number of flakes predicted to be found on site and the number of flakes actually recovered?

While the reason for the lack of flakes is unclear, it is apparent that flakes were not produced at the HWK-E site. Rather, the majority of cores were transported into the site having been reduced elsewhere. This is apparent because of the general lack of debitage at the site. However, the distribution of production behaviors (Figure 4.12d) does suggest that a limited number of the cores were reduced on site because OBA, OBC, and OBD flakes are present in proportions predicted by experimental expectations.

HWK-E Quartzite

The same established trend for quartzite utilization at DK and FLK-N is seen at HWK-E. Despite the dearth of basalt flakes versus basalt cores, there are only seven quartzite cores but 173 quartzite flakes. This represents 257% more quartzite cores than is experimentally expected. Further, these quartzite flakes are between 70-100% OBC flakes, continuing the production behavior trend identified at DK and FLK-N. Thus, similar to all Oldowan sites discussed thus far, it appears that noncortical quartzite flakes were transported to HWK-E independent of the cores that they were produced from.

HWK-E lies between 2.54-3.81 kilometers from the Naibor Soit quartzite (Blumenschine et al. 2008:80) and thus the transport of quartzite is costly here, as it is at DK and FLK-N. As expected given these transport costs, some quartzite flakes present at

HWK-E were produced in a more efficient manner than least effort production strategies predicts. These flakes produce a larger perimeter for the same mass of stone by increasing the relative length of the flake while preserving the ratio of the other dimensions (Figure 4.20).

V.A.1.d. FLK

FLK Basalt

The basalt assemblage at FLK-*Zinj* represents a deviation from the pattern described for DK, FLK-N, and HWK-E. While the basaltic material is still treated in a relatively economically efficient way (Figure 4.18) and represents an almost-identical distribution of production behaviors (Figure 4.12b) as compared to the other Olduvai Gorge Oldowan sites, the number of basalt flakes recovered from FLK is double the expected number of flakes given a least effort approach to manufacture and the presence of all artifacts. At FLK, 19 basalt cores were excavated by Leakey (1971), which, based on experimental expectations, suggests that approximately 165 flakes would have been produced from these cores (at an average of 8.67 flakes per core in Table 4.7). The actual number of excavated flakes and broken flakes at FLK is 326 flakes, 98% more flakes than expected. When compared directly to HWK-E, which only has 6% of the expected basalt flakes, the difference is striking.

Several explanations could explain this discrepancy. First, cores could have been transported away from FLK following flaking, thus increasing the apparent proportion of flakes to cores. Second, flakes could have been transported to FLK after being produced at another location. Third, cores could have been reduced in a significantly more efficient manner than the least effort approach predicts (Table 4.7).

The first explanation cannot be ruled out, given the pattern seen at HWK-E. At HWK-E the large discrepancy between the large number of basalt cores and the small number of basalt flakes led to the inference that flaking did not take place at the site; rather, the cores were, for the most part, transported to the site after being reduced elsewhere. FLK could represent such a site where reduction occurred and core transport followed. If a local basalt source was available, as has been geologically suggested, this explanation might make the most sense, except that the full range of production behaviors are present at the site.

The second explanation is less likely. There has been no evidence put forth thus far to suggest the transport of basalt flakes across the landscape, only evidence for quartzite flake transport. The distribution of production behaviors further corroborates this conclusion (Figure 4.12b). With the exception of the missing OBB flakes, which was discussed relative to HWK-E assemblages but is equally applicable to FLK and FLK-N assemblages, the FLK assemblage contains proportions of production behaviors close to the experimentally predicted values. In fact, the higher proportion of OBA flakes suggests that primary flaking was also taking place on site at FLK.

The third explanation is not likely, either. Though a subset of basalt flakes at FLK were produced in a way that made more efficient use of the raw material than a least effort approach predicts, this efficiency is minimal and only applies to an increased width of flakes. The consistently large platforms and thicknesses associated with the least effort strategy suggest that the basalt cobbles at FLK could not have been reduced to an extent that doubled their efficiency.

FLK Quartzite

FLK continues the established trend for quartzite utilization that has been discussed for DK, FLK-N, and HWK-E. At FLK, there are sixteen quartzite cores that, given Table 4.7, are expected to yield approximately 154 quartzite flakes. The actual number of excavated flakes and broken flakes is a staggering 1,824 flakes! This represents 1,188% of the experimentally expected quartzite flakes. Further, these quartzite flakes continue the trend of being dominated by OBC flakes (Figure 4.13b). Thus, similar to all Oldowan sites discussed thus far, it appears that noncortical quartzite flakes were transported to FLK independent of the cores that they were produced from.

FLK lies between 2.00-3.07 kilometers from Naibor Soit (Blumenschine et al. 2008:80) and thus the transport of quartzite is equally costly here as it is at DK, FLK-N, and HWK-E. As expected given these transport costs, a subset of quartzite flakes present at FLK were produced in a more efficient manner than least effort production strategies predicts. These flakes are the most efficiently produced of any of the Olduvai Gorge Oldowan sites (Figure 4.18), showing statistically significant differences from least effort expectations in platform area, width, maximum dimension, length, bulbar thickness, and thickness. This means that, as an assemblage, flakes produced in a manner outside of least effort expectations are longer, wider, and have a longer maximum dimension (more perimeter edge), while at the same time are thinner at the bulb of percussion and at the midpoint of the flake. Further, even with the reduction of mass and the increase of perimeter, the relative platform size is reduced, thus preserving more surface space for future platforms. This efficiency and skill of production is greater than at any other Oldowan site.

V.A.1.e. HWK-W

The site of HWK-W was included in the sample as a test of the sensitivity of BLA methodology for extremely small sample sizes. With a sample size of only four flakes, the behavioral conclusions of HWK-W are minimal, but the trend of quartzite flake transport remains apparent and that trend also continues with the sole transport of OBC flakes to HWK-W (Figure 4.13e). Such transport makes sense given the minimum distance to Naibor Soit is between 2.41-3.63 kilometers.

V.A.1.f. Olduvai Gorge broadly analyzed

Several informative patterns have become apparent through the discussion of the results relative to each site at Olduvai Gorge. First, Oldowan producing hominins are consistently treating quartzite and basalt differently in the production of stone tools. Second, flake production patterns consistently fit an economic explanation, inferring an inherent economic awareness in the ways that Oldowan producing hominins utilized resources and their environments. Oldowan producing hominins, to some extent, could control the skill with which they produced flakes depending on economic constraints.

First, at all Oldowan sites at Olduvai Gorge, quartzite fits two particular patterns: 1) there are more flakes present at the site than the number of cores suggests should be. This ranges from a minimum of 257% more than expected to a maximum of 1,188% of the expected value (Table 5.1). 2) The production behavior of these quartzite flakes is primarily (70-100%) represented by OBC (Figure 5.1). The combination of these factors strongly suggests that quartzite flakes were produced elsewhere and subsequently transported into these sites. It would make economic sense that hominins would have produced these quartzite flakes at the raw material source, Naibor Soit. This leads to the hypothesis that:

> **Hypothesis 1:** Upper Bed I/Lower Bed II exposures at Naibor Soit will contain sites with lithic assemblages with more OBA and OBB flakes (and potentially OBD flakes) than a least effort approach predicts.

However, this hypothesis is not testable given that no Oldowan exposures have been uncovered at Naibor Soit.

Following flake production, hominins selected small, light, OBC artifacts and transported them across the landscape for utilization, leaving behind cores and a predominance of OBA and OBB flakes. Given the significant distance between Naibor Soit and these sites and the potentially dangerous foraging route between the raw material source and the sites, it makes sense that hominins would have avoided carrying heavy pieces of raw material long distances. See Figure 5.1 (focusing on the blue lines) for a visual of what this flow of raw material across the landscape might have looked like.

Further, Blumenschine et al. (2009) draws attention to the Lower Bed II incision that created, what is colloquially called, “Crocodile Valley” due to the strong fossil evidence for crocodile presence and predation there. This valley would have created a geographic barrier that separated the FLK complex sites and HWK-E from a direct route to Naibor Soit for quartzite procurement. Thus the landscape became even more dangerous and the route for procurement became more circuitous, leading to the adaptive necessity of adopting an efficient and less costly way of procuring raw materials. Thus the linear routes outlined in Figure 5.1 represent an absolute minimum distance that hominins would have had to transport raw materials from Naibor Soit. The actual distance is likely to be significantly larger and include transport across landscapes with a high incidence of carnivore predation.

OBC quartzite flakes may have been functionally advantageous to other OBA and OBB quartzite flakes. Given the evidence that quartzite is more durable than other available materials (Tactikos 2005), a testable hypothesis about the morphology of OBC flakes becomes apparent. It is here hypothesized that OBC flakes, having less cortical edges than OBA and OBB flakes, are less prone to shatter during use and therefore are more functionally advantageous to quartzite flakes with more cortex. This hypothesis can easily be tested and quantified given further butchery experiments with OBA, OBB, and OBC flakes.

All sites have a presence of Oldowan quartzite cores, though. This means that some cores were transported across the landscape as well. If hominins were carrying larger, heavier pieces of quartzite, it would be economically expected (Blumenschine et al. 2008) that this quartzite would be reduced to a significant extent as it gets farther and farther from the raw material source. Subsets of quartzite flakes at all Olduvai Gorge sites suggest that this is also happening. These subsets of quartzite flakes fall outside of the morphological range that experimental evidence for least effort production predicts should exist (Figures 4.17-4.20). This leads to the production of a testable hypothesis:

> **Hypothesis 2:** flakes that exhibit morphologies outside of the expected range of variation for a least effort approach (made with a *more efficient* usage of raw material than expected) are more likely to have been produced on-site, as opposed to transported to the site having already been produced. These individual flakes will have a greater likelihood of refitting to cores found at the same site.

In other words, cores of quartzite carried across the landscape were flaked in a more careful manner than cores flaked at the raw material source (Naibor Soit) and thus result in flakes outside of the expected variation for a least effort strategy. This pattern is present at all Olduvai Gorge sites and thus allows for ample opportunity to test this hypothesis.

Basalt from Olduvai Gorge is differentially utilized across the landscape depending on the distance to a source for this material. For FLK, FLK-N, and HWK-E, the distance to the basalt procurement location was gathered is quite similar. However, the specific location for basalt procurement is difficult to determine. For each of these sites there is a distinct absence of OBB flakes (and consistent underrepresentation of OBA flakes). However, most of the core assemblages are quite large. This suggests that basalt cores were transported from their original source and eventually discarded at these sites, unlike quartzite cores. The lack of OBA and OBB flakes suggests that these flakes were removed elsewhere (and for OBB flakes, perhaps not at all, see discussion in section

Figure 5.1:

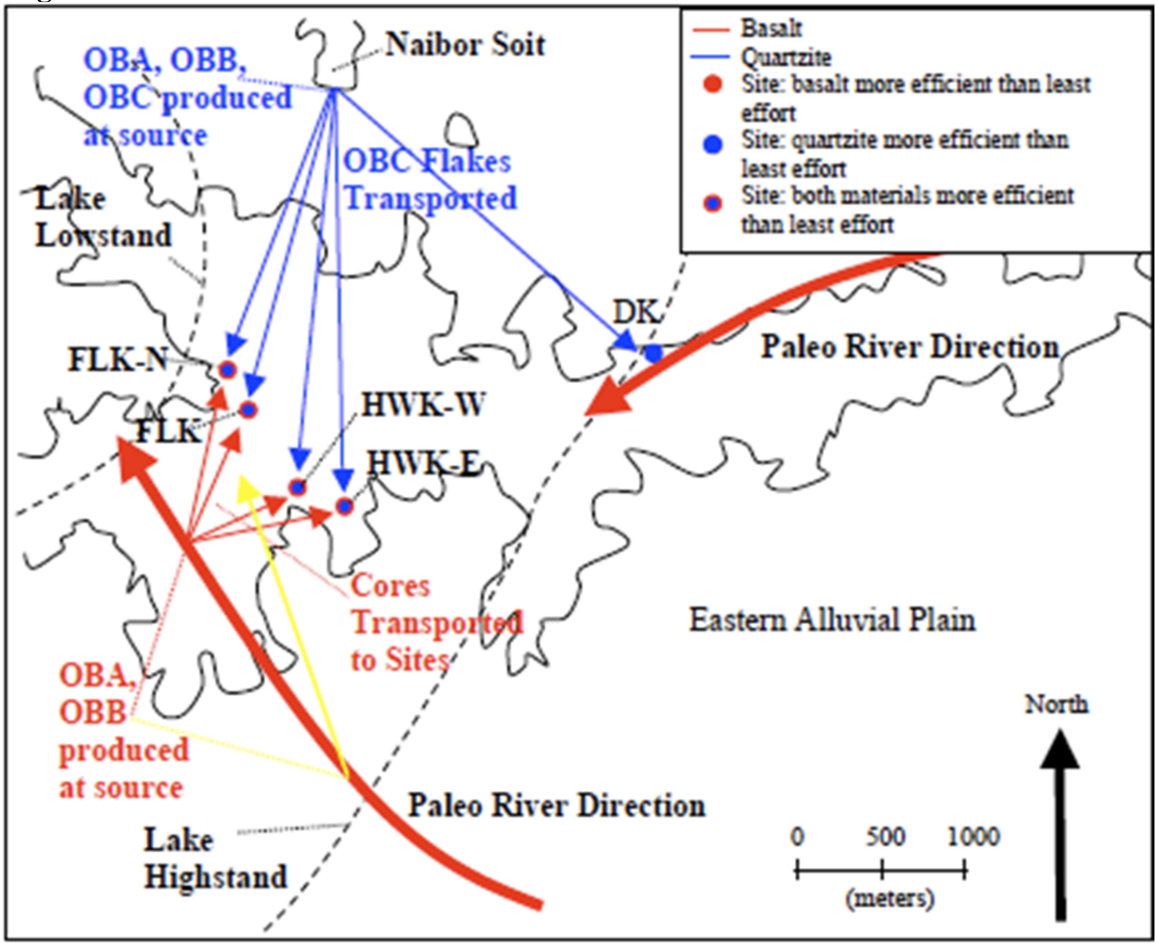


Figure 5.1: Aerial view schematic of Olduvai Gorge that shows how hominins moved lithic material around the landscape. Blue lines show the movement of quartzite from the Naibor Soit outcrop. Based on the predominance of OBC flakes at all Olduvai Gorge Oldowan sites and the lack of quartzite cores at the same sites, it is shown that OBA, OBB, and OBC flakes were produced at Naibor Soit (location of source flaking is approximated in this figure). After flake production, OBC flakes were consistently selected and carried across the landscape to locations for utilization. Red lines show the movement of basalt across the landscape. Basalt was available immediately adjacent to DK from river gravels and an undetermined distance from the other sites, also in the form of river gravels. For FLK, FLK-N, and HWK-E, patterns of production behavior suggest that initial flaking occurred at the source of this raw material, due to the lack of OBA and OBB flakes found at these sites (the source location is approximated in this figure). Cores that were initially flaked and proved to be quality raw material were transported across the landscape to other locations for further reduction and/or utilization. However, the fluvial source of basalt cobbles at Olduvai Gorge is difficult to determine with certainty. The yellow arrow indicates that a greater distance for basalt procurement is possible. Blue and red dots show the location of sites and whether or not subsets of flakes were produced in a manner more efficient than least effort experiments predict. Dots that are blue with a red surrounding line denote a site that has both quartzite and basalt flakes that are produced in such an efficient manner.

V.A.1.c.). It will be remembered from Figure 4.8, that Olduvai Gorge basalt is a less predictable material than is the quartzite. As hominins planned on transporting this material over the landscape as they foraged, it seems that they removed OBA flakes (and possibly, but not necessarily OBB flakes) at the source, possibly to test the raw material quality prior to transport.

Once basalt was transported, subsets of basalt at each site with basalt except DK were reduced in ways more efficient than experimentally predicted given a least effort approach (Figures 4.17-4.20). This treatment of transported basalt suggests an economic understanding of the procurement cost, transport cost, and the cost of returning to procure more basaltic material. Since the basalt may have been in closer proximity to site locations compared to quartzite, and since basalt cores were also potentially utilized not only for flakes but also as implements themselves, hominins transported the cores across the landscape. See Figure 5.1 (focus on the red lines) to visualize the flow of basalt across the Olduvai landscape. However, even if basalt required an equivalent transport cost in terms of distance as compared to quartzite at Olduvai Gorge, the same conclusions are drawn: hominins are economically assessing raw material quality, transporting material for use, and making efficient use of that raw material far from its procurement location.

DK represents a perfect case study for the economic relationship that Oldowan producing hominins at Olduvai Gorge had with their environment. As has been mentioned, at DK there is an abundance of basalt in the immediate environment. Hominins at DK, therefore, did not utilize basalt in an efficient manner. Instead, they actually treated basalt in an inefficient manner (Figure 4.17). The subset of basalt flakes falling outside of experimental expectations for a least effort production strategy is the only example at Olduvai Gorge or Koobi Fora in which deviation from least effort actually results in flakes with *less than efficient* production patterns. These basalt flakes at DK are thicker and have a reduced perimeter compared to least effort flakes. At the same times, hominins at DK utilizing quartzite were capable of producing a subset of these flakes that are *more* efficiently produced than least effort expectations. Oldowan hominins were, therefore, capable of altering their technological behaviors given the economic circumstances facing them: inefficient and expedient behaviors when there was no cost associated with procurement and transport, and efficient and curated behaviors when there was significant cost associated with procurement and transport.

V.A.2. Koobi Fora site analysis

The results from Figure 4.14 suggest that KBS assemblages generally fall within the expectation established via BLA experimental methods in terms of production behaviors present. Further, the flake features outlined in Figure 4.16 demonstrate that no significant differences exist among KBS assemblages; stone tools fall along a continuum of variation with no statistically distinct break. This suggests that Oldowan producing hominins at Koobi Fora were producing flakes using a technique indistinguishable from least effort production strategies at all KBS sites. However, this does not mean that all KBS sites are necessarily identical in terms of how they were technologically utilized. To establish archaeological deviation from the experimental expectation (Figure 4.14) and assess the possibilities of flake transport, core transport, or preference for flakes of particular morphology, each archaeological assemblage will be analyzed in a similar manner to those from Olduvai Gorge in the previous section. Further, the implications

Table 5.1: Archaeological samples of cores per site compared to the experimentally determined expectations of flakes per core (see Table 4.7) and the actual number of archaeological flakes recovered from the site

Site	Material	Cores (N)	Expected # Flakes	Actual # Flakes	Difference (%) (Actual/ Expected*100)
FxJj 1	Basalt	7	79	77	97
FxJj 3	Basalt	3	34	72	212
FxJj 10	Basalt	15	169	176	104
DK	Basalt	97	841	506	60.2
DK	Quartzite	9	86	233	270
FLK	Basalt	19	165	326	198
FLK	Quartzite	16	154	1824	1188
FLK-N	Basalt	95	824	173	21.0
FLK-N	Quartzite	9	86	672	781
HWK-E	Basalt	58	503	32	6.4
HWK-E	Quartzite	7	67	173	257

for assemblage-level morphological homogeneity will be discussed in terms of behavioral conclusions.

V.A.2.a. FxJj 1

Based on experimentally established expectations of Koobi Fora basalt assemblages, it is expected that given a least effort approach production strategy, flake assemblages will consist of a majority of OBC flakes, followed by OBD flakes, then OBB flakes, and finally, OBA flakes (Figure 4.15a, "experimental expectation"). Figure 4.15a provides a graphical representation of the expected range of behavioral classification given the misclassification rates calculated in the construction of the classification algorithm (Table 4.6). While in every misclassification scenario for FxJj 1 the proportion of OBC flakes is higher than expected, the *relative* proportions of behaviors is similar to expected variation (OBC is highest, followed by OBD, then OBB, and the lowest numbers of OBA). For FxJj 1, the misclassification scenario that assumes a maximum number of OBD and OBB flakes is very close to the experimentally determined expectation. The only reason that OBC and OBD flakes appear marginally higher than expected is because of the less-than-expected proportion of OBA and OBB flakes, which inflates the proportional appearance of OBC and OBD flakes. Further, the morphologies of FxJj 1 archaeological flakes that fall outside of least-effort approach expectations are not statistically distinct from the within-expectation assemblage range (Figure 4.16). In fact, this is true of all KBS sites and suggests that the least-effort strategy was utilized by Oldowan producing hominins at Koobi Fora.

The total number of whole flakes and broken flakes found within the excavated collections of FxJj 1 is 77 flakes (Harris and Isaac 1997:81). The total number of cores recovered from the excavated collections at FxJj 1 is seven cores. Based on the average number of flakes produced per core of Koobi Fora basalt (Table 4.7), the expected number of flakes at FxJj 1 given the number of cores recovered is 79 flakes, if all cores and flakes produced are at the site location. The assemblage collected from FxJj 1 represents 97% of the expected number of flakes, almost identical to the expected number of flakes. This suggests that most of the flake production was occurring on site and, if flakes were being utilized as a tool at the site location, none were transported away from the site and no flakes or heavily flaked cores were transported into the site. Broadly, FxJj 1 meets the expectations of a least effort production strategy due to the distribution of production behaviors on site and the close correlation between the experimentally expected number of flakes given the number of recovered cores and the actual number of flakes. Further, because of the close fit between the expected number of flakes on site and the actual number of flakes on site, it seems that cores were being flaked to relative exhaustion at FxJj 1.

The depositional environment of FxJj 1 archaeological collections suggests that hominins were occupying a floodplain environment adjacent to a stream channel that was part of a paleo-deltaic system (see Figure 3.10 and Harris and Isaac 1997:76; Braun 2006). River and stream channels brought basalt cobbles from the basin margins (12-15 km from FxJj 1), though the immediate deltaic environment of FxJj 1 was too low-energy to transport such large cobbles. Thus the hominins had to travel a distance to procure raw materials. Toth (1997) suggests that this distance could be three kilometers, which would require significant cost (this is an equivalent distance to Naibor Soit). The transport cost was enough that hominins would flake cores to exhaustion before procuring more raw materials. The fact that hominins did not implement a production strategy that was more economically efficient than a least effort strategy suggests that either (1) the cost was not high enough to warrant deviation from a least effort approach, or (2) Koobi Fora hominins did not possess the ability or accumulated cultural knowledge to exploit cobbles in a way other than through a least effort approach. A third option could be that raw materials were easier to procure than Toth (1997) suggests, which would support the former assertion that the cost was not high enough to warrant deviation from a least effort approach to flake manufacture. Braun (2006) suggests that cobbles *could* have been available in adjacent channel gravel beds, but these gravel beds are only hypothetical. However, given the least effort approach consistently utilized at Koobi Fora, it would seem that Koobi Fora hominins are treating their basalt more similarly to Olduvai Gorge basalt than they are to Olduvai Gorge quartzite. This might suggest closer proximity than Toth (1997) assumed.

The fact that, despite FxJj 1 fitting least effort expectations and being a high-integrity site, there have been no refitting pieces identifies at FxJj 1 (Harris, *pers. com.*) is unusual and currently unexplained. It may be that the very smallest pieces at FxJj 1 were winnowed away by low energy water erosion, but this would still not explain the lack of refits. Despite this abnormality, the small size of the assemblage and the close fit between least effort expectations for production behaviors, number of cores, and number of flakes, it appears that FxJj 1 was a single occupation locality.

Based on the similarity of archaeological materials to experimental expectations in terms of flake counts (Table 5.1), representation of production behaviors (Figure 4.15a), continuity of flake morphology (even at the extremes) (Figure 4.16), and the environmental location of FxJj 1, it appears that hominins at FxJj 1 were:

1) procuring basalt cobbles from a distance requiring relatively low procurement and transport costs,

2) producing flakes using a least-effort approach,

3) producing the majority of flakes on-site,

4) using flakes on-site,

5) flaking cores until they are nearly exhausted.

V.A.2.b. FxJj 3

FxJj 3 meets the expectations of a least effort approach to stone tool production based on the relative proportions of production behaviors present in the archaeological assemblage (Figure 4.15b). While the presence of OBA flakes is conspicuously missing, the distribution of production behaviors present given the classification algorithm constructed is nearly identical to the expected distribution at FxJj 3. Further, as is the case for FxJj 1 and all KBS sites, the morphology of flakes at FxJj 3 falls within one continuum that cannot statistically be separated from a least effort production strategy.

The total number of whole flakes and broken flakes found within the excavated collections of FxJj 3 is 72 flakes (Harris and Isaac 1997:95). The total number of cores recovered from the excavated collections at FxJj 3 is only three cores. Based on the average number of flakes produced per core of Koobi Fora basalt (Table 4.7), the expected number of flakes at FxJj 3 given the number of cores recovered is 34 flakes. The assemblage collected from FxJj 3 represents 212% of the expected number of flakes. This discrepancy is likely explained via the depositional and erosional environments of FxJj 3.

FxJj 3 is also called the "Hippo and Artifact Site," or HAS, due to the fact that the archaeological assemblage was found as a dense accumulation associated directly with a hippopotamus carcass. While the hippopotamus carcass has not yielded direct evidence for butchery at FxJj 3 (though cut marked bones were recovered from the surface of FxJj 3), other fossil evidence places hominins in a well-watered area with other game animals. Based on the presence of the relatively small assemblage of cores and flakes, it appears that FxJj 3 was an ephemeral butchery site, rather than an occupation site, and may represent an opportunistic scavenging event. FxJj 3 is a rather unusual site given its small assemblage size and expedient appearance of flake manufacture, butchery, and transport.

The depositional environment of FxJj 3 is similar to FxJj 1 in that it represents a low-energy floodplain environment that sits above the infill of a previously flowing paleochannel (Harris and Isaac 1997:84). FxJj 3, though, is sloped and therefore a substantial number of artifacts were eroded and collected as surface finds. The fact that many artifact re-fits were found from the FxJj 3 assemblage suggests that the excavated portion of the site was *in situ*, and that the excavated assemblage of lithic artifacts is complete.

If hominins were occupying FxJj 3 ephemerally as a butchery location, they may have transported some cores away from the site. Transport of cores could explain the higher number of flakes in the archaeological assemblage versus the experimental expectations. At FxJj 3 the relative size of both flakes and cores are quite small compared to other sites (Harris and Isaac 1997:94). Perhaps, then, hominins were reducing these three cores in a more efficient manner than least effort production strategies suggest. If this is the case, however, flake morphologies would be expected to differ from least effort approaches in terms of a more efficient use of raw material per flake (like they do at Olduvai Gorge sites). No KBS flakes differ to a statistically significant extent from least-effort expectations (Figure 4.16) and thus this explanation can be ruled out. Instead, it seems that hominins reduced some cores to exhaustion at FxJj 3, discarded these cores, and transported cores with available platforms away from the site. Lastly, some flakes and cores could have been eroded and removed from the site by environmental factors. Given that there are re-fits present at this site, the most logical explanation seems to be that hominins transported some cores away from the site, leaving behind only the smallest, most exhausted cores. This combination of evidence suggests that at FxJj 3, hominins were:

1) producing flakes using a least-effort approach,
2) producing flakes on-site,
3) utilizing flakes opportunistically on-site,
4) flaking cores until they are nearly exhausted,
5) transporting cores with available platforms away from the site, and
6) discarding cores that are exhausted of available platforms.

These conclusions are nearly identical to those of FxJj 1, with the exception that clear butchery behavior was being practiced by FxJj 3 hominins on-site and basalt cores were being transported away from the site. Transport of raw material suggests that a more significant cost of raw material procurement existed at FxJj 3 versus FxJj 1. Given the similarity in proximity to channel settings between FxJj 1 and FxJj 3, it is predicted that cobbles of an appropriate flaking size were not immediately available in the vicinity of FxJj 3. The ephemeral nature of the FxJj 3 butchery site also suggests an opportunistic utilization of resources that hominins encountered while foraging, not the creation of what M.D. Leakey would call a "living floor" and certainly not what G. Ll. Isaac would call a "central place" or "home base."

V.A.2.c. FxJj 10

Similar to FxJj 1 and FxJj 3, FxJj 10 meets the expectations of a least effort approach to stone tool production based on the relative proportions of production behaviors present in the archaeological assemblage (Figure 4.15d). While the presence of OBA and OBB flakes is lower than expected (like FxJj 1 and FxJj 3), the distribution of production behaviors present given the classification algorithm is nearly identical to the expected distribution at FxJj 10. Further, as is the case for all KBS sites, the morphology of flakes at FxJj 10 falls within one continuum that cannot statistically be separated from least effort production strategies (Figure 4.16).

The total number of whole flakes and broken flakes found within the excavated collections of FxJj 10 is 176 flakes (Harris and Isaac 1997:106). The total number of cores recovered from the excavated collections at FxJj 10 is 15 cores. Based on the average number of flakes produced per core of Koobi Fora basalt (Table 4.7), the expected number of flakes at FxJj 10 given the number of cores recovered is 169 flakes.

The assemblage collected from FxJj 10 represents only 4% more than the expected number of flakes. This correlation between experimental expectations and archaeological assemblage counts suggests that a least effort approach to flake manufacture was implemented by hominins at FxJj 10.

However, the depositional environment of FxJj 10 is slightly different than FxJj 1 and FxJj 3. FxJj 10 artifacts were excavated from a marginally coarser stratigraphic unit that represents a higher-velocity floodplain environment than was encountered at the other KBS sites (Harris and Isaac 1997:108-109). The stratigraphic context led to mixed conclusions about the integrity of the site and whether it may be fluvially disturbed. The amount of microdebitage on site, however, suggests that fluvial disturbance is minimal. This interpretation is used for analytical purposes here.

Toth (1997) suggests that at FxJj 10 many cobbles were not intensively flaked, based on relative number of choppers versus discoids and polyhedrons. However, least effort suppositions do not necessitate a cobble being intensively flaked. Rather, some cobbles yield fewer platforms than others because of their initial morphology and this affects how many potential flakes can be removed from a given cobble (revisit Table 4.12 and 4.13 for Koobi Fora basalt). In other situations, failed flake removals will alter the productivity of a given cobble. Thus if hominins were using a least effort approach to flake manufacture, as Table 5.1, Figure 4.15d, and Figure 4.16 suggest is occurring at FxJj 10, cobbles will be reduced until platforms are difficult to strike; for some cobbles this means many flakes will be removed, for other cobbles this means only a few flakes will be removed. Since the experimental component of this research includes such a large sample size of cobbles, an average of 11.27 flakes (Table 4.7) per cobble is an acceptable estimate that takes this variation in cobble productivity into account.

What is of particular interest to the discussion of raw material utilization is the continued lack of flake production that is more efficient than least effort approaches in the KBS. No cobbles of a size large enough to flake have been found within one kilometer of FxJj 10 (Harris and Isaac 1997:108), although they were inferred by Braun (2006:148) to be within 100 meters from the site. However, analysis of raw material types at FxJj 10 suggests transport of raw materials to the site (Braun 2006:150) and thus, based on the present knowledge of raw material distribution, it is argued here that cobbles were procured between 100 meters and one kilometer away from the site and carried over the landscape before they were flaked at FxJj 10. This represents a minimal transport cost (compared to quartz at Olduvai, for instance), and a transport cost equal to (and perhaps slightly more than) FxJj 1. No change in manufacturing strategy exists between FxJj 1 and FxJj 10.

This combination of evidence suggests that at FxJj 10, hominins were:

1) producing flakes using a least-effort approach,

2) transporting cores to the site from a distance that,

3) producing the majority of flakes on-site, and

4) flaking cores until they are nearly exhausted given available platforms.

V.A.2.e. FxJj 11 and FxJj 4

The inclusion of FxJj 11 and FxJj 4 in the sample for this study is mainly as a comparative tool for the BLA methodology. FxJj 11 has traditionally been classified as a

Karari site, and thus a later representation of stone tool technology than the other KBS sites. However, the technological attributes of the lithic assemblage described by Harris (1978) suggest that FxJj 11 does not have the same assemblage composition as other "Developed Oldowan" or "Karari" assemblages from the area. This is mainly due to the lack of "Karari Scrapers" (Harris 1978:278), which are defined as unifacial cores produced by consistently using the ventral side of a large flake or flat cobble as a platform. FxJj 11, therefore, potentially represents a later phase of technological development, but not a fully developed "Karari Industry." This is a natural progression for application of BLA methodology and allows for hypothesis construction of further experimental research. FxJj 4 represents a very small accumulation of artifacts and thus tests the sensitivity of BLA and the potential behavioral inferences that could come from such small accumulations.

The FxJj 11 archaeological assemblage consists of 14 cores and 195 whole and broken flakes (excluding angular fragments). Based on experimental expectations *of KBS technology*, it would be expected that for 14 cores, a total of 158 flakes would be present on site if a least effort approach was utilized, cores were flaked to exhaustion, and the entire assemblage is present on site. The archaeological assemblage, therefore, has 23% more flakes present than expected, given these assumptions. Further, there is an interesting departure in terms of the proportions of production behaviors present at FxJj 11 versus the KBS sites (Figure 4.15e). Whereas FxJj 1, 3, and 10 all have proportions of production behaviors that are reminiscent (if not very close) to the experimental expectations for a least effort production strategy, FxJj 11 has far more OBD flakes than expected and is the only Koobi Fora site that has OBA flakes present in any notable capacity. However, the morphology of flakes at FxJj 11 do not statistically deviate from the KBS sites in any significant way, even at the extremes (Figure 4.16). While it is clear given the distribution of production behaviors at FxJj 11 that hominins were reducing cobbles using more OBD flake removals, the small assemblage size, small size of the cores, and comparative morphology of the flakes links this site closely with the KBS Industry and not the Karari Industry, as it has traditionally been attributed to. However, though the cores are small, some of them exhibit single platform morphology, which is a hallmark of the Karari Industry technological process. FxJj 11, therefore, can be considered a transitional site in terms of the technological processes that were utilized.

At this point in the development of BLA methodology, only least effort strategies employed at Koobi Fora on basalt and Olduvai Gorge on basalt and quartzite have been systematically tested. If an assemblage begins to differ from this least effort approach, it is not presently possible to assess what other strategy that assemblage most closely resembles; this will require further systematic experimental research and careful statistical analysis. FxJj 11 may be more accurately assessed given a production strategy associated with the later "Karari Industry" as opposed to the earlier "KBS Industry" and this could account for the discrepancies seen in Figure 4.15 and Table 5.1. In other words, the production behaviors defined for the Oldowan least effort approach, are not necessarily the same behaviors that would relate to "Developed Oldowan" production strategies. However, the cores at FxJj 11 are heavily reduced, even for KBS standards, and discoidal in nature. This kind of assemblage suggests that a higher percentage of OBD flakes might be present.

FxJj 4, an accumulation of only three measured whole flakes for this study, does not contribute to the overall impact of site comparisons. However, these few flakes can still be individually identified to belonging to OBC and OBD flakes with a high degree of certainty (Figure 4.15c) and thus, although only minimally, provide a standardized measure from which to compare other Oldowan sites. However, such small samples must be viewed with caution because, as is evident from results in section *IV.A.* (Table 4.3), such small samples can suggest that variation exists where, in reality, there is only a continuum of variation.

V.A.2.f. Koobi Fora broadly analyzed

Koobi Fora Oldowan (KBS) sites are broadly uniform in the way that they treat basalt for flake production. The pattern that emerges through BLA methods is one of a continuous and consistent least effort reduction strategy. This is evident from three lines of evidence at each site: 1) the classification of the majority of flakes into Oldowan production behavioral categories based on morphological similarity to expectations (Figure 4.15a-e), 2) the continuous statistical correlation of KBS assemblages to experimental expectations (Figure 4.16), and 3) the relative proportions of production behaviors at each site (Figure 4.15a-e) closely resemble experimental distributions. This suggests that Oldowan producing hominins at Koobi Fora were, on average, flaking basalt cores nearly to exhaustion. The regular excavation of small, heavily reduced cores from KBS sites corroborates this experimentally-derived conclusion.

The KBS sites are all in landscape areas adjacent to waterways. This suggests that hominin foraging activity during this time period were likely tethered to water

(Rogers et al. 1994) and the safety of cover that the flora surrounding these areas provided. However, the deltaic environment of the KBS sites also posed potential risks in terms of predators seeking water sources and other dangerous fauna (Harris, *pers. com.*). These waterways did, though, provide both shelter and a regular source of hydration. They also provided gravel bars with basaltic raw material for the production of stone tools. As geological survey suggests, it seems that these gravel bars may have been sporadic, but the results presented here suggest that raw materials were available to KBS hominins within a distance small enough to preclude the adaptive necessity of efficiently utilizing raw material. However, this availability of raw material still suggests some procurement and transport costs. The costs for each KBS site appears to be enough that hominins continuously reduced cobbles to the point of near exhaustion, but not enough to force a more careful pattern of flake production.

That being said, the hominins responsible for the production of the KBS sites demonstrate forethought and lithic curation behaviors in two ways. First, as Figure 4.15a-e indicates, for all KBS sites (FxJj 1, 3, and 10) OBA and OBB flakes are consistently present in smaller proportions than expectations predict. By definition, the first flake removed from any given unmodified cobble *must* be an OBA flake. At the KBS sites, there are fewer OBA flakes present at a site than there are cobbles, suggesting that not all flakes are present at the site location. It will be recalled that Koobi Fora basalt represents the least predictable raw material in this study in terms of quality (Figure 4.8). In fact, 25% of the basalt cobbles utilized for this study, despite having no visibly identifiable inclusions, were not fit for flake production due to internal inconsistencies. If hominins were transporting raw materials across the landscape, which is a costly endeavor, they may have tested raw materials at their source location prior to transport to avoid the cost of transporting such poor materials. These initial flake removals would definitely consist of OBA flakes, and likely consist of OBB flakes. Since the majority of the expected flakes are consistently present at each KBS site, but OBA flakes and OBB flakes are consistently underrepresented at each KBS site, this explanation of testing raw material where cost is low is a logical conclusion and leads to a testable hypothesis (Hypothesis 3, defined in section *V.A.3.a*).

The second way that KBS hominins demonstrate forethought and lithic curation behavior concerns the way that they carried cores with available platforms across the landscape. FxJj 3, as has been noted, clearly lacks the number of cores necessary to have produced the excavated flake assemblage. Given the fauna associated at the site, it seems logical that hominins expediently came across this location while foraging but had the resources necessary to take advantage of the meat resources they encountered (whether this was the hippo found on site or other animals at the site). Following flake production (and presumably utilization), hominins discarded the exhausted cores rather than carrying them further across the landscape. Based on the size of the flake assemblage, it appears that they continued to carry cores with available platforms with them across the landscape, thus preserving further technological resources should they need them while foraging. If hominins were carrying cores that had been intensively flaked elsewhere with them across the landscape, then it is expected that there are sites on the paleolandscape where these cores were later exhausted and discarded. These sites may have more cores than the flake assemblage would suggest, and may well be located at or near the gravel bars where hominins could easily gain access to new cobbles for further flake production. Further, flake production at a site like FxJj 3 suggests that hammerstones were also being regularly transported across the landscape as a part of normal foraging behavior. Hammerstones would have been a valuable commodity due to their longevity, importance, and relative rarity.

V.A.3. Olduvai Gorge vs. Koobi Fora: what does this variation mean?

The research presented here is the first quantitative comparison of the Oldowan assemblages from Koobi Fora and Olduvai Gorge. Perhaps the most important conclusions to be drawn from this research, therefore, are the direct behavioral comparisons among Oldowan producing hominins from these separated paleolandscapes. Is the Oldowan one, homogeneous technology? Were hominins in different locations uniquely producing stone tools through time? Is stone tool variation due to behavior or is it a byproduct of raw material constraints? Is it possible to quantify technological cultural separation? The following sections discuss these questions, their answers, and the implications of these answers.

V.A.3.a. Differential production and transport behaviors

Is the Oldowan one, homogeneous technology? No, it is not. The Oldowan, as with all human technology, represents an adaptive response by hominins to manipulate their environments for their own benefit. Being the earliest evidence for a technological adaptation, the Oldowan has long been considered a “primitive” technology that only represents an expedient solution to environmental problems (see Bunn et al. 1980; Isaac 1981; discussion in Kimura 1999). However, this long held assumption that the Oldowan is "crude" and "simple," as well as one, homogeneous technology, is quantifiably inaccurate.

Oldowan producing hominins at Koobi Fora produced stone tools in a least effort manner, meaning that they used the simplest available platforms and did not have efficiency of flake production in mind while producing stone tools. Whether or not these hominins were capable of producing stone tools in a more efficient way is a question that cannot be answered conclusively at this point. The available evidence suggests that they *did not* produce flakes efficiently, but there is no way of determining if they *could* produce flakes in a more efficient manner at Koobi Fora.

The Oldowan from Olduvai Gorge is quantifiably different from the assemblages at Koobi Fora in that hominins at all Olduvai Gorge sites show the capacity to flake cores with more efficiency than the least effort approach predicts. Further, these Olduvai Gorge hominins show a greater ability to curate resources and economically assess how they will utilize them. Though the hominin populations responsible for the Oldowan lithic materials at Koobi Fora and Olduvai Gorge were penecontemporaneous, the hominins at Olduvai Gorge display a ranging behavior that is not as tethered to river and stream channels. This may be a response to how resources were distributed at Koobi Fora and Olduvai Gorge. At Koobi Fora, hominins were rather limited in the raw materials that were available to them. While small chert and phonolite cobbles were available in limited and unpredictable patches, basalt was available in large quantities. These basalts were transported from the more distant basin margins via the stream channels that the hominins relied on for tree cover and water, thus lithic production patterns are highly tethered to the location of water resources at Koobi Fora. At Olduvai

Gorge, basalts were also available in river and stream channel settings, fluvially transported from the highlands to the east and southeast. Olduvai Gorge hominins, though, had other raw material resources available to them at static locations: Naibor Soit quartzite, phonolite at Engelosin Hill to the north of Naibor Soit, and gneiss at the Kelogi inselberg that is located well to the south of paleolake Olduvai. During the Oldowan, hominins primarily exploited the quartzite resources at Naibor Soit and the basaltic resources in the river and stream channel settings. Though the basalt is still tethered to fresh water environments that would have provided a needed resource and tree cover to hominins, the presence of quartzite at all Oldowan sites at Olduvai Gorge demonstrates a broader ranging behavior. Further, transport of quartzite would have been dangerous given the conditions over this paleolandscape (see Blumenschine et al. 2008, 2009).

Unlike Koobi Fora, Olduvai Gorge hominins were clearly addressing their technology with forethought and economics in mind. Though quartzite is useful, it is costly to transport. Olduvai Gorge hominins understood this and produced flakes closer to the raw material source prior to transporting them across the landscape. By transporting smaller flakes (and some reduced cores) across the landscape, they retained the cutting edge that made the quartzite useful, but removed some of the transport costs associated with carrying heavier nodules of material across an already dangerous landscape. This pattern is evident across all Olduvai Gorge Oldowan sites and is not present at any Koobi Fora sites. Koobi Fora hominins did transport cores across the landscape, but for the most part, flake production was conducted on site, as the number of flakes and cores at FxJj 1 and FxJj 10 suggests.

Subsets of quartzite flakes at Olduvai Gorge sites all deviate morphologically from least effort expectations. These deviations demonstrate a reduction in the relative mass of the flake (in terms of reduced platform area, bulbar thickness, and/or technological thickness) while simultaneously increasing the relative effective edge of the flake (increasing length, width, and/or maximum dimension). Since producing flakes in a more efficient manner than expected would not necessarily be important when flakes were produced at the source of raw material (Naibor Soit), it follows that efficient flaking would increase as the distance to the raw material source increased. Economically, the higher the cost of replacing a raw material, the more likely one is to conserve that raw material (for a complete discussion of distance-decay models, see Blumenschine et al. 2008). It is hypothesized, therefore, that flakes exhibiting morphologies outside of least effort expectations were produced from cores on-site, as opposed to at the raw material source. This hypothesis is testable in that it predicts that refits of flakes to cores will occur between specific archaeological flakes and the cores excavated from the same site.

Transport of quartzite flakes is also evident in the distribution of production behaviors at each Olduvai Gorge site. Quartzite flakes are dominated (70-100% of the total quartzite flake assemblage) by flakes belonging to the "Oldowan Behavior C" category. Based on the experience of the author in the production of a large sample of quartzite flakes, it was noted that flakes without cortical edges are less friable than more cortical edges of flakes. Since experimental studies have demonstrated that quartzite flakes are the most useful Olduvai Gorge raw material for butchery tasks such as skinning and defleshing (Tactikos 2005:125-127), it would make sense that hominins would prefer flakes less apt to break during utilization. The vast predominance of quartzite OBC flakes at *all* Olduvai Gorge Oldowan sites suggests that hominins had a distinct preference for OBC flakes and very selectively chose and transported these flakes following their production.

Subsets of basalt flakes at Olduvai Gorge also show a trend toward efficient production, but to a lesser degree. This is expected given an economic theory for Oldowan flake production patterns because basalt is more readily available than quartzite at all Oldowan sites at Olduvai Gorge. However, as opposed to quartzite flakes, basalt cores were regularly transported around the landscape.

Both Koobi Fora and Olduvai Gorge hominins show the ability to curate cobbles of quality raw material. Basalts at Koobi Fora and Olduvai Gorge have a higher incidence of inclusions than quartzite, making them potentially poor candidates for flake production (Figure 4.8). To avoid the costly transport of heavy stone across a dangerous landscape, both Koobi Fora and Olduvai Gorge hominins likely struck OBA and OBB flakes from cores at their source (river and stream channels) to assess the quality of the core before the costly task of transporting it away. This is evident in the pattern of fewer OBA and OBB basalt flakes than expected given a least effort approach. At Olduvai Gorge, archaeological evidence, along with the lack of OBB flakes also suggests that hominins may have preferred non-cortical platforms to cortical platforms placed above a flake scar (which would result in flakes with OBB morphology). While the resulting flakes still morphologically fall under the umbrella of least effort flakes, the process and identification of platforms is actually deviating from these least effort approach expectations in Olduvai Gorge basalt cobble reduction. Thus the lack of OBA flakes is likely due to testing raw material at the source and the lack of OBB flakes is likely a combined effect of testing raw material and an apparent preference for non-cortical platforms.

For both Koobi Fora and Olduvai Gorge, flake production at the raw material source is potentially a testable hypothesis (whether in stream channels for basalts or at Naibor Soit for quartzite):

> **Hypothesis 3:** At both Koobi Fora and Olduvai Gorge, Oldowan sites excavated in fluvial settings *that naturally contain basalt cobbles* will contain primarily OBA and OBB flakes.

It is hypothesized that OBA and OBB flakes were produced and left behind at each respective raw material source. For basalts in stream channels, it is expected that fluvially disturbed sites from Upper Bed I and Lower Bed II times would possess a predominance of OBA and OBB flakes. Of course, such a hypothesis is notoriously difficult to test given how disturbed fluvial sites are and the corresponding lack of *in situ* materials to correlate such behavior patterns, but the prediction still stands that such sites exist. For quartzite flakes from Naibor Soit, it is hypothesized that flake production sites exist in deposits that were exposed during Upper Bed I and Lower Bed II times. These sites would contain mainly OBA and OBB flakes, and potentially some OBD flakes as well, but would lack the number of OBC flakes expected given a least effort approach to production. Further, these OBA, OBB, and OBD flakes would all fall within morphological expectations for a least effort manufacturing approach given that they were produced at the raw material source and thus economic factors were not a primary issue during production.

The BLA methods applied to Olduvai Gorge and Koobi Fora have begun to illustrate an economic model for raw material utilization in the Oldowan. Even in the Oldowan, hominins were cognizant of procurement and transport costs. In the case of Olduvai Gorge, these hominins were technologically capable of consistently altering their production behaviors to make more efficient use of raw materials than a least effort model of lithic production predicts. In the case of Koobi Fora, hominins demonstrate cobble transport, the ability to test for raw material quality, and economically flaking basalt cobbles to an exhausted state, but they do no demonstrate the ability to flake a cobble with an intentional efficiency.

Finally, it is important to note that the clarity of the conclusions demonstrated in this research for Olduvai Gorge is due primarily to the success of the landscape approach to archaeological inquiry undertaken there by Blumenschine and colleagues. Only through a thorough understanding of paleoenvironmental context, potential raw material transport patterns and costs, and large samples taken over a broad area, do clear patterns of hominin behaviors begin to emerge. Though the conclusions at Koobi Fora are just as interesting, the lack of a thorough landscape archaeological project limits the information regarding potential foraging behaviors, costs of ranging over a variable landscape, specific costs of raw material procurement, and other paleoenvironmental indicators. Future paleoecological and archaeological research at Koobi Fora that focuses on landscape archaeology within the KBS Member will significantly clarify the conclusions of this study.

In conclusion, Oldowan producing hominins show that stone tool production, while similar, began to deviate in these two locations. This research clearly demonstrates that the variability in Oldowan flake and core shape is not simply a byproduct of raw material constraints; rather, by utilizing identical units (Oldowan production behaviors) to statistically compare lithic assemblages, the similarities and dissimilarities of these sites are compared in objective and empirically-derived ways.

V.A.3.b. Technology as a marker for cultural variation

If the Oldowan was produced in distinctly different ways at Olduvai Gorge and Koobi Fora, and these differences are independent of raw material constraints, can this difference be defined in terms of "cultural variation?" Yes, this research argues that these conclusions demonstrate the beginning of technological cultural separation in the Oldowan.

The term "culture" can be defined in myriad ways (Williams 1983; Clifford and Marcus 1986; for a comprehensive review, see Sewell 1999). Sewell (1999) contrasts the idea of a singular, theoretical "culture" that represents an abstract form of social life and is associated with particular methods of analysis and academic discourse, to a more concrete application of the term "culture," which refers to specific sets of human behaviors in particular groups of people (for instance, Samoan culture or middle-class American culture). Similarly, the methods by which culture has been studied have shifted from understanding culture as a system of learned behaviors, to culture as a system of making meaning, to culture as a practice of individual and collective agency. More recent methodological approaches to culture treat it as "performative" in that individuals act out their perception of culture in different settings; people “practice” culture. While these discussions of the nuances of culture are of particular necessity for living human populations, it is necessary to think about how these definitions of culture might be manipulated to apply to past human populations. More specifically, it is important to theorize about how culture evolved in humans and what the earliest forms of cultural variation might look like.

Ethnologists have long acknowledged that technology is of particular importance when describing a culture. Lemonnier (1986:147) even suggested that an "…anthropology of technology is…taking shape, which considers techniques in and of themselves, and not solely their material effects or only the circumstances and social consequences of their application" as being pertinent to defining cultural activity. For this discussion, technology is of particular importance because it is what preserves in the geological record. As much as anthropologists would relish the opportunity to study aspects of the human evolutionary past that record thoughts, feelings, perspectives, and other metaphysical elements, the unfortunate reality is that the material past is all that preserves. This does not mean, however, that archaeological artifacts are inert, static, and culturally uninformative. Rather, a careful analysis of the human past brings dramatic realizations of how human life functioned and how humans interacted both within and between groups, though conclusions based on archaeological materials must be viewed only through a limited (and well defined) cultural lens. Further, the practice of experimental archaeology (see the introduction of section *V.B.* for a full discussion of experimental archaeology) links the present with the past in a dynamic way and even bridges the gap between archaeology and cultural anthropology by focusing on topics dealing with the anthropology of the body (Mascia-Lees 2011) and the physical production of material culture.

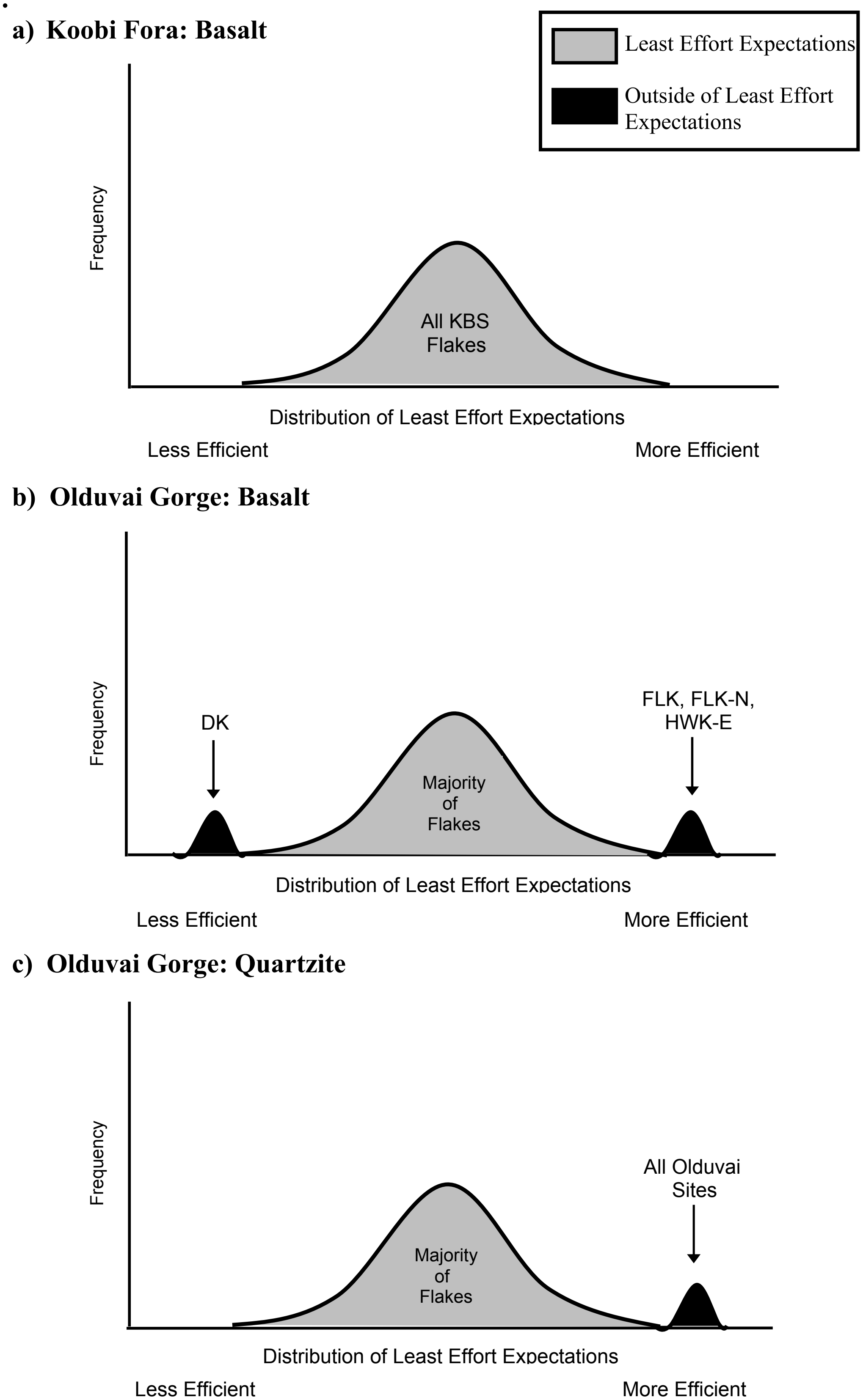
Modern analysis of chimpanzees (Whiten et al. 1999, 2005; Whiten 2005; Perry 2006; Lycett et al. 2007) has begun to suggest distinct "cultural" variation between chimpanzee populations. This variability can be defined in terms of the ways in which chimpanzee populations differentially manipulate their environments to their benefit (see Table 1 in Whiten et al. 1999:683). Further, Perry (2006:183) suggests that traditions and social norms can arise due to the compounding effects that external variables such as demographics, distributions of resources, and factors affecting safety, have on the psychological attributes of the populations with these external factors. In turn, these psychological attributes, such as attitudes toward the environment and other members of the social group, affect the formation of consistent behavioral patterns like traditions and other social norms. For social animals, like chimpanzees, orangutans, and humans (including our hominin ancestors), the ways in which they interact with their environments, and in turn the other social members of their groups, may well have a direct effect on the ways in which they manipulate their environments, and this manipulation, in turn, may preserve in the archaeological record. The earliest demonstrable manipulation of the environment for clear adaptive benefit is the usage of stone tools in the Oldowan.

With an understanding of what culture is and of the potential factors that contribute to the origin of traditions and social norms in the form of consistent behavioral patters, it is relevant to revisit Figure 2.7 (in Chapter 2) in light of the results in Chapter 4. In Figure 2.7, it was predicted that the variation of stone tool morphologies in the

Oldowan would be broad and thus more difficult to classify implements behaviorally than later periods of stone tool production. This figure is recreated in Figure 5.2 to idealize the results presented in Chapter 4 and discussed throughout this chapter. Figure 5.2a demonstrates that for KBS basalt flake production, the prediction of Figure 2.7a is accurate in that the morphologies of all KBS archaeological flakes form one, broad continuum of variation that demonstrates a least effort production strategy. Figure 5.2b demonstrates that for Olduvai Gorge basalt flake assemblages, while the majority of basalt flakes form a continuum of least effort morphologies, hominins had the ability to create subsets of flakes that were less efficient when basalt raw materials did not incur a cost to procure (the bump in frequency on the left of Figure 5.2b) and the ability to create subsets of flakes that were more efficient when basalt raw materials incurred more of significant cost (the bump in frequency on the right of Figure 5.2b). Figure 5.2c demonstrates that for Olduvai Gorge quartzite flake assemblages, while the majority of quartz flakes form a continuum of least effort morphologies, hominins had the consistent ability to create subsets of flakes that were more efficient than expected (the bump in frequency on the right of Figure 5.2c).

If social norms and the social transmission of such norms arise out of resource distribution and the psychological mechanisms that cope with such distributions, this research suggests that the earliest differential adaptation to such resources is visible in the comparison of stone tool procurement, transport, and production behaviors at Olduvai Gorge versus those at Koobi Fora. Hominins at Olduvai Gorge *consistently* demonstrate a pattern of raw material resource management in the form of economic efficiency in the use of raw material resources. While it can be argued that least effort

Figure 5.2:


a) Koobi Fora: Basalt
Least Effort Expectations
Outside of Least Effort Expectations
Frequency
All KBS Flakes
Distribution of Least Effort Expectations
Less Efficient
More Efficient
b) Olduvai Gorge: Basalt
Frequency
DK
FLK, FLK-N, HWK-E
Majority of Flakes
Distribution of Least Effort Expectations
Less Efficient
More Efficient
c) Olduvai Gorge: Quartzite
Frequency
All Olduvai Sites
Majority of Flakes
Distribution of Least Effort Expectations
Less Efficient
More Efficient

production of flakes does not necessarily require a cultural component other than copying rough behaviors, the maintenance of a system of production that is more efficient than a least effort approach demonstrates a consistency in production strategy and thus a distinct transmission of cultural information. If flakes are being produced in a particular way over time, whether that consists of efficient usage of raw material or preferences for non-cortical platforms, there is evidence that these production skills and/or preferences represent a unique technological cultural component.

It should be noted that this interpretation of cultural variation in the Oldowan is only concerned with "technological culture." As has been mentioned, only material culture can be used to infer cultural origins because this is all that preserves. Stone preserves particularly well and thus provides the most robust measure of variability in the archaeological record. The interpretation of cultural variation presented here is also presented independent of any assumptions of stone tool functionality. For BLA methodology, the measure of similarity is made exclusively in terms of flake production; no measure of flake utility or usage is made for classification or broad behavioral inferences.

V.A.3.c. Explaining cultural variation in the Oldowan

In Chapter 1, section D, the theoretical and practical concepts of Darwinian Archaeology was discussed. It will be remembered that arguments for applying aspects of the Darwinian selective process to material culture, and particularly technology, is justifiable because "products of technology are not simply adaptive reflections but rather active components of the adaptive process" (O'Brien and Lyman 2003a:99). However, even if material culture is not necessarily an "active component," but rather a stylistic variable, Darwinian methods still may apply (O'Brien and Lyman 2000; Brantingham 2007).

The results presented in this research demonstrate that in the Oldowan, technology was clearly an active component in the adaptive process. Further, the results presented here show that this adaptive role of Oldowan stone tools can be considered separately from the functional aspects so often attributed to stone tools. The transport patterns of flakes and cores at both Koobi Fora and Olduvai Gorge suggest there were costs to procurement and that hominins were economically aware of these costs. At Olduvai Gorge, this awareness of procurement and transport costs is particularly apparent for quartzite resources. The distance to procure these resources and the dangers associated with their procurement and transport led to a highly curated use of this raw material. Using only evidence of production behaviors present on site and the efficiency of those production behaviors, it can clearly be argued that production of quartzite flakes had an adaptive role; the more trips across dangerous landscapes to procure this raw material, the higher the likelihood of death via predation, or at a minimum, the more energy spent on the transport of materials. If raw materials could be gathered with more efficiency, both the cost of transport would go down and the frequency of procurement would go down. The high levels of OBC quartzite flakes, the consistent efficiency of quartzite flake production, and the small number of quartzite cores at each site indicates that hominins were aware of these costs and were actively trying to minimize them.

Similar arguments apply to the patterns of raw material testing, core transport, and core utilization for Koobi Fora and Olduvai Gorge basalts.

Though this research is not directly concerned with the functionality of the stone tools in question, it is hypothesized that if the adaptive role of stone tools was as high as is hypothesized, the adaptive (and perhaps caloric) return for these costs was even higher. To make stone tool procurement, transport, and production evolutionarily worthwhile, the stone tools must have provided access to resources that increased the safety, diet, caloric intake, or a combination of these to such an extent that they compensated for the costs associated with stone tool production.

The fact that flakes of basalt and quartzite at Olduvai Gorge were produced, in part, more efficiently than least effort manufacture predicts, suggests some fidelity in the ways that technological production behaviors were transmitted between individuals over time. To revisit the hypothetical arguments posited in section *I.D.*, Shott (2005:34) states that "any evolutionary account of transmission must be built around…models of the mechanisms that introduce variants into a population" (Shott 2005:34). Results from the research presented here provide such an explanatory device for the introduction of variation at Olduvai Gorge but not at Koobi Fora:

> **Hypothesis 4:** Exposure to raw materials of differential procurement costs is a prerequisite to differential flake production.

This hypothesis predicts that as new raw materials are encountered (perhaps through increased home ranges for hominins through time or through changing landscapes) by hominins, the differential procurement and transport costs of those raw materials, as well as the differential properties of the raw materials themselves, will contribute to the divergence of production behaviors. Under this hypothesis, hominins at Olduvai Gorge began early technological divergence from a least effort approach, and therefore technologically diverged from their Koobi Fora hominin counterparts, due largely to the fact that their landscape contained multiple raw materials, each with different properties, potential utility, and procurement and transport costs. At Koobi Fora, on the other hand, hominins were tethered to water resources and had only basalt cobbles as their primary means of stone tool manufacture.

Braun and Harris (2009:28) correctly suggest that "selective pressures acting on stone tool mediated resource acquisition should be directly reflected in attempts by Oldowan hominins to increase the efficiency of their technological organization." However, increases in efficiency are not necessarily as simple as Braun and Harris (2009) suggest. Flaking a core "more extensively" (Braun and Harris 2009:28) requires the potential forethought of platform production and maintenance so that the core does not quickly become exhausted of viable platforms via a least effort production strategy. Consistent deviation from least effort production strategies, in turn, suggests an in depth understanding of fracture mechanics, the potential for cultural transmission, and cognitive elements such as increased hand-eye coordination. Such adaptations toward efficient stone tool production are anything but simple and cannot be measured entirely by the level of exhaustion that cores demonstrate.

As the Developed Oldowan and the Acheulian begin to emerge with *Homo erectus*, there is a simultaneous expansion of home range and a change in the raw materials encountered. At Koobi Fora, hominins ranging farther toward the basin margin (into the Karari escarpment and beyond) encountered more basalt, but this time encountered large boulders of basalt from which they could extract larger flakes. Encountering this new resource led to the quintessential "Karari Industry" core form, the Karari Scraper, and also a departure from least effort reduction. Further, encountering this new resource led to the transmission of Karari Scraper production strategies. At Olduvai Gorge, hominins producing the Developed Oldowan encountered chert nodules at MNK for the first time as the lake level dropped (Kimura 1997, 1999). Preference for this raw material quickly increased among hominins and, as Hypothesis 4 predicts, likely produced new adaptive strategies for technological production. Similarly, early Acheulian hominins at Olduvai Gorge, with an increasing home range, encountered and took advantage of phonolite resources from the distant source at Engelosin Hill. The phonolite eroding from this tabular exposure produced nodules with natural morphology conducive to Acheulian biface production.

In conclusion, this research demonstrates that there is variation between the production patterns of stone tools at Koobi Fora and Olduvai Gorge. This variation is hypothesized to be largely due to the differential procurement and transport costs (including predator-prey risks) of the available raw materials, *but not* due to the fracture qualities of those raw materials. If further divergence of behaviors can be quantitatively measured for the Developed Oldowan at Koobi Fora and Olduvai Gorge, then it can be cogently argued that both temporal and geographic variation are present. Under dual-inheritance theory (Boyd and Richerson 1985), such consistent temporal and geographic variation suggests that social and cultural influence within populations is present and that learned and shared behaviors are adapted for local use. This conclusion is similar to the guided variation concept outlined by Boyd and Richerson (1985).

V.B. Implications of BLA for methodology in archaeology

Archaeological analyses notoriously suffer from broad behavioral inferences that necessarily have to be made (Dunnell 1971; Binford 1972; Aldenderfer 1987a, 1987b; Blumenchine and Peters 1998). Sample size cannot be controlled for because the assemblage is only what has been excavated. Assemblage completeness cannot usually be empirically assessed because inference of behaviors must stem from what is collected, not what *might* be collected. This is a primary reason that archaeological results are constantly reformed, updated, and changed; as excavated materials increase sample sizes and assemblage completeness, the behavioral analysis evolves.

The experimental model, results, and implications that were described in the previous chapters establish a foundation for the lithic production behaviors of Oldowan hominins. By producing assemblages of flakes on indigenous East African raw materials, each with empirically known and recorded sets of behaviors, the largest empirically complete assemblage of Oldowan flakes ever undertaken was created. Without some such empirical model for what morphological differences might be expected within the Oldowan, assemblage comparison is not grounded on any quantitative measure. In other words, prior to this research, if flakes appeared to look different at Koobi Fora as compared to Olduvai Gorge, one researcher might attribute these differences to behavioral differences, while another research might have attributed these differences to differential raw material constraints, and another would suggest functional differences;

none of these researchers would have empirically derived reasons for their conclusions. The model established via the BLA methodology removes these qualitative conclusions and replaces them with statistically effective measures for lithic production behaviors.

Of course, models necessarily make assumptions (Dunnell 1971; Binford 1972; Aldenderfer 1987a, 1987b), but the trade for these assumptions is a statistical foundation, a set of empirically determined expectations, and ideal conditions. Most importantly, the model provides the parameters by which null hypotheses can be tested. The assumptions of BLA lie primarily in the production of Oldowan stone tools. The rhetorical question so often applied to all paleoanthropological studies equally applies here: can modern humans ever accurately model what early hominins were doing? In the same way that measuring hominin ranging behavior by studying modern *Homo sapiens* hunter-gatherer populations may prove a false analogy, so too might modern stone tool manufacture inaccurately model true Oldowan production skills.

This criticism, while theoretically justified, is also nihilistic with regard to paleoanthropological research. If the goal of paleoanthropology is to assess and reconstruct the *behaviors* of Paleolithic populations, as the derivation of the name "paleoanthropology" suggests, then it is the job of the paleoanthropologist to consider all potential avenues to determine these behaviors. Experimental archaeology has proven an effective archaeological research method for a broad array of archaeological scenarios through time and space (for instance, Crabtree 1970, 1972; Callahan 1979; Toth 1982, 1985, 1987; Austin 1986; Amick et al. 1988; Ahler 1989; Hayden and Hutchings 1989; Jones 1994; Kuijt et al. 1995; Pelcin 1997a, 1997b; Bradbury and Carr 1999; Kyara 1999; Tactikos 2005; Braun et al. 2008; Eren et al. 2008; Iovita 2009; Diez-Martin et al. 2011).

By understanding and controlling all variables going into the production of a particular archaeological setting, archaeology begins to resemble a laboratory rather than an excavation grab bag of sorts. This research strongly supports experimental programs to establish models from which archaeological null hypotheses can be directly tested. Such hypotheses for this research, as well as improvements to the BLA experimental model are discussed in the following section.

V.B.1. Quantitative behavioral site comparisons

Some previous research has suggested that the Oldowan is not as homogeneous as was previously assumed. The most substantial of these papers concern the stone tool production skills of hominins at Lokalalei, West Turkana (Delagnes and Roche 2005) and of the technological variability in the Oldowan based on the early stone tools recovered from Gona, Ethiopia (Stout et al. 2010). While these studies are well-conceived and well-documented, they miss one significant point: if one makes the claim that the Oldowan "varies," one must also be able to demonstrate *what it varies from*. In other words, what is quantitative expectation of what the Oldowan *should* look like? If this expectation is not known, then there is no foundation from which to make the claim that the Oldowan "varies" in its technological form.

The BLA methodology defined by this dissertation and applied to the Oldowan archaeological localities of Koobi Fora and Olduvai Gorge provides a tool to quantitatively assess differential production behaviors in the Oldowan and thus provides such an expectation for variability within the Oldowan. Perhaps most importantly, this quantitative tool allows individual flakes and entire sites to be directly compared with other flakes and sites in equivalent behavioral units. This methodology breaks from the archaeological traditional of using typologies and basic assemblage characteristics to superficially assess similarities and differences between sites. Instead, BLA methodology assumes the null hypothesis that all stone tools were made using the same method and then identifies specific flakes and assemblage-level patterns that deviate from the null hypothesis.

In developing the BLA methodology, it is the hope of the author that these methods will be applied to assemblages more broadly so that vastly different assemblages might be directly compared. Such assemblage comparison can be used to explain how technology develops at one locality through time: how do production behaviors vary between the Oldowan and Developed Oldowan at Olduvai Gorge? How do "Oldowan" assemblages from different parts of the world deviate from each other in terms of production behaviors (for example, compared to Chauhan 2009; de Lumley et al. 2009; Fajardo 2009; Kuman and Field 2009; Sahnouni and van der Made 2009)? Do these production behaviors directly precede those utilized in the Acheulian at Olduvai Gorge, or does *Homo erectus* begin an entirely new process? The BLA methodology can also compare sites utilizing seemingly similar technological strategies over broad geographic space: how does production of Acheulian bifaces at Olduvai Gorge differ from those at Koobi Fora? How does biface production differ in East Africa versus South Africa? Sub-Saharan Africa versus North Africa? Africa versus the Middle East? Europe? South Asia? This methodology could address any combination of production strategy relationships through time and/or space. Such analyses would provide a sister-strategy to addressing cladistic change in biface core shape (Lycett and Gowlett 2008), for instance, by focusing on flake characteristics and core reduction rather than the shape of the discarded core.

Quantitative site comparison in terms of production behaviors is an exciting avenue to statistically assess how technology changed over time and the potential relationships between technological groups of humans. Though the null hypotheses for production strategies necessarily increase in complexity as the technology increases in complexity, the BLA strategy can theoretically be applied to all technological forms in which there are whole (and potentially even split or snapped) flakes.

V.B.2. Importance of the Oldowan as a foundation

In order to assess other technologies, time periods, and locations, the BLA methodology needed to be experimentally and statistically grounded. As section *II.B.4.a.* preliminarily outlined, without an understanding of the earliest technological production strategies, there would be no foundation from which to define other technologies in terms of concrete changes to the technological strategy. Now that the BLA method has been demonstrated as effective and has shown that even in the Oldowan there is deviation from the simple, least effort strategy traditionally imposed on the Oldowan, more complex production strategies can be defined, experimentally defined, and measured in terms of change against this Oldowan foundation.

There are two logical places to begin this expansion of the BLA approach. First, the Developed Oldowan at Koobi Fora and Olduvai Gorge can be experimentally assessed, defined, and then compared directly to the production behaviors and variation in the Oldowan assemblages analyzed in this research. This research provides an in-road to quantitatively explaining the changes that led to the rise of the Acheulian and the spread of the Acheulian around the world. Second, the Oldowan at Koobi Fora and Olduvai Gorge can be compared directly to other Oldowan assemblages, particularly the Gona, Ethiopia assemblages, the Lokalalei assemblages from west Lake Turkana, and the Kanjera, Kenya assemblages. The large number of refits at Lokalalei provides an unusually clear avenue for an experimental approach to their reproduction and also a different raw material to catalog using BLA methods.

A more complex expansion of the BLA approach would be to apply it to a complex Neolithic technology or Native American technology. By assessing the methodological ability of BLA to document and statistically explain the many complex behaviors utilized to create such stone tools (i.e. platform preparation, multiple stage thinning, soft-hammer flake production), it might be demonstrated that BLA is sensitive and effective enough to define both the simplest and the most complex technologies. If this was accomplished, the method could potentially link the methods used to study recent archaeological assemblages with the methods used to study the most ancient archaeological assemblages. This would be useful in promoting archaeologists "speaking" the same methodological language.

V.B.3. Methodological considerations

As the introduction to this subsection (*V.B.*) suggests, no model is perfect. Rather, a model provides a foundation from which to measure deviation and a laboratory sample from which to measure expected variation. This being said, there are several avenues that the author intends to take to strengthen this study and the methods used for BLA as a whole.

First, the experimental sample included in this analysis was produced by the author only. While the extensive sample size accounts for significant variation and, the author believes, is rather diagnostic of Oldowan technology as a whole, the sample would be strengthened by having other experienced flintknappers contribute experimental assemblages using identical experimental techniques. By assessing whether additional variation is added via "interobserver production," the sample and statistics would become more robust and reliable.

Second, the study can be criticized due to the extensive experience of the author as a stone tool producer. The fact that the author has the capacity to produce stone tools of much higher technological ability than Oldowan stone tools could influence the morphology of the resulting Oldowan experimental flakes. The results demonstrate that this criticism is not valid. Even though the skill of the author is greater than that of Oldowan producing hominins, the results of this study clearly demonstrate that Oldowan producing hominins at Olduvai Gorge were producing flakes in a *more efficient way than the author*. Thus, even if it was argued that modern human hand-eye coordination is better than early hominins, or that the strength of modern humans is greater, the data demonstrate that Oldowan producing hominins could produce flakes more efficiently than a modern human understanding of "least effort production skills."

Third, interobserver error margins should be placed on the measurements defined in this research. While several undergraduate students participated in this study and began the process of measuring lithic implements, the sample sizes were not large enough to make a meaningful comparison. Further, to make a fair comparison, professional lithic analysts should be used to assess interobserver error. Unfortunately, the time parameters and funding of this dissertation did not allow for the coordination of such efforts. Interobserver error margins will likely be established within the next year and these results will be included in future publications of this data.

Lastly, as this methodology stands, only whole flakes were measured in archaeological assemblages. Such limitations could, potentially, skew results toward a lower number of flakes than were actually produced on-site. However, even experimental assemblages demonstrate how many detached pieces simply cannot be measured (total sample size for detached pieces is N=3651; total sample size of measurable detached pieces is N=2828. This means that 22.5% of the total sample size is not measurable). Thus the *debitage* collected from each experimental sample may be comparable to that produced by hominins, and since all *debitage* was collected, labeled, and stored, this is certainly a testable hypothesis. Future adaptations of the BLA methodology will include systematic study of how partial flakes (split, snapped, and otherwise broken) can be included for statistically bounded behavioral classification.

Chapter VI: Conclusion

The research presented in the previous chapters develops a methodology called Behavioral Lithic Analysis (BLA) and applies it to archaeological assemblages. The purpose of BLA is to bypass the analytical problems of typologically assessing archaeological lithic assemblages and replace it with an objective and quantitative method that defines flake assemblages in terms of the specific behaviors utilized to produce them. The BLA method relies on controlled experimental research that utilizes native raw materials to establish a statistically founded model for the expected variability of a given technology. To establish expectations for variability, large sample sizes are necessarily required.

The Oldowan technology of East Africa is used to test the applicability of and provide a foundation for the BLA methodology. All Oldowan whole flakes from the archaeological localities of Koobi Fora and Olduvai Gorge were measured using specific, behaviorally relevant measurements. These same measurements were taken on a large experimentally produced sample of Oldowan flakes, made on basalt from Koobi Fora, basalt from Olduvai Gorge, and quartzite from Olduvai Gorge. These replicated flakes were produced under controlled circumstances and utilized a “least effort approach” to flake production, as is normally assumed of the Oldowan. Thus the null hypothesis of whether flakes were made under least effort assumptions (the simplest platform at a given time was utilized) was tested.

Results demonstrate several important factors about the BLA methodology and variation in Oldowan stone tool technology. First, the BLA methodology produces a robust classification system that allows for behavioral classification of flakes into particular, experimentally established categories and places a misclassification statistic on each classification. The classification of individual flakes and entire assemblages, therefore, allow for archaeological assemblages to be statistically compared in terms of the production behaviors utilized to create them. Further, the null hypothesis of production techniques used to produce a technology can be tested. Second, the application of Oldowan archaeological assemblages to this process demonstrates that while the null hypothesis that a least effort manufacturing strategy was employed at Koobi Fora cannot be rejected, this null hypothesis can be rejected for subsets of quartzite and basalt flakes at Olduvai Gorge. This has significant implications for the potential transmission of production information between hominins and can be interpreted in terms of the origins of material culture, when combined with data relevant to how Oldowan producing hominins interacted with resources on their landscapes.

Data attained through the BLA methodology also lends itself to determining important reconstructions of hominin procurement and transport strategies. The results demonstrate that all Oldowan producing hominins in these localities possessed a firm understanding of economic factors related to the procurement and transport costs of the raw materials at their disposal. At Koobi Fora, hominins tested raw material prior to transport and transported cores to and from sites, usually discarding cores only when exhausted. However, because Koobi Fora hominins appear to be tethered to water resources, the procurement costs of basalt cobbles appear to be low relative to Olduvai Gorge and did not lead to the rise of efficiency in flake production. However, unlike Olduvai Gorge, locations for raw material procurement were not static over time at Koobi Fora. Changing fluvial settings and changing intensity of current flow would have differentially transported basalt cobbles of different sizes at different times to different places. It has thus been difficult to specifically reconstruct the distances of KBS sites to raw material procurement areas. Based on the evidence of this study, it appears that costs were high enough at Koobi Fora to warrant 1) testing cobbles for quality at the site where they were procured prior to transport and 2) flaking to exhaustion following transport. Costs at Koobi Fora were not high enough, however, to effect a change in how Oldowan producing hominins there produced stone tools. At Koobi Fora, there is no deviation from least effort assumptions, as established by the BLA model in this study.

At Olduvai Gorge, hominins demonstrate a more comprehensive understanding of raw material economics and of efficiency in flake production, as established by the BLA model of this study. It is hypothesized that this comprehensive understanding is an effect of the differential access they had to raw materials on the landscape. Transport of quartzite across the landscape had significant costs associated with it in terms of energy and safety, and thus there was an adaptive advantage to hominins making efficient use of their raw materials. Basalt also had costs associated with them, but more on the level of the costs that Koobi Fora hominins encountered when procuring basalt. It seems that the ability to efficiently produce stone tools was applied, therefore, not only to the high-cost quartzite, but also to the lower cost basalt. This is in stark contrast to the manner in which Koobi Fora hominins consistently produced flakes that directly mirror least effort predictions.

The differences seen in the production of flakes at Koobi Fora versus Olduvai Gorge are independent of raw material constraints; rather they are dependent on raw material costs and the technological mechanisms that hominins utilized to cope with these costs. At Olduvai Gorge there is a consistent trend toward more efficient flake manufacture and this implies an adaptive trend and the transmission of such skills between individuals. It is argued, therefore, that the trend toward efficiency at Olduvai Gorge and the lack of such a trend at Koobi Fora is the earliest quantifiable evidence for cultural variation in the hominin lineage. This definition of culture is tied only to technology, but the inferred economic understanding of hominins and the social implications for such control of ranging behavior and maintenance of ranging behavior costs, is suggestive of the broader trend toward the formation of traditions and learned behaviors.

The application of BLA to a broader set of technologies has the potential to explain how production behaviors changed from one technology to another, over space and through time. Now that an objective, statistically bound model has been established for Oldowan technology, these Oldowan assemblages become directly comparable to any other lithic assemblage to which BLA methodology is applied. It is now possible to directly compare archaeological sites in equivalent units that are independent of raw material constraints.

Further, future studies that apply BLA methods can help to explain the evolutionary pattern and subsequent maintenance of technologies such as the production of Acheulian bifaces. Such studies can then address questions seeking to explain whether or not these bifaces actually represent a singular technology or whether they represent multiple, distinct technological processes, or whether the Acheulian has affinities with Oldowan production patterns at all. The quantitative foundation of Oldowan variability established by this research begins such evolutionary discussions of technology. For instance, later technologies such as the Developed Oldowan and the Acheulian can now be discussed *in terms of* specific Oldowan variation in production behaviors and aspects of procurement and transport behaviors.

References:

Ahler, S.A. (1989a). Mass analysis of flaking debris: studying the forest rather than the tree. In *Alternative Approaches to Lithic Analysis*, Eds: D.O. Henry and G.H. Odell, 85-118.

Ahler, S.A. (1989b). Experimental knapping with KRF and midcontinental cherts: overview and applications. *In*: (Eds: D. Amick and R. Mauldin) Experiments in Lithic Technology. BAR International Series 528, 199-234.

Aiello, L.C. (1992). Allometry and the analysis of size and shape in human evolution. *Journal of Human Evolution* 22, 127-147.

Albert, R.M. and Bamford, M.K. (2012). Vegetation during UMBI and deposition of Tuff IF at Olduvai Gorge, Tanzania (ca. 1.8 Ma) based on phytoliths and plant remains. *Journal of Human Evolution* 63, 342-350.

Aldenderfer, M.S. (1987a). On the structure of archaeological data. *In:* (Ed: M.S. Aldenderfer) Quantitative Research in Archaeology. Sage Publications, Newbury Park, CA, 89-113.

Aldenderfer, M.S. (1987b). Assessing the impact of quantitative thinking on archaeological research: historical and evolutionary insights. *In:* (Ed: M.S. Aldenderfer) Quantitative Research in Archaeology. Sage Publications, Newbury Park, CA, 9-29.

Amick, D.S., Mauldin, R.P. and Tomka, S.A. (1988). An evaluation of debitage produced by bifacial core reduction of a Georgetown Chert nodule. *Lithic Technology* 17, 26-36.

Amick, D.S. and Mauldin, R.P. (1989). Comments on Sullivan and Rozen's "Debitage Analysis and Archaeological Interpretation". *American Antiquity* 54, 166-168.

Andersson, M. (1994). Sexual Selection. Princeton University Press, Princeton.

Andrefsky, W. (1998). Lithics. Cambridge University Press, Cambridge.

Asfaw, B., Beyene, Y., Suwa, G., Walter, R.C., White, T.D., WoldeGabriel, G., and Yemane, T. (1992). The earliest Acheulean from Konso-Gardula. *Nature* 360, 732-735.

Ashley, G.M., Barboni, D., Dominguez-Rodrigo, M., Bunn, H.T., Mabulla, A.Z.P., Diez-Martin, F., Barba, R., and Baquedano, E. (2010). Paleoenvironmental and paleoecological reconstruction of a freshwater oasis in savannah grassland at FLK North, Olduvai Gorge, Tanzania. *Quaternary Research* 74, 333-343.

Austin, R.J. (1986). The experimental reproduction and archaeological occurrence of bifaces notching flakes. *Lithic Technology* 15, 96-100.

Bamford, M.K. (2012). Fossil sedges, macroplants, and roots from Olduvai Gorge, Tanzania. *Journal of Human Evolution* 63, 351–363

Bamford, M.K., Stanistree, I.G., Stollhofen, H. and Albert, R.M. (2008). Late Pliocene grassland from Olduvai Gorge, Tanzania. *Palaeogeography, Palaeoclimatology, Palaeoecology* 257, 280-293.

Bamforth, D.B. (2002). Evidence and metaphor in evolutionary archaeology. *American Antiquity* 67, 435-452.

Barboni, D., Ashley, G.M., Dominguez-Rodrigo, M., Bunn, H.T., Mabulla, A.Z.P. and Baquedano, E. (2010). Phytoliths infer locally dense and heterogeneous paleovegetation at FLK North and surrounding localities during upper Bed I time, Olduvai Gorge, Tanzania. *Quaternary Research* 74, 344-354.

Barsky, D. (2009). An overview of some African and Eurasian Oldowan sites: evaluation of hominin cognition levels, technological advancement and adaptive skills. *In*: (Eds: E. Hovers and D.R. Braun) Interdisciplinary Approaches to the Oldowan. Springer, Dordrecht, The Netherlands, 39-47.

Behrensmeyer, A.K., Potts, R., Plummer, T., Tauxe, L., Opdyke, N. and Jorstad, T. (1995). The Pleistocene locality of Kanjera, Western Kenya: stratigraphy, chronology and paleoenvironments. *Journal of Human Evolution* 29, 247-274.

Bettinger, R.L. and Eerkens, J. (1997). Evolutionary implications of metrical variation in Great Basin projectile points. *In*: (Eds: C.M. Barton and G.A. Clark) Rediscovering Darwin: Evolutionary Theory in Archaeological Explanation. Archaeological Papers of the American Anthropological Association, No. 7., Arlington, VA., 177-191.

Bettinger, R.L. and Eerkens, J. (1999). Point typologies, cultural transmission, and the spread of bow-and-arrow technology in the prehistoric Great Basin. Reprinted in (Eds: M.J. O'Brien and R.L. Lyman). (2003). Style, Function, Transmission: Evolutionary Archaeological Perspectives. The University of Utah Press, Salt Lake City, UT, 105-117.

Binford, L.R. (1972). Contemporary model building: paradigms and the current state of Palaeolithic research. In: *Models in Archaeology*. Ed: D.L. Clarke. Methuen and Co., London, 109-166.

Binford, L.R. (1983). Working at Archaeology. Academic Press, New York.

Binford, L.R. (1984). Faunal remains from Klasies River Mouth. Academic Press, London.

Binford, L.R. and Binford, S.R. (1966). A preliminary analysis of functional variability in the Mousterian of Levallois facies. *American Anthropologist* 68(2), 238-295.

Bisson, M.S. (2000). Nineteenth century tools for twenty-first century archaeology? Why the Middle Paleolithic typology of Francois Bordes must be replaced. *Journal of Archaeological Method and Theory* 7(1), 1-48).

Blumenschine, R.J. and 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., and 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. and Ebert, J. (2008). Effects of distance from stone source on landscape-scale variation in Oldowan artifact assemblages in the Paleo-Olduvai Basin, Tanzania. *Journal of Archaeological Science* 35, 76-86.

Blumenschine, R.J., Masao, F.T., Stanistreet, I.G. (2009). Changes in hominin transport of stone for Oldowan tools across the eastern Olduvai Basin during Lowermost Bed II times. *In:* (Eds: K. Schick and N. Toth, N.) The Cutting Edge: New Approaches to the Archaeology of Human Origins. Stone Age Institute Press, Gosport, Indiana, pp. 1-15.

Blumenschine, R.J., Masao, F.T., Stollhofen, H., Stanistreet, I.G., Bamford, M.K., Albert, R.M., Njau, J.K., and Prassack, K.A. (2012). Landscape distribution of Oldowan stone artifact assemblages across the fault compartments of the eastern Olduvai Lake Basin during early lowermost Bed II times. *Journal of Human Evolution* 63, 384-394.

Bordes, F. (1950). Principes d'une methode d'etude des techniques de debitage et de la typologie du Paleolithique ancien et moyen. *L'Anthropologie* 54, 19-34.

Bordes, F. (1961a). Typologie du Paleolithique ancien et moyen. Publications de l'Institut de Prehistoire de L'Universite de Bordeaux, Bordeaux.

Bordes, F. (1961b). Mousterian cultures in France. *Science* 134(3482), 803-810.

Boyd, R. and Richerson, P.J. (1985). Culture and the Evolutionary Process. University of Chicago Press, Chicago, Il.

Bradbury, A.P. and Carr, P.J. (1999). Examining stage and continuum models of flake debris analysis: an experimental approach. *Journal of Archaeological Science* 26, 105-116.

Brantingham, P.J., Olsen, J.W., Rech, J.A., Krivoshapkin, I.A. (2000). Raw material quality and prepared core technologies in Northeast Asia. *Journal of Archaeological Science* 27(3), 255–271.

Brantingham, P.J. (2003). A neutral model of stone raw material procurement. *American Antiquity* 68(3), 487-509.

Brantingham, P.J. (2007). A unified evolutionary model of archaeological style and function based on the Price equation. *American Antiquity* 72(3), 395-416.

Braun, D.R. (2006). Ecology of Oldowan Technology: Koobi Fora and Kanjera South. Dissertation, Rutgers University, New Brunswick, NJ.

Braun, D.R., and Harris, J.W.K. (2003). Technological developments in the Oldowan of Koobi Fora: innovative techniques of artifact analysis. In J. M. Moreno, R. M. Torcal, & I. T. Sainz (Eds.), Oldowan: rather more than smashing stones. Barcelona: University of Barcelona Press, 117-144.

Braun, D. and Harris, J.W.K. (2009). Plio-Pleistocene technological variation: a view from the KBS Mbr., Koobi Fora Formation. *In:* (Eds: K. Schick and N. Toth) The cutting edge: new approaches to the archaeology of human origins. Gosport, IN: Stone Age Institute Press, 17-32.

Braun, D.R., Tactikos, J.C., Ferraro, J.V. and Harris, J.W.K. (2005). Flake recovery rates and inferences of Oldowan hominin behavior: a response to Kimura 1999, 2002. *Journal of Human Evolution* 48, 525-531.

Braun, D.R., Tactikos, J.C., Ferraro, J.V., Arnow, S.L. and Harris, J.W.K. (2008). Oldowan reduction sequences: methodological considerations. *Journal of Archaeological Science* 35, 2153-2163.

Braun, D.R., Plummer, T., Ferraro, J.V., Ditchfield, P. and Bishop, L.C. (2009). Raw material quality and Oldowan hominin toolstone preferences: evidence from Kanjera South, Kenya. *Journal of Archaeological Science* 36, 1605-1614.

Breuil, H. (1913). Les subdivisions du Paleolithique superieur et leur signification. *Congres International d'Anthropologie et d'Archeologie Prehistorique*, Geneva, 165-238.

Brew, J.O. (1946). Archaeology of Alkali Ridge, Southeastern Utah. Peabody Museum, Cambridge, Vol. XXI.

Brezillon, M. (1968). La denomination des objets de Pierre Taillee. Centre National de la Recherche Scientifique, Paris.

Brown, F.H. and Feibel, C.S. (1991). Stratigraphy, depositional environments and palaeogeography of the Koobi Fora Formation. *In*: (Ed: J.M. Harris), Koobi Fora Research Project Volume 3: stratigraphy, artiodactyls and palaeoenvironments. Clarendon Press, Oxford, pp. 1-30.

Brown, F.H. and Gathogo, N. (2002). Stratigraphic Relation between Lokalalei 1A and Lokalalei 2C, Pliocene Archaeological Sites in West Turkana, Kenya. *Journal of Archaeological Science* 29, 699-702.

Buchanan, B. and Collard, M. (2008). Testing models of early Paleoindian colonization and adaptation using cladistics. *In* (Ed: M.J. O'Brien) Cultural Transmission and Archaeology: Issues and Case Studies. Society for American Archaeology, Washington, D.C., 59-76.

Bunn, H.T., Harris, J.W.K., Isaac, G., Kaugulu, Z., Kroll, E., Schick, K., Toth, N., and Behrensmeyer, A.K. (1980). FxJj 50: an early Pleistocene site in Northern Kenya. *World Archaeology* 12, 109-136.

Callahan, E. (1979). The basics of bifaces knapping in the Eastern Fluted Point Tradition: a manual for flintknappers and lithic analysts. *Archaeology of Eastern North America* 7, 1-180.

Cavalli-Sforza, L.L. and Feldman, M.W. (1981). Cultural Transmission and Evolution: A Quantitative Approach. Princeton University Press, Princeton, NJ.

Cerling, T.E. (1979). Paleochemistry of Plio-Pleistocene Lake Turkana, Kenya. Palaeogeogr. Palaeoclimatol. Palaeoecol. 27, 247e285.

Cerling, T. E. and Brown, F.H. (1982). Tuffaceous marker horizons in the Koobi Fora region and the Lower Omo Valley. *Nature* 299, 216-221.

Chauhan, P.R. (2009). Was There an Oldowan Occupation in the Indian Subcontinent? A Critical Appraisal of the Earliest Paleoanthropological Evidence. *In:* (Eds: K. Schick and N. Toth) The cutting edge: new approaches to the archaeology of human origins. Gosport, IN: Stone Age Institute Press, 33-54.

Chavaillon, J. (1976). Evidence for the technical practices of Early Pleistocene hominids. *In*: (Eds: Y. Coppens, F.C. Howell, G. Ll. Isaac, and R.E.F. Leakey) Earliest Man and Environments in the Lake Rudolf Basin. University of Chicago Press, Chicago, 565-573.

Clark, D.J. (1966). Precision and definition in African Archaeology. *South African Archaeological Bulletin* 21(83), 114-121.

Clark, G.A. (1987). Paradigms and paradoxes in contemporary archaeology. *In*: (Ed: M. Aldenderfer) Quantitative Research in Archaeology: Progress and Prospects. Sage Publications, Beverly Hills, 30-60.

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

Clarkson, C. and Hiscock, P. (2011). Estimating original flake mass from 3D scans of platform area. *Journal of Archaeological Science* 38, 1062-1068.

Clifford, J. and Marcus, G.E. (1986). The poetics and politics of ethnography. University of California, Berkeley Press, Berkeley, CA.

Colton, H.S. and Hargrave, L.L. (1937). Handbook of Northern Arizona Pottery Wares. Bulletin 11. Museum of Northern Arizona, Flagstaff.

Copeland, S.R. (2007). Vegetation and plant food reconstruction of lowermost Bed II, Olduvai Gorge, using modern analogs. *Journal of Human Evolution* 53, 146-175.

Cotterell, B. and Kamminga, J. (1987). The formation of flakes. *American Antiquity* 52(4), 675-708.

Crabtree, D.E. (1970). Flaking stone tools with wooden implements. *Science* 169, 146-153.

Crabtree, D.E. (1972). An introduction to flintworking. *Occasional Papers of the Idaho Museum of Natural History* 28.

Davis, Z.J. and Shea, J.J. (1998). Quantifying lithic curation: An experimental test of Dibble and Pelcin's original flake-tool mass predictor. *Journal of Archaeological Science* 25, 603-610.

de Heinzelin, J., Clark, J.D., White, T., Hart, W., Renne, P., WoldeGabriel, G., Beyene, Y. and Vrba, E. (1999). Environment and behavior of 2.5-Million-Year-Old Bouri hominids. *Science* 284, 625-629.

de la Torre, I. (2004). Omo revisited: evaluating the technological skills of Pliocene hominids. *Current Anthropology* 45(4), 439-465.

de la Torre, I. and Mora, R. (2005). Unmodified lithic material at Olduvai Bed I: manuports or ecofacts? *Journal of Archaeological Science* 32, 273-285.

de Lumley, H., Barsky, D., and Cauche, D. (2009). Archaic Stone Industries from East Africa and Southern Europe: Pre-Oldowan and Oldowan. *In:* (Eds: K. Schick and N. Toth) The cutting edge: new approaches to the archaeology of human origins. Gosport, IN: Stone Age Institute Press, 55-92.

de Mortillet, G. (1867). Promenades préhistoriques à l'Exposition universelle, Paris.

Delagnes, A. and Roche, H. (2005). Late Pliocene hominid knapping skills: The case of Lokalalei 2C, West Turkana, Kenya. *Journal of Human Evolution* 48, 435-472.

Dibble, H.L. (1981). Technological Strategies of Stone Tool Production at Tabun Cave (Israel). Ph.D. dissertation, University of Arizona.

Dibble, H.L. (1984). Interpreting typological variation of Middle Paleolithic Scrapers: function, style, or sequence of reduction? *Journal of Field Archaeology* 11, 431-436.

Dibble, H.L. (1987). The interpretation of Middle Paleolithic scraper morphology. *American Antiquity* 52(1), 109-117.

Dibble, H.L. (1995). Biache Saint-Vaast, level IIA: A comparison of analytical approaches. *In*: (Eds: H. Dibble and O. Bar-Yosef) The Definition and Interpretation of Levalloi Technology. Prehistory Press, Madison, WI, 93-116.

Dibble, H.L. (1997). Platform variability and flake morphology: a comparison of experimental and archaeological data and implications for interpreting prehistoric lithic technological strategies. Lithic Technology 22, 150-170.

Dibble, H. L. (1998). Comments on ''quantifying lithic curation: An experimental test of Dibble and Pelcin's original flake-tool mass predictor'' (Z. J. Davis and J. J. Shea.) *Journal of Archaeological Science* 25, 611–613.

Dibble, H.L. and Whittaker, J.C. (1981). New experimental evidence on the relation between percussion flaking and flake variation. *Journal of Archaeological Science* 8, 283-296.

Dibble, H.L. and Pelcin, A. (1995). The effect of hammer mass and velocity on flake mass. *Journal of Archaeological Science* 22, 429-439.

Diez-Martin, F., Yustos, P.S., Dominguez-Rodrigo, M., and Prendergast, M.E. (2011). An experimental study of bipolar and freehand knapping of Naibor Soit quartz from Olduvai Gorge (Tanzania). *American Antiquity* 76(4), 690-708.

Ditchfield, P., Hicks, J., Plummer, T., Bishop, L.C., and Potts, R. (1999). Current research on the Late Pliocene and Pleistocene deposits north of Homo Mountain, southwestern Kenya. *Journal of Human Evolution* 36(2), 123-150.

Dominguez-Rodrigo, M, Mabulla, A.Z.P., Bunn, H.T., Diez-Martin, F., Baquedano, E., Barboni, D., Barba, R., Dominguez-Solera, S., Sanchez, P., Ashley, G.M., and Yravedra, J. (2010). Disentangling hominin and carnivore activities near a spring at FLK North (Olduvai Gorge, Tanzania). *Quaternary Research* 74, 363-375.

Dunnell, R.C. (1971). Systematics in Prehistory. The Free Press, NY.

Dunnell, R.C. (1978). Style and function: a fundamental dichotomy. *American Antiquity* 43, 192-202.

Dunnell, R.C. and Wenke, R.J. (1980). If you've nothing better to do, Honk. *American Antiquity* 45, 612-613.

Eerkens, J.W. and Bettinger, R.L. (2008). Cultural transmission and the analysis of stylistic and functional variation. *In* (Ed: M.J. O'Brien) Cultural Transmission and Archaeology: Issues and Case Studies. Society for American Archaeology, Washington, D.C., 21-38.

Ensor, H.B. and Roemer, E. (1989). Comments on Sullivan and Rozen's debitage analysis and archaeological interpretation. *American Antiquity* 54(1), 175-178.

Eren, M.I., Greenspan, A. and Sampson, C.G. (2008). Are Upper Paleolithic blade cores more productive than Middle Paleolithic discoidal cores? A replication experiment. *Journal of Human Evolution* 55, 952-961.

Fajardo, B. (2009). The Oldest Occupation of Europe: Evidence from Southern Spain. *In:* (Eds: K. Schick and N. Toth) The cutting edge: new approaches to the archaeology of human origins. Gosport, IN: Stone Age Institute Press, 115-135.

Falsetti, A.B., Jungers, W.L., and Cole III, T.M. (1993). Morphometrics of the callitrichid forelimb: a case study in size and shape. *International Journal of Primatology* 14, 551-572.

Feibel, C.S. and Brown, F.H. (1993). Microstratigraphy and paleoenvironments. *In*: (Eds: Walker, A. and Leakey, R.), The Nariokotome *Homo erectus* Skeleton. Harvard University Press, Cambridge, pp. 21-39.

Fisher, R.A. (1930). The Genetic Theory of Natural Selection. Clarendon Press, Oxford.

Ford, J.A. (1952). On the concept of types. *American Anthropologist* 56, 42-54.

Ford, J.A. (1962). A quantitative method for deriving cultural chronology. Technical Bulletin, no. 1, Pan American Union, Washington, D.C.

Frison, G.C. (1968). A functional analysis of certain chipped stone tools. *American Antiquity* 33, 149-155.

Gardin, J.C. (1980). Archaeological Constructs. Cambridge University Press, Cambridge.

Geneste, J.M. (1985). Analyse lithique d'industrie Mousteriennes du Perigord: une approche technologique du comportnemnt des groupes humains au Paleolithique Moyen. Doctoral thesis, University of Bordeaux I, France.

Goodwin, A.J.H. and van Riet Lowe, C. (1929). The stone age cultures of South Africa. *Annals of the South African Museum* 27, 1-289.

Gould, S.J. (1996). Full House: The Spread of Excellence from Plot to Darwin. Harmony, NY.

Gowlett, J.A.J. (1988). A case of the Developed Oldowan in the Acheulean? *World Archaeology* 20(1), 13-27.

Harris, J.W.K. (1978). The Karari Industry: It's place in East African prehistory. Ph.D. Dissertation, UC Berkeley.

Harris, J.W.K. and Isaac, G. Ll. (1976). The Karari industry: early Pleistocene archaeological evidence from the terrain east of Lake Turkana, Kenya. *Nature* 262, 102-107.

Hay, R.L. (1976). *Geology of the Olduvai Gorge*. Berkeley: University of California Press.

Hayden, B. and Hutchings, W.K. (1989). Whither the billet flake? In *Experiments in Lithic Technology*. Eds: D.S. Amick and R.P. Mauldin, 235-257. BAR International Series 528.

Hiscock, P. and Clarkson, C. (2009). The reality of reduction experiments and the GIUR: reply to Eren and Sampson. *Journal of Archaeological Science* 36, 1576-1581.

Iovita, R. (2009). Ontogenetic scaling and lithic systematics: method and application. *Journal of Archaeological Science* 36, 1447-1457.

Isaac, G.L. (1984). The archaeology of human origins: studies of the Lower Pleistocene in East Africa 1971-1981. *Advances in World Archaeology* 3, 1-87.

Isaac, G.Ll., and Behrensmeyer, A.K. (1997). Geological Context and Paleoenvironments. *In:* (Eds: Isaac, G.Ll. and Isaac, B.) Koobi Fora Research Project volume 5, Plio-Pleistocene Archaeology. Clarendon Press, Oxford, pp. 12-53.

Isaac, G. Ll. and Harris, J.W.K. (1975). The scatter between the patches. 19th Annual Meeting of the Kroeber Anthropological Society, Berkeley.

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

Isaac, G. Ll. and Harris, J.W.K. (1997). Sites stratified within the KBS Tuff: Reports. *In:* (Eds: G. Ll. Isaac and B. Isaac) Koobi Fora Research Project, Plio-Pleistocene Archaeology Volume 5. Clarendon Press, Oxford, 71-114.

Isaac, G. Ll., Leakey, R.E.F. and Behrensmeyer, A.K. (1971). Archeological Traces of Early Hominid Activities, East of Lake Rudolf, Kenya. *Science* 173, 1129-1134.

Jelinek, A.J. (1976). Form, function, and style in lithic analysis. *In*: (Ed: C.E. Cleland) Cultural Change and Continuity. Academic Press, New York. 19-33.

Jones, P.R. (1994). Results of experimental work in relation to the stone industries of Olduvai Gorge. *In*: (Eds: M.D. Leakey and D.A. Roe) Olduvai Gorge, Vol.5. Cambridge University Press, Cambridge, 254-298.

Jordan, P. and Shennan. S. (2003). Cultural transmission, language, and basketry traditions amongst the California Indians. *Journal of Anthropological Archaeology* 22, 42-74.

Kibunjia, M. (1994). Pliocene archaeological occurrences in the Lake Turkana basin. *Journal of Human Evolution* 27, 159-171.

Kidder, A.V. (1915). Pottery of the Pajarito Plateau and of some adjacent regions in New Mexico. *American Anthropological Association, Memior* 2, 407-462.

Kimball, L.R. (1987). A consideration of the role of quatitative archaeology in theory construction. *In:* (Ed: M.S. Aldenderfer) Quantitative Research in Archaeology. Sage Publications, Newbury Park, CA, 114-125.

Kimura, Y. (1997). The MNK Chert Factory site: the chert-using strategy by early hominids at Olduvai Gorge, Tanzania. *African Study Monographs* 18(1), 1-28.

Kimura, Y. (1999). Tool-using strategies by early hominids at Bed II, Olduvai Gorge, Tanzania. *Journal of Human Evolution* 37, 807-831.

Kimura, Y. (2002). Examining time trends in the Oldowan technology at Beds I and II, Olduvai Gorge. *Journal of Human Evolution* 43, 291-321.

Kuijt, I. and Russell, K.W. (1993). Tur Imdai Rockshelter, Jordan: debitage analysis and historic Bedouin lithic technology. *Journal of Archaeological Science* 20, 667-680.

Kuijt, I., Prentiss, W.C. and Pokotylo, D.L. (1995). Bipolar reduction: an experimental study of debitage variability. *Lithic Technology* 20, 116-127.

Kuman, K. (2001). An Acheulean factory site with prepared core technology near Taung. *South African Archaeological Bulletin* 56, 8-22.

Kuman, K. and Field, A.S. (2009). The Oldowan Industry from Sterkfontein Caves, South Africa. *In:* (Eds: K. Schick and N. Toth) The cutting edge: new approaches to the archaeology of human origins. Gosport, IN: Stone Age Institute Press, 151-170.

Kyara, O. (1999). Lithic raw materials and their implications on assemblage variation and hominid behavior during BED II, Olduvai Gorge, Tanzania. Ph.D. Dissertation. Rutgers, the State University of New Jersey.

LaPlace, G. (1968). Recherches de typologie analytique. *Origini* 2, 7-64.

Leakey, L.S.B. (1931). The Stone Age Cultures of Kenya Colony. Frank Cass & Co. (1971 Edition), Cambridge University Press, Cambridge.

Leakey, L.S.B. (1935). The Stone Age Races of Kenya. Oxford University Press, London. (1970 Edition)

Leakey, M.D. (1970). Early artefacts from the Koobi Fora area. *Nature* 226, 228-230.

Leakey, M.D. (1971). *Olduvai Gorge*. Cambridge University Press, London.

Lemonnier, P. (1986). The study of material culture today: toward an anthropology of technical systems. *Journal of Anthropological Archaeology* 5, 147-186.

Lenoir, M. (1995). Recurrent centripetal debitage (Levallois and Discoidal): continuity or discontinuity? *In*: (Eds: H.L. Dibble and O. Bar-Yosef) The Definition and Interpretation of Levallois Technology. Prehistory Press, Madison, WI. 249-256.

Lepre, C.J., Quinn, R.L., Joordens, J.C.A., Swisher, C.C., and Feibel, C.S. (2007). Plio-Pleistocene facies environments from the KBS Member, Koobi Fora Formation: implications for climate controls on the development of lake-margin hominin habitats in the northeast Turkana Basin (northwest Kenya). *Journal of Human Evolution* 53, 504-514.

Lycett, S.J. (2009). Are Victoria West cores “Proto-Levallois”? A phylogenetic assessment. *Journal of Human Evolution* 56, 175-191.

Lycett, S.J. and Gowlett, J.A.J. (2008). On questions surrounding the Acheulean “tradition'.” *World Archaeology* 40, 295-315.

Lycett, S.J., von Cramon-Taubadel, N., and Foley, R.A. (2006). A crossbeam co-ordinate caliper for the morphometric analysis of lithic nuclei: a description, test and empirical examples of application. *Journal of Archaeological Science* 33, 847-861.

Lycett, S.J., Collard, M. and McGrew, W.C. (2007). Phylogenetic analyses of behavior support existence of culture among wild chimpanzees. *Proceedings of the National Academy of Sciences* 104(45), 17588-17592.

Mace, R., Holden, C.J., and Shennan, S. (2005). The Evolution of Cultural Diversity: A Phylogenetic Approach. UCL Press, London.

Magne, M. and Pokotylo, D. (1981). A pilot study in bifacial lithic reduction sequences. *Lithic Technology* 10, 34-47.

Martin, R.D. (1993). Allometric aspects of skull morphology in Theropithecus. *In*: (Ed: N.G. Jablonski) Theropithecus: The Rise and Fall of a Primate Genus, Cambridge University Press, Cambridge, UK. 273-298.

Mascia-Lees, F. E. (Ed.). (2011). A Companion to the Anthropology of the Body and Embodiment (Vol. 22). Wiley-Blackwell.

Mauldin, R.P. and Amick, D.S. (1989). Investigating patterning in debitage from experimental bifacial core reduction. *In:* (Eds: D.S. Amick and R.P. Mauldin) Experiments in Lithic Technology, BAR International Series 528. 67-88.

Mayr, E. (1982). The Growth of Biological Thoughts: Diversity, Evolution, and Inheritance. Harvard University Press, Cambridge, MA.

McHenry, L.J. (2009). Element mobility during zeolitic and argillic alteration of volcanic ash in a closed-basin lacustrine environment: case study Olduvai Gorge, Tanzania. *Chemical Geology* 265, 540-552.

McHenry, L.J. (2012). A revised stratigraphic framework for Olduvai Gorge Bed I based on tuff geochemistry. *Journal of Human Evolution*, 63, 284-299.

McPherron, S.P., and Dibble, H.L. (1999). Stone tool analysis using digitized images: examples from the Lower and Middle Paleolithic, Lithic Technology 24, 38-52.

Mora, R. and de la Torre, I. (2005). Percussion tools in Olduvai Gorge Beds I and II (Tanzania): implications for early human activities. *Journal of Anthropological Archaeology* 24, 179-192.

Morgan, L.H. (1877). Ancient Society. Holt, New York.

O'Brien, M.J. and Lyman, R.L. (2000). Applying Evolutionary Archaeology, A Systematic Approach. Kluwer Academic/Plenum Publishers, New York.

O'Brien, M.J. and Lyman, R.L. (2003a). Cladistics and Archaeology. The University of Utah Press, Salt Lake City.

O'Brien, M.J. and Lyman, R.L. (2003b). Style, Function, Transmission: Evolutionary Archaeological Perspectives. The University of Utah Press, Salt Lake City.

O'Brien, M.J., Darwent, J., and Lyman, R.L. (2001). Cladistics is useful for reconstructing archaeological phylogenies: Paleoinidan points from the Southeastern United States. *Journal of Archaeological Science* 28, 1115-1136.

O'Brien, M.J., Lyman, R.L., Collard, M., Holdne, C.J., Gray, R.D. and Shennan, S.J. (2008). Transmission, phylogenetics, and the evolution of cultural diversity. *In* (Ed: M.J. O'Brien) Cultural Transmission and Archaeology: Issues and Case Studies. Society for American Archaeology, Washington, D.C., 39-58.

Odell, G.H. (2003). Lithic Analysis. Springer Press, New York.

Patterson, L.W. and Sollberger, J.B. (1978). The replication and classification of small size lithic debitage. *Plains Archaeologist* 23, 103-112.

Patterson, L.W. (1982). Replication and classification of large sized debitage. *Lithic Technology* 11, 50-59.

Pelcin, A. (1996). Controlled experiments in the production of flake attributes. Ph.D. Dissertation, University of Pennsylvania.

Pelcin, A. (1997). The formation of flakes: the role of platform thickness and exterior platform angle in the production of flake initiations and terminations. *Journal of Archaeological Science* 24, 1107-1113.

Pelcin, A. (1998). The threshold effect of platform width: A reply to Davis and Shea. *Journal of Archaeological Science* 25, 615–620.

Perry, S.E. (2006). What Cultural Primatology Can Tell Anthropologists about the Evolution of Culture. *Annual Review of Anthropology* 35, 171-190.

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

Petrie, W.M.F. (1899). Sequences in prehistoric remains. *Journal of the Royal Anthropological Institute of Great Britain and Ireland* 29, 295-301.

Peyrony, D. (1933). Les industries “aurignaciennes” dans le basin de la Vezere. *Bulletin de la Societe Prehistorique Francaise* 30, 543-559.

Plummer, T. and Potts, R. (1995). Hominid fossil sample from Kanjera, Kenya: description, provenance, and implications of new and earlier discoveries. *American Journal of Physical Anthropology* 96, 7-23.

Plummer, T., Bishop, L.C., Ditchfield, P., and Hicks, J. (1999). Research on Late Pliocene Oldowan sites at Kanjera South, Kenya. *Journal of Human Evolution* 36(2), 151-170.

Potts, R. (1991). Why the Oldowan? Plio-Pleistocene toolmaking and the transport of resources. *Journal of Anthropological Research* 47, 153-176.

Prat, S., Brugal, J.-P., Tiercelin, J.-J., Barrat, J.-A., Bohn, M., Delagnes, A., Harmand, S., Kimeu, K., Kibunjia, M., Texier, P.-J., and Roche, H. (2005). First occurrence of early Homo in the Nachukui Formation (West Turkana, Kenya) at 2.3-2.4 Myr. *Journal of Human Evolution* 49, 230-240.

Prentiss, W.C. (1998). The reliability and validity of a lithic debitage typology: implications for archaeological interpretation. *American Antiquity* 63(4), 635-650.

Quinn, R.L., Lepre, C.J., Wright, J.D., and Feibel, C.S. (2007). Paleogeographic variations of pedogenic carbonate d13C values from Koobi Fora, Kenya: implications for floral compositions of Plio-Pleistocene hominin environments. *Journal of Human Evolution* 53, 560-573.

Rasband, W.S., 2007. ImageJ. U.S. National Institutes of Health, Bethesda, MD, USA, http://rsb.info.nih.gov/ij/index.html

Reti, J.S. (2009). Quantified Oldowan lithic artifact production: results and discussion of Behavioral Lithic Classification. PaleoAnthropology 2009:A1-A40.

Rezek, Z., Lin, S., Iovita, R. and Dibble, H.L. (2011). The relative effects of core surface morphology on flake shape and other attributes. *Journal of Archaeological Science* 38, 1346-1359.

Richerson, P.J. and Boyd, R. (2005). Not by Genes Alone. The University of Chicago Press, Chicago, Il.

Rindos, D. (1980). Symbiosis, instability, and the origins and spread of agriculture: a new model. *Current Anthropology* 21, 751-772.

Roche, H. (2000). Variability of lithic productions in East Africa. *Acta Anthropologica Sinica*, Supplement 19, 98-103.

Roche, H., Delagnes, A., Brugal, J.P., Feibel, C., Kibunjia, M., Mourre, V., and Texier, P.-J. (1999). Early hominid stone tool production and technical skill 2.34 Myr ago in West Turkana, Kenya. *Nature* 399, 57-60.

Rogers, M.J. (1997). A landscape archaeological study of East Turkana, Kenya. Ph.D. Dissertation. Rutgers University, New Brunswick, NJ.

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

Sackett, J.R. (1973). Style, function and artifact variability in palaeolithic assemblages. *In*: (Ed: C. Renfrew) The Explanation of Culture Change. University of Pittsburgh Press, Pittsburgh. 317-325.

Sackett, J.R. (1991). Straight archaeology French style: the phylogenetic paradigm in historic perspective. *In*: (Ed: G.A. Clark) Perspectives on the Past. University of Pennsylvania Press, Philadelphia. 109-139.

Sahnouni, M. and van der Made, J. (2009). The Oldowan in North Africa within a Biochronological Framework. *In:* (Eds: K. Schick and N. Toth) The cutting edge: new approaches to the archaeology of human origins. Gosport, IN: Stone Age Institute Press, 179-210.

Schick, K.D. (1987). Modeling the fomation of early stone age artifact concentrations. *Journal of Human Evolution* 16, 789-807.

Schick, K.D. and Toth, N. (1993). Making Silent Stones Speak. Simon and Schuster, NY.

Schiffer, M.B. (1995). Behavioral Archaeology. University of Utah Press, Salt Lake City, UT.

Schiffer, M.B. and Skibo, J.M. (1997). The explanation of artifact variability. *American Antiquity* 62, 27-50.

Sellet, F. (1993). Chaine op´eratoire: The concept and its applications. Lithic Technology 18, 106–112.

Semaw, S. (2006). The oldest stone artifacts from Gona (2.6-2.5 Ma), Afar, Ethiopia: Implications for understanding the earliest stages of stone knapping. *In:* (Eds: N. Toth and K. Schick) The Origins of Human Technology: Studies into the Early Stone Age (Oldowan). CRAFT Press, Bloomington, IN, 43–66.

Semaw, S., Renne, P., Harris, J.W.K., Feibel, C.S., Bernor, R.L., Fesseha, N. and Mowbray, K. (1997). 2.5-million-year-old stone tools from Gona, Ethiopia. *Nature* 385, 333-336.

Semaw, S., Simpson, S.W., Quade, J., Renne, P.R., Butler, R.F., McIntosh, W.C., Levin, N., Dominguez-Rodrigo, M., and Rogers, M.J. (2005). Early Pliocene hominids from Gona, Ethiopia. *Nature* 433, 301-305.

Sewell, William H., Jr. (1999). The Concept(s) of Culture. In: (Eds: V.E. Bonnell and L. Hunt) Beyond the Cultural Turn. Berkeley: University of California Press, 35-61.

Shennan, S. (2002). Genes, Memes and Human History. Thames and Hudson, London.

Shott, M.J. (1994). Size and form in the analysis of flake debris: review and recent approaches. *Journal of Archaeological Method and Theory* 1, 69-110.

Shott, M.J. (1996). An exegesis of the curation concept. *Journal of Anthropological Research* 52, 259-280.

Shott, M.J. (2008). Darwinian evolutionary theory and lithic analysis. *In* (Ed: M.J. O'Brien) Cultural Transmission and Archaeology: Issues and Case Studies. Society for American Archaeology, Washington, D.C., 146-157.

Shott, M. J., Bradbury, A. P., Carr, P. J., and Odell, G. H. (2000). Flake size from platform attributes: Predictive and empirical approaches. *Journal of Archaeological Science* 27, 877–894.

Spencer, M., Davidson, E.A., Barbrook, A.C., and Howe, C.J. (2004). Phylogenetics of artificial manuscripts. *Journal of Theoretical Biology* 227, 503-511.

Speth, J.D. (1972). Mechanical basis of percussion flaking. *American Antiquity* 37(1), 34-60.

Sponheimer, M. and Lee-Thorp, J.A. (1999). Isotopic evidence for the diet of an early hominid, *Australopithecus africanus*. *Science* 283(5400), 368-370.

Steward, J.H. (1941). Review of "Prehistoric Culture Unites and their Relationships in Northern Arizona" by H.S. Colton. *American Antiquity* 6, 366-367.

Stollhofen, H., Stanistreet, I.G., McHenry, L.J., Mollel, G.F., Blumenschine, R.J., and Masao, F.T. (2008). Fingerprinting facies of the Tuff IF marker, catastrophe for early hominin palaeoecology, Olduvai Gorge, Tanzania. Palaeogeography, Palaeoclimatology, Palaeoecology 259, 382_409.

Stout, D., Toth, N. and Schick, K. (2006). Comparing the neural foundations of Oldowan and Acheulean toolmaking: a pilot study using positron emission tomography (PET). *In:* (Eds: N. Toth and K. Schick) The Oldowan: Case Studies Into the Earliest Stone Age. Stone Age Institute Publication Series 1. Stone Age Institute Press, Gosport, IN, 321-331.

Sullivan, A.P. (1987). Probing the sources of variability: a regional case study near Homolovi Ruins, Arizona. *North American Archaeologist* 8, 41-71.

Sullivan, A.P. and Rozen, K.C. (1985). Debitage analysis and archaeological interpretation. *American Antiquity* 50, 755-779.

Tactikos, J.C. (2005). A landscape perspective on the Oldowan from Olduvai Gorge, Tanzania. Dissertation, Rutgers University, New Brunswick, NJ.

Tehrani, J. and Collard, M. (2002). Investigating cultural evolution through biological phylogenetic analyses of Turkmen textiles. *Journal of Anthropological Archaeology* 21, 443-463.

Tomaskova, S. (2005). What is a burin? Typology, technology, and interregional comparison. *Journal of Archaeological Method and Theory* 12(2), 79-115.

Toth, N. (1982). The stone technologies of early hominids from Koobi Fora, Kenya. Ph.D. dissertation, UC Berkeley.

Toth, N. (1985). The Oldowan reassessed: A close look at early stone artifacts. *Journal of Archaeological Science* 12, 101-120.

Toth, N. (1987). Behavioral inferences from Early Stone artifact assemblages: an experimental model. *Journal of Human Evolution* 16, 763-787.

Toth, N. (1997). The artefact assemblages in light of experimental studies. *In:* (Ed: G.L Isaac) Koobi Fora Research Project. Clarendon Press, Oxford. 363-401.

Toth, N. and Schick, K. (2006). The Oldowan: Case Studies Into the Earliest Stone Age. Stone Age Institute Publication Series 1. Stone Age Institute Press, Gosport, IN.

Van der Merwe, N., Masao, F.T., and Bamford, M.K. (2008). Isotopic evidence for contrasting diets of early hominins *Homo habilis* and *Australopithecus boisei* of Tanzania. *South African Journal of Science* 104(3-4), 153-155.

Van Riet Lowe, C. (1945). The evolution of the Levallois technique in South Africa. *Man* 45, 49-59.

van Schaik, C.P. (2003). Local traditions in orangutans and chimpanzees: social learning and social tolerance. *In:* (Eds: D. Fragaszy and S. Perry) The Biology of Traditions: Models and Evidence. Cambridge University Press, Cambridge, UK. 297–328.

Watson, R.A. (1973). Limitations on archaeological typologies and on models of social systems. *In*: (Ed: C. Renfrew) The Explanation of Culture Change. University of Pittsburgh Press, Pittsburgh. 317-325.

Whiten, A., Goodall, J., McGrew, W.C., Nishida, T., Reynolds, V., Sugiyama, Y., Tutin, C.E.G., Wrangham, R.W., and Boesch, C. (1999). Cultures in chimpanzees. *Nature* 399, 682–685.

Whiten, A., Horner, V., and de Waal, F.B.M. (2005). Conformity to cultural norms of tool use in chimpanzees. *Nature* 437, 737-740.

Whittaker, J.C. (1994). Flintknapping: Making and Understanding Stone Tools. University of Texas Press, Austin.

Williams, R. (1983). Culture and Society: 1780-1950. New York: Columbia University Press.

Young, D.E. and Bonnichsen, R. (1984). Understanding stone tools: a cognitive approach. Peopling of the Americas Process Series I. University of Maine at Orono.

Zabrodsky, H. and Avnir, D. (1995). Continuous symmetry measures. *Journal of American Chemical Society* 117, 462-473