Ecological perspectives on technological diversity at Kanjera South

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**Abstract**

The aspects of hominin behavior responsible for Oldowan stone tool variation have been the focus of much debate. There is some consensus that Oldowan artifact variation arises from a combination of ecological and cultural factors. These factors are often examined independently of one another. The diversity of raw material types and technological strategies present at the site of Kanjera South provide an opportunity to examine the interaction effect of ecology and culture on Oldowan stone tool variation. Here we combine previous analyses of raw material properties, provenance, and technology with quantitative measures of core reduction intensity and tool utilization to examine the influence of both ecological and techno-cultural factors on stone tool variation at Kanjera South. The results of this analysis show that technological variation at Kanjera South reflects a dynamic relationship between raw material properties, provenance, and hominin mobility. Cores produced on raw materials from distant sources are more reduced than locally sourced raw materials. Distant raw materials are generally more resistant to edge attrition compared to those available locally which may have incentivized their transport over long distances. Moreover, the variation in stone tool reduction is not constistent with neutral models of stone tool transport and discard. This suggests that the lithic assemblage at Kanjera South may reflect a structured land-use strategy that may relate to the resource rich nature of the Homa Penninsula. This pattern of stone tool utilization also has an impact on the technological strategies employed by Oldowan tool makers at Kanjera South. Cores produced on raw materials from distant sources also exhibit more complex core reduction strategies than locally acquired materials. While this pattern is partially due to the differences in the quality of knappable stone, bifacial centripetal and multifacial core-reduction strategies also arise due to the continuous transport and use of exotic raw materials. These results demonstrate that ecological factors such as raw material provenance and physical properties have strong impacts on reduction intensity and the technological strategies utilized by hominins. Yet, not all stone tool variation at Kanjera South can be explained by this relationship. These results suggest that Oldowan stone tool variation should not be examined from a strictly ecological or technological perspective, but rather within the context of its broader cultural-ecological system.

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# 1. Introduction

The Oldowan is relatively simplistic as it consists primarily of core and flake tools (Leakey 1971). In contrast to earlier typological approaches, experimental models by (Toth 1985) suggest that the Oldowan is a simple core and flake industry whose primary goal is the removal of flakes with sharp cutting edges. In spite of its superficial simplicity, Oldowan stone tool variation is a vast resource of information regarding Early Pleistocene hominin behavior. Technological analyses show that Oldowan hominins had at least a basic understanding of the general principles of flaking and selection of suitable tool stones for artifact manufacture (Braun et al. 2019; D. R. Braun, Plummer, Ferraro, et al. 2009; Delagnes and Roche 2005; de la Torre 2004; Roche et al. 1999; Semaw 2000; Stout et al. 2005). In addition, Oldowan hominins also transported stone tools various distance to the places where they are used and discarded (Blumenschine and Peters 1998; D. R. Braun, Ditchfield, et al. 2008; Harmand 2009; Hay 1976; Isaac 1984; Potts 1991; Toth 1985). Despite early suggestions that the Oldowan was a largely expedient tool kit (Chavaillon 1970), it may reflect a more nuanced technical system, where raw material is acquired, transported, utilized, maintained and eventually discarded (Isaac 1984).

A major difficulty in the study of Oldowan hominin behavior is linking variation in artifacts to individual influences on behavior (Gallotti 2018; Roche, Blumenschine, and Shea 2009). While socio-cognitive approaches only require examining technological strategies present in the artifacts themselves, ecological analyses require integrated ecological and functional data sets. Demonstrating the influence of ecological parameters on stone tool use requires establishing spatial relationships between measures of stone tool utilization and landscape features such as raw material sources and paleogeographic settings (Blumenschine and Peters 1998; Blumenschine et al. 2008; Blumenschine, Stanistreet, and Masao 2012; D. R. Braun, Rogers, et al. 2008; Braun, et al. 2009; Isaac and Isaac 1997; Rogers 1997). While previous work on this topic has demonstrated the influence of raw material access on Oldowan assemblages (Blumenschine et al. 2008), little work has been done demonstrating its direct influence on technological variation in the Oldowan. The site of Kanjera South provides an opportunity to do so. Extensive research on the technological context has characterized not only the technological strategies employed by hominins, at this site, but also the landscape context of the site (Behrensmeyer et al. 1995; D. R. Braun, Ditchfield, et al. 2008; D. R. Braun, Plummer, Ditchfield, et al. 2009; D. R. Braun, Plummer, Ferraro, et al. 2009; Ditchfield et al. 2018; Bishop et al. 2006; Kent 1942; Lemorini et al. 2014, 2019; Oliver et al. 2019; Plummer, Bishop, et al. 2009; Plummer et al. 2001, 1999; Plummer and Bishop 2016). Here we present an integrated approach that examines Oldowan lithic technology from an ecological context. The results of this study contribute to the exploration of ecological and socio-cultural influences on Oldowan artifact variation.

# Background

# 1.2. Background to Kanjera South

***Insert* Figure 2**

The 2.0 Ma site of Kanjera South is situated on the northern side of the Homa Peninsula on the edges of the Nyanza Rift near the shores of Lake Victoria (Plummer et al., 1999; Ditchfield et al., 2019, figure 2). The extensive excavation of a 3 meter deep sequence of silts and clays recovered over 3000 fossils and similar numbers of stone artifacts (Plummer et al., 2009a). The stratigraphy at Kanjera South is made up of approximately 30 m of fluvial, colluvial and lacustrine sediments (Ditchfield et al. 2018). Extensive research on the geochronology and sedimentary context has demonstrated that the ithics and fossils accumulatedpredominantly due to hominin activity (Behrensmeyer et al., 1995; Plummer et al., 2009a, 2009b; Ferraro et al., 2013; Ditchfield et al., 2019). as well as enamel isotope studies landscape surrounding

Extensive geological surveys of the Homa Peninsula and the surrounding area reveal a high diversity of igneous and metamorphic rocks that provided a wide range of suitable materials that hominins could utilize for flake production. As such, this diversity is reflected in the lithic assemblage. More than 16 different rock types are represented in the assemblage but the bulk of the material is produced on 8 of them. Geochemical finger printing of the lithic material makes it possible to further subdivide the lithic assemblage to two broad categories of raw material provenance: local and exotic (table 1). Local materials suggest are derived from the Homa Mountain Carbonatite center (Figure 2). Drainages running off the flanks of this mountain would have carried materials such as phonolite, limestone, and fenetized rocks within the immediate vicinity of Kanjera South. Sources of the exotic materials, such as quartzite, rhyolite, andesite, and granite are located more inland from Lake Victoria in places such as the Kisi Highlands and Oyugis (Figure 2). While these materials were likely acquired from river channels traveling west-ward toward Kanjera South, they are not present in Pleistocene river conglomerates west of the Samanga fault. This has been used to imply that exotic materials were transported at least 10 kilometers to Kanjera South.

Kanjera South is not only unique the number of raw material represented but also the diversity of technological production strategies present within the assemblage. Unlike other Oldowan sites from timeframe, the flake production strategies range from simple unifacial techniques to bifacial and multi-facial techniques. Previous work has suggested that some this diversity reflects the differences in the quality of the raw materials at the site or the need to maximize the amount of flakes removed from a high quality materials (Braun et al., 2009). The wide ranging in the diversity of materials from local and exotic sources and technological reduction strategies provides an opportunity to investigate the dynamics between hominin land-use patterns, stone tool production and Oldowan assemblage variability.

**Insert Figure 3**

# 2. Materials and methods

*2.1 Materials*

To explore the relationship between land-use and Oldowan assemblage variability w (Table 2) To examine the effect of stone tool transport on assemblage variability the relationship between raw material provenance and stone tool utilization was examined. Therefore, the preexisting knowledge (see above) regarding raw material provenance, raw material properties, and core exploitation strategies was combined with an in depth analysis of the lithic material that was designed to quantify the intensity of stone tool utilization prior to their discard at Kanjera South.

To this end a total 1500 stone artifacts (171 cores and 1329 flakes) were characterized using a series of continuous and ordinal variables. Table XX provides a detailed summary of the number of lithics per raw material included. In addition, to the previously published technological analysis, the cores were also categorized using the commonly used diachritic types defined by de la Torra and Mora (de la Torre and Mora, 2005). These data were then used to predict the reduction intensity of the cores and the flake sequence number of the flakes.

*2.2 Estimating Core Reduction Intensity*

Reduction intensity is a commonly inferred attribute within lithic analysis. Within Oldowan and

Acheulean research, core reduction intensity has been understood through a variety of ranging from those as simple as mass, the number of flake scars to more sophisticated methods that use linear models to estimate the degree to which a core has been reduced. Simple measures such as mass and the number of flake scars are not always appropriate as nodules selected for exploitation as cores are sometimes not similar in size. This particularly the case at Kanjera South where toolstones originate from a variety of sources and can vary substantially in size. The number of flake scars also do not reflect a 1 to 1 relationship with reduction intensity the continuous removal of flakes will erase evidence of previous removals [REFS]. Furthermore, the reduction intensity of cores likely influences a variety of attributes that interact throughout the reduction sequence. As a result, multi-variate estimates of core reduction intensity provide a way to consider a suite of variables in tandem.



Here we follow methods outlined by Douglass et al. (2018) to estimate the reduction intensity of individual cores in terms of the proportion of mass lost prior to its discard using a predictive generalized linear model. This model considers, the number of flake scars, exploitation surfaces, the number of exploitation surface convergences, the proportion of cortex, and average platform angle to estimate core reduction intensity. The number of flake scars intuitively refers to the number of previous flake removals present on the core. The number of exploitation surfaces refers to the number of areas of the core where flakes were removed along a similar axis. This variable is related to core rotation which is argued to increase as core reduction increases (e.g. Delagnes and Roche 2005). The number of exploitation surface convergences documents the number of times different exploitation surfaces intersect with each other. Throughout reduction exploitation surfaces with different flaking axes tend to converge (Braun 2005, Douglass et al 2017). The proportion of cortex has an intuitive relationship with core reduction intensity. That is, the total proportion of the core that possesses cortical surface area will diminish during reduction. Average platform angle, measured in degrees, refers to the mean angle between striking surfaces. Various experimental replication studies show that, as this angle approaches 90°, it becomes increasingly difficult to detach a flake (Cotterell, Kamminga, and Dickson 1985). Therefore, as a core approaches exhaustion, the platform angles on the core are likely to approach 90°.

These variables are then combined using a predictive generalized linear mixed model to estimate the percentage of mass lost from the core. This predictive model was developed.

The added benefit of this model is that it is directly applicable to the materials analyzed in here, as it is was developed in validated on experimental material and a subset of archaeological material from Kanjera South (D. R. Braun, Tactikos, et al. 2008). These details are discussed in Douglass et al. (2017).

## 2.2. Flake Sequence Estimates

Flake sequence is a common analytical method in American archaeology (Andrefsky 2009; Bamforth 1986) but is also applied to Early Stone Age assemblages in various forms (D. R. Braun, Tactikos, et al. 2008; de la Torre Ignacio 2011; Stout et al. 2010; Toth 1985). In the Early Stone Age, flake sequences are most commonly characterized using Toth types, which classifies flakes into six different stages depending on the presence of cortex on a flake’s platform and dorsal surface (Toth 1985). Here we follow D. R. Braun, Tactikos, et al. (2008), using a multi-linear model to estimate flake sequence values. This methodology is specifically focused on understanding the approximate location of a flake within a reduction sequence. Unlike Toth’s flake types, which is focused on relative sequence information, the multi-linear model allows for an absolute placement of a flake within a reduction set (within a prescribed error). The multiple linear regression uses flake length, width, number of platform facets, number of flake scars, and the number of flake scar directions; specific details for each measurement are clearly outlined in D. R. Braun, Tactikos, et al. (2008: 2156, Fig 3). Before the sequence number can be estimated, the number of flake scars and amount of dorsal cortex must be divided by the log of the surface area of the flake (D. R. Braun, Tactikos, et al. 2008). These variables are then used by the predictive model to estimate the flake sequence number. Flake sequence estimates have a maximum error between +/- 8 sequences. However, an application of the method to refitting sequences from the Koobi Fora formation showed it always places flakes in their relative order(D. R. Braun, Tactikos, et al. 2008). Therefore, while information derived from individual flake sequence estimates may be coarse-grained, it remains useful for assemblage scale comparisons.

## 2.3. Edge to mass ratios

Measurements of tool use are often associated with enumerating the details of the reduction of artifacts (Dibble 1995; Eren and Sampson 2009). This is largely because of the reductive nature of stone technology (i.e. the process of producing stone tools always produces a smaller byproduct). However, some have also reviewed the general efficiency of this flaking process (Braun and Harris 2003; Brantingham and Kuhn 2001; Eren, Greenspan, and Sampson 2008; Muller and Clarkson 2016). Unfortunately, the study of efficiency in artifact production is not well standardized. There are some studies that investigate the overall efficiency of specific knapping strategies (Brantingham and Kuhn 2001; Eren et al. 2008). Others review efficiency as it pertains to individual flaking events within an overall technological framework (Braun and Harris 2003). Identifying the mechanisms that result in highly efficient tool forms is not well understood (Lin et al. 2013; Dogandži’c, Braun, and McPherron 2015). Yet it is clear that there is variation in how efficient some technologies are (even though the metric for identifying efficiency is debated; Eren et al. 2008). Assuming that most stone tools are produced to create sharp edges, one possible measure is estimating the amount of sharp edge produced per given unit of mass. Technologies that produced a higher amount of edge per volume of material can be considered more efficient (Braun and Harris 2003). Here we use a measure of edge that is based on tracing the edge of whole flakes (Braun and Harris 2003; Isaac and Isaac 1997). To calculate efficiency this edge estimate is divided by the logarithmic transformation of mass. The reason for this transformation is that mass increases in three dimensions (i.e. volumetrically) and the edge of a flake increases in two dimensions. The logarithmic transformation of mass prevents distortions of this ratio that are the result of general size parameters. For example, very small flakes have relatively high edge for a given amount of mass, but this is not always the most efficient way to produce the greatest amount of edge relative to volume (e.g. see discussions on this topic in Kuhn 1991). Flakes that have high amounts of edged relative to their mass tend to be relatively thin flakes, and there is the possibility that the efficiency of these tools is limited by their capabilities to complete certain tasks (e.g. tacks that require intensive use of edges such as hide scraping may not be feasible with relatively thin flakes). Here we calculate the edge to mass ratio of flakes within raw material categories. We then aggregate this measure across raw materials types to assess the overall efficiency of a given raw material. These aggregate measures are likely more reflective of the generalized pattern of efficiency in tool production over time at the Kanjera South locality.

2.3 Comparisons

# 3. Results

## 3.1. Core Utilization

Core reduction intensity estimates reveal that there is a wide range of variation in the amount of mass that was removed from the cores at Kanjera South. Some cores were minimally utilized whereas others were reduced as much as 95% of their original mass. There is also a significant relationship between core reduction intensity and raw material type (Kruskal-Wallis, *p* < 0.0001). This pattern appears to be driven by raw material provenance. Cores produced on raw material types that originate from more distant sources (BBa, BFe, BQu, NyR, and OGr) are on average more substantially reduced than those that occur locally (FNy, HPh, HLi) (Kruskal-Wallis, *p* < 0.001; Fig. 4).

Insert Figure 4

The application of the flake sequence model to the Kanjera South assemblage reveals a similar pattern to that found in the core reduction intensity analysis. Flake sequence values range from the first flakes off the core to the 30th flake in the sequence. As with core reduction intensity, raw material type has a significant influence on flake sequence values (Kruskal-Wallis, *p* < 0.001). The largest differences are, again, those between rock types derived from more distant sources and those found locally. Flakes produced on rock types from more distant raw material sources are from later in the reduction sequence (Fig. 5), while flakes from the locally found materials are from earlier stages of reduction. Interestingly, there is a striking amount of homogeneity in the distribution of flake sequence values associated with exotic or distant raw materials. Aside from Bukoban Felsite (BFe) the inter-quartile range of flake sequence values are very similar from distant sources. Even though Bukoban Felsite has a wider range than the others, its median is nearly the same as the others. The flake sequence values associated with flakes from the local materials are also similar to each other but show slightly more variation. Homa Phonolite exhibits the widest range of flake sequence values.

Insert Figure 5

As previously reported (D. R. Braun, Plummer, Ditchfield, et al. 2009), the Kanjera core assemblage is comprised of a wide variety of technological types or core reduction strategies. The frequency of core reduction strategies present shows a significant relationship with the raw material type (Fishers exact test, *p* < 0.001). In general, raw materials that derive from more distant sources, are represented by core reduction strategies that involve a greater number of core rotations or more complex rotations (i.e. centripetal flaking; Fig. 6). Though unifacial and unidirectional reduction strategies are present in small frequencies, there is a greater representation of centripetal, bifacial and multifacial exploitation strategies in materials from more distant origins (Fig. 6). On the other hand, local materials such as the Fenetized Nyanzian (FNy) and Homa Phonolite (HPh) are represented by greater number of unifacial or uni-directional core reduction strategies (Fig. ). Homa Limestone, runs contrary to this general pattern. Although Homa Limestone is found in abundance locally, cores produced on this raw material type are often multi-facially reduced. However, as is addressed in the discussion this is likely related to the properties of the raw material itself (D. R. Braun, Plummer, Ditchfield, et al. 2009). When core reduction intensity is compared according by core reduction strategy an interesting pattern emerges. Unifacial and unipolar, core reduction strategies result in less reduction than strategies that require bifacial, multifacial or polyhedral strategies (Kruskal Wallis, *p* < .001) (Figure 6). In other words, core reduction strategies that require fewer core rotations, such as unifacial and unidirectional strategies, are less reduced than those that involve more complex rotation strategies.

Insert Figure 6

## 3.2. Flake efficiency

Analysis of the relative proportion of edge to mass in flakes indicates significantly different technological strategies applied to the different raw materials from the Kanjera South assemblage. Although the mean values of the different raw materials are relatively similar, the overall distribution of values indicates that rock types from sources that are further away from Kanjera South (e.g. rhyolite, felsite, quartzite) are produced in a way that allows for much higher efficiency values than those seen in the rock types found close to Kanjera South. In particular, the relatively low values seen in the Fenetized Nyanzian and Homa limestone indicate that flakes made on these rock types were produced in a manner that does not increase the use life of these cores (D. R. Braun, Rogers, et al. 2008; Shott 1996; Shott and Sillitoe 2004). In particular the differences between the rocks types from the Kisii highlands (Bukoban quartzite, felsite and basalt) show signficant differences from those rock types that can be found in the drainages near Kanjera (e.g. Homa Limestone and Fenetized Nyanzian, *p* < 0.01 for all pairwise comparisons between Homa Limestone and all Bukoban rock types; *p* <0.001 for all comparisons between Fenetized Nyanzian and all other rock types Kruskal-Wallis Rank Sum test, Chi2 = 312.70, df = 5, pairwise comparisons between raw materials use Dunnn’s Test with Benjamin-Hochberg correction for multiple comparisons). It should be noted that even though there are significant differences between the edge to mass ratios, the distributions show significant overlap (Fig. 7). This indicates that while it is physically possible to produce flakes with similar edge to mass ratios in each raw material type, hominins at Kanjera South did not implement this strategy as frequently on raw materials that were locally abundant. Hominins at Kanjera South consistently produced flakes with greater edge and less mass from rock types that came from more distant sources. We only include rock types that have greater than 50 flakes because the wide variance in values seen in this measure results in wilidly divergent values in small samples.

Insert Figure 7

# 4. Discussion

## 4.1. The influence of raw material properties

The results of this study show an interaction between stone tool utilization, raw material type and core reduction strategies. The most striking distinction is the difference in the degree of utilization of materials from local and distant sources. That is, cores that are derived from the drainages of the more distant Kisi highlands are significantly more reduced than those from local sources. This is also reflected in the flake sequence data. Within the Kanjera South flake assemblage, those produced on exotic raw materials are more likely to be from later in the reduction sequence than flakes from locally sourced materials (Fig. 5). This difference can be explained by a few different factors. Firstly, raw material properties play a role in causing these differences. The local fenetized rocks (FNy) are often discarded before complete reduction because of the intersection of removals with step fractures or preexisting internal fracture planes present in the highly metasomatized rocks (D. R. Braun, Plummer, Ferraro, et al. 2009). The chalky nature and block-like geometry of Homa limestone (HLi) also limits the number of flakes that can be removed. In contrast, the majority of raw materials from more distant sources possess fewer flaws and fracture more predictably than those found locally (D. R. Braun, Plummer, Ferraro, et al. 2009).

However, differences in material properties do not explain all of the differences in reduction intensity between local and exotic materials. If all of the cores that were discarded due to presence of internal flaws are removed from the assemblage, the overall pattern remains. In addition, Homa phonolite, a local raw material, does not have the defects common in other local raw materials but it is still less reduced than the nonlocal raw materials. In contrast with the other exotic materials, the properties of the Oyugis granite (OGr) also constrains the removal of flakes. The particularly coarse grained nature of this rock type alters its fracture pattern. It is difficult to maintain angles of less than 90 degrees. It is likely that hominins could only exploit pre-existing angles on these granite blocks, thus limiting the degree that they could be reduced (D. R. Braun, Plummer, Ditchfield, et al. 2009). Despite the limitations imposed by its material properties, Oyugis granite is still more reduced than any of the local raw materials (Fig. 4). Previous research shows that the exotic raw materials that were transported to Kanjera South not only fracture more predictably but also produce flakes with more durable edges (D. R. Braun, Plummer, Ferraro, et al. 2009; de la Torre 2004; Ludwig and Harris 1998). The need to reduce relatively lower quality material may be related to the durability and the efficiency of the produced edges. In other words, flakes produced on local rock types have shorter use-lives because their edges dull more quickly. The consequence of this, is that for any given use, more flakes of a local raw material are required. In this sense, the high abundance of these materials and the relatively quick dulling of their cutting edges may explain the high frequency of local raw materials in the Kanjera South assemblage.

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## 4.2. Implications for Land use

The stark differences in the degree of core utilization according to raw material origin also reflects a dynamic hominin land-use system. Flake sequence values associated with exotic materials are often from later in the sequence than those associated with local raw materials. This pattern could indicate that cores from exotic sources were often utilized prior to their arrival and discard at Kanjera South. The presence of highly reduced exotic materials in contrast with lightly reduced local materials may imply that hominins that visited the Homa Peninsula may have discarded more utilized exotic materials as they collected materials that were proximal to Kanjera as part of a mobile toolkit. This pattern has been observed at the site of FxJj 50 from the Okote Mbr. of the Koobi Fora Fm. (D. R. Braun, Harris, and Maina 2009). This may further suggest that stone tool acquisition and discard behavior may relate to the need to maximize the amount of utility hominins carried with them. In this sense, hominins would have made decisions to discard raw material when opportunities to increase the amount useable volume was prssent. The core reduction pattern at Kanjera South is also consistent with expectations of raw material procurement and utilization when conditions are neutral. Under neutral conditions, raw materials from more distant sources will be, on average, more reduced, than those from local sources (Brantingham 2003; Pop 2016). The fact that cores from more distant sources are more reduced than those from local sources is consistent with this pattern. This ‘distance-decay’ pattern has been observed in numerous archaeological studies (eg., Blumenschine et al., 2008; Close, 1999; Newman, 1994; Toth, 1985). In addition, neutral expectations state that the variance in tool reduction intensity will decrease with distance from a given source. In other words, the variance in the amount of stone tool reduction intensity should be substantially lower in assemblages of tools from distant sources. The converse is also predicted by the distance-decay model. Variance in core reduction will be much greater in local sources.

This prediction of the distance-decay model is not supported by the Kanjera South data. In contrast, while exotic materials are reduced more more substantially than local materials, the interquartile ranges of flake sequence and core reduction measures of assemblages from distant sources are as wide (or wider) than those associated with local sources. This argues against a null hypothesis that the patterns seen in the lithic assemblage at Kanjera South formed under neutral conditions (i.e., no intentional attempt to increase the use life of artifacts from distant sources). It has been hypothesized that deviations from the neutral model of this nature may arise due to increasingly linear movements toward specific locations (Brantingham 2003; D. R. Braun, Rogers, et al. 2008). Moreover, subsequent work modeling the influence of directed movement towards attractors has shown that while a distance-decay pattern remains visible, tools from earlier stages of reduction will be over-represented (i.e. greater variance in reduction) (Reeves, 2019). Thus, the greater than expected range in variance in the reduction intensity of distantly sourced cores may suggest that hominins directed their movement to Kanjera South.

The concept that hominins directed their movement toward Kanjera South, is supported by other archaeological and paleoecological evidence. Numerous taphonomic studies of the faunal assemblage from Kanjera South have verified that hominins efficiently exploited small bovids and may have processed larger carcasses that were scavenged from carnivores. (Ferraro et al., 2013; Oliver et al., 2019). Use-wear studies that demonstrate that hominins carried out a variety of resource processing activities with the stone artifacts that were produced at Kanjera South, including butchery and the processing of a variety of plants, including underground storage organs (USOs; Lemorini et al., 2014, 2019). These studies attest to the resource rich environment in which Kanjera South was situated. These resources ultimately made the Kanjera South locale and the Homa Pennisula an attractive place for hominins, most likely for centuries given that the finds were made through three meters of sequence (upper KS-1 through KS-3). Thus, the patterns evinced by this study are the result of the repeated visitation by hominins over generations to Kanjera South, and these patterns likely reflect the broader foraging ecology of Oldowan Tool makers.

## 4.3. The interacting effect of land-use and material properties on lithic technology at Kanjera South.

The results of this study may also suggest that tool utilization, raw material properties and foraging ecology may interact in complex ways that structure the patterns of artifact variation we see at Oldowan sites. Kanjera South artifacts include a wide range of reduction strategies (D. R. Braun, Plummer, Ditchfield, et al. 2009; Plummer, Bishop, et al. 2009; Plummer et al. 2001; Plummer and Bishop, 2016). These strategies have a similar appearance to the descriptions of tool forms that have been described in other Oldowan contexts (de la Torre and Mora, 2005). Interestingly the different reduction strategies present at Kanjera South seem to be related to reduction intensity. Cores that are described as having bifacial, multifacial and/or centripetal patterns of removals exhibit high levels of reduction. Few of the unifacial cores and partial bifacial cores show this increased level of reduction intensity (Fig. 6). It could be argued that this pattern is a consequence of the predictive model used to estimate core reduction intensity. The reduction intensity model predicts higher reduction intensity as core rotation increases. This is a pattern that has been identified in some experimental models of Oldowan core reduction (Douglass et al., 2017). However, this is not necessarily the case. Despite the fact that cores produced on Oyugis Granite and Homa Limestone are often irregular and multi-facial, the predictive model still discriminates between different levels of reduction in these cores. Complimentary support can be found in the flakes made from these raw materials. Flakes made from exotic cores exhibit flake sequence values that suggest they were produced from later in the flaking sequence. This independent line of evidence suggests that the predictive model of core reduction is not over estimated due to rotation. Rather, this model of reduction intensity is accurately identifying estimates of the length of core use life in these exotic cores. Therefore it is possible to examine the representation of various core reduction strategies in terms of raw material properties and land-use.

The representation of reduction strategies in each raw materials type also follows the interaction between raw material properties and broader land-use that is described above. Raw material properties have been shown to influence reduction intensity decisions previously (D. R. Braun, Plummer, Ditchfield, et al. 2009). The frequent application of unifacial reduction strategies to the locally obtained FNy may result from the limitations imposed by the internal flaws often present in the rock. In other words, hominins may have only been able to exploit a single surface on these metasomatized rocks before the knapping process encountered an internal flaw. Rather than attempt to overcome the flaw by rotating the core, the high abundance of FNy at KJS may have made it easier to simply discard the core and acquire a new nodule. High discard rates in contexts of abundant raw material has been observed in numerous archaeological and ethnographic contexts (Andrefsky, 2008). Moreover, the technological analysis of the cores suggests that the high representation of irregular multi-facial cores produced in Homa Limestone (HLi) and Oyugis Granite (OGr) are the result of continuous core rotation to exploit naturally occurring angles (D. R. Braun, Plummer, Ditchfield, et al., 2009). The exploitation of naturally occurring angles in rocks is a fairly common feature of Oldowan hominins. (Delagnes and Roche, 2005). Yet these mechanical issues do not explain all of the patterns seen at Kanjera South. Homa phonolite is one of the most homogeneous raw materials found at Kanjera South. Hominins at Kanjera South frequently implemented bifacial reduction strategy in these cores. It was possible to implement longer reduction chains in this material than was possible with the other local materials. Yet the these cores are never reduced to the same degree as that seen in the exotic raw materials.

The cores produced on raw materials from the area surrounding Kanjera South (i.e., local materials) exhibit an even representation of various core reduction strategies. The same pattern is not seen in rocks transported over large distances. Exotic raw materials show a strong bias toward more reduced, complete bifacial and multifacial reduction strategies (Fig. 6). While the HPh shows a high frequency of bifacial reduction, this reduction is only partial (Fig. 6). Moreover, cores with multi-facial or centripetal flaking strategies are seldom produced on Homa Phonolite (Fig. 6). This contrasts sharply with the prevalence of more intense core reduction strategies involving greater degrees of core rotation in rock types from further sources (e.g., Bukoban quartzite). This suggests that raw material properties is not the only factor influencing core reduction strategies.

The results of the edge-to-mass ratio data suggest that hominins applied a strategy that more efficiently produced flakes on rock types transported from greater distances from Kanjera South. In addition, previous research shows that exotic raw materials also produce more durable cutting edges (D. R. Braun, Plummer, Ferraro, et al., 2009). These two factors may have incentivized the retention of exotic raw materials within the hominin tool-kit. The stock of these ‘high quality’ raw materials would have become increasingly more expensive (i.e., in time and energy) to rejuvenate as hominins moved away from the Kisi highlands (D. R. Braun, Ditchfield, et al., 2008). In this light, the high frequency of the bifacial and multifacial reduction strategies may have arisen from a need to maximize the amount utility that could be extracted from these cores. The exploitation of multiple flake removal surfaces on a core allows a core to remain active in a toolkit for a longer period of time. In later times hominins more frequently retouched formalized tools when the availability of raw materials becomes scarce (Clark and Barton, 2017). In a similar sense, the application of complete bifacial and multifacial strategies may have allowed hominins to utilize these high quality exotic materials longer to optimize resource acquisition at Kanjera South.

It could be argued that this pattern reflects the high level planning and foresight required to utilize and transport tools within this dynamic system. However, simpler explanations should also be considered. Modeling work has shown that tools will inevitably become more utilized as they are transported from the source, even under neutral or random conditions (Brantingham, 2003; Pop, 2016; Reeves, 2019). Experimental research has also shown that the wide range of formal types defined by Leakey (1971) could arise through a least effort flaking strategy (Toth 1985, 1982). More recently, Moore and Perston (2016) showed cores will eventually become bifacial or even multi-facial when the flaking procedure is systematically randomized. Thus, it may be possible to produce the differences in reduction intensity and reduction strategies observed between local and exotic materials by simply combining the influence of simple flaking procedures, stone tool transport, and raw material selection. Given the relationship between core reduction patterns and stone tool reduction intensity, the data from Kanjera South may suggest that different reduction strategies reflect different points on a reduction continuum rather than intentionally imposed strategies or socially mediated patterns of production. A similar notion has been proposed from LCT variability (Iovita and McPherron, 2011). Oldowan researchers must consider the possibility that, in some cases, Oldowan core variability arises due to an interaction of simple flaking rules with broader ecological parameters. In this sense, some Oldowan core variation may be an emergent phenomenon, rather than a direct reflection of the intentions or information that was transmitted to the knapper.

# 4.4. Implications for the Oldowan as a whole

The site of Kanjera South is unique in relation to Oldowan sites of a similar age or older. Many of the sites 2 million years old or older are situated in close proximity to raw materials sources and are comprised of a singular reduction strategy (Roche, Blumenschine, and Shea 2009; Plummer and Finestone, 2018). In contrast, the assemblage at Kanjera South shows a substantial representation of exotic raw materials and a diversity of different core reduction strategies. The results from Kanjera South elucidate how the interaction of raw material properties, foraging ecology, and landscape scale constraints on raw material availability influence technological variability in the Oldowan. While many sites show strong selection for specific materials, the frequent use of unifacial reduction strategies at sites such as Lokalelei 2C, East Gona, Hadar, Omo, Ledi Geraru may relate to the overall abundance of knappable material that is immediately available at these site (Braun et al., 2019; Kimbel et al., 1996; Roche et al., 1999; Stout et al., 2005). In other words, there maybe little incentive to exhaustively reduce a core when material is so abundant (Clark and Barton, 2017).

Kanjera South is also the only site from this time frame that is situated in an open grassland (Plummer, Ditchfield, et al. 2009). Humans tend to travel farther and more frequently in open arid environments than those that live in more productive environments (Burnside et al., 2012). Moreover savanna-adapted chimpanzees from Fongoli also possess a larger home range and practice fission-fusion less frequently (Pruetz and Bertolani, 2009). If this was also the case for the hominins at Kanjera South, these factors may have required new technological strategies in order to accommodate expanded home range sizes. On a broader scale the technological diversity represented at Kanjera South may reflect adaptations to the specific contextual conditions at this locale. The stimulus for increasing the use lives of cores (through reduction intensity and efficient use of raw material) at Kanjera South may have been foraging activities that quickly dulled artifact edges (e.g., butchery and USO processing; D. R. Braun, Ditchfield, et al., 2008; Lemorini et al., 2014) that were more frequently carried out in open habitats (Ferraro et al., 2013, 2019; Plummer, Bishop, et al., 2009).

Finally while the preceding analysis emphasizes the role of the broader environment and land-use on technological variability, ecology is not the sole driver of Oldowan technical variation. The inter-quartile ranges in figure 6 show a substantial amount of overlap between the reduction intensity and core reduction strategies. This suggests, that not all variation can be explained by environmental parameters such as raw material avalaibility and material properties. Moreover, inter-site differences between West Turkana sites are not easily explained factors such as raw material availability alone (Roche et al., 2018). This unexplained variation may be the result of socio-cultural dynamics that may have maintained information regarding the stone tool production process between groups. However, the fidelity and the mechanisms that underlie the maintenance of this information remain an open debate (Hovers, 2012; Morgan et al., 2015; Stout et al., 2019; Tennie et al., 2016, 2017). However, the results of this analysis show that it may be counterproductive for research on Oldowan technology to focus on specific aspects of stone tool technology (Fig. 1). Rather studies should examine the Oldowan within the broader socio-ecological system. It may be the interaction between function, ecology and sociality that provide information on the cultural capacity of Oldowan tool makers.

# 5. Conclusion

Despite the superficial simplicity of the Oldowan, its variability reflects a complex interconnection of ecological, behavioral and social factors. These factors are inextricably linked even though researchers often study them components in isolation. The lithic assemblage from Kanjera South provides an excellent opportunity to examine the interacting effects of raw material properties, provenance and availability of rock types and presumably social variation in the form of Oldowan artifacts. This is especially important given the context of other information we have from Kanjera that indicates that hominins butchered multiple small animals at this site and engaged in other subsistence strategies. Combination of quantitive measures of stone tool reduction with qualitative characterizations of lithic technology (e.g D. R. Braun, Plummer, Ditchfield, et al., 2009; Plummer and Bishop, 2016) provides new insights into the ecological factors that influence oldowan technology, and hominin behavior.

The fact that exotic materials are much more substantially reduced that from local sources reflects the differences in the quality of the raw materials available. The higher quality of the exotic materials would have incetivized the transport of these materials over longer distances. In this light, these differences in reduction also highlight that Oldowan tools were part of a mobile tool kit that reflects a broader land-use strategy. The marked differences in reduction intensity in combination with the paucity of early sequence flakes also suggests that exotic materials were often utilized prior to their arrival at Kanjera south. Although exotic materials are more reduced than local marerials the variance in the amount of stone tool reduction exhibited in the Kanjera South assemblage does not adhere to neutral expectations. This result suggests that the lithic assemblage at Kanjera South reflects a structured land-use pattern, that may indicate that hominins directed their movement, at least on occassion, to Kanjera South.

This pattern also appears to have an influence on the technological strategies employed by Oldowan tool makers at Kanjera South. The relationship between core reduction strategies and reduction intensity indicates that raw material quality and provenance have a strong influence on the technological variation observed within a lithic assemblage. While these results show that ecological parameters have a strong effect on stone tool variation, a substantial amount of variation remains unexplained by ecology alone. Overall, these results suggest that future studies must utilize a more integrated approach to understand the behavioral significance of the Oldowan.

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