

Ecological perspectives on technological diversity at Kanjera South

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Abstract

The aspects of hominin behavior responsible for Oldowan stone tool variation has 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 interacting 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 a 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

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which may have incentivized their transport over long distances. Moreover, the variation in stone tool reduction is not consistent 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 Peninsula. 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 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.

¹ **Introduction**

² The Oldowan is relatively simplistic as it consists primarily of core and flake
³ tools (Leakey 1971). In contrast to earlier typological approaches, experimental
⁴ models by (Toth 1985) suggest that the Oldowan is a simple core and flake
⁵ industry whose primary goal is the removal of flakes with sharp cutting edges. In
⁶ spite of its superficial simplicity, Oldowan stone tool variation is a vast resource
⁷ of information regarding Early Pleistocene hominin behavior. Technological
⁸ analyses show that Oldowan hominins had at least a basic understanding of
⁹ the general principles of flaking and selection of suitable tool stones for artifact
¹⁰ manufacture (Braun et al. 2019; D. R. Braun, Plummer, Ferraro, et al. 2009;
¹¹ Delagnes and Roche 2005; de la Torre 2004; Roche et al. 1999; Semaw 2000;
¹² Stout et al. 2005). In addition, Oldowan hominins also transported stone tools
¹³ various distance to the places where they are used and discarded (Blumenschine
¹⁴ and Peters 1998; D. R. Braun, Ditchfield, et al. 2008; Harmand 2009; Hay
¹⁵ 1976; Isaac 1984; Potts 1991; Toth 1985). Despite early suggestions that the
¹⁶ Oldowan was a largely expedient tool kit (Chavaillon 1970), it may reflect a
¹⁷ more nuanced technical system, where raw material is acquired, transported,
¹⁸ utilized, maintained and eventually discarded (Isaac 1984).

¹⁹ A major difficulty in the study of Oldowan hominin behavior is linking
²⁰ variation in artifacts to individual influences on behavior (Gallotti 2018; Roche,
²¹ Blumenschine, and Shea 2009). While socio-cognitive approaches only require
²² examining technological strategies present in the artifacts themselves, ecological
²³ analyses require integrated ecological and functional data sets. Demonstrating
²⁴ the influence of ecological parameters on stone tool use requires establishing
²⁵ spatial relationships between measures of stone tool utilization and landscape
²⁶ features such as raw material sources and paleogeographic settings (Blumenschine
²⁷ and Peters 1998; Blumenschine et al. 2008; Blumenschine, Stanistreet, and Masao

28 2012; D. R. Braun, Rogers, et al. 2008; D. R. Braun, Plummer, Ditchfield, et
29 al. 2009; Isaac and Isaac 1997; Rogers 1997). While previous work on this topic
30 has demonstrated the influence of raw material access on Oldowan assemblages
31 (Blumenshine et al. 2008), little work has been done demonstrating its direct
32 influence on technological variation in the Oldowan. The site of Kanjera South
33 provides an opportunity to do so. Extensive research on the technological context
34 has characterized not only the technological strategies employed by hominins, at
35 this site, but also the landscape context of the site (Behrensmeyer et al. 1995;
36 D. R. Braun, Ditchfield, et al. 2008; D. R. Braun, Plummer, Ditchfield, et
37 al. 2009; D. R. Braun, Plummer, Ferraro, et al. 2009; Ditchfield et al. 2018;
38 Bishop et al. 2006; Kent 1942; Lemorini et al. 2014, 2019; Oliver et al. 2019;
39 Plummer, Bishop, et al. 2009; Plummer et al. 2001, 1999; Plummer and Bishop
40 2016). Here we present an integrated approach that examines Oldowan lithic
41 technology from an ecological context. The results of this study contribute to
42 the exploration of ecological and socio-cultural influences on Oldowan artifact
43 variation.

44 **Background**

45 Given the dynamic system that Oldowan tools ultimately reflect, it is argued
46 that stone tool variation is influenced by function, ecology, culture and cognition
47 (Gallotti 2018; Isaac 1984; Plummer, Bishop, et al. 2009; Toth and Schick
48 2006) (Figure 1). Understanding the role of function in shaping Oldowan stone
49 tool variation is constrained. The uses of Oldowan tools beyond evidence of
50 cutting, and flake production is not well known. A small number of use-wear
51 studies are beginning to shed light on the diversity of functions that Oldowan
52 flakes were used for (Keeley and Toth 1981; Lemorini et al. 2014, 2019). The
53 impact of these functions on Oldowan stone tool variation remains unclear. As a

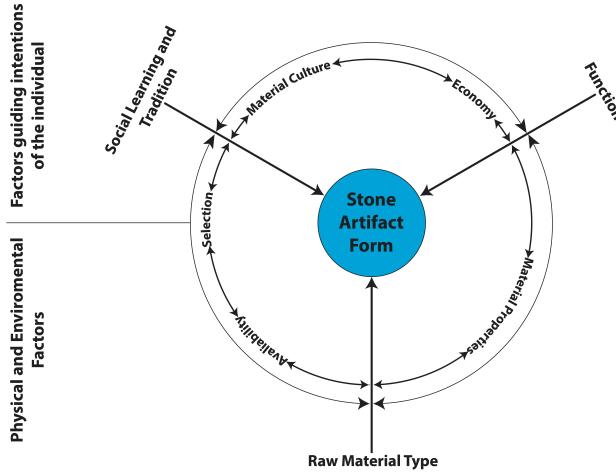


Figure 1: A diagram of factors that contribute to stone tool variation. Adopted from Isaac (1984).

54 result, Oldowan studies have focused primarily on drawing behavioral inferences
 55 from explorations of hominin ecology, culture and cognition derived from the
 56 morphological variation in stone tools. However, these various aspects of hominin
 57 life-ways are seldom studied in tandem.

58 The ecological approach views tools as an extra-somatic mechanism for
 59 solving environmental problems (Binford 2001). This approach was originally
 60 championed by the work of Glynn Isaac, John Desmond Clark, and their students
 61 (Clark 1975; Harris 1978; Isaac and Isaac 1997; Shick 1987; Toth 1987, 1982).
 62 In this perspective technology is considered to be a dynamic process that is
 63 adapted to the temporal and spatial distribution of resources (Bamforth 1990;
 64 Isaac and Harris 1976; Isaac 1981; Ludwig and Harris 1998; Nelson 1991; Peters
 65 and Blumenshine 1995; Rogers, Harris, and Feibel 1994; Toth 1985). In essence
 66 this approach investigates artifacts as dynamic objects that are a part of the

67 hominin foraging system. One component of this approach is the concept that
68 artifacts reflect movement of stone resources across landscapes often referred to
69 as the “the flow of stone” model (Isaac 1984). Some artifacts are produced and
70 discarded whereas others are transported away from the site. Understanding how
71 this flow of stone through structured landscapes produces inter-site assemblage
72 variability provides insight into the ecology and foraging strategies of early
73 hominins (Blumenshine, Stanistreet, and Masao 2012). As a result, a variety of
74 models have been proposed and debated for how assemblage composition, lithic
75 attributes and artifact density reflect land-use patterns at multiple spatial scales
76 (Binford 1976; Foley 1981a, 1981b; Isaac 1983, 1981; Isaac and Harris 1976;
77 Shick 1987; Toth 1987). Ecologically oriented research often measures aspects
78 of stone tool variation in relation to measures of tool utilization and transport.
79 Quantitative or ordinal variables such as mass, length, proportion of cortex,
80 and flake scar density are often compared alongside landscape variables such as
81 distance to raw material source and paleogeographic context (Andrefsky 2009,
82 2008; Blumenshine, Stanistreet, and Masao 2012; Bunn et al. 1980; Davies,
83 Holdaway, and Fanning 2018; Douglass 2010; Holdaway, Stern, and Chauhan
84 2004; Brantingham 1998; Kuhn, Raichlen, and Clark 2016; Toth 1987). Examples
85 of this type of approach includes studies of artifact variation throughout the
86 Okote Member of the Koobi Fora Formation. Paleogeographic context appears
87 to influence the transport patterns and reduction intensity of these artifacts
88 when they are discarded (D. R. Braun, Rogers, et al. 2008; Rogers, Harris,
89 and Feibel 1994; Rogers 1997; Stern, Porch, and McDougall 2002). At Olduvai,
90 quartz artifacts vary in size and abundance according to their distance from a
91 large outcrop of quartz called Naibor Soit (Blumenshine et al. 2008). Measures
92 of cortex and core reduction have shed light on the dynamic input-output system
93 under which Oldowan lithic assemblages form (Bunn et al. 1980; Rogers 1997;

⁹⁴ Toth 1987; D. R. Braun, Rogers, et al. 2008).

⁹⁵ An alternative approach to the ecological focus, is one where the actions and
⁹⁶ thoughts associated with stone tool production are highlighted (Sellet 1993). This
⁹⁷ is sometimes referred to as the technological approach (Soressi and Geneste 2011).
⁹⁸ From this perspective, the variation seen in all technology stems from socially
⁹⁹ mediated images and thoughts (Inizan et al. 1999). The various combinations of
¹⁰⁰ ways to flake, shape or retouch stone are argued to reflect the different knapping
¹⁰¹ strategies that characterize the skills of a group or individual (Delagnes and
¹⁰² Roche 2005). From this perspective stone tools reflect the cognitive capacity
¹⁰³ and the technical competence of Oldowan tool makers (Roche, Blumenschine,
¹⁰⁴ and Shea 2009; Schick and Toth 1994; Stout et al. 2015; Stout and Chaminade
¹⁰⁵ 2009; Toth and Schick 2018). In particular, certain components of the artifact
¹⁰⁶ production process (e.g. complex series of nested goals) appear to require specific
¹⁰⁷ cognitive traits (Wynn and Coolidge 2016). Oldowan variation is interpreted
¹⁰⁸ as differences in skills, cultural traditions, or even different taxa (Delagnes and
¹⁰⁹ Roche 2005; Roche et al. 1999, 2018; Roche, Blumenschine, and Shea 2009;
¹¹⁰ Stout et al. 2010). Technological analyses have been instrumental in revealing
¹¹¹ the rules that govern stone artifacts production. Analysis of lithic assemblages
¹¹² from West Turkana in Kenya show that hominins had already mastered flake
¹¹³ removal and how to maintain and exploit pre-existing platforms (Delagnes and
¹¹⁴ Roche 2005).

¹¹⁵ Moreover, differences in the arrangement of flake scars, refit sequences, the
¹¹⁶ frequency of knapping accidents are used to infer different production strategies
¹¹⁷ from Oldowan lithic assemblages. Differences in the inferred skill of toolmakers at
¹¹⁸ Lokalelei 1 and 2c are so striking that the author suggested that the differences
¹¹⁹ arise from 2 different social groups or possibly different species of hominins
¹²⁰ (Delagnes and Roche 2005). At Gona, differences in the proportion of reduction

strategies between sites have been argued to reflect cultural traditions of specific groups (Stout et al. 2010, 2019). At a broader scale, some researchers have argued that the variation in the Oldowan is similar to the regional variation in the observed in chimpanzee cultures (Barham and Mitchell 2008; Whiten et al. 1999; Whiten, Schick, and Toth 2009). The social context within this variation is interpreted to reflect potentially different social learning mechanisms in the archaeological record (Morgan et al. 2015; Stout et al. 2019).

The vast majority of research on Oldowan artifacts can be identified as falling into one the previously described categories (i.e. either ecologically focused or socially mediated). The singular focus of most Oldowan research on either ecological or technological questions has an impact on the current status of Oldowan research. The manner in which the Oldowan is described, and the methods used to describe it, depend heavily on the theoretical position of the analyst (la de Torre and Mora 2009). In a way, this is problematic because as figure 1 demonstrates, the factors that contribute to stone tool variability are not mutually exclusive and likely interact with one another. For example, the strategy used to reduce a core will affect the proportion of different Toth types produced (Stout et al. 2019, 2010). This will also likely influence how cortex is distributed across a landscape (Toth 1987). Therefore in the absence of a more integrated approach, differences in the representation of flake types (i.e. Toth Types) between two sites could be interpreted as varied foraging techniques when in reality they result from different tool reduction strategies (or possibly a combination of both). Therefore, in this example, reduction strategy and measurements of cortex must both be considered before discussing the aspects of behavior reflected in a given assemblage. In other words, without considering the broader ecological context of the Oldowan it may be impossible to disentangle technical competence of Oldowan knappers from technological variability (or

¹⁴⁸ *vice versa).*

¹⁴⁹ Distance - decay relationships between the location of tool-stone sources and
¹⁵⁰ stone tool discard is prevalent in Oldowan assemblages (Blumenschine et al.
¹⁵¹ 2008; D. R. Braun, Rogers, et al. 2008; Toth 1985). However, these patterns
¹⁵² are often described in terms of reduction intensity, size of flakes and cores, or
¹⁵³ the representation of cortex. Oldowan cores that are more reduced often involve
¹⁵⁴ greater levels of core rotation (Toth 1982). It is possible that differences in
¹⁵⁵ technological strategies may sometimes arise due to raw material abundance.
¹⁵⁶ Moreover, it may be that Oldowan stone tool variation may be the result of
¹⁵⁷ a complex interaction between social mechanisms of information transfer and
¹⁵⁸ ecological context. Understanding the significance of Oldowan variability requires
¹⁵⁹ an integrated approach which considers the context of tool use as well as the
¹⁶⁰ context of availability of resources. The assemblage of Oldowan artifacts from
¹⁶¹ Kanjera South provide the opportunity to understand an artifact record within
¹⁶² the context of raw material availability and technological variability (Plummer
¹⁶³ and Bishop 2016).

¹⁶⁴ **Background to Kanjera South**

¹⁶⁵ The site of Kanjera South is situated on the northern side of the Homa
¹⁶⁶ Peninsula on the edges of the Nyanza Rift near the shores of Lake Victoria
¹⁶⁷ (Plummer, Ditchfield, et al. 2009; Plummer et al. 1999). The archaeological site
¹⁶⁸ is in an amphitheater of sediment that has been exposed by the Kanjera River
¹⁶⁹ that is draining off the Homa Mountain carbonatite complex (figure: \ref{map}).
¹⁷⁰ This volcanic edifice dominates the sedimentary processes and basement geology
¹⁷¹ of the region (LeBas 1970). The site of Kanjera South was excavated from a 3
¹⁷² meter stacked sequence of clays and silts that record extensive hominin behavior
¹⁷³ in the form of stone artifacts and bones with surface modifications that are

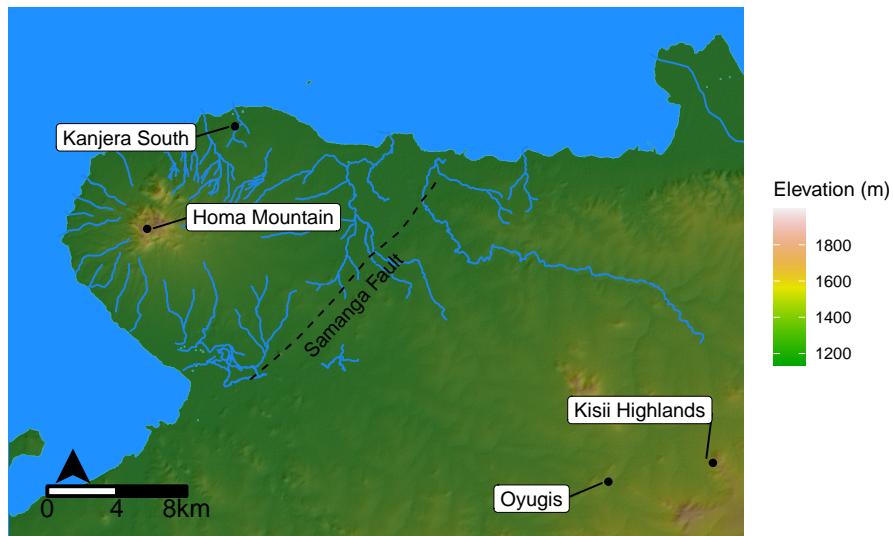


Figure 2: A map of the Homa Peninsula. Kanjera South is situated to the East of Homa Mountain. The Homa Mountain carbonatite center is the primary source of the local raw materials including Homa limestone (HLi), Homa Phonolite (HPh), and Fenetized nyanzian rocks (F Ny). Distant or exotic raw materials originate much farther to the east but they can be found in drainages east of the Samanga Fault. These include Bukoban andesite (BBa), Bukoban felsite (BFe), Bukoban quartzite (BQu), Nyanzian rhyolite (NyR), and Oygus granite (OGr)

174 indicative of the butchery of meat and acquisition of marrow (D. R. Braun,
175 Plummer, Ditchfield, et al. 2009; Plummer, Ditchfield, et al. 2009). Extensive
176 excavation has recovered over 3000 fossils and similar numbers of stone artifacts
177 (Plummer, Bishop, et al. 2009). The stratigraphy at Kanjera South is made up of
178 approximately 30 m of fluvial, colluvial and lacustrine sediments (Ditchfield et al.
179 2018). This stratigraphic sequence is well dated to ~2. Ma using a combination
180 of paleomagnetic and biochronological markers. These sediments are formally
181 assigned to the Southern Member of the Kanjera Fm (Behrensmeyer et al. 1995;
182 Plummer et al. 1999). There are five beds at Kanjera South (from oldest to
183 youngest KS-1 to KS-5) with artifacts and fossils concentrated in the sands
184 and silts of upper KS-1 to KS-3 (Ditchfield et al. 2018). Lithics and fossils are
185 thought to have been predominantly accumulated by hominins except for those
186 found within thin, discontinuous conglomerates which represent brief intervals
187 of higher energy water flow (Ditchfield et al. 2018; Ferraro et al. 2013).

188 The lithic assemblage recovered from excavations at Kanjera South repre-
189 sents one of the largest single accumulations of Oldowan artifacts in association
190 with modified fossil bone (Plummer 2004). The largest site (169 m^2) yielding the
191 bulk of the archaeological finds was Excavation 1. The frequencies of different
192 bovids in these beds indicates that the Kanjera South landscape, unlike the
193 setting of most of the Oldowan sites, was dominated by a grasslands as opposed
194 to trees (Plummer, Ditchfield, et al. 2009). This is further supported by the
195 stable isotope analysis of pedogenic carbonates and tooth enamel indicating a
196 relatively high proportion of plants that use a C4 photosynthetic pathway. The
197 fossils associated with the stone artifacts at Kanjera South exhibit substantial
198 evidence of hominin involvement in the accumulation of materials (Ferraro et
199 al. 2013). Evidence from bone surface modifications as well as the proportions
200 of bones modified are similar to patterns seen in “hominin first” experimental

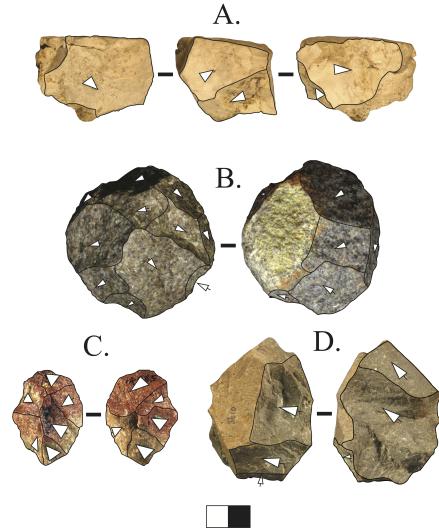


Figure 3: Examples of the found at Kanjera South. (A) Core produced on Homa limestone. (B) Core produced on Oyugis granite. (C) Core produced on Bukoban quartzite. (D) Core produced on Fenetized nyanzian.

201 datasets for small mammals, while larger mammals show more mixed access
 202 (Ferraro et al. 2013). The totality of the zooarchaeological evidence at Kanjera
 203 strongly implicates a scenario where hominins had early access to small carcasses.
 204 Evidence from mortality profile data also supports the inference that hominins
 205 may have been able to access smaller carcasses prior to carnivores and that
 206 larger carcasses were at times scavenged (Oliver et al. 2019).

207 The stone artifacts from Kanjera South reflect a wide diversity of technological
 208 adaptations (D. R. Braun, Plummer, Ditchfield, et al. 2009). The high diversity
 209 of the local geology on the Homa Peninsula provided a wide choice of different
 210 raw material types that hominins could incorporate into their toolkit . There
 211 are 16 formally described raw material types with many additional types that
 212 only appear in small quantities within the assemblage (D. R. Braun, Plummer,
 213 Ditchfield, et al. 2009). A detailed provenance study of the rock types used to

make stone artifacts at Kanjera documented two features that distinguish the Kanjera South assemblage from many other Oldowan assemblages. The first is the presence of transport to Kanjera South from conglomerates that are at least 10 km away from the site (D. R. Braun, Ditchfield, et al. 2008). The second is the systematic selection of rocks that have specific mechanical properties (D. R. Braun, Plummer, Ferraro, et al. 2009). Hominins selected rocks that fracture consistently and also had edges that resisted wear. The selection of certain rock types exceeds that which is seen in other Oldowan assemblages. Furthermore the intensity of selective behaviors seems to parallel rock properties. These differences in rock properties are reflected in the flaking technology (figure 3). Unidirectional and multidirectional flaking patterns feature prominently in this assemblage. However, the flaking patterns track raw materials differences and there appears to be a concerted effort to extend the use life of cores in some raw materials by increasing the length of flaking sequences in some raw materials. These different technological strategies applied to different raw materials results in a high diversity of core reduction strategies in the Kanjera South Assemblage (D. R. Braun, Plummer, Ditchfield, et al. 2009).

In addition to information regarding the transport and selection of certain raw materials, detailed studies of the micro-wear on the stone artifacts from Kanjera provide insights into artifact use (Lemorini et al. 2014, 2019). Usewear evidence suggests that the tool used by hominin at Kanjera were used for a variety of different activities. Most of these actions involve cutting, and the different raw materials appear to be used on different substrates. Usewear studies also suggests that some of the stone tools were used for modifying wood. This suggests that hominins were using stone artifacts to fashion other wooden tools (Lemorini et al. 2019). Combined with the transport information, the sum of the information about stone artifacts at Kanjera South suggests that stone artifacts

²⁴¹ represented a significant component of the extractive foraging adaptation of
²⁴² Oldowan hominins.

²⁴³ **Methods**

²⁴⁴ Oldowan tools undergo a series of transformations, through the removal
²⁴⁵ of flakes, from the time they are acquired until they are ultimately discarded
²⁴⁶ (Andrefsky 2009). As reviewed above, the flake removal process relates to a
²⁴⁷ diversity of social and economic factors surrounding tool use and production.
²⁴⁸ Here we explore the interaction of these factors on stone tool variability. As
²⁴⁹ such, this study combines the pre-existing knowledge of stone tool production
²⁵⁰ regarding, raw material properties, provenience and technology at Kanjera South
²⁵¹ with newly applied measures of stone tool utilization. This provides a novel
²⁵² means to understand Oldowan stone tool production from a multifaceted point of
²⁵³ view in which the relationships between stone tool utilization, landscape-scale raw
²⁵⁴ material constraints, and stone tool production strategies can be investigated.

Table 1: A list of rock types included in this analysis

Raw.Material	Abreviation	Origin	Provenance
Fenitized nyanzian	FNy	Homa Mountain	Local
Homa limestone	HLi	Homa Mountain	Local
Homa phonolite	HPh	Homa Mountain	Local
Bukoban andesite	BBa	East of Samanga Fault	Exotic
Bukoban felsite	BFe	East of Samanga Fault	Exotic
Bukoban quartzite	BQu	East of Samanga Fault	Exotic
Nyanzian rhyolite	NyR	East of Samanga Fault	Exotic
Oygus granite	OGr	Oygus	Exotic

255 We characterize the technology of stone tools produced on both distant and
256 local materials at Kanjera South (Table 1) through the study of the core and
257 complete flake assemblages (i.e. our analysis at this time does not incorporate
258 angular fragments). Tool utilization for cores was measured in terms of reduction
259 intensity. We estimate the proportion of mass lost prior to its discard following
260 the methods outlined in (Douglass et al. 2017). In addition, tool utilization
261 is also examined by estimating the relative proportion of flakes in the Kanjera
262 South assemblage that derive from early or later parts of the reduction sequence.
263 We identify the sequence order that flakes were removed from their cores by using
264 previously published models that use quantitative measures of flakes to predict
265 their placement in a reduction sequence (D. R. Braun, Tactikos, et al. 2008).
266 Flake sequence refers to the order that flake was removed from the core. Flake
267 sequence data provides an independent measure of tool utilization that could
268 be compared to the estimates of core reduction. Additionally, it also provides
269 a way to examine the amount of flake production that occurred at Kanjera
270 South. If cores were transported directly to Kanjera South and reduced, then
271 the early flake sequences (i.e. the first flakes off the core) would be present in the
272 assemblage. However, if early stage flakes are not present in the assemblage then
273 it can be inferred that cores were utilized elsewhere prior to their transport to
274 and discard at Kanjera South. Measures of core reduction intensity are analyzed
275 along-side technological strategies (e.g. bidirectional) utilized in core reduction.
276 Furthermore, core reduction and flake sequence values can also be examined
277 according to raw material type. This provides a means to examine the impact
278 of raw material properties and provenience on core reduction and technology.
279 The integration of these multiple lines of evidence allows us to place stone tool
280 variability at Kanjera south within the broader technological system in which it
281 took place.

282 *Characterizing Stone Tool Utilization.*

283 Tool utilization has been extensively researched in lithic analysis (see And-
284 fresky 2009 for overview). Most studies of tool utilization focus on the degree
285 of artifact reduction as a proxy for the use-life of an artifact (although these
286 things are related but they are not the same; Shott (1996)). Reduction intensity
287 can be calculated for a variety of artifact types (Dibble 1995). Currently several
288 methods exist for estimating the extent of core reduction. The majority of these
289 methods rely on establishing linear relationships between core attributes and the
290 amount of mass lost during artifact production to predict mass removed from a
291 core (Clarkson 2013; Douglass et al. 2017). This study uses the methods outlined
292 in Douglass et al. (2017) to estimate core reduction intensity as the proportion of
293 mass lost. The predictive model developed by Douglass et al. (2017) incorporates
294 a series of core attributes beyond simply surface area and total number of flake
295 scars. This model considers, the number of flake scars, exploitation surfaces,
296 the number of exploitation surface convergences, the proportion of cortex, and
297 average platform angle to estimate core reduction intensity.

298 The *number of flake scars* intuitively refers to the number of previous flake
299 removals present on the core. The *number of exploitation surfaces* refers to the
300 number of areas of the core where flakes were removed along a similar axis. This
301 variable is related to core rotation which is argued to increase as core reduction
302 increases (e.g. Delagnes and Roche 2005). The *number of exploitation surface*
303 *convergences* documents the number of times different exploitation surfaces
304 intersect with each other. Throughout reduction exploitation surfaces with
305 different flaking axes tend to converge (Braun 2005, Douglass et al 2017). The
306 proportion of cortex has an intuitive relationship with core reduction intensity.
307 That is, the total proportion of the core that possesses cortical surface area will
308 diminish during reduction. *Average platform angle*, measured in degrees, refers

³⁰⁹ to the mean angle between striking surfaces. Various experimental replication
³¹⁰ studies show that, as this angle approaches 90°, it becomes increasingly difficult
³¹¹ to detach a flake (Cotterell, Kamminga, and Dickson 1985). Therefore, as a core
³¹² approaches exhaustion, the platform angles on the core are likely to approach 90°
³¹³ (Douglass et al. 2017). Specifically, the method by Douglass et al. (2017) utilizes
³¹⁴ a generalized linear mixed model to examine the effects of predictor variables on
³¹⁵ core reduction intensity and ultimately predict the percentage of mass lost from
³¹⁶ a core. The added benefit of this model is that it is directly applicable to the
³¹⁷ materials analyzed in here, as it was developed in validated on experimental
³¹⁸ material and a subset of archaeological material from Kanjera South (D. R.
³¹⁹ Braun, Tactikos, et al. 2008). These details are discussed in Douglass et al.
³²⁰ (2017).

³²¹ *Flake Sequence Estimates*

³²² Flake sequence is a common analytical method in American archaeology
³²³ (Andrefsky 2009; Bamforth 1986) but is also applied to Early Stone Age as-
³²⁴ semblages in various forms (D. R. Braun, Tactikos, et al. 2008; de la Torre
³²⁵ Ignacio 2011; Stout et al. 2010; Toth 1985). In the Early Stone Age, flake
³²⁶ sequences are most commonly characterized using Toth types, which classifies
³²⁷ flakes into six different stages depending on the presence of cortex on a flake's
³²⁸ platform and dorsal surface (Toth 1985). Here we follow D. R. Braun, Tactikos,
³²⁹ et al. (2008), using a multi-linear model to estimate flake sequence values. This
³³⁰ methodology is specifically focused on understanding the approximate location of
³³¹ a flake within a reduction sequence. Unlike Toth's flake types, which is focused
³³² on relative sequence information, the multi-linear model allows for an absolute
³³³ placement of a flake within a reduction set (within a prescribed error). The
³³⁴ multiple linear regression uses flake length, width, number of platform facets,
³³⁵ number of flake scars, and the number of flake scar directions; specific details for

336 each measurement are clearly outlined in D. R. Braun, Tactikos, et al. (2008)
337 (page 2156, figure 3). Before the sequence number can be estimated, the number
338 of flake scars and amount of dorsal cortex must be divided by the log of the
339 surface area of the flake (D. R. Braun, Tactikos, et al. 2008). These variables
340 are then used by the predictive model to estimate the flake sequence number.
341 Flake sequence estimates have a maximum error between +/- 8 sequences. How-
342 ever, an application of the method to refitting sequences from the Koobi Fora
343 formation showed it always places flakes in their relative order(D. R. Braun,
344 Tactikos, et al. 2008). Therefore, while information derived from individual flake
345 sequence estimates may be coarse-grained, it remains useful for assemblage scale
346 comparisons.

347 *Edge to mass ratios*

348 Measurements of tool use are often associated with enumerating the details of
349 the reduction of artifacts (Dibble 1995; Eren and Sampson 2009). This is largely
350 because of the reductive nature of stone technology (i.e. the process of producing
351 stone tools always produces a smaller byproduct). However, some have also
352 reviewed the general efficiency of this flaking process (Braun and Harris 2003;
353 Brantingham and Kuhn 2001; Eren, Greenspan, and Sampson 2008; Muller and
354 Clarkson 2016). Unfortunately, the study of efficiency in artifact production
355 is not well standardized. There are some studies that investigate the overall
356 efficiency of specific knapping strategies (Brantingham and Kuhn 2001; Eren
357 et al. 2008). Others review efficiency as it pertains to individual flaking events
358 within an overall technological framework (Braun and Harris 2003). Identifying
359 the mechanisms that result in highly efficient tool forms is not well understood
360 (Lin et al. 2013; Dogandžić, Braun, and McPherron 2015). Yet it is clear that
361 there is variation in how efficient some technologies are (even though the metric
362 for identifying efficiency is debated; Eren et al. 2008). Assuming that most stone

363 tools are produced to create sharp edges, one possible measure is estimating
364 the amount of sharp edge produced per given unit of mass. Technologies that
365 produced a higher amount of edge per volume of material can be considered more
366 efficient (Braun and Harris 2003). Here we use a measure of edge that is based
367 on tracing the edge of whole flakes (Braun and Harris 2003; Isaac and Isaac
368 1997). To calculate efficiency this edge estimate is divided by the logarithmic
369 transformation of mass. The reason for this transformation is that mass increases
370 in three dimensions (i.e. volumetrically) and the edge of a flake increases in
371 two dimensions. The logarithmic transformation of mass prevents distortions
372 of this ratio that are the result of general size parameters. For example, very
373 small flakes have relatively high edge for a given amount of mass, but this is not
374 always the most efficient way to produce the greatest amount of edge relative
375 to volume (e.g. see discussions on this topic in Kuhn 1991). Flakes that have
376 high amounts of edged relative to their mass tend to be relatively thin flakes,
377 and there is the possibility that the efficiency of these tools is limited by their
378 capabilities to complete certain tasks (e.g. tacks that require intensive use of
379 edges such as hide scraping may not be feasible with relatively thin flakes). Here
380 we calculate the edge to mass ratio of flakes within raw material categories. We
381 then aggregate this measure across raw materials types to assess the overall
382 efficiency of a given raw material. These aggregate measures are likely more
383 reflective of the generalized pattern of efficiency in tool production over time at
384 the Kanjera South locality.

385 **Results**

386 *Core Utilization*

387 Core reduction intensity estimates reveal that there is a wide range of variation
388 in the amount of mass that was removed from the cores at Kanjera South. Some

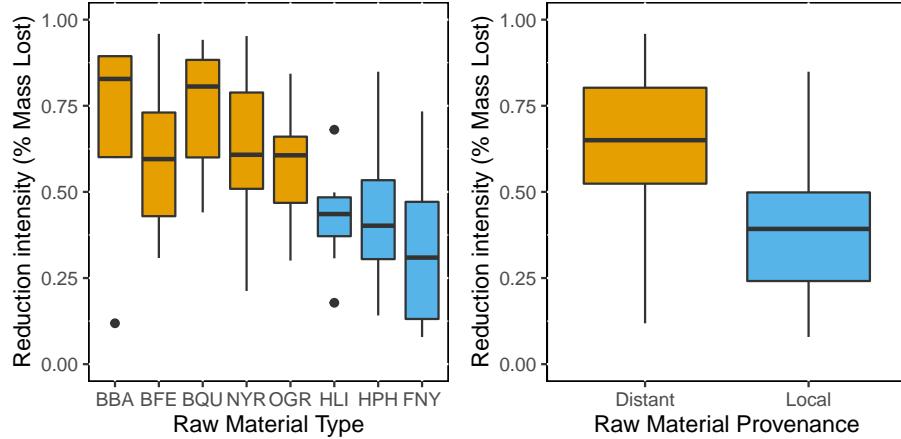


Figure 4: The distribution of core reduction intensity values as predicted by the GLMM (Douglass et al 2017). The results show stark differences in the degree of reduction in materials originating from more distant sources than those that originate from local sources of stone.

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, $p = < .0001$). 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, $p < .001$, 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, $p < .001$). 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 (figure 5), while flakes from the locally found materials are from earlier stages of reduction 5.

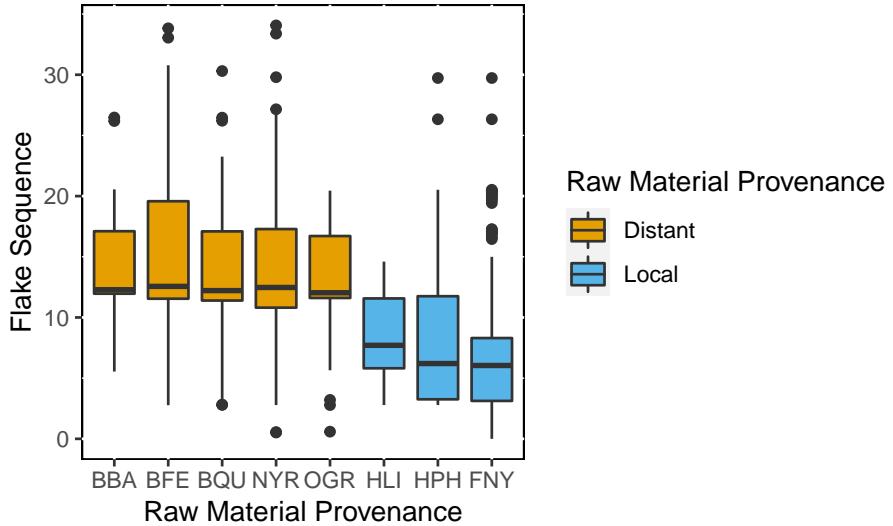


Figure 5: The distribution of flake sequence values present within the Kanjera South flake assemblage. The primary differences in flake sequence values are between materials originating from more distant sources than those that originate from local sources of stone.

405 Interestingly, there is a striking amount of homogeneity in the distribution of
 406 flake sequence values associated with exotic or distant raw materials. Aside from
 407 Bukoban Felsite (BFe) the inter-quartile range of flake sequence values are very
 408 similar from distant sources. Even though Bukoban Felsite has a wider range
 409 than the others, its median is nearly the same as the others. The flake sequence
 410 values associated with flakes from the local materials are also similar to each
 411 other but show slightly more variation. Homa Phonolite exhibits the widest
 412 range of flake sequence values.

413 As previously reported (D. R. Braun, Plummer, Ditchfield, et al. 2009),
 414 the Kanjera core assemblage is comprised of a wide variety of technological
 415 types or core reduction strategies. The frequency of core reduction strategies
 416 present shows a significant relationship with the raw material type (Fishers
 417 exact test, p-value: < .001). In general, raw materials that derive from more
 418 distant sources, are represented by core reduction strategies that involve a

419 greater number of core rotations or more complex rotations (i.e. centripetal
420 flaking, figure: 6). Though unifacial and unidirectional reduction strategies
421 are present in small frequencies, there is a greater representation of centripetal,
422 bifacial and multifacial exploitation strategies in materials from more distant
423 origins (Figure: 6). On the other hand, local materials such as the Fenetized
424 Nyanzian (FNy) and Homa Phonolite (HPh) are represented by greater number
425 of unifacial or uni-directional core reduction strategies (Figure: 6). Homa
426 Limestone, runs contrary to this general pattern. Although Homa Limestone
427 is found in abundance locally, cores produced on this raw material type are
428 often multi-facially reduced. However, as is addressed in the discussion this is
429 likely related to the properties of the raw material itself (D. R. Braun, Plummer,
430 Ditchfield, et al. 2009). When core reduction intensity is compared according by
431 core reduction strategy an interesting pattern emerges. Unifacial and unipolar,
432 core reduction strategies result in less reduction than strategies that require
433 bifacial, multifacial or polyhedral strategies (Kruskal Wallis, P-value: < .001)
434 (Figure: 6). In other words, core reduction strategies that require fewer core
435 rotations, such as unifacial and unidirectional strategies, are less reduced than
436 those that involve more complex rotation strategies.

437 *Flake efficiency*

438 Analysis of the relative proportion of edge to mass in flakes indicates signifi-
439 cantly different technological strategies applied to the different raw materials
440 from the Kanjera South assemblage. Although the mean values of the different
441 raw materials are relatively similar, the overall distribution of values indicates
442 that rock types from sources that are further away from Kanjera South (e.g. rhy-
443 olite, felsite, quartzite) are produced in a way that allows for much higher
444 efficiency values than those seen in the rock types found close to Kanjera South.
445 In particular, the relatively low values seen in the Fenetized Nyanzian and Homa

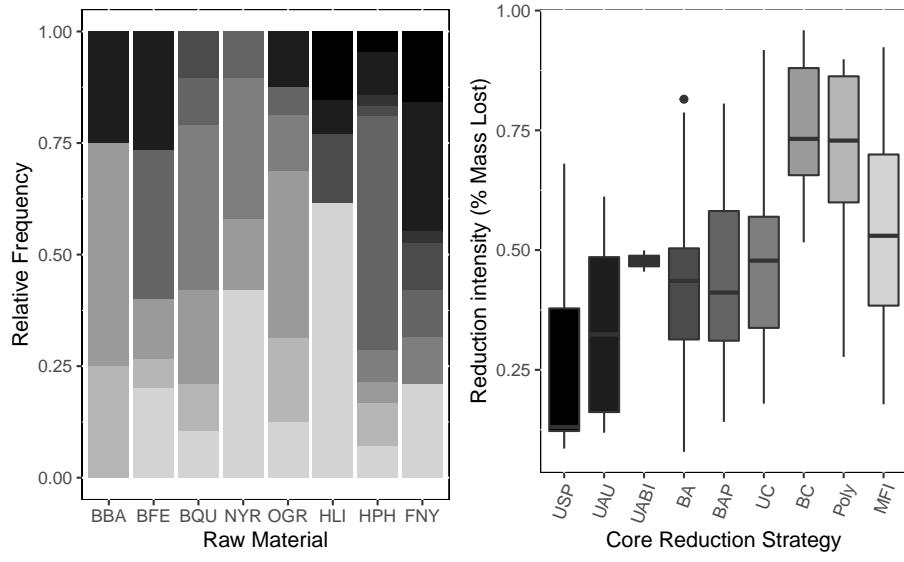


Figure 6: Left: The distribution of core reduction strategies by raw material type. With the exception of Homa Limestone, raw materials that derive from the Kisi highlights more greatly represented by complex core reduction strategies than those that can be found in the immediate vicinity of Kanjera South. Right: The distribution of reduction intensity values according to reduction strategy. **USP**: Unifacial Simple Partial. **UAU**: Unidirectional abrupt unifacial. **UABI**: Unifacial abrupt bidirectional. **BA**: Bidirectional Abrupt. **BAP** Bifacial Partial. **UC**: Unifacial centripetal. **BC**: Bifacial Centripetal. **Poly**: Polyhedral. **MFI**: Mutifacial Irregular. The colors of the boxplots correspond with the representation of different reduction strategies in the left figure.

446 limestone indicate that flakes made on these rock types were produced in a
447 manner that does not increase the use life of these cores (D. R. Braun, Rogers,
448 et al. 2008; Shott 1996; Shott and Sillitoe 2004). In particular the differences
449 between the rocks types from the Kisii highlands (Bukoban quartzite, felsite
450 and basalt) show significant differences from those rock types that can be found
451 in the drainages near Kanjera (e.g. Homa Limestone and Fenetized Nyanzian,
452 $p < .01$ for all pairwise comparisons between Homa Limestone and all Bukoban
453 rock types; $p < .001$ for all comparisons between Fenetized Nyanzian and all
454 other rock types Kruskal-Wallis Rank Sum test, $\chi^2 = 312.70$, $df = 5$, pairwise
455 comparisons between raw materials use Dunn's Test with Benjamin-Hochberg
456 correction for multiple comparisons). It should be noted that even though there
457 are significant differences between the edge to mass ratios, the distributions show
458 significant overlap (Figure \ref{flake_efficiency}). This indicates that while it
459 is physically possible to produce flakes with similar edge to mass ratios in each
460 raw material type, hominins at Kanjera South did not implement this strategy
461 as frequently on raw materials that were locally abundant. Hominins at Kanjera
462 South consistently produced flakes with greater edge and less mass from rock
463 types that came from more distant sources. We only include rock types that have
464 greater than 50 flakes because the wide variance in values seen in this measure
465 results in wildly divergent values in small samples.

466 Discussion

467 *The Influence of Raw Material Properties*

468 The results of this study show an interaction between stone tool utilization,
469 raw material type and core reduction strategies. The most striking distinction
470 is the difference in the degree of utilization of materials from local and distant
471 sources. That is, cores that are derived from the drainages of the more distant

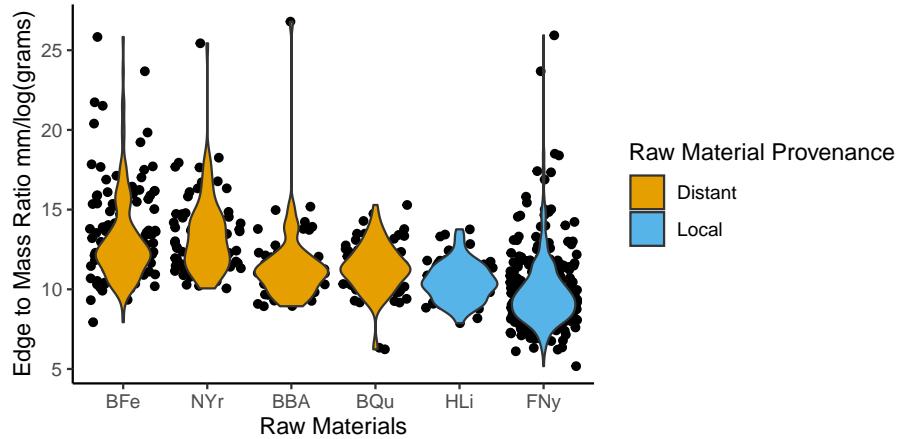


Figure 7: Boxplots of the measures of flake efficiency. Y-axis represents perimeter of flakes divided by a logarithmically transformed mass value.

472 Kisi highlands are significantly more reduced than those from local sources.
 473 This is also reflected in the flake sequence data. Within the Kanjera South
 474 flake assemblage, those produced on exotic raw materials are more likely to be
 475 from later in the reduction sequence than flakes from locally sourced materials
 476 (Figure 5). This difference can be explained by a few different factors. Firstly,
 477 raw material properties play a role in causing these differences. The local
 478 fenitized rocks (FNy) are often discarded before complete reduction because of
 479 the intersection of removals with step fractures or preexisting internal fracture
 480 planes present in the highly metasomatized rocks (D. R. Braun, Plummer, Ferraro,
 481 et al. 2009). The chalky nature and block-like geometry of Homa limestone (HLi)
 482 also limits the number of flakes that can be removed. In contrast, the majority
 483 of raw materials from more distant sources possess fewer flaws and fracture more
 484 predictably than those found locally (D. R. Braun, Plummer, Ferraro, et al.
 485 2009).

486 However, differences in material properties do not explain all of the differences
 487 in reduction intensity between local and exotic materials. If all of the cores that

488 were discarded due to presence of internal flaws are removed from the assemblage
489 (figure 6), the overall pattern remains. In addition, Homa phonolite, a local
490 raw material, does not have the defects common in other local raw materials
491 but it is still less reduced than the nonlocal raw materials. In contrast with
492 the other exotic materials, the properties of the Oyugis granite (OGr) also
493 constrains the removal of flakes. The particularly coarse grained nature of this
494 rock type alters its fracture pattern. It is difficult to maintain angles of less than
495 90 degrees. It is likely that hominins could only exploit pre-existing angles on
496 these granite blocks, thus limiting the degree that they could be reduced (D. R.
497 Braun, Plummer, Ditchfield, et al. 2009). Despite the limitations imposed by its
498 material properties, Oyugis granite is still more reduced than any of the local raw
499 materials (figure 4). Previous research shows that the exotic raw materials that
500 were transported to Kanjera South not only fracture more predictably but also
501 produce flakes with more durable edges (D. R. Braun, Plummer, Ferraro, et al.
502 2009; de la Torre 2004; Ludwig and Harris 1998). The need to reduce relatively
503 lower quality material may be related to the durability and the efficiency of
504 the produced edges. In other words, flakes produced on local rock types have
505 shorter use-lives because their edges dull more quickly. The consequence of this,
506 is that for any given use, more flakes of a local raw material are required. In this
507 sense, the high abundance of these materials and the relatively quick dulling of
508 their cutting edges may explain the high frequency of local raw materials in the
509 Kanjera South assemblage.

510 *Implications for Land use*

511 The stark differences in the degree of core utilization according to raw material
512 origin also reflects a dynamic hominin land-use system. Flake sequence values
513 associated with exotic materials are often from later in the sequence than those
514 associated with local raw materials. This pattern could indicate that cores from

515 exotic sources were often utilized prior to their arrival and discard at Kanjera
516 South. The presence of highly reduced exotic materials in contrast with lightly
517 reduced local materials may imply that hominins that visited the Homa Peninsula
518 may have discarded more utilized exotic materials as they collected materials
519 that were proximal to Kanjera as part of a mobile toolkit. This pattern has been
520 observed at the site of FxJj 50 from the Okote Mbr. of the Koobi Fora Fm. (D.
521 R. Braun, Harris, and Maina 2009). This may further suggest that stone tool
522 acquisition and discard behavior may relate to the need to maximize the amount
523 of utility hominins carried with them. **In this sense, hominins would have**
524 **made decisions to discard raw material when opportunities to increase**
525 **the amount useable volume was present.** The core reduction pattern at
526 Kanjera South is also consistent with expectations of raw material procurement
527 and utilization when conditions are neutral. Under neutral conditions, raw
528 materials from more distant sources will be, on average, more reduced, than
529 those from local sources (Brantingham 2003; Pop 2016). The fact that cores from
530 more distant sources are more reduced than those from local sources is consistent
531 with this pattern. This “distance-decay” pattern has been observed in numerous
532 archaeological studies (eg. Blumenschine et al. (2008); Close (1999); Newman
533 (1994); Toth (1985)). In addition, neutral expectations state that the variance in
534 tool reduction intensity will decrease with distance from a given source. In other
535 words, the variance in the amount of stone tool reduction intensity should be
536 substantially lower in assemblages of tools from distant sources. The converse is
537 also predicted by the distance-decay model. Variance in core reduction will be
538 much greater in local sources.

539 This prediction of the distance-decay model is not supported by the Kanjera
540 South data. In contrast, while exotic materials are reduced more more substan-
541 tially than local materials, the interquartile ranges of flake sequence and core

542 reduction measures of assemblages from distant sources are as wide (or wider)
543 than those associated with local sources. This argues against a null hypothesis
544 that the patterns seen in the lithic assemblage at Kanjera South formed under
545 neutral conditions (i.e. no intentional attempt to increase the use life of artifacts
546 from distant sources). It has been hypothesized that deviations from the neutral
547 model of this nature may arise due to increasingly linear movements toward
548 specific locations (Brantingham 2003; D. R. Braun, Rogers, et al. 2008). More-
549 over, subsequent work modeling the influence of directed movement towards
550 attractors has shown that while a distance-decay pattern remains visible, tools
551 from earlier stages of reduction will be over-represented (i.e. greater variance
552 in reduction) (Reeves 2019). Thus, the greater than expected range in variance
553 in the reduction intensity of distantly sourced cores may suggest that hominins
554 directed their movement to Kanjera South.

555 The concept that hominins directed their movement toward Kanjera South,
556 is supported by other archaeological and paleoecological evidence. Numerous
557 taphonomic studies of the faunal assemblage from Kanjera South have verified
558 that hominins efficiently exploited small bovids and may have processed larger
559 carcasses that were scavenged from carnivores. (Ferraro et al. 2013; Oliver et al.
560 2019). Use-wear studies that demonstrate that hominins carried out a variety
561 of resource processing activities with the stone artifacts that were produced at
562 Kanjera South, including butchery and the processing of a variety of plants,
563 including underground storage organs (USOs) (Lemorini et al. 2014, 2019).
564 These studies attest to the resource rich environment in which Kanjera South
565 was situated. These resources ultimately made the Kanjera South locale and
566 the Homa Peninsula an attractive place for hominins, most likely for centuries
567 given that the finds were made through three meters of sequence (upper KS-1
568 through KS-3). Thus, the patterns evinced by this study are the result of the

569 repeated visitation by hominins over generations to Kanjera South, and these
570 patterns likely reflect the broader foraging ecology of Oldowan Tool makers.

571 *The interacting effect of land-use and material properties on lithic technology at*
572 *Kanjera South.*

573 The results of this study may also suggest that tool utilization, raw material
574 properties and foraging ecology may interact in complex ways that structure the
575 patterns of artifact variation we see at Oldowan sites. Kanjera South artifacts
576 include a wide range of reduction strategies (D. R. Braun, Plummer, Ditchfield,
577 et al. 2009; Plummer, Bishop, et al. 2009; Plummer et al. 2001; Plummer and
578 Bishop 2016). These strategies have a similar appearance to the descriptions of
579 tool forms that have been described in other Oldowan contexts (de la Torre and
580 Mora 2005). Interestingly the different reduction strategies present at Kanjera
581 South seem to be related to reduction intensity. Cores that are described as
582 having bifacial, multifacial and/or centripetal patterns of removals exhibit high
583 levels of reduction. Few of the unifacial cores and partial bifacial cores show
584 this increased level of reduction intensity (Figure 6). It could be argued that
585 this pattern is a consequence of the predictive model used to estimate core
586 reduction intensity. The reduction intensity model predicts higher reduction
587 intensity as core rotation increases. This is a pattern that has been identified
588 in some experimental models of Oldowan core reduction (Douglass et al. 2017).
589 However, this is not necessarily the case. Despite the fact that cores produced
590 on Oyugis Granite and Homa Limestone are often irregular and multi-facial,
591 the predictive model still discriminates between different levels of reduction in
592 these cores. Complimentary support can be found in the flakes made from these
593 raw materials. Flakes made from exotic cores exhibit flake sequence values that
594 suggest they were produced from later in the flaking sequence. This independent
595 line of evidence suggests that the predictive model of core reduction is not over

596 estimated due to rotation. Rather, this model of reduction intensity is accurately
597 identifying estimates of the length of core use life in these exotic cores. Therefore
598 it is possible to examine the representation of various core reduction strategies
599 in terms of raw material properties and land-use.

600 The representation of reduction strategies in each raw materials type also
601 follows the interaction between raw material properties and broader land-use
602 that is described above. Raw material properties have been shown to influence
603 reduction intensity decisions previously (D. R. Braun, Plummer, Ditchfield, et al.
604 2009). The frequent application of unifacial reduction strategies to the locally
605 obtained FNy may result from the limitations imposed by the internal flaws
606 often present in the rock. In other words, hominins may have only been able to
607 exploit a single surface on these metasomatized rocks before the knapping process
608 encountered an internal flaw. Rather than attempt to overcome the flaw by
609 rotating the core, the high abundance of FNy at KJS may have made it easier to
610 simply discard the core and acquire a new nodule. High discard rates in contexts
611 of abundant raw material has been observed in numerous archaeological and
612 ethnographic contexts (Andrefsky 2008). Moreover, the technological analysis
613 of the cores suggests that the high representation of irregular multi-facial cores
614 produced in Homa Limestone (HLi) and Oyugis Granite (OGr) are the result
615 of continuous core rotation to exploit naturally occurring angles (D. R. Braun,
616 Plummer, Ditchfield, et al. 2009). The exploitation of naturally occurring angles
617 in rocks is a fairly common feature of Oldowan hominins. (Delagnes and Roche
618 2005). Yet these mechanical issues do not explain all of the patterns seen at
619 Kanjera South. Homa phonolite is one of the most homogeneous raw materials
620 found at Kanjera South. Hominins at Kanjera South frequently implemented
621 bifacial reduction strategy in these cores. It was possible to implement longer
622 reduction chains in this material than was possible with the other local materials.

623 Yet the these cores are never reduced to the same degree as that seen in the
624 exotic raw materials.

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

636 The results of the edge-to-mass ratio data suggest that hominins applied a
637 strategy that more efficiently produced flakes on rock types transported from
638 greater distances from Kanjera South. In addition, previous research shows that
639 exotic raw materials also produce more durable cutting edges (D. R. Braun,
640 Plummer, Ferraro, et al. 2009). These two factors may have incentivized the
641 retention of exotic raw materials within the hominin tool-kit. The stock of these
642 “high quality” raw materials would have become increasingly more expensive
643 (i.e. in time and energy) to rejuvenate as hominins moved away from the Kisi
644 highlands (D. R. Braun, Ditchfield, et al. 2008). In this light, the high frequency
645 of the bifacial and multifacial reduction strategies may have arisen from a need
646 to maximize the amount utility that could be extracted from these cores. The
647 exploitation of multiple flake removal surfaces on a core allows a core to remain
648 active in a toolkit for a longer period of time. In later times hominins more
649 frequently retouched formalized tools when the availability of raw materials

650 becomes scarce (Clark and Barton 2017). In a similar sense, the application of
651 complete bifacial and multifacial strategies may have allowed hominins to utilize
652 these high quality exotic materials longer to optimize resource acquisition at
653 Kanjera South.

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

677 **Implications for the Oldowan as a whole.**

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

693 Kanjera South is also the only site from this time frame that is situated in
694 an open grassland (Plummer, Ditchfield, et al. 2009). Humans tend to travel
695 farther and more frequently in open arid environments than those that live
696 in more productive environments (Burnside et al. 2012). Moreover savanna
697 adapted Chimpanzees from Fongoli also possess a larger home range and practice
698 fission-fusion less frequently (Pruetz and Bertolani 2009). If this was also the
699 case for the hominins at Kanjera South, these factors may have required new
700 technological strategies in order to accommodate expanded home range sizes.
701 On a broader scale the technological diversity represented at Kanjera South
702 may reflect adaptations to the specific contextual conditions at this locale. The
703 stimulus for increasing the use lives of cores (through reduction intensity and

704 efficient use of raw material) at Kanjera South may have been foraging activities
705 that quickly dulled artifact edges (e.g., butchery and USO processing) (D. R.
706 Braun, Ditchfield, et al. 2008; Lemorini et al. 2014) that were more frequently
707 carried out in open habitats (Ferraro et al. 2013; Lemorini et al. 2019; Plummer,
708 Bishop, et al. 2009).

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

727 Conclusion

728 Despite the superficial simplicity of the Oldowan, its variability reflects a com-
729 plex interconnection of ecological, behavioral and social factors. These factors

730 are inextricably linked even though researchers often study them components
731 in isolation. The lithic assemblage from Kanjera South provides an excellent
732 opportunity to examine the interacting effects of raw material properties, prove-
733 nance and availability of rock types and presumably social variation in the
734 form of Oldowan artifacts. This is especially important given the context of
735 other information we have from Kanjera that indicates that hominins butchered
736 multiple small animals at this site and engaged in other subsistence strategies.
737 Combination of quantitative measures of stone tool reduction with qualitative
738 characterizations of lithic technology (e.g D. R. Braun, Plummer, Ditchfield, et
739 al. (2009); Plummer and Bishop (2016)) provides new insights into the ecological
740 factors that influence oldowan technology, and hominin behavior.

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

755 This pattern also appears to have an influence on the technological strategies
756 employed by Oldowan tool makers at Kanjera South. The relationship between

757 core reduction strategies and reduction intensity indicates that raw material
758 quality and provenance have a strong influence on the technological variation
759 observed within a lithic assemblage. While these results show that ecological
760 parameters have a strong effect on stone tool variation, a substantial amount of
761 variation remains unexplained by ecology alone. Overall, these results suggest
762 that future studies must utilize a more integrated approach to understand the
763 behavioral significance of the Oldowan.

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