

¹ Imposed form in the Early Acheulean? Evidence from Gona, ² Afar, Ethiopia

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Abstract

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20 1 Introduction

²¹ The imposition of intended form on artifacts has long been viewed as a watershed in human cognitive and cultural evolution and is most commonly associated with the emergence of “Large

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23 Cutting Tools” (LCTs) in the Early Acheulean (Holloway, 1969; Isaac, 1976; Kuhn, 2020). However,
24 this interpretation of Acheulean LCTs as intentionally designed artifacts remains controversial.
25 Alternative proposals range from the possibility that LCTs were unintended by-products of flake
26 production (Moore & Perston, 2016; Noble & Davidson, 1996) to the suggestion that their form
27 was “at least partly under genetic control” (Corbey et al., 2016). Even accepting that LCT form
28 was to some extent intended, there is substantial disagreement over the specificity of design.
29 Some analyses have indicated that shape variation in Acheulean handaxes is largely a result of
30 resharpening (Iovita & McPherron, 2011; McPherron, 2000) whereas others find form to be unre-
31 lated to reduction intensity and more likely to reflect normative expectations of what handaxes
32 should look like (García-Medrano et al., 2019; Shipton & Clarkson, 2015b; Shipton & White, 2020).
33 Such debates about shape of Acheulean LCTs may appear narrowly technical but have broad
34 relevance for evolutionary questions including the origins of human culture (Corbey et al., 2016;
35 Shipton & Clarkson, 2015b; Tennie et al., 2017), language (Stout & Chaminade, 2012), teaching
36 (Gärdenfors & Höglberg, 2017), brain structure (Hecht et al., 2015), and cognition (Stout et al.,
37 2015; Wynn & Coolidge, 2016). To examine these questions, we studied the complete collection
38 of Early Acheulean flaked pieces from 5 sites at Gona Project Area and compared them with
39 Oldowan cores from 2 published sites at Gona. By comparing shape variation to measures of
40 flaking intensity and patterning, we sought to identify technological patterns that might reveal
41 intent.

42 1.1 Identifying design

43 There is a broad consensus that refined handaxes and cleavers from the later Acheulean resulted
44 from procedurally elaborate, skill intensive, and socially learned production strategies (Caruana,
45 2020; García-Medrano et al., 2019; Moore, 2020; Sharon, 2009; Shipton, 2019; Stout et al., 2014)
46 although debate over the presence of explicit, culturally transmitted shape preferences continues
47 (Iovita & McPherron, 2011; Moore, 2020; Shipton & White, 2020; Wynn & Gowlett, 2018). There is
48 much less agreement regarding the less heavily worked and formally standardized LCTs typical
49 of the earliest Acheulean (Beyene et al., 2013; Diez-Martín et al., 2015; Lepre et al., 2011; Semaw
50 et al., 2018; Torre & Mora, 2018). Such forms continue to occur with variable frequency in later
51 time periods (McNabb & Cole, 2015), and may be especially prevalent in eastern Asia (Li et al.,
52 2021). Although formal types have been recognized in the Early Acheulean and are commonly
53 used to describe assemblages, many workers now see a continuum of morphological variation

54 (Duke et al., 2021; Kuhn, 2020; Presnyakova et al., 2018) including the possibility that simple flake
55 production remained an important (Shea, 2010) or even primary (Moore & Perston, 2016) purpose
56 of Early Acheulean large core reduction.

57 Typologically, LCTs are differentiated from Mode 1 pebble cores on the basis of size (>10cm) and
58 shape (elongation and flattening) (e.g., Isaac, 1977). This consistent production of large, flat, and
59 elongated cores in the Achuelean has long been thought to reflect the pursuit of desired functional
60 and ergonomic properties for hand-held cutting tools (Wynn & Gowlett, 2018). Unplanned
61 flaking can sometimes produce cores that fall into the LCT shape range (Moore & Perston, 2016)
62 and this is one possible explanation of the relatively small “probifaces” that occur in low
63 frequencies in Oldowan assemblages (Isaac & Isaac, 1997). However, the Early Acheulean is
64 clearly distinguished from the Oldowan by the production of larger artifacts necessitating the
65 procurement and exploitation of larger raw material clasts. Although studies of handaxe variation
66 often focus on shape rather than size, this shift is an important aspect of artifact design with
67 relevance to both production and function.

68 Production of larger tools was accomplished either through a novel process of detaching and
69 working Large Flake Blanks (LFBs) from boulder cores or simply by using larger cobble and slab
70 cores (Isaac, 1969; Semaw et al., 2018; Torre & Mora, 2018). Both may involve similar flaking
71 “strategies” (e.g., bifacial or multifacial exploitation) to those present in the Oldowan (Duke et al.,
72 2021) but require more forceful percussion to detach larger flakes. This increases the perceptual
73 motor difficulty of the task (Stout, 2002) and in many cases may have been accomplished using
74 different percussive techniques and supports (Semaw et al., 2009). These new challenges would
75 have increased raw material procurement (Shea, 2010) and learning costs (Pargeter et al., 2019) as
76 well as the risk of serious injury (Gala et al., 2023) associated with tool production. This strongly
77 implies intentional pursuit of offsetting functional benefits related to size increase. These likely
78 included tool ergonomics and performance (Key & Lycett, 2017) as well as flake generation,
79 resharpening, and reuse potential (Shea, 2010). Early Acheulean LCT production is thus widely
80 seen as a part of shifting hominin behavioral ecological strategies including novel resources and
81 mobility patterns (Linares Matás & Yravedra, 2021; Rogers et al., 1994).

82 The degree of intentional design reflected in the shape of Early Acheulean LCTs is more difficult to
83 determine. For example, LFB production using a simple “least effort” bifacial/discoidal strategy
84 will tend to generate predominantly elongated (side or end struck) flakes (Toth, 1982) whether

85 or not this is an intentional design target. Similarly, the difficulty of flaking relatively spherical
86 cobbles (Toth, 1982) might bias initial clast selection and subsequent reduction toward flat and
87 elongated shapes even in the absence of explicit design targets. On the other hand, it has been
88 argued that the shape of Early Acheulean LFBs was intentionally predetermined using core
89 preparation techniques (Torre & Mora, 2018) and many researchers perceive efforts at intentional
90 shaping in the organization of flake scars on Early Acheulean handaxes and picks (Beyene et
91 al., 2013; Diez-Martín et al., 2015; Duke et al., 2021; Lepre et al., 2011; Semaw et al., 2009; Torre
92 & Mora, 2018). To date, however, the identification of Early Acheulean shaping has generally
93 relied on qualitative assessment by lithic analysts. Such assessment may in fact be reliable, but is
94 subject to concerns about potential selectivity, bias, and/or overinterpretation (Davidson, 2002;
95 Moore & Perston, 2016). Notably, a 3-dimensional morphometric (3DGM) study by Presnyakova,
96 et al. (2018) concluded that LCT shape variation in the Okote Member (~1.4 mya) at Koobi Fora
97 was largely driven by reduction intensity rather than different knapping strategies. However, this
98 study did not directly address the presence/absence of design targets constraining the observed
99 range of variation.

100 In later Acheulean contexts, reduction intensity effects are commonly equated with resharpening
101 and seen as an alternative to intentional form imposition (McPherron, 2000). Across heavily-
102 worked and relatively standardized LCT assemblages (e.g., Shipton & White, 2020), a *lack* of asso-
103 ciation between morphology and reduction intensity has been used as an argument-by-elimination
104 for the presence of imposed morphological norms or “mental templates” (García-Medrano et
105 al., 2019; Shipton et al., 2023; Shipton & Clarkson, 2015c). However, in the less heavily-worked
106 and more heterogeneous assemblages typical of the early Acheulean (Kuhn, 2020), it is equally
107 plausible that increasing reduction intensity would reflect degree of primary reduction rather
108 than subsequent resharpening (Archer & Braun, 2010). In this case, reduction intensity effects
109 on morphology would have the opposite interpretation: more reduction should result in closer
110 approximation of a desired form if such were present. For example, Beyene, et al. (2013) found
111 that increasing flake scar counts were associated with increasing handaxe refinement through
112 time at Konso, Ethiopia, which may reflect a more general trend in the African Acheulean (Shipton,
113 2018).

114 Interpretive approaches address this quandary by “reading” the organization of scars on individ-
115 ual pieces to infer intent, but an adequate method to objectively quantify these insights has yet

¹¹⁶ to be developed. Current measures of reduction intensity, such as the scar density index (SDI)
¹¹⁷ (Clarkson, 2013), are designed to estimate total mass removed from a core and are reasonably
¹¹⁸ effective (Lombao et al., 2023). However, mass removal was not the objective of Paleolithic flaking.
¹¹⁹ Indeed, knapping efficiency is usually conceived as generating an outcome while *minimizing*
¹²⁰ required mass removal. This is true whether the desired outcome is a useful flake, a rejuvenated
¹²¹ edge, or a particular core morphology. In simple flake production, mass removed is probably
¹²² a good reflection of the completeness of exploitation (“exhaustion”) of cores and may have im-
¹²³ plications for required skill (Pargeter et al., 2023; Toth, 1982) as well as raw material economy
¹²⁴ (Reeves et al., 2021; Shick, 1987). However, in core shaping and resharpening, mass removal would
¹²⁵ typically represent an energetic and raw material cost to be minimized, and might even interfere
¹²⁶ with function (Key, 2019). Without further information, relationships between artifact shape and
¹²⁷ reduction intensity are thus open to conflicting interpretations as evidence of intentional design
¹²⁸ or its absence.

¹²⁹ Li, et al. (2015) proposed a Flaked Area Index (FAI) as an alternative to SDI as a measure of
¹³⁰ reduction intensity, arguing that its validity is supported by an observed correlation ($r=0.424$) with
¹³¹ SDI. However, they also explain that “flaked area does not necessarily relate to the number of flake
¹³² scars...a small number of large scars can produce a large area of scar coverage, and conversely, a
¹³³ large number of small scars can produce a small area of scar coverage.” (p. 6). We suggest that
¹³⁴ what FAI actually captures is the spatial extent modifications to the surface of a core. It is thus
¹³⁵ complementary to the measure of volume reduction provided by SDI and provides additional
¹³⁶ information to inform technological interpretations. For example, a correlation between FAI and
¹³⁷ artifact form without any effect of SDI would suggest a focus on “least-effort” shape imposition
¹³⁸ whereas the opposite pattern would be consistent with relatively intense resharpening of spatially
¹³⁹ restricted areas on the core. A lack of shape correlation with either measure would be expected
¹⁴⁰ for simple debitage with no morphological targets whereas a strong correlation with both would
¹⁴¹ indicate a highly “designed” form achieved through extensive morphological and volumetric
¹⁴² transformation. In the current study we thus considered SDI and FAI together in order to evaluate
¹⁴³ evidence of intentional shaping in the early Acheulean of Gona.

¹⁴⁴ **1.2 Measuring artifact form and modification**

¹⁴⁵ Three-dimensional scanning and geometric morphometric (3DGM) methods are increasingly
¹⁴⁶ common in the study of LCT form and reduction intensity ([Archer & Braun, 2010](#); [Caruana, 2020](#);
¹⁴⁷ [Li et al., 2015, 2021](#); [Lycett et al., 2006](#); [Presnyakova et al., 2018](#); [Shipton & Clarkson, 2015c](#)).
¹⁴⁸ These methods provide high-resolution, coordinate-based descriptions of artifact form including
¹⁴⁹ detailed information about whole object geometric relations that is not captured by conventional
¹⁵⁰ linear measures ([Shott & Trail, 2010](#)). This includes measures of surface area used to compute
¹⁵¹ both SDI and FAI measures ([Clarkson, 2013](#); [Li et al., 2015](#)). At the time of writing, however, 3D
¹⁵² scans are available for only a small number of Gona artifacts, including 33 of the Oldowan and
¹⁵³ Acheulean flaked pieces used in this study ([Figure 1](#)). Despite continuing improvements, 3DGM
¹⁵⁴ methods still impose additional costs in terms of data collection and processing time as well as
¹⁵⁵ required equipment, software, and training. Importantly, 3DGM methods cannot be applied to
¹⁵⁶ pre-existing photographic and metric data sets (e.g., [Marshall et al., 2002](#)), including available
¹⁵⁷ data from Gona. For this reason, and to better understand the relative costs and benefits of
¹⁵⁸ 3DGM more generally, we sought to test the degree to which conventional measurements can
¹⁵⁹ approximate 3DGM methods and produce reliable results by directly comparing our conventional
¹⁶⁰ measures with 3DGM analysis of the 33 available scans.

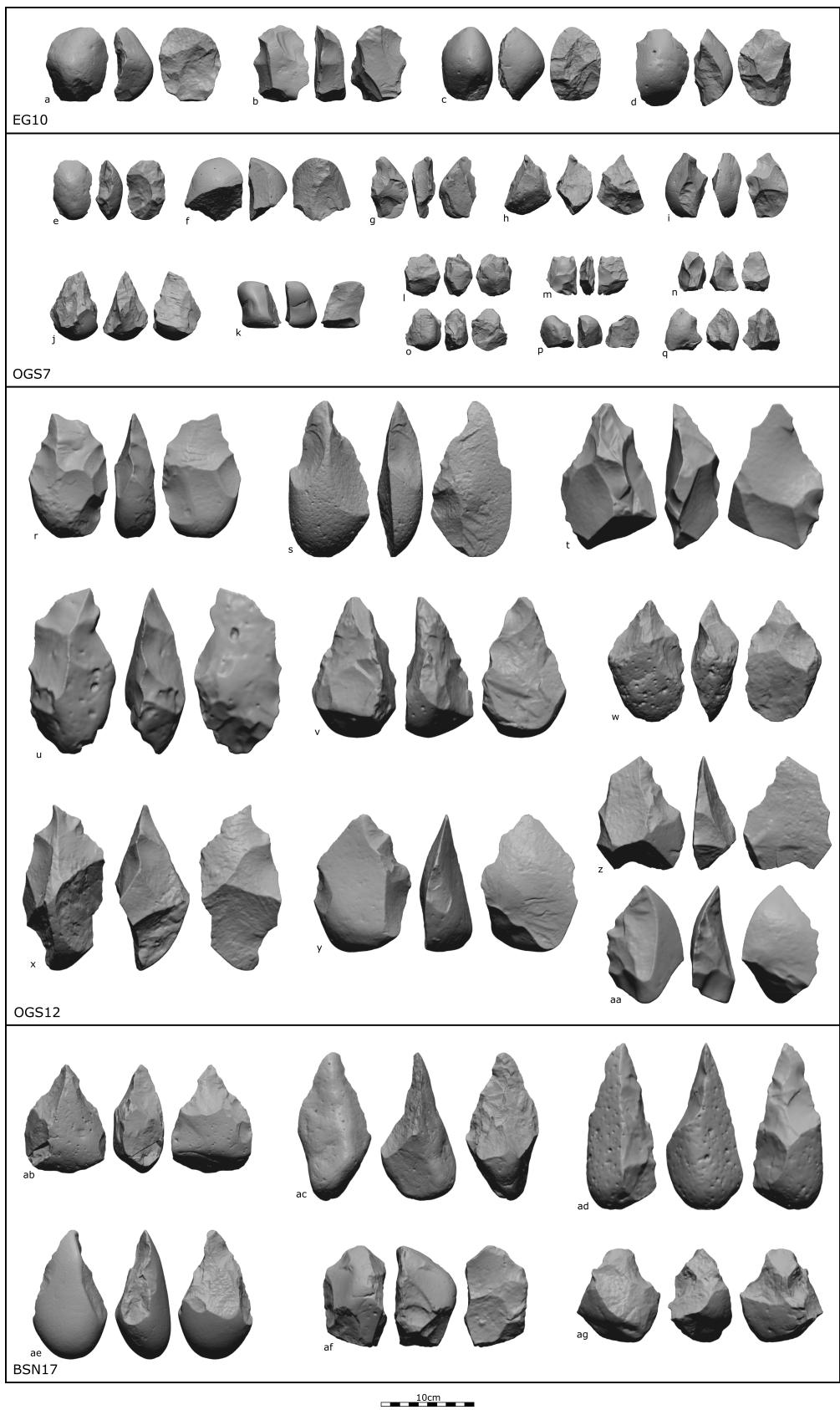


Figure 1: 3D Artifact scans from Gona used in this study.

161 For our study, we are specifically concerned with the accurate description of morphological
162 variation and estimation of artifact surface and flaked areas. With respect to morphology, we
163 were encouraged by the fact that aspects of form variation relevant to our research question (i.e.,
164 core elongation, flattening, and pointedness) are relatively simple to describe using sparse data.
165 3DGM studies of LCTs collect vast amounts of shape data but may discard upward of 50% of the
166 observed variation in order to focus on two or three interpretable principal components. Across
167 studies, these PCs consistently correspond to basic features like elongation, relative thickness,
168 pointedness, and position of maximum thickness that also emerge from lower-resolution spatial
169 data ([Archer & Braun, 2010](#); [García-Medrano et al., 2019](#); [Lycett et al., 2006](#)) and studies employing
170 linear measures rather than spatial coordinates ([Crompton & Gowlett, 1993](#); [Pargeter et al., 2019](#)).
171 There is less evidence that conventional methods can accurately estimate artifact surface and
172 flaked areas. Clarkson ([2013](#)) advocated the use of 3D surface area measures as more accurate
173 than estimation from linear measures (e.g., surface area of a rectangular prism defined by artifact
174 dimensions). However, he also found that the error introduced by the linear approach was a
175 highly systematic, isometric overestimation of surface area and that results correlated with direct
176 3D measures with an impressive $r^2 = 0.944$ and no effect of variation in core shape. Insofar as
177 it is variation in the relationship between surface area and flaking intensity that is of interest,
178 rather than absolute artifact size, such systematic overestimation may not be problematic. Similar
179 concerns apply to the estimation of flaked area. Traditionally, such estimates have been done “by
180 eye” as a percentage of the total artifact surface (e.g., [Dibble et al., 2005](#)). Such estimations have
181 been found to be reasonably accurate when compared to 3D methods, but with the potential for
182 substantial error on individual artifacts ([Lin et al., 2010](#)). The accuracy of by-eye estimation has
183 yet to be systematically studied in Early Stone Age cores like those from Gona.

184 1.3 The Early Acheulean at Gona

185 Early Acheulean sites in the Gona Project area are distributed over a wide area within the Dana
186 Aoule North (DAN), Ounda Gona South (OGS), and Busidima North (BSN) drainages in the
187 Busidima Formation ([Quade et al., 2004](#)) and range in age from approximately 1.7 to 1.2 mya
188 ([Semaw et al., 2018](#)). The specific sites included in the current analysis are DAN-5, OGS-5, OGS-12,
189 and BSN-17, all estimated to ca. 1.7 – 1.4 mya by stratigraphic position in the Gona sequence
190 ([Quade et al., 2008](#); [Semaw et al., 2020](#)). The Busidima Formation accumulated through fluvial
191 deposition by the ancestral Awash River (Type I context) and its smaller tributary channels (Type

192 II context) (Quade et al., 2004, 2008). Oldowan sites at Gona all occur in Type I sediments,
193 indicating channel bank/margin (OGS-7) or proximal floodplain (EG-10, EG-12) contexts close
194 to the large, hetero-lithic clasts available from point bars in the axial river channel (Quade et al.,
195 2004; Stout et al., 2005). Acheulean sites continue to occur in Type I contexts (BSN-17, DAN-5)
196 but are also found in Type II sediments (OGS-5, OGS-12,) reflecting increased utilization of large
197 perennial tributaries to the ancestral Awash River (Quade et al., 2008). Clasts locally available
198 in these tributaries were relatively small, implying that the large flakes and cobbles used to
199 produce Acheulean artifacts were initially sourced from the axial river. A similar pattern of habitat
200 diversification and increasing lithic transport distances has been described at other sites and
201 may be typical of the early Acheulean (Hay, 1976; Linares Matás & Yravedra, 2021; Rogers et
202 al., 1994). As with other early (i.e. >1.0 mya (Presnyakova et al., 2018; Stout, 2011)) Acheulean
203 assemblages, the Gona collections include numerous “crudely made” handaxes and picks on large
204 flake blanks and cobbles, as well as large (> 10cm) unmodified flakes, flaked pieces interpreted
205 typo-technologically as Mode 1 cores (see Figure 1af), and smallerdebitage (Semaw et al., 2018;
206 Semaw et al., 2020).

207 2 Materials and Methods

208 2.1 Materials

209 2.1.1 Archaeological Sample

210 Artifact collections analyzed here include *in situ* pieces excavated from intact stratigraphic
211 contexts and surface pieces systematically collected from the sediments eroding from these
212 layers. Surface pieces are included because the current technological analysis does not require
213 more precise spatial association, stratigraphic, and chronological control. Our sample comprises
214 the total collection of flaked pieces (Isaac & Isaac, 1997) and large (>10 cm) detached pieces from
215 each site, regardless of typo-technological interpretation.

216 2.2 Methods

217 2.2.1 Artifact Classification

218 Artifacts were classified according to initial form (pebble/cobble, detached piece, or indetermi-
219 nate), presence/absence of retouch, technological interpretation (“Mode 1” core vs. “Mode 2”

²²⁰ LCT), and archaeological context (Oldowan vs. Early Acheulean sites). LCTs were additionally
²²¹ classified as handaxes, knives, or picks following definitions from Kleindienst ([1962](#)). The validity
²²² of technological interpretations and typological classifications was assessed through cluster
²²³ analysis based on artifact shape and reduction intensity variables.

²²⁴ **2.2.2 Artifact Measurement**

²²⁵ Conventional linear measures capture the direction (e.g., length > breadth) but not the location of
²²⁶ geometric relations (e.g., position of maximum breadth). We address this by collecting linear mea-
²²⁷ sures defined by homologous semi-landmarks. All artifacts were oriented along their maximum
²²⁸ dimension, which was measured and defined as “length.” The next largest dimension orthogonal
²²⁹ to length was used to define the plane of “breadth,” with the dimension orthogonal to this plane
²³⁰ defined as “thickness” Width (W_1, W_2, W_3) and thickness (T_1, T_2, T_3) measures were then collected
²³¹ at 25%, 50%, and 75% of length, oriented so that 25% Width > 75% Width. To partition variation
²³² in shape from variation in size, we divided all linear measures by the geometric mean ([Lycett et](#)
²³³ [al., 2006](#)). GM-transformed variables were then submitted to a Principal Components Analysis
²³⁴ (covariance matrix) to identify the main dimensions of shape variation.

²³⁵ Our semi-landmark measurement system allowed us to improve on the prism-based surface area
²³⁶ formula ($2LW + 2LT + 2WT$) by using our 7 recorded dimensions to more tightly fit three prisms
²³⁷ around the artifact: $SA = W_1T_1 + 2(.33L * W_1) + 2(.33L * T_1) + 2(.33L * W_2) + 2(.33L * T_2) + 2(.33L *$
²³⁸ $W_3) + 2(.33L * T_3) + W_3T_3$. Surface area calculated in this way correlates with mass^{2/3} at $r^2 = 0.947$
²³⁹ in our sample. Calculated surface area was then used to derive the Scar Density Index: SDI =
²⁴⁰ number of flake scars > 1cm per unit surface area ([Clarkson, 2013](#); [Shipton & Clarkson, 2015a](#)).
²⁴¹ The Flaked Area Index (FAI: flaked area divided by total surface area) ([Li et al., 2015](#)) was estimated
²⁴² directly “by eye” as a percentage of the total artifact surface.

²⁴³ **2.2.3 3D Methods**

²⁴⁴ Artifact scans (N=33) were cleaned, smoothed, and re-meshed using MeshLab. The 3D triangular
²⁴⁵ mesh of each scan was computed using Kazhdan and Hoppe’s ([2013](#)) method of screened Poisson
²⁴⁶ surface reconstruction in MeshLab. 3DGM analysis was conducted using the *AGMT3-D* program
²⁴⁷ of Herzlinger and Grosman ([2018](#)). Artifacts were automatically oriented according to the axis
²⁴⁸ of least asymmetry, then manually oriented in the interests of standardization with the length,

width, and thickness dimensions defined by the longest axis, followed by the next two longest axes perpendicular to the first. The wider end of the artifacts was positioned as the proximal end (base), and more protruding surfaces were oriented towards the user in the first orthogonal view. Then, a grid of 200 homologous semi-landmarks were overlain on each artifact's surface. Generalized Procrustes and Principal Component analyses were then undertaken to explore the shape variability of the sample. The surface area of each artifact was calculated using the *Artifact3-D* program of Grosman et al. (2022). *Artifact3-D* was also used to automatically identify the flake scar boundaries and compute each scar's surface area, using the scar analysis functions of Richardson et al. (2014).

2.2.4 Analyses

Measurement Validation: To assess the adequacy of shape descriptions based on our linear measures, we directly compared these with shape as quantified by 3D methods on the 33 artifacts for which scans are available. GM-transformed linear measures from these 33 artifacts were submitted to a variance-covariance matrix PCA. PCs with an eigenvalue greater than the mean were retained for analysis and the results compared qualitatively (morphological interpretation of PCs) and quantitatively (correlation of artifact factor scores) to 3D results. Accuracy of surface area and flaked area estimates was also assessed by correlation with 3D results.

3 Results

3.1 Measurement Validation

A PCA on GM transformed linear measures the 33 artifacts identified two PCs accounting for 75.6% of the variance. Linear-PC1 (Eigenvalue = 0.189) explained 55.2% of the variance. Factor loadings (Table 1) for Linear-PC1 reflect artifact elongation (i.e., an anti-correlation of length vs. distal width and thickness). This A PCA on GM transformed linear measures the 33 artifacts identified two PCs accounting for 75.6% of the variance. Linear-PC1 (Eigenvalue = 0.189) explained 55.2% of the variance. Factor loadings (Table 1) for Linear-PC1 reflect artifact elongation (i.e., an anti-correlation of length vs. distal width and thickness). This closely parallels the length vs. width and thickness tradeoff captured by 3DGM-PC1 (Figure 3a) and is reflected in a tight correlation of artifact scores produced by the two PCs ($r = 0.903$, $p < 0.001$, Figure 3c). Comparison with

conventional shape ratios (Table 2) similarly indicates that both Linear-PC1 and 3DGM-PC1 largely capture variation in artifact elongation. A second factor (Linear-PC2, eigenvalue = 0.07) explained an additional 20.4% of variance. This factor was less strongly correlated with its 3DGM counterpart (3DGM-PC2; $r = 0.344$, $p = 0.050$) probably because Linear-PC2 describes anticorrelated variation in width and thickness (i.e., broad and flat vs. thick and pointed; Tables 1 & 2) whereas 3DGM-PC2 more purely isolates convergence (Table 2). The remainder of the shape variability explained by Linear-PC2 is captured by higher order 3DGM-PCs like 3DGM-PC3 to 5, which comprise the contribution of the left and right lateral margins to relative thickness. Including a third dimension in the GM analysis generates PCs that identify more specific shape attributes, but the underlying morphological variability captured by both the 2D and 3D analyses remains similar. Together, 3DGM-PC2 ($r = 0.344$, $p = 0.050$), 3DGM-PC3 ($r = -0.416$, $p = 0.016$), 3DGM-PC4 ($r = 0.458$, $p = 0.007$), and 3DGM-PC5 ($r = -0.352$, $p = 0.044$) correlate well with Linear-PC2, cumulatively capturing whether the items are broad and flat or thick and pointed.

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