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COMPARING MORPHOLOGICAL VARIABILITY IN HANDAXES FROM PENHILL FARM AND AMANZI SPRINGS, EASTERN CAPE, SOUTH AFRICA

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ABSTRACT
Recent excavations at Penhill Farm and Amanzi Springs have reinvigorated interest in the Acheulean archaeological record of the Eastern Cape Province, South Africa. While this research now provides valuable detail on hominin adaptations in environments that differ from the interior, few Acheulean assemblages in this region have been recorded or thoroughly analysed. Here we compare Acheulean handaxes from Penhill Farm and the Amanzi Springs Area 1 locality to help characterise the expression of this technocomplex in the Eastern Cape. We employ a multivariate analysis of allometry to highlight the relationship between shape variance in relation to the size of handaxes, which further provide perspective on shaping processes. Results demonstrate high levels of techno-morphological variability that may distinguish Acheulean handaxes in the Eastern Cape region from sites elsewhere. We further argue that morphological variation in handaxes from Penhill Farm and Amanzi Springs may have also been influenced by site function, discard behaviours and group mobility patterns. These data refute the notion that the Acheulean technocomplex represents a single, homogenous technological entity, but rather was a flexible tradition that was influenced by region-specific factors.

Keywords: handaxes, allometry, Acheulean, Penhill Farm, Amanzi Springs

1. Introduction

Acheulean sites in the Sundays River Valley (SRV, namely Penhill – PHF, Atmar and Bernol Farms) and at Amanzi Springs (AMS; located in the neighbouring Coega River Valley) have increased resolution both on the timing and nature of technological trends within the Earlier Stone Age sequence of the Eastern Cape Province (Fig. 1) (Lotter & Kuman 2018a, b; Caruana & Herries 2020, 2021; Lotter 2020a, b, in press a; Lotter & Caruana 2021; Mesfin et al. 2021; Herries et al. in press; Lotter et al. submitted). The SRV and AMS are within 25 km of each other, and their raw materials are both predominated by similar quartzite lithologies (Deacon 1970; Lotter & Kuman 2018a, b; Lotter 2020a, b; Lotter & Caruana 2021; Mesfin et al. 2021; Herries et al. in press). While the Sundays River sites are older (ca. <1.4 to >0.5 Ma) than AMS (ca. 0.4 Ma), this paper explores whether there are consistencies in the morphological features of handaxes, given that these sites have similar proximities to usable toolstone sources.

Comparisons between Acheulean sites in the Eastern Cape have never been conducted, and the degree of technological variability observed within this region remains unknown. While numerous Acheulean localities have been documented in the Eastern Cape (see Davies 1971, 1972; Sampson 1974), only a few have been described, and with varying levels of detail (e.g., Geelhoutboom – Laidler 1947; AMS – Deacon 1970). Characterising Acheulean technology from the Eastern Cape is important for investigating regional trends in tool production and mobility patterns. The Acheulean technocomplex has been described as a conservative cultural entity due to the ubiquity of large cutting tools (LCTs; e.g., handaxes and cleavers) and their common forms (Clark 1994; Corbey et al. 2016). However, some studies have noted regional differences in handaxe forms that suggest either adaptations to local raw materials, differences in motor-cognitive capacities or the possibility of population-level cultural traditions in Acheulean technology (Wynn & Tierson 1990; Lycett & Gowlett 2008; Shipton & Petraglia 2011; White et al. 2019). We focus on handaxes because they have been used to characterise differences in both morphologies and production strategies across the Acheulean technocomplex.

We use a multivariate analysis of allometry to investigate the relationship between the size and shape of these tools (Crompton & Gowlett 1993; Gowlett & Crompton 1994). This method provides insight into how knappers balanced the morphological (i.e., size + shape) proportions throughout reduction processes. Given the elongated nature of these tools, Acheulean toolmakers manage width and thickness proportions to maintain intended shapes, edge angles and the centre of mass (Gowlett 2006, 2011, 2013, 2021). Thus, understanding how specific proportions of handaxes scale with size provides insight into the shaping strategies of ancient knappers. We assess allometric differences between Penhill Farm and Amanzi Springs to highlight levels of techno-morphological variability, which are then compared to other Acheulean sites beyond the Eastern Cape Province. In contrast to the notion of cultural conservatism defining the Acheulean technocomplex, our study highlights differences in both the allometric patterns and shaping processes that structured handaxe forms across the analysed assemblages. We argue that differences in handaxe morphologies at PHF and AMS were influenced by site function, raw material constraints and group mobility, which in turn define patterns of regional variation.

Here we present the first preliminary comparison between PHF and AMS to explore regional variability.

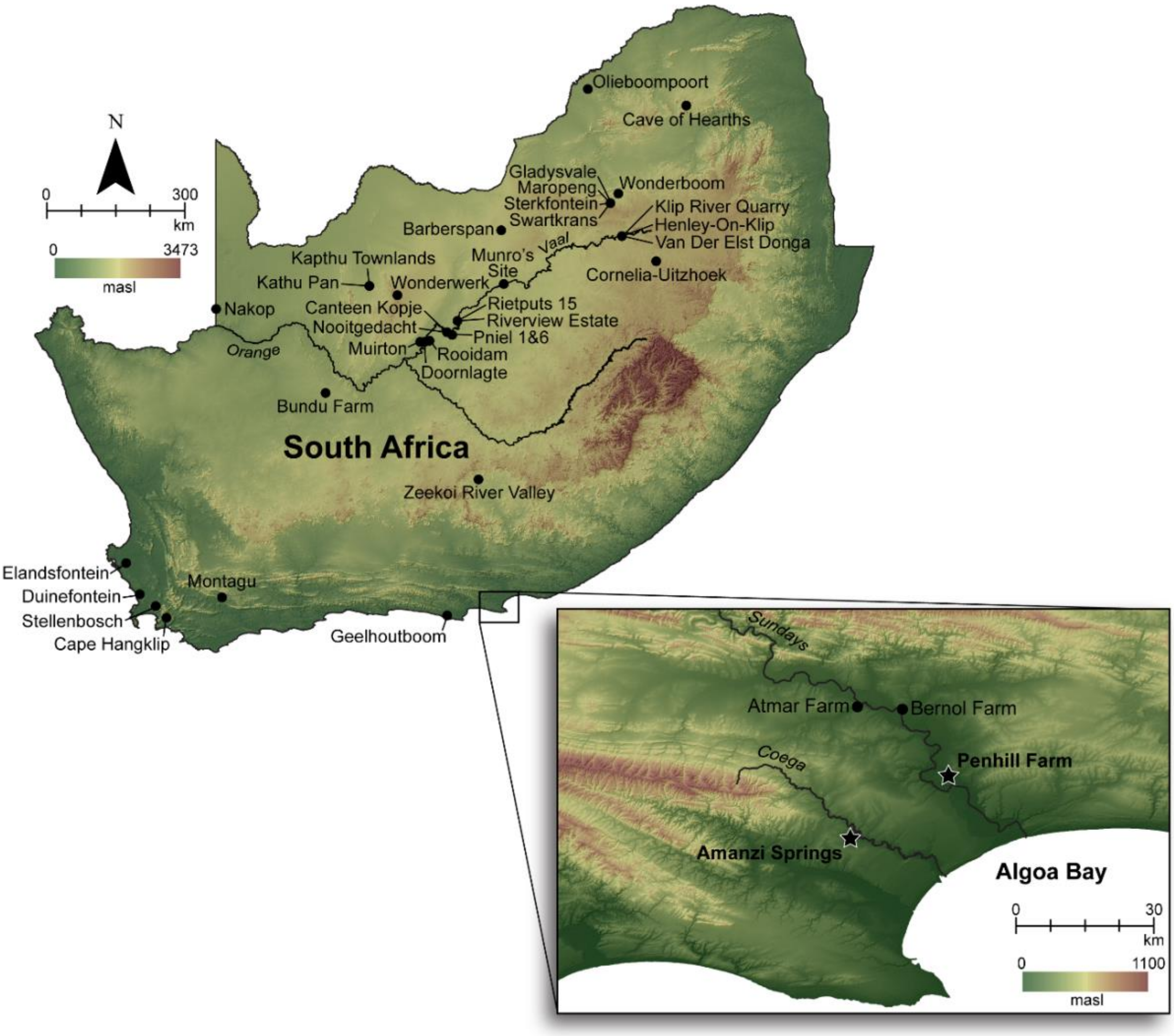

Figure 1. Map of South Africa (upper left) showing the geographic distribution of Acheulean sites. Inlay (bottom right) shows the location of Penhill Farm (Sundays River Valley) and Amanzi Springs (Coega River Valley).

2. Background

Regional trends or one homogenous entity?

Since its definition, the Acheulean technocomplex has been conceptualised as a wide-spread, homogenous cultural entity, largely based on the ubiquity of LCTs. Upon initial observations, handaxes are relatively consistent in their morphology across both spatial and temporal scales, which have led some researchers to suggest that Acheulean culture was 'static' in nature (Clark 1994; Corbey et al. 2016). However, focused studies on the size and shape of these tools have consistently noted high levels of variability, which now defines modern research agendas in Acheulean archaeology (see Lycett et al. 2016).

In South Africa, research on handaxe morphologies have identified trends in variability that challenge past notions of 'refinement through time' (Hodgson 2015). Comparisons between early and later Acheulean assemblages have revealed that the later period is typified by a high degree of variation in both size and shape, and that planview symmetry is not correlated with chronology (Li et al. 2018; Caruana 2020, 2021; Caruana & Herries 2021). However, differences in shaping strategies are noted between early and later Acheulean handaxes, where the latter examples show an increase in thinning of tip regions (Caruana 2020, 2021).

While variability through time has been explored in the South African Acheulean, the question of regional trends remains open to interpretation. Past research has noted potential inter-regional differences in handaxe forms. Comparing later Acheulean assemblages from eastern Africa, India, West Asia and Europe, Wynn and Tierson (1990) noted that handaxes from Israel were distinct in planview shape, which were consistently wider in form. Given the chronological affiliation to the Middle Pleistocene of sites compared, they hypothesised that shape differences were either due to raw materials or potentially local cultural traditions. Lycett and Gowlett (2008) used multivariate statistics to compare handaxes from eastern Africa, Korea and India to assess variation across the 'Movius line'. They found subtle differences in linear proportions that may reflect regional differences, supported by within-group variation in knapping techniques and cultural transmission. Shipton and Petraglia (2011) compared handaxes from the Arabian Peninsula, India, Korea, China, and eastern Africa to test if the eastern Asian Acheulean assemblages were similar to those from Africa. Their results suggested that handaxes from Korea and the Baise (Bose) Basin in China were morphometrically distinct in terms of refinement (width/thickness – w/th) and weight, respectively.

Thus, inter-regional comparisons have the potential to refine our understanding of Acheulean variability. While the reasons for variation in handaxe forms are debateable, regional trends in how handaxes were reduced and their resulting shapes may distinguish Acheulean assemblages. For example, Li et al. (2021) used geometric morphometric methods to assess variability in handaxe morphologies from the Baise Basin in China and found that 'tongue-like' handaxe tips were characteristic of this area, which may represent a regional adaptation to wood working (also see Lei et al. 2021; Li & Lotter submitted). This corroborates some of Shipton and Petraglia's (2011) earlier conclusions that the Baise Basin handaxes are regionally distinct, which may have implications for functionality and mobility patterns (Li et al. 2021, 2022).

Therefore, it is increasingly important to examine variability on regional scales, although such studies are largely lacking in the southern African context. Given the general dearth of information on the Eastern Cape Acheulean, we attempt to characterise handaxe production and morphologies through comparing samples from PHF and AMS Area 1. Below we test the hypothesis that handaxe technology is ubiquitous within this region and compare resulting trends with other early and later Acheulean assemblages to contextualise our results. A brief summary of the sites is presented below to characterise the handaxe samples.

Penhill Farm

PHF occurs in Terrace 9 of the lower Sundays River Valley, in one of thirteen terraces that occur within the lower valley that collectively span the Miocene to the Holocene (Erlanger et al. 2012). Their sedimentological composition is predominantly gravel and fine silts and sands, the former of which are extremely rich in quartzite and sandstone and account for >95% of all clasts downstream (Ruddock 1948; Hattingh 1994; Hattingh & Rust 1999). Their geological composition reflects that of the upstream Klein Winterhoek Mountains, which comprise the easternmost limit of the Cape Fold Mountains (Witteberg Group, Cape Supergroup) (Ruddock 1948; Hattingh 1994; Hattingh & Rust 1999). In addition, a limited number of clasts from the Zuurberg basalt and Enon, Kirkwood, and Sundays River Formations are also present in the terrace gravels (Hattingh 1994).

During a recent cosmogenic isochron burial dating study of the terraces, Erlanger and colleagues (2012) observed *in situ* Acheulean handaxes at PHF and their dating results provided an age of 1.36±0.36 Ma (later revised to 1.37±0.16 Ma) for the local deposition of the Terrace 9 alluvium, within which they suspected the artefacts were preserved (Granger et al. 2013). Subsequently, Lotter (2016) conducted an excavation to target the artefact-bearing deposits and later established that the artefacts are instead preserved within a secondary context debris flow, which infilled the base of an erosional channel (gully or donga) that cut its way into the surrounding sterile Terrace 9 alluvium. As a result, the PHF burial age does not pertain directly to the artefacts but rather, it serves as a maximum chronological constraint (for discussion on new dating currently underway, see Lotter et al. submitted).

Basic techno-typological descriptions and regional inter-site comparisons of the PHF assemblage have been provided in several recent papers (Lotter & Kuman 2018a, Lotter 2020a, b; Lotter & Caruana 2021; Mesfin et al. 2021; Lotter in press a, b). It is comprised of 9904 artefacts in total, a limited number of LCTs (n=49, with n=16 handaxes), and over 85% of all artefacts have been produced on quartzite and less frequently on siltstone (n=363, 7.5%) and hornfels (n=255, 5.2%). Lotter (2020a) explores the techno-morphological characteristics of the PHF handaxes through several analyses, documenting trends in the mean technological measurements and size ratios where there are clear differences between those made on quartzite (n=11, 68.8%) and those on siltstone (n=5, 31.2%), the only two raw materials represented. The latter are consistently larger and heavier, more elongated and less refined, and this is the result of the larger blank properties of siltstone as opposed to underlying differential trends in shaping by raw material (Lotter 2020a; Lotter & Caruana 2021). In terms of production, large flake blanks were favoured and flaked bifacially across the majority of tool portions while retaining some cortex. Given the abundance of suitably large cobbles in the local landscape, this illustrates a clear preference by hominins to procure large flakes for tool blanks, versus using what was immediately available in exposed terraces and from the nearby river. Given the on-site abundance of flaking debris and debitage, it is clear that production accounts for the majority of activities, but the over-representation of flakes on raw material types that are not reflected in the core sample talks to the possibility of some off-site flaking. This is further supported by the consistent over-representation of large flakes (60 mm up to those >120 mm) on-site when compared with the negative flake scar dimensions on core surfaces, along with a series of flake, core and scar ratios (see Lotter & Caruana 2021). Collectively, this supports the idea that hominins were acquiring large flake blanks possibly from large boulder cores off-site (as documented at other SRV sites, see Lotter & Kuman 2018b), subsequently transporting them on-site specifically for handaxe production. Overall, this talks to variable procurement strategies and mobility throughout the valley for tool production purposes, which is further supported by Mesfin et al. (2021) in their recent investigation of local raw material exposures and their comparison of local cobble blank properties to those in the PHF assemblage (Mesfin et al. 2021).

Amanzi Springs

AMS was first systematically excavated by Inskeep (1965) followed by Deacon (1970), who excavated two spring eyes, referred to as Areas 1 and 2. Deacon (1970) originally described three sedimentary Members (Enqurha, Rietheuvel, and Balmoral; ordered oldest to youngest), although Herries et al. (in press) recently reassessed the stratigraphy of Area 1 and dated its artefact-bearing layers using a combination of single-grain, thermally transferred optically stimulated luminescence, multi-grain post-infrared stimulated luminescence and palaeomagnetic techniques to ~400 ka.

In terms of the lithic assemblages from AMS, quartzite lithologies represent the vast majority of raw materials used to produce artefacts at Areas 1 and 2 (Deacon 1970; Herries et al. in press). In fact, 98.8% of the Area 1 assemblage is comprised of quartzites derived from the Enon Formation (Uitenhage Group) (Herries et al. in press). These quartzites were initially formed within the Peninsula Formation Sandstones (Table Mountain Group), located in the eastern Cape Fold Belt, and incorporated into the Enon conglomerates during pre-Cretaceous times (Booth & Shone 2002; Muir et al. 2017). As the Enon conglomerates were eroded during or after the Cretaceous period, quartzite nodules were deflated onto the landscape around Amanzi Springs and incorporated into the bedload of the nearby Coega River (~2 km north of the spring sites) (Deacon 1970; Herries et al. in press).

Deacon (1970: 11) initially described the AMS lithic collections as "large and unstandardised," noting variation in their morphologies across all tool types. Later, Sharon (2007) compared linear measurements of handaxes from Amanzi Springs to 21 other Acheulean sites across Africa, West Asia and India, and found that they were significantly larger in both thickness and mass proportions. He suggested that AMS may in fact represent a 'workshop' site where handaxes and cleavers were discarded before being thinned, similar to STIC (Morocco) and Isimila K19 (Tanzania). Caruana and Herries (2020, 2021; Herries et al. in press) have recently supported the workshop hypothesis for the Area 1 spring eye. They used linear measurements and three-dimensional scans of Area 1 handaxes to compare morphologies with other Acheulean sites in South Africa, including the Cave of Hearths (<780 ka; Latham & Herries 2009) and Rietputs 15 (~1.31 Ma; Leader et al. 2018). In an initial study, Caruana and Herries (2020) used Gowlett's (Crompton & Gowlett 1993; Gowlett & Crompton 1994) methods for analysing multivariate allometry to compare handaxes from AMS Area 1, the Cave of Hearths and Rietputs 15, which found that the Area 1 specimens were larger in width, thickness and mass proportions. While they characterised allometric trends across all three sites, Caruana and Herries (2020) found that the Area 1 handaxes were more morphologically similar to the Rietputs 15 rather than to the Cave of Hearths, despite the Middle Pleistocene chronology of the Area 1 assemblage.

Later, Caruana and Herries (2021) examined the potential causes of the 'large and unstandardised' morphologies of Area 1 handaxes and compared their variability to the size of step and hinge fractures (surface flaws). They hypothesised that a significant correlation between these features might indicate that the development of surface flaws during handaxe reduction impeded shaping processes and led to early discard. They further analysed handaxe cross-sectional shapes in the tip region to assess the intensity of bifacial thinning that took place (see Caruana 2022). A significant relationship was found between morphological variability and the size of surface flaws, and tip cross sections were found to be amorphous and triangular in shape, which indicated a lack of thinning. Caruana and Herries (2021) concluded that the majority of Area 1 handaxes were likely abandoned after primary shaping, which skewed morphological variability in this assemblage and corroborated the workshop hypothesis (see Barkai et al. 2002; Sharon 2007).

More recently, Herries et al. (in press) found more of evidence of on-site LCT manufacturing at Area 1 including giant cores, large flake blanks and bifacial shaping flakes. They suggest that Middle Pleistocene hominins periodically occupied AMS to take advantage of the unique floral and faunal resources, as well as access useable toolstone. Occupational sequences may not have been long as Acheulean groups were likely highly mobile, but the number of stone tools recovered from Area 1 implies that groups repeatedly returned to the spring sites over the Middle Pleistocene period. In terms of handaxes, Herries et al. (in press) found that they were larger and more variable in linear proportions when compared to cleavers, picks and knives. They further noted that the surfaces of these tools lacked signs of extensive thinning despite the affiliation of this assemblage to the later Acheulean period. Cortical surfaces ranged from 0-30% in handaxes, which was mostly concentrated on mid and basal tool portions, and an average of 15.5 flake scars were recorded. Herries et al. (in press) also found that 57.3% of handaxes were made on cobbles, while 30.5% were produced on large flake blanks.

3. Materials and methods

All the handaxes from PHF (n=16) and 75 from AMS Area 1 (hereafter AMS1) were examined (Fig. 2). We note that the unequal sample sizes may skew perspectives on degrees of morphological variation. However, multivariate allometry is largely based on the independent assessment of assemblages to identify size-shape relationships, which limits any potential issues of statistical 'overpowering' by the

AMS1 sample. We further compared these Eastern Cape assemblages with 85 handaxes from Rietputs 15 (~1.31 Ma; Leader et al. 2018), and 50 handaxes from the Cave of Hearths (<0.78 Ma; Latham & Herries 2009), which are used here as representative samples of early and later Acheulean, and to compare morphological variability in southern Africa handaxes (Li et al. 2018; Caruana 2020).

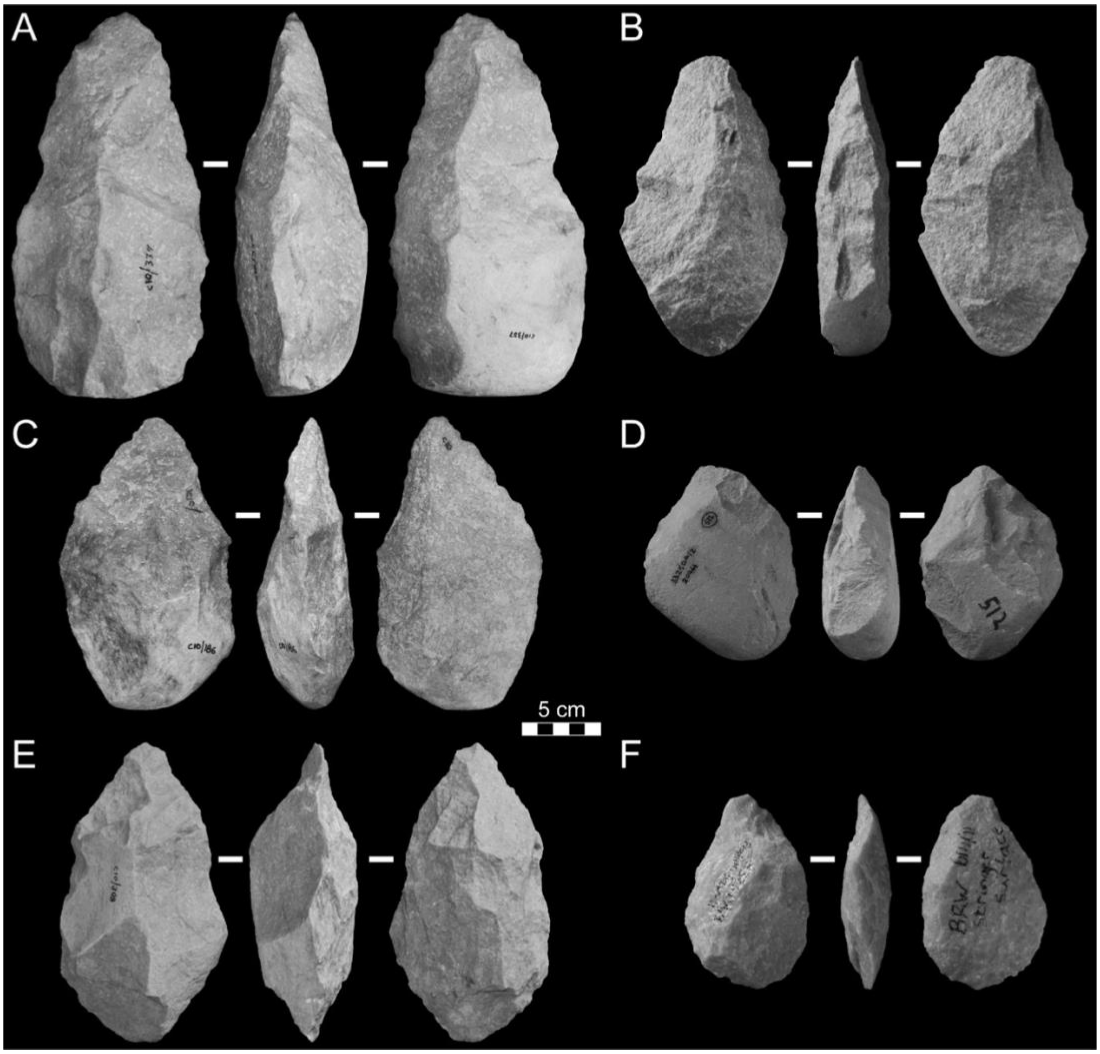

Figure 2. Handaxes from Amanzi Springs Area 1 (a, c, e) and Penhill Farm (b, d, f).

To compare handaxe morphologies we draw upon Crompton and Gowlett's (1993; Gowlett & Crompton 1994) multivariate allometry (MVA) methods, which calculates allometric components (AC) for linear measurements. This is operationalised through principal component analysis (PCA) using a covariance matrix on log-transformed variables. The first principal component (PC1) subsequently captures size variation. Rescaling PC1 coefficients to a mean of one can then be used as ACs that measure size-shape relationships, where values of one represent isometry (variables remain constant with increases in size), while values under one represent negative allometry (variables that decrease with increases in size) and values over one represent positive allometry (variables that increase with increases in size) (Crompton & Gowlett 1993). Comparing allometric trends (i.e., ACs) with degrees of variation in linear measurements, calculated through coefficient of variation (CV) scores, further provides insights into the balance of size-shape proportions in handaxes, which Crompton and Gowlett (1993; Gowlett & Crompton 1994; Gowlett 2006) used to define reduction 'rule-sets'. Consistency in handaxe proportions through allometric scaling suggests that Acheulean toolmakers managed the proportions of handaxes through the knapping process relative to their size, which had potential functional implications (Gowlett 2006; Key et al. 2016; Key & Lycett 2017, 2020). We utilise these MVA methods while appreciating their potential shortfalls when being used to infer reduction intensity (see recent work by Mika et al. in press) – something that is not explored in this paper.

We present the following set of analyses to explore morphological variability in handaxes from PHF and AMS1:

1. We compared linear measurements (mm), including maximum length, width, thickness; width and thickness for tip, midsection and base regions (defined as 1/5, 1/2 and 3/5 of the tool length); the position of the widest point measured from the base end. We also compare mass (g), surface area (mm^2), total scar count and the Scar Density Index (SDI – scar count/surface area; see Shipton & Clarkson 2015); and elongation (l/w) and refinement (w/th) ratios defined by Roe (1969). We use Mann-Whitney U tests to compare these variables in terms of significant differences (α=0.05), and boxplots to graphically represent techno-morphological trends.
2. We conducted a PCA of PHF and AMS1 based on ten linear measurements (maximum length, width, thickness; width and thickness for tip, midsection and base regions; the position of the widest point measured from the base end), which were log-transformed to minimise the effects of non-normality. We exclude mass due to its overlap with geometric size as noted by Crompton and Gowlett (1993). A covariance matrix was used to conduct the PCA to highlight size-shape relationships in multivariate space.
3. Inter-site MVA: we first plotted CV values for PHF, AMS1, Rietputs 15 and the Cave of Hearths based on the ten linear measurements used on the MVA. A second series of PCAs were conducted using a covariance matrix to highlight size-shape relationships. PC1 coefficients were extracted and scaled to a mean of one, which are used as AC scores. A line graph was used to compare allometric trends between the four assemblages, which highlight trends in size-shape relationships.
4. A third PCA was conducted that combined PHF and AMS1 samples into a single 'Eastern Cape sample' to calculate AC scores, which were then compared to Rietputs 15 and the Cave of Hearths to test the notion of regional trends.

4. Results

Techno-morphological traits

Table 1 compares techno-morphological traits of handaxes between PHF and AMS1, the Cave of Hearths and Rietputs 15. Mean and median values for all linear measurements are larger in the AMS1 sample when compared to PHF. Mann-Whitney U tests comparing linear measurements and mass are significant, aside from position of maximum width (PMW) and midsection width (SOM Table 1). Figure 3 displays boxplots for mass, SDI, elongation and refinement variables, which provide some perspective on general techno-morphological patterns. Mass is higher in the AMS1 sample when compared to PHF, although SDI values are not significantly different, suggesting that neither assemblage was intensely reduced. Elongation values are significantly higher in AMS1 when compared to PHF, although the opposite trend is observed in refinement. AMS1 handaxes are also significantly larger than Rietputs 15 and the Cave of Hearths in terms of mass, while the Cave of Hearths is significantly higher in SDI values when compared to all other assemblages. PHF is slightly smaller in elongation when compared to Cave of Hearths, although Mann-Whitney U results are near the alpha level, while AMS1 shows significant differences with the Cave of Hearths. For refinement, PHF is higher in proportion when compared to Rietputs 15, and AMS1 shows the opposite trend with the Cave of Hearths.

Principal component analysis – Penhill Farm and Amanzi Springs Area 1

In the PCA comparing PHF and AMS1, ten principal components were extracted. The first principal component (PC1) accounted for overall size, and all variables loaded strongly onto this axis, aside from PMW (SOM Tables 1-3). The second principal component (PC2) is more complex, where maximum thickness, along with tip, midsection and base thicknesses load strongest onto the positive axis, and PMW defines the negative end, along with length and tip width to a lesser extent (SOM Tables 2 & 3). The principal component scatterplot displays differences in group clustering patterns for PHF and AMS1, where PHF is skewed towards the negative end of PC1, and slightly towards negative PC2, while AMS1 is centred with an even dispersion of points on both PC axes (Fig. 4). These scatter patterns suggest that PHF geometric shape-size variables are consistently smaller when compared to AMS1 (Table 1).

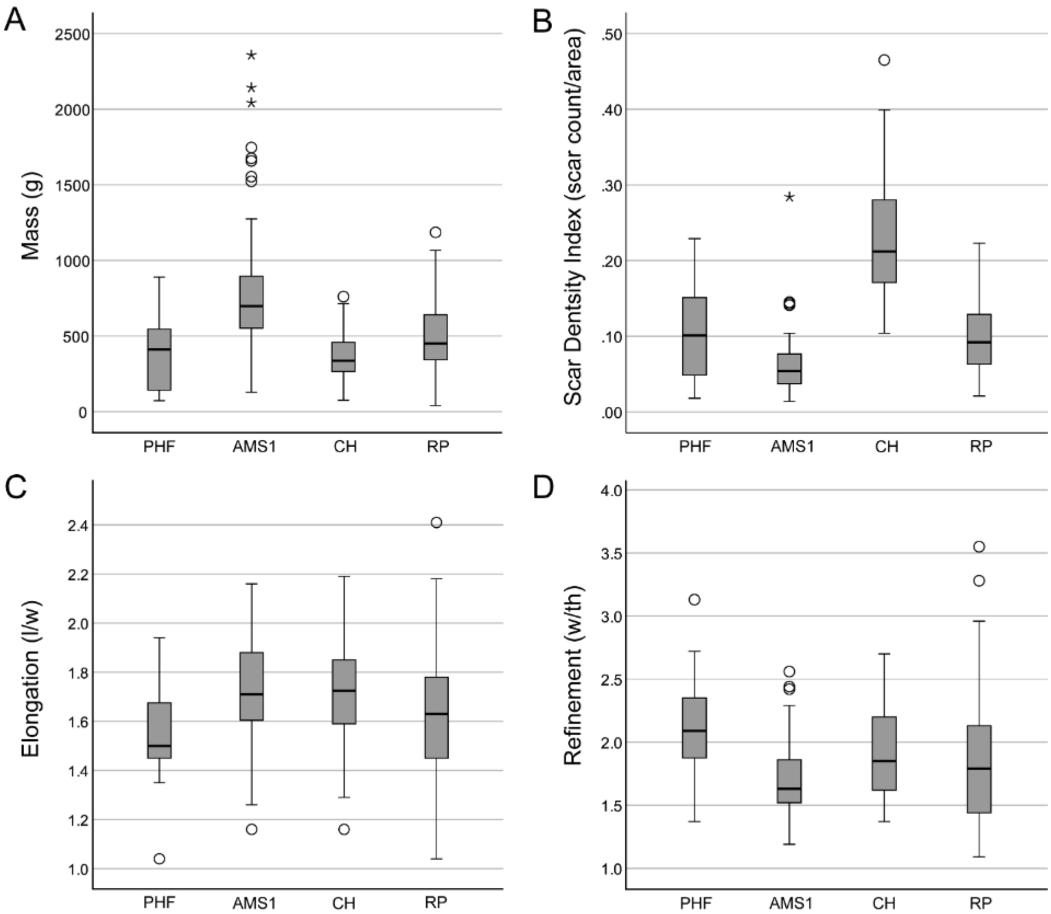

Figure 3. Boxplot graphs displaying techno-morphological traits for Penhill Farm (PHF), Amanzi Springs (AMS1), the Cave of Hearths (CH) and Rietputs 15 (RP).

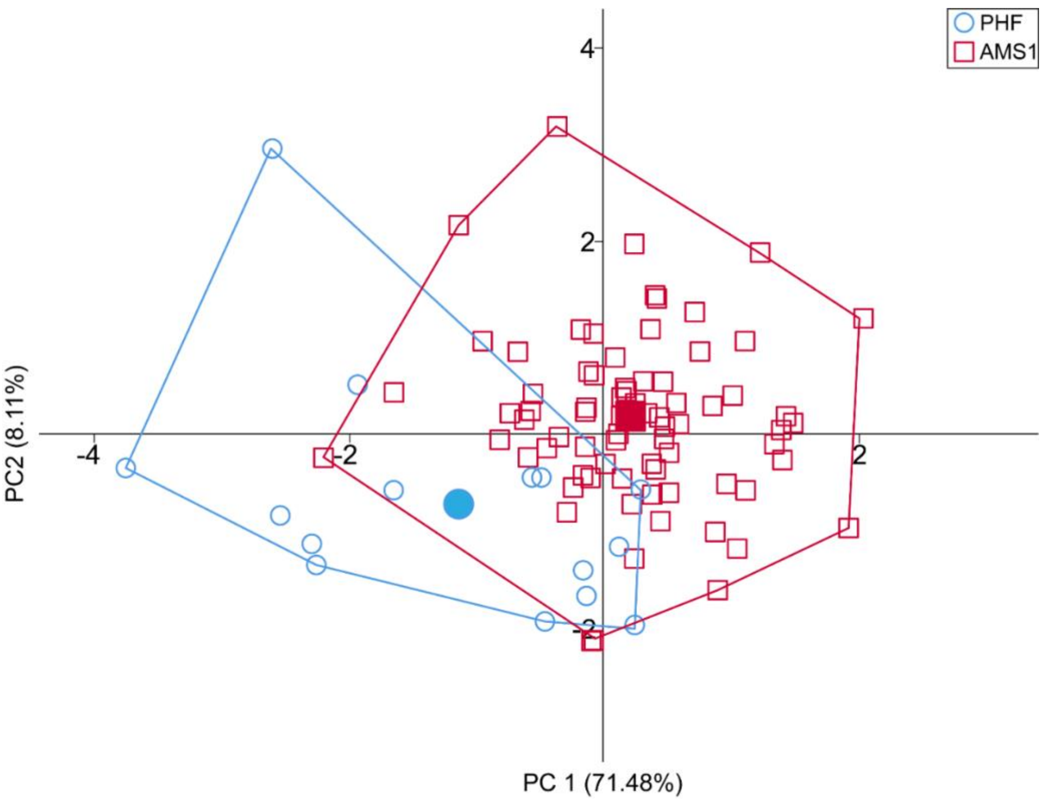

Figure 4. A principal component scatterplot graph comparing Penhill Farm (PHF) and Amanzi Springs (AMS1).

Table 1. Descriptive statistics of handaxe measurements from Penhill Farm (PHF), Amanzi Springs Area 1 (ASA1), Cave of Hearths (CoH) and Rietputs 15 (RP15) (L=length; W=width; Th=thickness; PMW=point of maximum width; TW=tip width; TTh=tip thickness; MW=midsection width; BW=base width; M=mass; A=area; S#=scar number; SDI=scar density index; EL=elongation; RF=refinement).

	L	W	Th	PMW	TW	TTh	MW	MTh	BW	BTh	M	A	S#	SDI	EL	RF
PHF																
Mean	116.6	73.8	36.2	52.0	47.3	21.7	70.6	34.6	61.5	32.7	369.5	17285.2	13.9	0.1	1.6	2.1
Median	112.0	78.0	36.0	50.0	46.0	20.2	66.4	32.7	61.6	34.0	411.8	17906.7	15.0	0.1	1.5	2.1
Min	73.0	50.0	16.0	11.0	27.3	10.6	46.5	16.0	46.0	13.4	72.4	6983.8	4.0	0.0	1.0	1.4
Max	185.0	102.0	57.0	99.0	65.1	33.6	93.4	56.8	81.7	49.9	889.9	34338.7	24.0	0.2	1.9	3.1
SD	37.8	16.4	11.2	24.8	11.8	7.0	15.8	11.6	11.4	10.5	258.0	8878.9	6.0	0.1	0.2	0.5
CV	32.4	22.2	31.0	47.7	24.9	32.1	22.4	33.5	18.6	32.2	69.8	51.4	43.3	64.5	14.9	21.1
ASA1																
Mean	160.1	93.3	55.7	54.8	67.3	33.0	81.4	48.7	84.3	47.8	807.7	29442.7	15.8	0.1	1.7	1.7
Median	159.7	92.3	55.2	52.4	65.4	31.1	82.2	48.0	83.1	46.0	697.2	28070.3	16.0	0.1	1.7	1.6
Min	90.5	45.3	35.0	16.1	33.6	19.3	39.7	30.8	40.8	24.5	127.7	8450.3	5.0	0.0	1.2	1.2
Max	240.5	129.8	89.8	111.1	107.1	62.6	123.1	77.5	119.6	99.2	2358.0	61160.9	35.0	0.3	2.2	2.6
SD	30.9	16.7	10.8	18.7	13.6	8.4	15.0	9.8	15.5	12.6	443.5	10285.4	5.8	0.0	0.2	0.3
CV	19.3	17.9	19.3	34.2	20.2	25.4	18.5	20.1	18.4	26.4	54.9	34.9	36.9	62.6	12.2	17.9
CoH																
Mean	137.3	79.8	43.0	91.5	39.6	23.4	74.9	32.8	66.0	41.8	368.3	183.8	39.9	0.2	1.7	1.9
Median	134.8	81.2	43.0	86.7	40.2	22.4	76.6	32.2	64.9	36.3	336.0	174.5	38.0	0.2	1.7	1.9
Min	77.4	47.7	22.6	46.1	14.8	11.1	42.6	16.5	29.2	18.1	76.0	67.7	12.0	0.1	1.2	1.4
Max	209.3	110.5	68.3	151.9	70.3	44.4	110.5	47.1	95.5	82.9	761.0	330.4	106.0	0.5	2.2	2.7
SD	31.8	12.8	9.1	23.4	13.1	7.0	15.8	7.6	15.7	16.3	156.8	56.8	13.9	0.1	0.2	0.3
CV	23.1	16.1	21.2	25.5	33.1	30.1	21.1	23.1	23.8	39.0	42.6	30.9	34.9	34.7	12.9	18.0
PR15																
Mean	135.7	83.3	47.9	45.4	51.9	29.0	72.1	40.8	73.4	40.3	486.8	21971.7	20.2	0.1	1.6	1.8
Median	134.4	82.2	46.5	44.0	51.0	28.9	72.8	39.7	73.3	38.3	450.3	20450.5	18.0	0.1	1.6	1.8
Min	84.3	52.6	20.5	18.7	34.1	16.1	5.2	20.2	43.8	13.5	41.0	9255.9	7.0	0.0	1.0	1.1
Max	192.6	120.7	73.6	91.0	73.7	44.7	101.6	66.9	102.9	68.5	1185.6	37964.8	50.0	0.2	2.4	3.6
SD	25.3	12.9	12.2	13.8	9.6	6.4	14.4	9.6	11.3	11.3	231.8	6545.8	8.7	0.1	0.3	0.5
CV	18.7	15.5	25.5	30.4	18.4	22.1	19.9	23.6	15.4	28.2	47.6	29.8	42.9	47.1	15.5	27.2

Multivariate allometry – Penhill Farm and Amanzi Springs Area 1

Figure 5 displays CV scores for the geometric variables used in the multivariate analysis of allometry, which shows that the PHF sample is highest in scores for seven of the ten linear measurements. Although, this may be an effect of sample size, where the low number of handaxes in the PHF sample somewhat inflates variation. The highest peaks of CV scores (observed left to right) for the PHF sample occur for length, PMW, tip thickness, mid thickness, and base thickness. In the AMS sample, peaks are found in PMW, and tip and base thicknesses, while the Rietputs 15 sample mimics the trends for PHF, and the Cave of Hearths shows peaks in PMW, tip width, tip thickness, along with base width and base thickness. While each assemblage shows differences in variance levels, PMW and base thickness are highest across Figure 5.

The analysis of MVA reveals variation in the allometric scaling of handaxe proportions between the four handaxe assemblages (Table 2; Fig. 6). AC scores for tip thickness show a consistent pattern of isometry relative to size growth across the handaxe assemblages. For PHF, maximum width, as well as tip, midsection and base width variables consistently show negative allometric patterns, suggesting that these variables decrease as overall size increases. The point of maximum width in PHF handaxes shows the highest increase in allometric scaling when compared to all other assemblages. Interestingly, the length, width and thickness proportions of the AMS1 handaxes show near isometric scaling patterns, with width and thickness variables showing some trend towards negative allometry. The Rietputs 15 sample is highly variable when compared to all other assemblages, which shows negative allometric trends for length, tip and base width variables, while maximum thickness, tip, midsection and base thicknesses increase relative to size scaling. The Cave of Hearths sample shows a high propensity for negative allometry, aside from tip thickness (isometric) and PMW and base thickness (positive allometry).

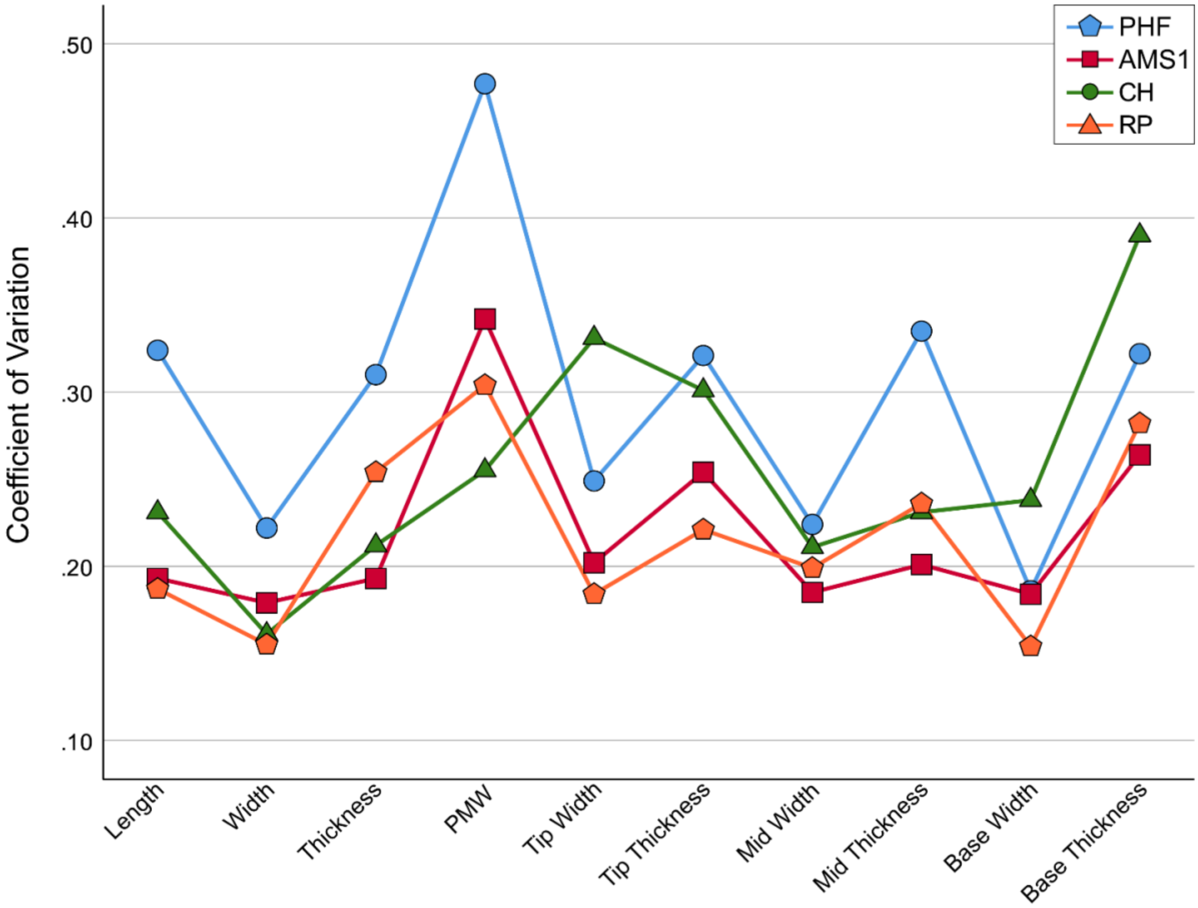

Figure 5. Line graph displaying coefficient of variation scores for Penhill Farm (PHF), Amanzi Springs (AMS1), the Cave of Hearths (CH) and Rietputs 15 (RP).

Table 2. Principal component 1 (PC1), allometric component (AC) and coefficient of variation (CV) scores for assemblages analysed in this study.

Site name	**Penhill Farm**			**Amanzi Springs**			**Cave of Hearths**			**Rietputs 15**			**Eastern Cape Sample**		
Measurements	**PC1**	**AC**	**CV**	**PC1**	**AC**	**CV**	**PC1**	**AC**	**CV**	**PC1**	**AC**	**CV**	**PC1**	**AC**	**CV**
Length	0.10	0.87	0.32	0.12	0.91	0.19	0.15	0.96	0.23	0.08	0.58	0.19	0.11	0.94	0.25
Width	0.06	0.48	0.22	0.10	0.79	0.18	0.07	0.45	0.16	0.06	0.42	0.16	0.08	0.64	0.20
Thickness	0.12	1.04	0.31	0.10	0.74	0.19	0.12	0.78	0.21	0.22	1.55	0.25	0.14	1.12	0.26
PMW	0.35	3.06	0.48	0.26	2.00	0.34	0.43	2.82	0.26	0.16	1.11	0.30	0.20	1.63	0.37
Tip width	0.07	0.65	0.25	0.12	0.90	0.20	0.07	0.48	0.33	0.07	0.45	0.18	0.11	0.91	0.25
Tip thickness	0.10	0.84	0.32	0.14	1.08	0.25	0.16	1.07	0.30	0.14	0.96	0.22	0.15	1.21	0.30
Mid width	0.06	0.50	0.22	0.11	0.80	0.19	0.10	0.65	0.21	0.19	1.32	0.20	0.07	0.56	0.19
Mid thickness	0.13	1.12	0.34	0.10	0.79	0.20	0.10	0.65	0.23	0.19	1.30	0.24	0.12	1.02	0.24
Base width	0.03	0.24	0.19	0.11	0.85	0.18	0.08	0.52	0.24	0.06	0.39	0.15	0.08	0.69	0.22
Base thickness	0.13	1.19	0.32	0.15	1.16	0.26	0.24	1.60	0.39	0.28	1.91	0.28	0.16	1.28	0.29

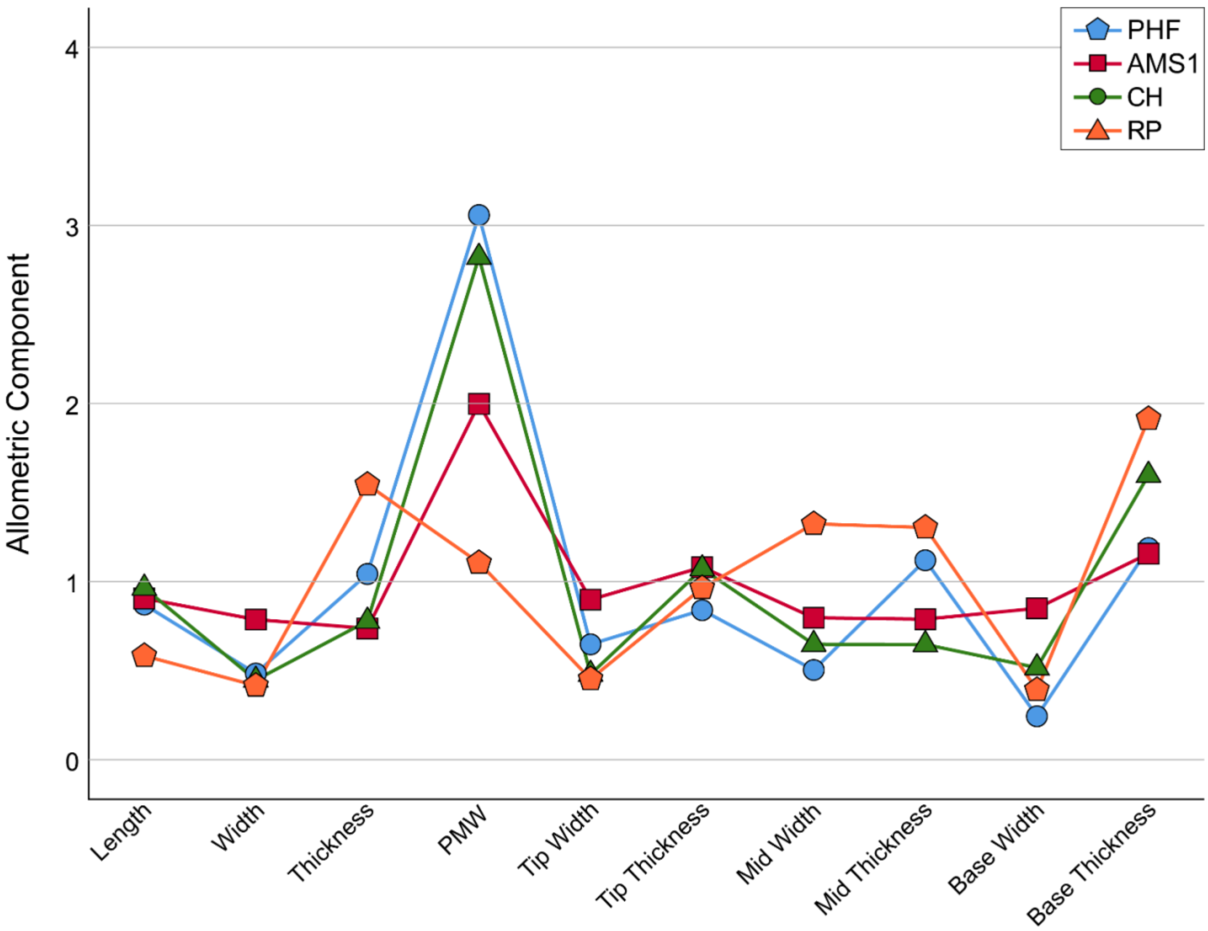

Figure 6. Line graph displaying allometric component scores for Penhill Farm (PHF), Amanzi Springs (AMS1), the Cave of Hearths (CH) and Rietputs 15 (RP).

Figure 7 displays AC plotted against CV scores for PHF and AMS1, which provides insight into variable groups that share similar relationships between allometry and variability. For instance, the PHF sample shows two loose variable groupings, the first comprised of width dimensions (maximum, tip, midsection and base), which are low in variance and decrease relative to allometric scaling; and a second group comprised of length and thickness variables (maximum, tip, midsection and base), which are higher in variance yet nearly isometric. On the other hand, the AMS1 sample shows two tightly grouped variable sets, one comprised of length, width (maximum, tip and midsection) and thickness (maximum and midsection), which are low in variance and decrease slightly with allometric scaling; and a second group of tip and base thickness variables that are higher in variance and increase slightly with allometric scaling. For both samples, PMW represents their own single group of extreme positive allometry.

Multivariate allometry – regional comparisons

To understand regional patterns of variability, we combined the PHF and AMS1 datasets into a single 'Eastern Cape Acheulean' sample. We note limitations in using two sites to represent variation for an entire region of South Africa, where much of the Acheulean archaeology remains understudied or undocumented. We consider this analysis a preliminary set of results from which methods can be used for further characterising the Eastern Cape Acheulean expression. Figure 8 compares CV values of linear measurements relative to Rietputs 15 and the Cave of Hearths, where the Eastern Cape sample is more variable in length, width and midsection thickness. Lastly, AC values for the Eastern Cape sample were determined thorough the MVA methods described above, which showed positive allometric trends for maximum, tip, and base thicknesses, as well as PMW, while maximum, midsection and base width dimensions display negative allometric trends (Fig. 9). Length and tip width show slight negative allometric patterns, while midsection thickness is isometric.

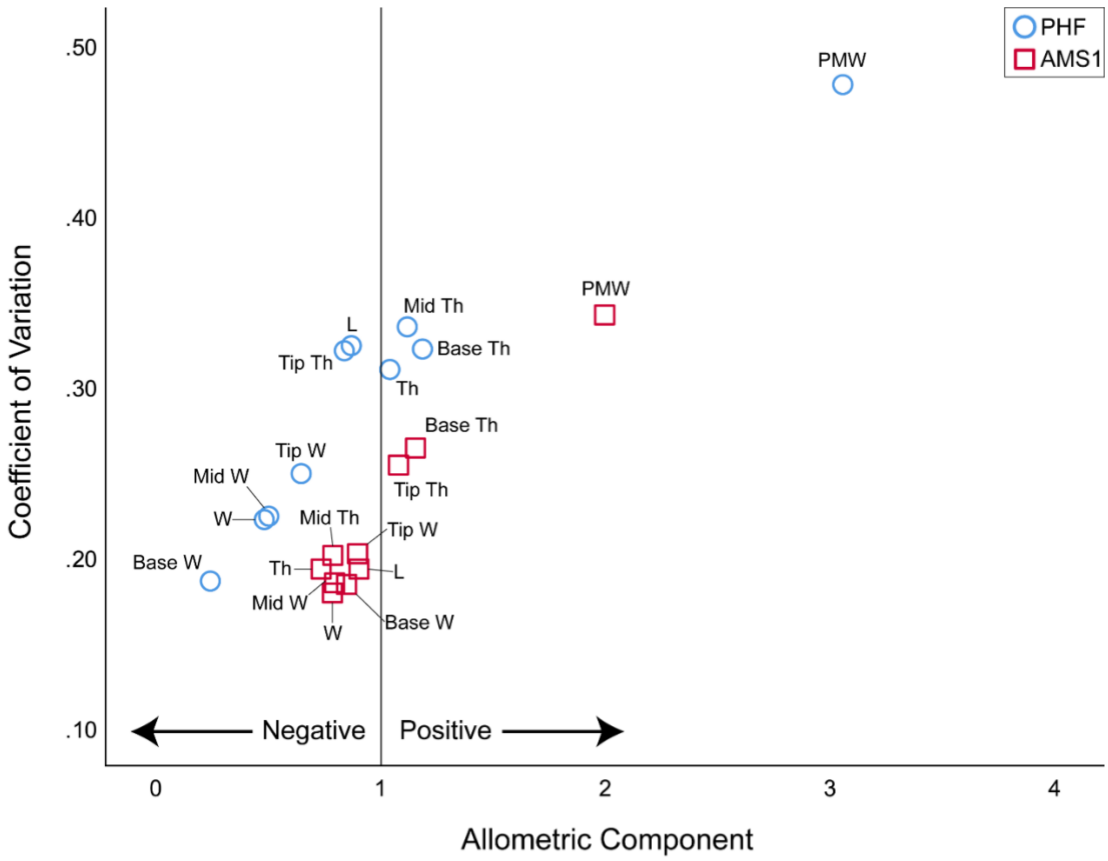

Figure 7. Scatterplot graph regressing coefficient of variation against allometric component scores for Penhill Farm (PHF) and Amanzi Springs (AMS1), where negative values show less allometric variation and positive values show greater variation.

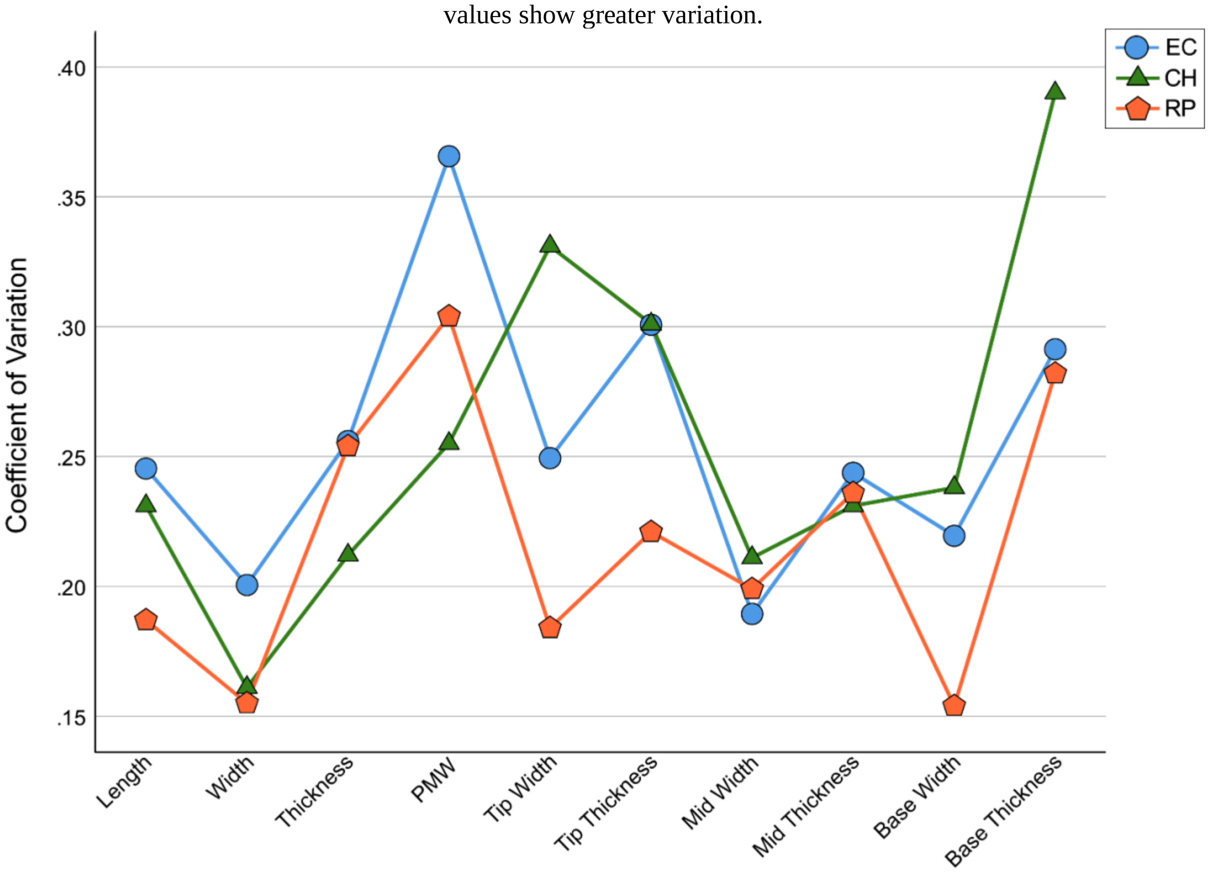

Figure 8. Line graph displaying coefficient of variation scores for the Eastern Cape sample (Penhill Farm + Amanzi Springs) with the Cave of Hearths (CH) and Rietputs 15 (RP).

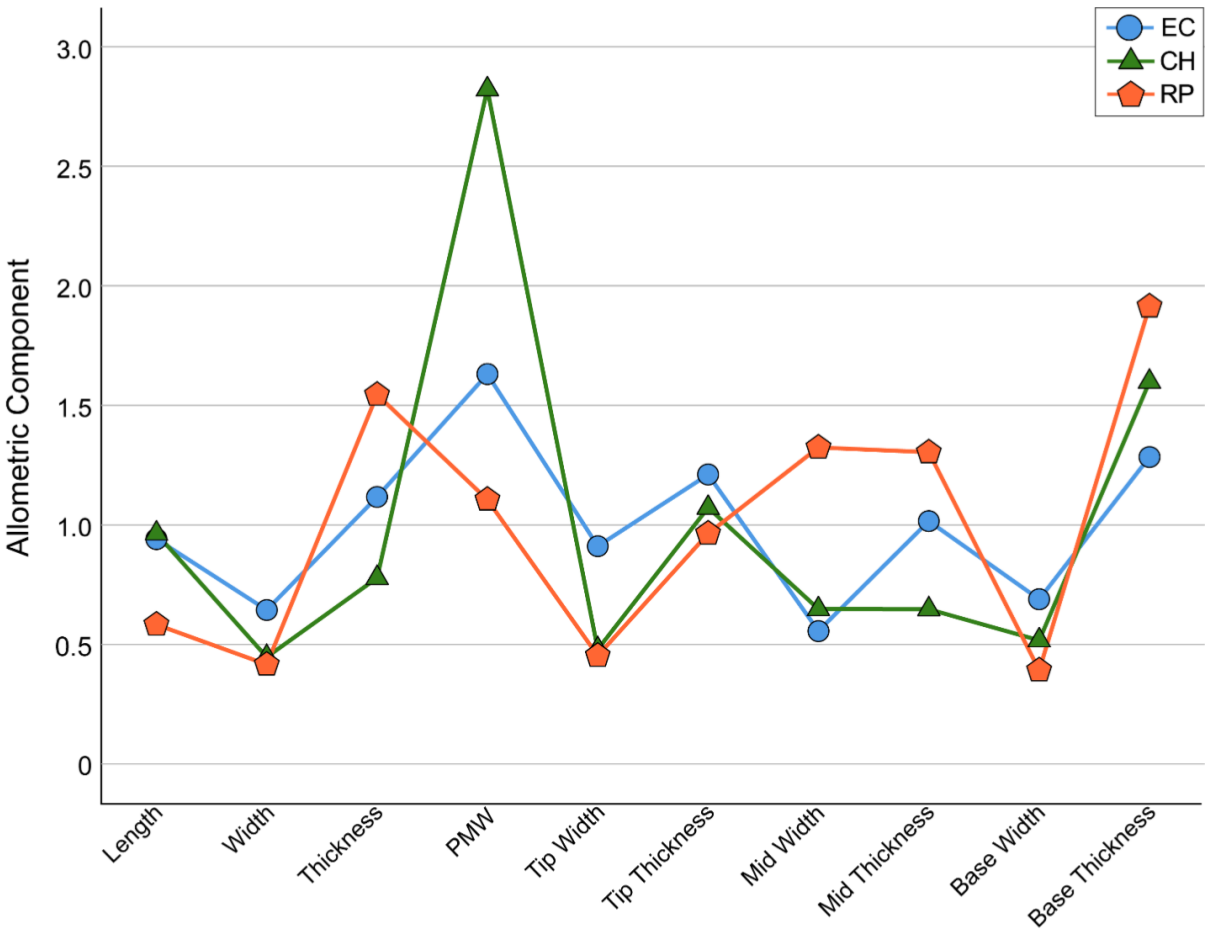

Figure 9. Line graph displaying allometric component scores for the Eastern Cape sample (Penhill Farm + Amanzi Springs) with the Cave of Hearths (CH) and Rietputs 15 (RP).

5. Interpreting 'rule-sets' from allometric relationships

Inter-assemblage comparisons

Looking at differences between PHF and AMS1 highlighted in techno-morphological variables shows that the AMS1 assemblage is larger in overall geometric size (Figs 3 & 4). While there are no differences in reduction intensity (SDI), the refinement ratio distinguishes PHF as thinner relative to width proportions, which may potentially relate to a higher frequency of flake blank use. Comparing general trends in variation, PHF shows higher CV values in maximal length, width and thickness proportions (Fig. 5). The thickness of tip, midsection and base proportions in the PHF handaxes are also substantially higher when compared to AMS1. These CV scores provide insight into what aspects of handaxe morphologies were standardised, in terms of low variance. Overall, the AMS1 sample seems more standardised across length, width, thickness, as well as midsection width, midsection thickness and base width proportions.

Turning attention towards allometric trends, the PHF handaxes show a clustering of near isometric trends in maximal length and thickness, as well as in thickness proportions across the tip, midsection and base proportions (Figs 6 & 7). Width proportions in the PHF handaxe generally showed trends towards negative allometry, with base width showing the most negative allometric pattern. The AMS1 sample shows slightly negative allometric trends for length, and most width and thickness proportions, while tip and base thickness increase slightly with allometric scaling (Figs 6 & 7).

In breaking down comparisons between variance and allometric trends, specific 'rule-sets' can be interpreted (see Crompton & Gowlett 1993). The concept of a rule set is based on the notion that allometric scaling of specific proportions (i.e., length, width, thickness, etc.) correlates to high and low levels of variance. When specific proportions display low variance, they are relatively more standardised and were likely managed by ancient knappers throughout reduction processes. As mentioned above, controlling certain proportions of handaxes in relation to their size likely impacted their utility (Gowlett 2006, 2011, 2013, 2021; Key & Lycett 2017, 2020). However, CV scores are a relative measurement of variance. To define a meaningful point in which to distinguish high versus low variance, CV scores for all linear measurements for PHF and AMS1 were averaged to a value of 2.5. Thus, CV scores above this level might be considered high relative to the PHF and AMS1 assemblages.

Based on this, interpreting patterns in Figure 7, we see that width in the tip, midsection and base width regions of PHF handaxes were standardised, which also show similar trends towards negative allometry. This suggests that PHF knappers were likely focused on reducing width proportions in larger handaxes. Interestingly, Lotter (2020a) showed that secondary shaping on tips and midsections was higher when compared to base regions, which corroborates differential patterns of reduction across handaxe bodies. Conversely, thickness proportions in PHF handaxes were not as standardised, which may have been 'pre-determined' during the production of large flake blanks that were transported to the PHF area (Lotter & Kuman 2018b; Lotter 2020a; Lotter & Caruana 2021). Within the AMS1 handaxes, most variables aside from tip and base thickness proportions were relatively standardised. Caruana and Herries (2020, 2021) have argued that most of these artefacts were likely abandoned after primary shaping, and thus their similarities in length, width and thickness proportions were also likely influenced by the use of raw material packages. Cobble reduction predominates LCT shaping processes in the AMS1 sample, which suggests that knappers were collecting raw material packages based on overall size (Caruana & Herries 2020). Tip and bases thicknesses were seemingly difficult to control for the AMS1 knappers, which corresponds with the fact that evidence of thinning is rare in the LCTs at this locality (Caruana 2021; Caruana & Herries 2020, 2021).

Inter-regional comparisons

When grouping PHF and AMS1 into a single, Eastern Cape (EC) sample, trends in variance (i.e., CV) are generally high when compared to Rietputs 15 and the Cave of Hearths (Fig. 8). Averaging CV scores between the EC, Rietputs 15 and the Cave of Hearths samples provides a value of 2.4, which we use to define high versus low levels of variance. In the EC sample, only mid width and base width show relatively low levels of variance, i.e., standardisation. In the Rietputs 15 handaxes, length and width proportions were generally low in variance, as well as width across the tip, midsection and base regions (Fig. 8). Thickness and base thickness display relatively high levels of variance. When comparing these trends to allometry, thickness and width in the midsection, as well as base thickness proportions increase with size scaling (Fig. 9). This suggests that knappers either had difficulties in managing thickness in larger handaxes, specifically in the base region, or raw material packages were highly variable. Li et al. (2018) demonstrated equal proportions of cobble (33.3%) versus flake blank (36.8%) use, which may account for variability in thickness proportions. They also showed that primary and secondary shaping were higher in tip and midsection regions of these tools when compared to bases. Overall, knapping strategies may have been more focused on managing the length to width relationship rather than thickness proportions.

In the Cave of Hearth sample, maximal proportions in length, width and thickness, as well as midsection width, midsection thickness and base width show low patterns of variance (Fig. 8). On the other hand, proportions of tip width, tip thickness and base thickness vary considerably, which also show patterns of positive allometry (Fig. 9). Thus, the Cave of Hearth knappers seemingly did not focus on reducing the tip proportions, nor base thickness of larger handaxes. Interestingly, Li et al. (2018) showed that primary and secondary shaping were fairly standardised across the entire body of handaxes at this site. Thus, the influence of raw materials on handaxe morphologies was comparatively less at the Cave of Hearths when compared to the rest of the sites analysed in this study. The trends observed in the Cave of Hearths handaxes may instead relate to a more classic pattern of larger handaxes representing those that were less reduced. As handaxes became smaller throughout reduction sequences, their tip width and thickness proportions decreased proportionately.

6. Conclusion

Our study demonstrates a high degree of variability in the techno-morphological traits of handaxes from

PHF and AMS1 (see Table 1). Some of this variability is significantly different when compared to other Acheulean assemblages on an inter-assemblage scale, which may reflect trends that are characteristic of the Eastern Cape. However, both the PHF and AMS1 handaxes show some consistency in linear measurements, and constraints on size-shape relationships, specifically in width to thickness proportions.

From a regional perspective, an emerging pattern of differential reduction in handaxes is beginning to emerge (Li et al. 2018; Caruana & Herries 2020, 2021; Lotter 2020a). This corroborates the notion that handaxes may not have become more ‘refined’ through time in terms of their proportions overall, nor their symmetrical planview shapes (cf. McNabb & Cole 2015; Li et al. 2018; Caruana 2020). The causes of variation in handaxes are perhaps more complex than initially perceived and cannot be simply explained by ‘trends through time’. When we contextualise results for PHF and AMS1, we see different pattern of behaviours at these sites. At PHF, Middle Pleistocene hominins were seemingly visiting the area to exploit raw materials within exposed terraces of the Sundays River. While collecting and reducing cores for small flakes (<10cm) and formal tool production, large flake blanks for shaping handaxes were brought into the area (Lotter & Kuman 2018a; Lotter 2020a; Lotter & Caruana 2021). These archaeological trends speak the fact that hominins visited the PHF area to produce flake tools, while some shaping of LCTs took place at other localities. Handaxe variation at PHF was undoubtedly impacted by mobility patterns where only specific portions of LCT production processes were carried out on site.

On the other hand, hominin populations were likely periodically visiting spring sites at AMS to exploit natural resources and raw materials to specifically shape LCTs (Caruana & Herries 2020, 2021; Herries et al. in press). The higher frequencies of handaxes and cleavers at AMS1 (~10% of the total lithic assemblage; see Herries et al. in press) when compared to PHF (~0.3% of the total lithic assemblage; see Lotter & Kuman 2018a) infers differences in technological behaviours. Thus, the function of AMS1 as a possible ‘LCT workshop’ also impacts handaxe variability, where the discard of artefacts after primary shaping results in specimens that are larger than numerous other Acheulean assemblages (Sharon 2007; Caruana & Herries 2020, 2021). Thus, we assume that highly reduced LCTs that had gone through thinning and finishing stages at AMS1 were transported off site.

Putting these patterns together, the handaxes from PHF and AMS1 suggest that raw material packages and specifically the use of flake blanks versus cobbles influenced differences in morphological proportions. Similarities in the structure of quartzites corroborate previous findings that the quality of raw material alone does not constrain artefact morphologies (see Eren et al. 2014; Dogandžić et al. 2020). The larger size of AMS1 handaxes reflects the use of large cobbles to shape handaxes, whereas a focus on flake blanks likely constrained the proportions of the PHF specimens. Beyond this, group mobility patterns were also influential to some degree. Transport of blanks into PHF and finished pieces out of AMS1 influenced observed levels of variation. Discard behaviours and tool transport at these sites left handaxes at different stages of reduction. Such factors skew levels of morphological variability at an assemblage level, which are in turn directly related to the movement of Acheulean populations on the wider landscape. Local and inter-regional variability in LCTs is likely the result of raw material use, site-specific reduction behaviours and group mobility patterns. Therefore, preliminary insights into handaxe variability suggest that the Acheulean is not a static technological entity. Rather the Acheulean reflects a flexible system of toolmaking, centred around a tradition of shaping specific forms that were carried out according to access to raw materials and the movement of Acheulean people.

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Supplementary online material
Caruana & Lotter Supplementary Online Material File 1

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