An Acheulian Balancing Act: A Multivariate Examination of Size and Shape in Handaxes from Amanzi Springs, Eastern Cape, South Africa

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Summary: Variation in handaxe shape has been a focal point for interpreting Acheulian assemblages and implications for behavioural and cognitive capacities in early hominins. The work of John Gowlett has had a significant impact on this research in examining the influence of size on handaxe forms. This has advanced multivariate methods for investigating the covariance of size and shape in these tools. Gowlett's approach has been applied to a number of East African sites, albeit never extensively operationalised in South Africa. Here we provide a multivariate approach towards the function of allometry in South African handaxe assemblages with specific focus on Amanzi Springs. Our findings suggest continuity in allometric trends across Africa with some differences between eastern and southern sites.

Biographies:

Andy I.R. Herries undertook his BSc Archaeological Science, MSc Geoarchaeology and PhD in Palaeoanthropology and Geomagnetism in the Department of Archaeology, Classics and Egyptology at the University of Liverpool between 1994 and 2003. After hearing Professor John Gowlett talk about early hominin evolution in a first year World Prehistory class he decided that Palaeoanthropology was the discipline he was going to study going forward. He went to South Africa as part of the Makapansgat Middle Pleistocene Research Project run by the University of Liverpool in 1997 and has now been working in Africa for the past 22 years; including with John Gowlett at Cornelia in South Africa and Kilombe in Kenya. Since 2011 he has been an Associate Professor in the Department of Archaeology and History at La Trobe University, Melbourne, Australia where he is currently the Head of Department and Head of the Palaeoscience Labs. He is a co-director of the Amanzi Springs Archaeological Project (ASAP) and runs an international field school at the early hominin site of Drimolen, South Africa.

Matthew V. Caruana received a BA in Cultural Anthropology from the University of California, Los Angeles in 2000, an MA in Archaeology from the University of Manchester, England and a PhD in archaeology from the University of the Witwatersrand, South Africa in 2015. Since moving to South Africa in 2009, he has conducting field work at numerous Plio-Pleistocene sites including Taung, Drimolen, Maropeng, Barberspan Dam, Swartkrans Cave, as well as Koobi Fora in Kenya. He is currently a co-director of the Amanzi Springs Archaeological Project (ASAP) and oversees excavations at Swartkrans Cave in South Africa.

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Introduction

For the past fifty years, analysing the shape of handaxes has defined approaches towards investigating the significance of Acheulian large cutting tools (LCTs) (Ashton and McNabb, 1995; Ashton and White, 2003; Bordes, 1961; Brink *et al.*, 2012; Crompton and Gowlett, 1993; Gowlett, 2013, 2006; Gowlett and Crompton, 1994; Graham and Roe, 1970; Hodgson, 2015; Iovita and McPherron, 2011; Isaac, 1977; Lycett and Gowlett, 2008; McNabb, 2009; McNabb *et al.*, 2004; McNabb and Cole, 2015; McPherron, 2003, 2000, 1999, Roe, 1976, 1964; Shipton, 2013; Shipton and Clarkson, 2015; White, 1995; Wynn, 1979; Wynn and Teirson, 1990). It is generally accepted that the continuity of handaxe shape across Acheulian assemblages is a product of imposed form by early hominins, which represents a critical transition towards tool-shaping in the evolution of lithic technology (e.g. Ambrose, 2001; Klein, 2009). From this perspective, the study of shape can provide insight into the manufacturing processes that governed this consistency, as well as underlying cognitive and behavioural capacities (Ashton and McNabb, 1995; Ashton and White, 2003; Brink *et al.*, 2012; Iovita and McPherron, 2011; McPherron, 2006, 2003, 2000, 1999; White, 1995; Wynn, 1995, 1979; Wynn and Teirson, 1990). The seminal work of Bordes (1961) and Roe (1968, 1964) established methods for quantifying handaxe shape through sets of metric measurements, which have since been adapted and applied to Acheulian assemblages from Africa, Europe and the Middle East (Crompton and Gowlett, 1993; Gowlett, 2009; Gowlett and Crompton, 1994; Grosman *et al.*, 2008; Isaac, 1977; Li *et al.*, 2018; Sharon, 2007). An important aspect of this research is how handaxe shape varies at the intra- and inter-assemblage levels, which has been a central topic for debates focused on cognitive and behavioural capacities underlying handaxe production (Ashton and McNabb, 1995; Ashton and White, 2003; Iovita and McPherron, 2011; McPherron, 2006, 2003, 2000, 1999; Nowell *et al.*, 2003; Park *et al.*, 2003; White, 1995; Wynn, 1995, 1979; Wynn and Teirson, 1990).

While shape has played an important role in advancing our understanding of handaxes, size-based variation is an equally significant factor for examining the complexity of their forms. In fact, size proportions and shape are interconnected as the combination of length, breadth and thickness determines the resulting form, i.e. pointed vs. ovate handaxes. While size-based variation remains an under-explored aspect of lithic technology, Gowlett and colleagues (Crompton and Gowlett, 1993; Gowlett, 2013, 2011, 2009, 2006; Gowlett and Crompton, 1994) have pioneered methods for investigating how size and shape co-vary in handaxes across African Acheulian sites. This has highlighted the multivariate nature of these tools with specific focus on how variability in handaxes shape directly relates to variation in geometric size.

The focal point of Gowlett's work has described an allometric relationship between size and shape in handaxes, finding that metric proportions (length, breadth, thickness and mass) vary disproportionally in relation to geometric size. This has established that the maintenance of metric proportions is an important constraint on the consistency of shape, e.g. the ratio of length to breadth. In fact, Gowlett (2011) has found that the L/B ratio is relatively uniform throughout Acheulian assemblages at ~0.61. Gowlett (Crompton and Gowlett, 1993; Gowlett and Crompton, 1994) has suggested that such proportional relationships represents manufacturing 'rule-sets'. For instance, the L/B ratio demonstrates that as handaxe length is extended breadth decreases, resulting in a narrow plan-view shape (Crompton and Gowlett, 1993). He concluded that this is likely a functional relationship in controlling the overall mass of the artefact, where if length and breadth grew at an isometric rate (linearly), weight would increase exponentially. In turn, this would affect the functionality of handaxes as object mass

is a critical concern for manual manipulation in tool use (Bril *et al.,* 2009; Visalberghi *et al.*, 2009).

Building upon this insight, Gowlett (2006) has argued that the trends highlighted by multivariate covariation and proportional consistency in handaxes further reveals "imperatives" relating to their production. These are the essential features of these tools that underlie their consistency in size and shape. One of the most significant examples of this is the principal of elongation, where handaxes increase in length relative to breadth exponentially, although this can vary considerably on an individual artefact basis (Gowlett, 2013). This likely relates to the extension of useable cutting edge in these tools, but also relates to other factors including the positioning of centre of mass and cutting edge angle. In this sense, the factors that are critical for the use-life of these tools are 'true variables' that can be investigated through Gowlett's multivariate approach.

Shape continues to be a focal point for Acheulian research on LCTs, increasingly through the application of geometric morphometric methods (Archer and Braun, 2010; Iovita and McPherron, 2011; Lycett and von Cramon-Taubadel, 2008). Yet 'size-free' methods have specifically been developed in lithic analyses to trace the influence of shape on tool forms in archaeological assemblages (Buchanan, 2006; Lycett *et al.,* 2006; Shott *et al.*, 2007). While these avenues of research are undoubtedly valuable, the question remains does removing size effects in examining shape variability in lithic artefacts limit (to some degree) an important aspect of their production? With respect to handaxes, Gowlett and Crompton (Crompton and Gowlett, 1993; Gowlett and Crompton, 1994) have described ubiquitous allometric trends in size and shape covariation across Acheulian sites, which suggests that understanding changes in shape requires a parallel insight into changes in size. Gowlett's interpretations of rule-sets based on investigating this covariation supports the notion that 'size-reduction' in handaxe analysis can potentially diminish a critical aspect of shape variability.

While Gowlett has thoroughly examined multivariate allometry in East African handaxes to understand shape variation, the application of these techniques in South African assemblages remains preliminary (Gowlett and Crompton, 1994; Brink *et al.*, 2012). Here we present an initial investigation into the effects of allometric variation within South African handaxe assemblages with a focus on material from Hilary Deacon's (1970) Area 1 excavations of Amanzi Springs, Eastern Cape, South Africa (Figure 1). This site represents one of the few Acheulian assemblages in southern Africa that preserves layered stratigraphy representing primary deposition of Acheulian technology. It is also unique in being a spring deposit rather than a more common secondary alluvial (e.g. Vaal River) or cave setting (e.g. Sterkfontein) (Herries, 2011). Although Amanzi Springs has yet to be dated using reliable, modern techniques, Deacon (1970: 111) described the material as a Late Acheulian assemblage. If this is accurate, then it should compare with other assemblages from this period, such as Cave of Hearths (<780 ka), Montagu Cave, and potentially also Wonderwerk Cave whose oldest Acheulian deposits have been dated to either side of the Brunhes-Matuyama Reversal at 780 ka based on uranium-lead dating (Herries, 2011; Herries and Latham, 2009; Kuman, 2007; Pickering, 2015; Stammers *et al.*, 2018). Other sites such as Duinefontein 2 (~1.1 to <~0.3 Ma) and Elandsfontein (Cutting 10; 1.1-0.6 Ma) could also fall within this time range or are just slightly younger than the Acheulian site of Cornelia-Uitzoek at 1.07-1.01 Ma (dates recalculated based on Singer [2014]) (see Braun *et al.*, 2013; Brink *et al.*, 2012; Herries, 2011).

To analyse allometric variation, the Amanzi Springs handaxes are compared with a recently published dataset of measurements from Cave of Hearths (<780 ka; Late Acheulian predominantly on quartzite; Herries and Latham, 2009) and Rietputs 15 (sometime between ~1.5 and ~1.1 Ma; Early Acheulian; on hornfels & andersite; Herries, 2011; Kuman & Gibbon, 2018) by Li et al. (2018), which correlate with those used in Gowlett's multivariate approach. As such, due to its younger age and the similarity of raw material (quartzite) it is expected that

the size and shape of handaxes at Amanzi Springs will compare closely to Cave of Hearths and highlight trends in 'refinement' as Late Acheulian handaxes are thought to be more standardized in shape and thinner than cruder forms from earlier Acheulian periods (Hodgson, 2015; Kuman, 2007; Shipton, 2013; Wynn, 1979; although see Li *et al*., 2018). The aim of this study is twofold: 1) to characterize the handaxes of Amanzi Springs and identify any differences in size and shape with Cave of Hearths and Rietputs 15; and 2) to characterize what 'rule-sets' guided the production of South African handaxes, which will test Gowlett's hypothesis that allometric trends are consistent across Africa.

Multivariate Allometry

The multivariate methods developed by Gowlett and Crompton (Crompton and Gowlett, 1993; Gowlett and Crompton, 1994) provide a rigorous agenda for understanding allometric effects on size adjustments in relation to handaxe shape. They employed principal component analysis (PCA) and discriminant analysis (DA) to understand how size structures datasets of handaxe measurements that correspond to their form. There are several important assumptions that must be considered when implementing this approach, one of the most significant being that size and shape are covariates. As briefly mentioned above, increases in length, breadth and thickness in handaxes are managed through proportional adjustments to maintain specific shape parameters. As such, multivariate tests can be used to identify what variables drive variation in handaxe forms within and between assemblages. This is a valuable approach for understanding what aspects of handaxes vary most on a larger chronological and/or geographical scale. Secondly, measuring 'size' cannot be interpreted from a single metric measurement, such as length or breadth. Although PCA is based on multidimensional scaling of variables that can be used to condense multiple measurements into a single 'size component', Gowlett and Crompton (Crompton and Gowlett, 1993; Gowlett and Crompton, 1994) used PCA to this effect in their analyses of Kilombe and Kariandusi handaxes. Analysing multiple localities at these sites and others, they subjected metric measurements, based on Bordes (1961) and Roe (1968, 1964) systems, to independent PCAs using a covariance matrix. The first principal component (PC1) then condensed size effects into a single variable (Buchanan, 2006; Buchanan and Collard, 2007; Shott *et al*., 2007).

PC1 was then used to calculate allometric coefficients (ACs) for handaxes from East African sites that represented patterns of growth on positive, neutral (isometric) and negative allometric scales (Crompton and Gowlett, 1993; Gowlett and Crompton, 1994). They then compared shape changes in handaxes of different sizes and raw materials within and between these sites to characterize patterns of dimensional relationships within East African handaxes. Herein lies the crux of Gowlett's multivariate approach, which is to calculate what variables demonstrate statistically significant relationships throughout the adjustment of dimensional proportions. Gowlett and Crompton (Crompton and Gowlett, 1993; Gowlett and Crompton, 1994) used purpose-written software to calculate ACs, which was based on the angle of PC1 coordinates. The principal behind this is based on the allometric equation, $y = bx^a$, which has been used in biological sciences to model shape changes in response to size growth in animal species using log-transformed variables (Jolicoeur, 1963). Essentially, ACs are calculated by rescaling the loading scores of PC1 to a mean of 1.0, where AC scores greater than 1.0 indicate positive allometric growth, those equal to 1.0 indicate isometry (neutral growth) and scores less than 1.0 indicate negative allometric growth (Diniz-Filho *et al*., 1994; Strauss, 1985).

Gowlett and Crompton (ibid) used this as a means of comparing trends in growth between measurement variables, which in turn highlighted features of handaxes that are important for understanding their consistency in form. For instance, the PCA for Kilombe found that the first 3 PC scores described 90% of variation in handaxes, of that PC1 (i.e.

geometric size) accounted for approximately 60%. PCs 2 and 3 were associated with thickness and breadth in planform, which equally accounted for the remaining 30% of variation. These relationships between variables were used to identify what dimensions play a key role in defining shape changes in handaxes, which the authors used to describe rule-sets for their production that predict proportional relationships between size and shape.

Lastly, they used DA to examine the statistical power of size and shape variables to discriminate *a priori* handaxe groups (defined by geographic location). The assumption here is that the consistency in handaxe form should result in considerable overlap between groups, particularly handaxes derived from a close geographical proximity, i.e. a region or individual site (Crompton and Gowlett, 1993). They tested this in grouping Kilombe handaxes according to excavation locality (Z, EH, AC, AH & AD), where locality Z handaxes exhibited some different trends in allometric growth when compared to the remaining assemblages. Results showed that 54% of handaxes were correctly assigned to their respective groups with the highest proportion of correct attributions belonging to locality Z handaxes at 79%. Thickness and breadth measurements were the most reliable discriminators, which demonstrated that multivariate analysis of allometry in handaxes can distinguish important size variables for investigating handaxe shape variability.

Amanzi Springs

Reviewing Gowlett's approach towards multivariate allometry demonstrates its statistical power to highlight correlations in dimensional proportions relating to shape. The focus of this research is to apply these methods for investigating similarities and differences in handaxes from Amanzi Springs. This assemblage is important for characterizing the South African Acheulian, although it is rarely discussed in archaeological research despite being a rare stratified site and also having an apparent association with wood and botanical remains (Deacon, 1970). This is perhaps in part because it is undated. Deacon (1970) confidently assigned the material to the Late Acheulian, albeit recognized that some elements of the assemblage seemed to demonstrate an unstandardized appearance (see below). A brief review of Amanzi Springs is presented below to discuss some of the points of comparison with Cave of Hearths and Rietputs 15 and the significance of using a multivariate approach to examine how these assemblage relate.

Site Description and Excavation History

Amanzi Springs (~10 km NE of Uitenhage, Eastern Cape, South Africa) is a large thermal spring mound located on a hill which borders the Coega River Valley to the southwest and contains at least 11 archaeological-bearing spring eyes (Figure 1). The site was first described by Ray Inskeep in 1963 who took note of the abundance of Acheulian lithic material and wood eroding out of the rim of one of the eyes (Inskeep, 1965). He described the spring eyes as circular craters largely comprised of clay sediments overlain by an ironstone crust. They would originally have been horseshoe shaped, with the spring flowing out of the open end, although our initial resurvey of the site has indicated that many of the springs have been extensively altered by historic use for irrigating some of the earliest citrus farms in South Africa. This includes furrowing as noted by Deacon (1970) as well as the building of dams across the originally open ends of the horseshoe shaped springs. The sediment for the building of these dams seems to have come from the furrows or the more general scraping out of the centre of the spring eyes. This created large heaps of Acheulian stone tools that are now ex-situ. Inskeep excavated (Cutting 1) into in-situ deposits on the northern edge of one of the

largest of these spring eyes towards the southern end of the site (defined as Area 1 by Deacon), which yielded an assemblage of Acheulian artefacts (N= 1017) (Figure 2).

Deacon took over excavations at the site in 1964 through 1966 for his Master's thesis (Deacon, 1966), additionally opening 13 cuttings, three squares and two 'deep soundings' across Area 1 and a second spring eye (Area 2) at the southernmost extent of the site (Figure 2). After briefly extending Inskeep's cutting in Area 1 (Square 2), Deacon's unpublished records (as well as Deacon, 1966; 1970) show that much of his first season was spent excavating Area 2 (Cuttings 4, 5, 6, 7, 8 and 9 and Square 3). In the following season Deacon returned to Area 1 further extending Cutting 1 and opening Cutting 10 and Square 1. His final phase of excavation then explored other parts of Area 1 (Cuttings 11, 12 and 13), which was aimed at exposing an expanded stratigraphic sequence. Cutting 10, which is our main focus here is essentially a large scale extension of Cutting 1 and is around 9 – 15 m long E-W and 5 – 6 m wide N-S.

Local Geology and Stratigraphy

Amanzi Springs is an outlet for the Uitenhage Artesian Basin (UAB) system, which is the largest of its kind in South Africa (Mclear, 2001). The springs are part of the Coega Ridge Aquifer formed within quartzites of the Table Mountain Group and the basal sandstone and conglomerate layers of the Enon Formation. This is overlain by impermeable mudstones and siltstones of the Uitenhage Group which forms an aquiclude (Mclear, 2001). The aquifer is restricted to relatively narrow, well-defined zones of intense fracturing and stretches from immediately west of Amanzi Springs, eastward along Coega Ridge to the coast. Major changes to the UAB were caused by borehole drilling at Amanzi Springs between 1908 and 1916, which impeded spring discharge (Maclear, 2001).

The UAB was an open basin flanked in the South and West by mountains of quarzitic Table Mountain Sandstone (TMS) during the earlier Jurassic period (~204-146 Ma; Mclear, 2001). The TMS forms the bedrock in the area within which the Coega Ridge Aquifer developed, as well as the core of Amanzi hill on which the springs are situated. Pebble to boulder alluvial deposits were washed from these mountains under a high energy environment and accumulated along the western margin of the basin, forming the Enon Formation conglomerate during the late Jurassic to early Cretaceous (~146 Ma) (Mclear, 2001). Clays were then deposited uncomfortably on the Enon Formation to form the mudstones and siltstones of the early Cretaceous Kirkwood Formation (~146-100 Ma) (Mclear, 2001). These deposits are the basal sediments within and around the spring eyes as shown by Deacon (1970) in his Area 2 Cutting 5 excavation (termed 'basal clays' or 'variegated marl'). Younger deposits also occur in the form of a silcrete cap at the top of Amanzi hill (likely early Cenozoic: from ~65 Ma; Mclear, 2001). Silcrete artefacts of Middle Stone Age character occur in some of the spring eyes at the site. Silcrete does not appear to have been used for Acheulian artefacts at least in the Area 1 deposits, as it was at Elandsfontein (Braun *et al*. 2013).

In Areas 1 and 2, Deacon (1970) and Butzer (1973) defined three stratigraphic members (Figure 3) across the two areas excavated at Amanzi Springs primarily comprised of sediments that welled up from deep subsurface strata (Butzer, 1973), presented from oldest to youngest:

Enqhura: Consists of 'basal clays' overlain by white sands and then marginal clays. Although this member was only minimally excavated by Deacon, Acheulian artefacts were recovered from its surface (white sands) in Square 1 of Area 1 and from three surfaces within the white sands in Area 2 (Cutting 6 and Deep Sounding). Butzer (1973) described the sands as well-laminated and coarse in Area 1, but lacking silty-clay inclusions as seen in similar deposits

within Area 2. The sand represents periods of high spring volume, while the underlying and overlying clays represent periods of low flow.

Rietheuvel: In Area 1, the Rietheuvel Member is described as a brown herbaceous sand (BHS; with wood preservation) grading S to N to a Greenish Clayey Sand (GCS) at the base, and overlain by Grey Black Silts (GBS) in the northern sector of Cutting 1 and 10. In Area 2, it is described as an upper unit of grey-black silts and lower brown humic sands (BHS; aka 'Brown Sands' in Butzer, 1973). However, throughout Deacon's excavation notes, this member is also described as white sandy silt grading S to N to a yellow clayey silts overlain by blue-black material (clay) in the western area of Cutting 10 and in Cutting 1. Butzer (1973) further described the deposits as grey sands grading to pale yellow silt loam. This phase ends with a major truncation and disconformity. The majority of the Acheulian artefacts were said to occur in the top of this member in Cutting 1 based on Deacon's observations. This is in the base of GBS and top of the BHS-GCS. Deacon's (1970) artefact samples 1 – 3 come from this zone. Sample 3 is stratigraphically the lowest and was recovered entirely within GCS, although at the eastern end of Cutting 10 this same unit is also defined as yellow clayey sands in Deacon's notes. In this same area, the GCS (called Blue Black material in Deacon's notes) covers the entire N-S width of Cutting 10 and is not restricted to the northern area as in the western part of Cutting 10 and Area 1. This sample was recovered from five trenches spaced across the northern part of Cutting 10. Deacon's (1970) sample 1 is described in his notebooks as stratigraphically the next set of lithics coming from the surface of and within the yellow clayey sands (thus BHS-GCS). This was recovered from an easterly extension of Cutting 10. The uppermost sample 2 was recovered entirely within GBS along the northern wall of Cutting 10. While all of samples 1 and 3 were recovered from spits within the various units, some of Sample 2 were piece plotted. Contrary to Inskeep (1965), Deacon stated that the wood-bearing zones in the stratigraphic sequence at Amanzi Springs were likely naturally accumulated and that no positive relationship with artefact accumulations could be identified.

Balmoral: Consists of poorly sorted sands with some well-stratified facies and channel fill deposits that form after the disconformity (Deacon, 1970). This unit generally grades upwards from loamy sands to sandy loam (Butzer, 1973). It is marked by the occurrence of ironstone deposits and layers cemented by iron that cap the older members and have stopped their erosion. The iron originates from the spring water, which in turn is derived from pyrite-rich sandstones from the basement TMS (Butzer, 1973). Deacon (1970) noted that Acheulian artefacts were excavated from this unit (sample 4), although he never analysed this material. While his published plans suggest Sample 4 artefacts only come from the central area of Cutting 10 (all of the artefacts from this sample were piece plotted), they are generally more concentrated in the southern part of this area and similar pothole fill artefacts were also excavated from this Member in Cutting 1. Whether this 'pothole fill' (Deacon, 1970) represents accumulation of artefacts within the time period represented by the younger Balmoral Member or a deflation, lag surface from the erosion of Acheulian artefacts out of the Rietheuvel Member during the major phase of erosion represented by the disconformity, is not certian, but our preliminary analysis of the stratigraphy suggests this is likley the case. The base of this Member was only excavated in Deacon's (1970) 'Deep Sounding' within Cutting 1 of Area 1 and was archaeologically sterile. Due to the question over the relationship of this material to the Rietheuvel Member Acheulian it has not been included in our analysis?

Assemblage Characteristics

The Amanzi Springs assemblages were initially described by Deacon (1970: 98), who highlighted the "heavy and unstandardized" nature of this material. Figure 4 shows ordinal categories relating to cortex percentages and flake scar counts for handaxes, which demonstrate that while they preserve an average of 10 – 30% cortical surfaces, the amount of flaking is fairly extensive (averaging 16 scars per specimen). However, flaking patterns show that the majority of reduction is restricted to primary shaping phases as these tools lack thinning and retouch (Figure 5). Large flaking blanks (>10cm) were used to produce handaxes are prevalent within the assemblage, including end- and side-struck and 'cobble opening' (*eclát entame*) methods (Inizan *et al*., 1999; Sharon, 2011, 2009). There is some evidence for tip preparation within the handaxes and rough-out forms. Deacon (1970) also noted this, referring to a "five flake pattern" of tip-shaping restricted to cobble-reduced tools, which suggests a trend towards the production of pointed forms versus ovates (Figure 6).

In terms of raw materials, our recent review of the lithic assemblage found that the majority of lithics are made on Enon quartzites and all handaxes analysed here are composed on this material type. Our survey of the sites suggests that Enon quartzite clasts are scattered all over the Amanzi Springs hillside and appear to form the main raw material source for the Acheulian artefacts. These materials are also located within the poorly-sorted terrace gravels of the Coega River, within 2 km of the site (see Figure 2). This suggests a local raw material sourcing and transport strategy, which can be observed at some of the more well-known Acheulian sites in South Africa including Cave of Hearths (McNabb, 2009), Sterkfontein Member 5 West (Acheulian Infill) (Kuman, 1994; Kuman and Gibbon, 2018), Doornlaagte (Mason, 1988), Canteen Kopje (Mcnabb and Beaumont, 2011) and the Rietputs Formation (Gibbon *et al*., 2009; Kuman and Gibbon, 2018). In general, quartzite exploitation plays an important role in the South African Acheulian tradition, which becomes a widely utilized material type during this period. However, the structural and fracture properties of quartzites vary greatly on a regional scale in South Africa.

Interestingly, Deacon (1970: 98) also noted that the Amanzi Springs handaxes varied considerably in their size and shape, which pointed towards an unstandardized assemblage, albeit did not exclude it from an "advanced" phase of the Acheulian industry. Moreover, Deacon's analysis of Amanzi Springs LCTs led him to conclude that the general use of 'refinement' qualities in handaxes (i.e. symmetry in plan-view and/or thinness) cannot be used as a definitive chronological marker for Acheulian assemblages (although see Kuman, 2007; Shipton 2013). In fact, recent debate on handaxe shapes have found that examining assemblages as a collection of 'finished' artefacts that were discarded only after their use-life potential had expired, disregards potential influences of raw materials and continuous reduction and resharpening (Ashton and McNabb, 1995; Ashton and White, 2003; Iovita and McPherron, 2011; McPherron, 2006, 2003, 2000, 1999; White, 1995). From this perspective, every discarded handaxe recovered from the archaeological record has not reached some sort of end-point on a production scale, especially when some show evidence of being re-worked over time or constrained by raw material properties. For this reason, the theoretical assumptions held here are that handaxes, like all other lithic artefacts, represent various stages of production and any variation in size and shape related back to practical concerns such as functionality and constraints on reduction.

Materials

The focus of this analysis is on the handaxes of Amanzi Springs and understanding how they compare in terms of size and shape to other South African Acheulian assemblages. A sample of 57 handaxes from the Area 1 artefact collection were selected for comparison with the Cave of Hearths and Rietputs 15 assemblages. Concerning the latter two sites,

measurements were taken from a useful dataset published in Li, et al. (2018), which compares handaxes from these sites to understand changes in production techniques through the Early versus Late Acheulian periods. The contexts of these assemblages have been reviewed in numerous publications, although brief descriptions are necessary for understanding their comparability to Amanzi Springs.

Cave of Hearths is located within the Makapan Valley system near the town of Mokopane, Limpopo Province (see Figure 1). It was originally discovered by van Riet Lowe (1938) in 1937, although it was first systematically excavated by Mason (1988) between 1953-4. This exposed an expansive cultural sequence from the Later, Middle and Earlier Stone Ages preserved in 11 stratigraphic layers (Beds), overlain by an Iron Age deposit (Bed 12) (Mason, 1988; McNabb and Sinclair, 2009). Beds 1 – 3 have yielded a large, Late Acheulian assemblage, which has since been dated to a maximum age of 780 ka based on palaeomagnetism (Herries and Latham, 2009). The artefacts are largely made on locally-sourced quartzite materials and show increased amounts of thinning and retouch when compared to Amanzi Springs. While this site has often been referenced as a 'type assemblage' for the Late Acheulian in South Africa, McNabb's (2009) most recent assessment of the Beds 1 – 3 materials found that the LCTs were also largely unstandardized. This was based on the variability of shape within their tips, which further questions the notion of 'refinement' in the Late Acheulian period of South Africa (also see McNabb *et al.*, 2004). However, the unstandardized nature of this assemblage and the consistency of quartzite use should find some parallels to the Amanzi Springs materials. Given this material comes from a primary depositional setting within a limestone cave, it might be considered that the artefacts are more likely to represent intended end products as they are not being recovered from near to their raw material source, which is predominantly quartzite (McNabb, 2009). As such, the site is broadly comparable to Amanzi Springs with regards its raw material, if not its depositional setting.

Rietputs 15 is located on the Vaal River near the town of Windsorton (Northern Cape Province) (see Figure 1), where artefacts were identified and collected within alluvial gravels during a mining operation (Gibbon *et a*l., 2009; Kuman and Gibbon, 2018). The Vaal River gravel sequence has been used as a benchmark for dating Acheulian site in South Africa since the 1940's (see van Riet Lowe, 1952), which has been divided into sequential terraces ('Older' and 'Younger') that preserve artefacts from all Stone Age techno-complexes in South Africa (Butzer *et al.*, 1973). Rietputs 15 fits into the 'younger' gravel sequence (Butzer *et al.*, 1073; Gibbon *et al.*, 2009; Helgren, 1978) and the Pit 5 artefacts (analysed in Li *et al.*, 2018) have been dated to sometime between ~1.5 and ~1.1 Ma (1.31 ± 0.21 to 1.27 ± 0.20 Ma) based on cosmogenic burial methods (Herries, 2011; Kuman and Gibbon, 2018). The assemblage is almost exclusively made on Ventersdorp lava, which include andesite and other forms of diabase rock. Handaxes are not extensively flaked and vary considerably in shape (Kuman and Gibbon, 2018). Handaxes from Pit 5 at Rietputs 15 are included here to test how the extent of size and shape variation in this assemblage compares to Amanzi Springs. As stated above, Deacon (1970) described Amanzi Springs' lithics as unstandardized, which may show some affinities to an Early Acheulian assemblage in terms of handaxe shapes. Although given the possible age restriction on the formation of Amanzi Springs to a younger Pleistocene period, it is expected that the assemblage will compare more closely to the Late Acheulian and thus Cave of Hearths, especially given that they are both made on quartzite. Some variation in these assemblages based on the fracture properties and hardness of medium grained igneous rocks versus quartzite is expected. However, the increased use of quartzite materials throughout the Acheulian industry in South Africa should reflect a mastery over any raw material constraints on handaxe production.

Methods

The dataset used here combined published measurements for Rietputs 15 and Cave of Hearths handaxes by Li, et al. (2018) with similar measurements from Amanzi Springs based on Bordes (1961) and Roe (1976, 1964), which were compared according to Gowlett's multivariate approach. Gowlett included breadth-at-midpoint (BM) and thickness-at-midpoint (TM) measurements, which were not used in the Li, et al. (2018) dataset and thus excluded in this analysis for comparability. Gowlett and Crompton (1994: 30) stated that TM is largely "a redundant variable if T [thickness] is available," which was assumed the same for BM. Similarly, mass was also excluded from these analyses as the variables used here account for geometric size and thus volumetric measurements (i.e. weight) are redundant (Crompton and Gowlett, 1993). Non-parametric tests were chosen here for comparison as approximations to the normal distribution in archaeological data cannot be assumed. The initial exploration of the data involved a basic analysis comparing length, breadth, thickness and mass (g), as well as elongation (L/B) and refinement (B/Th). These data were explored through boxplots and Kruskal-Wallis tests to accommodate more than two samples. These would reveal any variation present between these measurements and if so, what assemblages demonstrated significant differences. In following Gowlett's assumptions, length, breadth, thickness and mass should demonstrate a power relationship consistent with allometric growth patterns. To test this, regression analyses were used to plot length, breadth and thickness against mass. The reasoning for using mass as a dependent variable is that it is most comparable to the total volume (and thus the size) of artefacts.

Next, multivariate techniques employed by Gowlett and Crompton (Crompton and Gowlett, 1993; Gowlett and Crompton, 1994), discussed above, were used to explore allometric patterns in the combined dataset. The first step consisted of log-transforming all variables for PCAs analysing individual sites using a covariance matrix. The PC1 scores were then used to calculate ACs for each measurement variable through rescaling loadings to a mean of 1.0 (Diniz-Filho *et al.*, 1994; Strauss, 1985). ACs were used to compare allometric relationships between handaxe shapes between South African sites. Coefficients of variation for measurement variables were also calculated for comparison with ACs to understand how they vary on an allometric scale (Crompton and Gowlett, 1993). A second PCA was then run on the complete dataset to explore the dispersion of variation on component scores. This was used to highlight what variables play significant roles in handaxe shape variability in these South African assemblages.

It is expected that most of the variation will be explained by PC1 and similar trends in PC2 (thickness) and PC3 (breadth in planform) as seen in the Kilombe and Kariandusi analyses (Crompton and Gowlett, 1993; Gowlett and Crompton, 1994. This will be used to test Gowlett's hypothesis that 'rule-sets' in handaxe production are consistent across Africa. A set of PCAs were then run on individual sites to verify these results and test the consistency of PC loading trends in the PCA run on the combined dataset to identify allometric trends. Finally, a DA was used to test the ability of the variables to discriminate between site groups. It should be expected that Cave of Hearths and Amanzi Springs would exhibit a fair amount of cross-classification due to their assignment to the Late Acheulian and their more similar raw material (e.g. quartzite). This will test the ability of handaxe size and shape to distinguishing between assemblages and test the notion of refinement that Deacon (1970) questioned when reviewing the Amanzi Springs lithic materials.

Results

Exploratory Results

The combined dataset was subjected to an exploratory analysis of basic dimensions (L, B, Th & M) between sites, which yielded unexpected results. Figure 7 demonstrates that Amanzi Springs is considerably larger in overall geometric size when compare to both Rietputs 15 and Cave of Hearths. A Kruskal-Wallis test found significant differences for all variables between groups (L: x^2= 40.57, p< 0.001; B: x^2= 27.57, p< 0.001; Th: x^2= 39.25, p< 0.001; M: x^2= 53.98, p< 0.001). Another test was then run to compare Cave of Hearths and Amanzi Springs as Late Acheulian assemblages, which also confirmed significant differences (L: x^2= 14.65, p< 0.001; B: x^2= 16.87, p< 0.001; Th: x^2= 31.45, p< 0.001; M: x^2= 43.97, p< 0.001). Elongation (L/B) and refinement (B/Th) Figure 8, showed mixed patterns, where Amanzi Springs demonstrates that handaxes are more elongated, yet are the least refined (Figure 8). Kurskal-Wallis results confirmed significant differences between these variables as well (El: x^2= 20.46, p< 0.001; Rf: x^2= 13.58, p= 0.001). A separate test was again run between Cave of Hearths and Amanzi Springs for elongation and refinement, which only returned a significant difference for refinement (El: x^2= 1.43, p= 0.231; Rf: x^2= 12.28, p< 0.001). This is unexpected for two Late Acheulian assemblages, especially considering that Rietputs 15 shows displays more refinement that Amanzi Springs.

Examining the regression results, a power relationship was observed between all linear measurements and mass as previously predicted by Gowlett (Crompton and Gowlett, 1993; Gowlett and Crompton, 1994) (Figure 9). An interesting trend to note is that r^2 values were higher for Amanzi Springs in length and slightly for width, although not for thickness. This suggests the presence of an allometric relationship between basic dimensions (L, B & Th) when compared to volumetric size (mass), which generally correlates highest in the Amanzi Springs handaxes. Another significant feature of the regression analyses is the overall clustering patterns of plot scores for Amanzi Springs when compared to the other sites, which consistently group towards the higher spectrum of values. This shows that similar to Gowlett's conclusions about allometric effects on size, shape and mass, handaxes from Amanzi Springs approximately 15cm in length will weigh around 500 g, while an increase in length to 20cm doubles the weight (~1000 g; see Crompton and Gowlett, 1993).

Next, Table 1 compares mean, standard deviation and coefficient of variation (CV) values for all measurements used in the multivariate analysis, also including mass, elongation and refinement. An interesting pattern emerges here demonstrating that the Late Acheulian assemblages (Cave of Hearths and Amanzi Springs) are considerably more variable than Rietputs 15. This result was also found in Li et al. (2018), who suggested that variability is perhaps a more characteristic factor of Late Acheulian handaxes in South Africa than refinement. CV values for variables are graphically displayed in Figure 10, which shows some distinct patterns between sites. Rietputs 15 is consistently less variable aside from thickness dimensions, which may be a consequence of raw material restrictions in terms of package size and shapes of Ventersdorp lavas available in the Vaal River gravels. Cave of Hearths is more variable in L, B and Th variables when compared to Amanzi Springs, which are only comparable in PMB. Although when CV values for mass are considered, Amanzi Springs is nearly double the volumetric size of the other sites. This pattern suggests that while handaxes size for Amanzi Springs were considerably larger, they were more restricted in shape variation than Cave of Hearths, and in thickness aspects compared to Rietputs 15.

Multivariate Allometry Results

Allometric coefficients were then calculated according to Gowlett's multivariate procedures (Crompton and Gowlett, 1993). Table 2 displays both PC1 and AC scores by site. Figure 11 displays the graphic results for AC scores, which highlights allometric trends for shape variables at these South African sites. Upon a visual comparison to results for Kilombe

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and Kariandusi, the South African sample displays similar patterns to East African assemblages (see Figure 20 in Gowlett and Crompton, 1994). As such, PMB shows the highest, positive allometric score, while BB displays the opposite pattern. B and BB show greater trends towards negative allometry in the South African sample than Kilombe and by comparison, allometric trends in South African handaxes plot closely with Kapthurin and Kariandusi (Gowlett and Crompton, 1994).

Further, AC and CV scores were compared in a bivariate plot according to mean values, which displays the general relationship between these factors for the measured variables. Figure 12 displays these results for allometric and variation patterns, which is comparable to results reported for Kilombe (see Figure 8 in Crompton and Gowlett, 1993). However, there are some disparities in these patterns that differentiate the East and South African handaxes to a degree. Crompton and Gowlett (1993) grouped variables according to trends in negative-to-positive allometry and high-to-low variation, identifying a linear relationship between allometric and variation trends. They found that variables fell into three basic patterns: 1) basic planform and butt variables (negative allometry/low variation); 2) thickness variables (negative allometry/average variation); and 3) pointedness variables (positive allometry/high variation).

A similar linear correlation was detected for the variables used to compare South African handaxes (r^2= 0.98, p< 0.001), where PMB (highest allometric coefficient) displays the highest amount of variation and B and BB show the opposite trend. However, the grouping of variables demonstrates differences in correlative patterns. For the South African sample, four basic groups are found: 1) general plan-view and profile shape (negative allometry/low variation); 2) butt thickness (isometry/low variation); 3) tip shape (positive allometry/average variation); and 4) point of maximum breadth (positive allometry/high variation). The needs to create four groups was motivated by the isometric trend in butt thickness, which is closely related to tip shape variables, albeit should be separated on its trend of 'geometric' growth (i.e. 1:1 increase with size).

Assessing these groups, some general patterns emerge. Primarily, there is a relationship between the overall shape of handaxes and geometric growth, which shows that size increases in handaxes negatively correlate with maximum dimensions in plan and profile views. This suggests that knappers consistently constrain their overall proportions to maintain shape. The second pattern relates to butt thickness growing at an isometric rate with size, which suggests that this variable is relatively stable throughout production. This likely correlates to the location of the centre of mass in handaxes, which is a critical variable in their use (Gowlett, 2006; Grosman *et al.*, 2008; Park *et al.*, 2003). The third pattern includes both tip shape and PMB because they show similar positive allometric trends, albeit the latter variable shows maximum variation. Breaking this third pattern down, tip breadth and thickness grow at an increasingly faster rate to geometric increase in size. This likely correlates to maintaining elongation in handaxes as the widest and thickest aspects of these tools tend to be located towards the butt end. As such, accelerating growth in the tip then counteracts trends towards ovate shapes and maintains a prominent pointed tip. Lastly, the positioning of PMB is also critical towards maintaining the centre of mass in handaxes and as tool forms increase, the need to position the PMB towards the mid-point of overall length is important for avoiding butt-heavy products. As Gowlett (2011, 2013) found, smaller handaxes tend to have wider plan-view shapes (increased breadth relative to length), typically concentrated towards the butt-end, which is manifested as an average ratio of 0.75. Whereas larger handaxes tend to be comparatively thinner in plan-view (decreased breadth relative to length), manifested as an L/B ratio of 0.50 (Gowlett, 2011).

While these patterns are useful to understand some principals underlying the size/shape relationship, assumed to reflect the knapper's control over the form of these tools, a second PCA on the entire dataset was then used to see if AC/CV patterns could be condensed into

more meaningful 'rule-sets' (Crompton and Gowlett, 1993; Gowlett and Crompton, 1994). A KMO-Bartlett's test was used to test the strength of the PCA (KMO= 0.848; Bartlett's: $x^2=$ 1508.53, df= 28, p< 0.001), which demonstrated that results were suitable for multivariate analysis. Figure 13 shows the results comparing the first 3 principal components, which represented over 93% of the variance. When the loading scores for the first 3 PCs are compared (Figure 14), some patterns are different to Crompton and Gowlett's (1993) findings for Kilombe handaxes. For instance, length accounted for the most variation on the PC1 (79%) axis, with all other variables loading relatively weaker. Given that PC1 represents geometric size, length seems to correlate strongest with this factor in these handaxes. Yet as Crompton and Gowlett (1993) noted, this correlation doesn't account for most allometric variables discussed above. PC2 (8%) was most strongly correlated with both breadth (B, BA & BB) and thickness (T, TA & TB) variables. This suggests that positive allometric trends in tip shape (TA & BA) co-vary with plan-view (B & BB) and profile (T & TB) shape below the point of maximum breadth and thickness. In this sense, as handaxes increase in geometric size, tip shape increases while the lower portions of these tools decrease, which likely relate to managing the positioning of the centre of mass. Finally, PC3 (6%) represents variation in PMB, which correlates to the trends highlighted above in Figure 12. These results substantiate the AC/CV patterns in allometric growth in handaxes, which are discussed in more detail below.

To verify these results, three PCAs for individual sites were run separately to test the representative nature of trends highlighted above. Component loadings for individual sites were then compared to test the findings displayed in Figures 13 and 14. This confirmed that PC loadings for variables were broadly similar between Amanzi Springs, Cave of Hearths and Rietputs 15 (data not presented here). Interestingly, Amanzi Springs and Rietputs 15 were similar in loading scores across PCs 1 – 3, which parallel those found in the PCA for the complete dataset discussed above. Cave of Hearths displayed slight deviation in component loadings for PMB, which loaded onto PC 2 more positively and similarly for BB onto PC3. This suggests that perhaps PMB plays more of a role in variation for the Cave of Hearths handaxes, possibly correlating to variability in raw material package size and the extent of flaking. Li, et al. (2018) have shown that Cave of Hearths handaxes are more extensively flaked when compared to Rietputs 15. Coupled along with CV scores in Table 1, Cave of Hearths shows the most variability in length, suggesting a correlation between this dimension and the positioning of PMB. Regardless of this difference, the PCAs for individual sites corroborate that PCs 2 and 3 reflect allometric patterns in how tip and butt shape variables co-vary during increases in geometric growth.

Finally, the results of the DA show that Amanzi Springs handaxes are distinct from the Rietputs 15 and the Cave of Hearths assemblages (Figure 15). In fact, the latter two assemblages show the most overlap, which is unexpected given one of these assemblages is meant to represent the Early Acheulian and the other the Late Acheulian. The greater correlation between these two and not between Amanzi Springs and the Cave of Hearths is even more unexpected given they have both been classified as Late Acheulian and are made predominantly on quartzite, unlike the older Rietputs 15. The first function captures 88% of the variance, in which length and tip breadth are the best discriminators. This suggests that geometric size is again correlated with length, which is distinguishing factor for Amanzi Springs handaxes. Thickness and breadth variables then load strongest onto the second function, which reiterates the results of the PCA above. Table 3 displays the cross-validated classification results for specimens assigned to groups by site. It is clear that the DA validates the *a priori* groups with 71.5% of specimens assigned correctly. However, this high percentage is mostly driven by 87.9% rate of Amanzi Springs handaxes correctly discriminated. Approximately 30% of Rietputs 15 and Cave of Hearths handaxes, respectively were incorrectly assigned to one another, exhibiting the most significant amount of overalp between

groups. The fact that Amanzi Springs remains undated needs to be considered when interpreting these results, yet if this assemblage is Late Acheulian, its unstandardized nature complicates the typological principal that 'refinement' is a characteristic of handaxes from this period of the Acheulian industry (Deacon, 1970; Li *et al*., 2018).

Discussion

As Crompton and Gowlett (1993) discussed over 20 years ago, there was likely no strict set of rules governing the production of handaxes in Acheulian times. There are a number of factors including raw materials, function, style and the individual knapper that resulted in wide-ranging variability when handaxe size and shape are investigated in the modern era. When the South African sites compared here are examined, similarities suggest basic guidelines for understanding the relationship between size and shape. This can then be used to interpret rule-sets underlying handaxe production, albeit these are not rigidly applicable to every specimen (Crompton and Gowlett, 1993). Nonetheless, the results presented here demonstrate that allometry is a common factor of handaxe shape across the African continent and that rule-sets are indeed consistent (on a general level) between eastern and southern regions.

Allometric Trends in South African Handaxes

When allometric patterns are compared between the AC/CV and PCA results, two principal 'rule-sets' are detected relating to shape variables in these South African handaxes, which corroborate Gowlett's (Crompton and Gowlett, 1993; Gowlett and Crompton, 1994) previous findings for East African assemblages. The primary factor is that the basic dimensions (L, B, and Th) show negative allometric patterns, suggesting constrains on general proportions as handaxes increase in size (Figures 11 and 12). As such, shape is an important concern in the overall production process of these tools. Maintaining proportions of basic dimensions in this sense restricts the shape of handaxes to predetermined forms. However, variance in allometric patterns at individual sites and artefact levels supports the notion that production processes were likely only guided by a shared concept of form rather than a strict operational construct (McNabb *et al*., 2004). It is more probable that the resulting variability in handaxe shapes is a product of practical concerns including raw materials, functionality and reduction intensity (Ashton and McNabb, 1995; Ashton and White, 2003; McNabb and Cole, 2015; McPherron, 2006, 2003, 2000, 1999; White, 1995).

Secondly, the balance between plan-view and profile shape is a critical factor, albeit this relationship is inversely correlated. This pertains to the upper and lower halves of handaxes, above and below the point of maximum breadth and thickness. The upper portion relates to adjustments tip shape (i.e. tip breadth and thickness) that correlate positively with size, while the lower portions relates butt shape, which is isometric-to-negatively correlated with size. Combined with variability in the point of maximum breadth, this balance between tip and butt shape likely relates to the length-to-breadth ratio in handaxes observed by Gowlett (2011), which showed that increases in length correlated with 'skinnier' plan-view shapes. The critical variable operating here is likely the positioning of the centre of mass (Gowlett, 2006; Grosman *et al*., 2008; Saragusti *et al*., 2005). As stated above, Gowlett (2006) argued that specific 'imperatives' related to the proportions of handaxe shape. The centre of mass is critical for the use of handaxes in terms of the balance of the tool, reiterating the 'balance' of tip and butt shapes found the multivariate results above. In this respect, the motor-perceptual capacities of hominin tool-use (like all other primates) were linked to the overall shape and weight of the implement, which in terms effects manual dexterity (Bril *et al*., 2010, 2009; Visalberghi *et al*.,

2009). The balance of handaxes likely impacted their manual manipulation in food-processing activities, thus tools too heavily weighted towards their tip or butt ends were likely not as efficient, as gripping and dexterity would have to compensate for these issues (Crompton and Gowlett, 1993).

Lastly, another remarkable point demonstrated in the PCA analyses is the stability of trends reflected in the South African handaxes across temporal, geographical and raw material boundaries. As stated above, PC loading trends in PCAs run for individual sites were broadly similar, even though Rietputs 15 is comprised on Ventersdorp lavas while quartzite dominates the other assemblages. In fact, the only deviation in PC loading patterns was seen in Cave of Hearths, which is expected to plot closely with Amanzi Springs due to similarities in raw materials and industrial affiliation. This could reflect some differences in raw material package size and shape, function or skill, which McNabb *et al.* (2004) suggested to be a controlling factor in handaxe production. Nonetheless, the stability of patterns corroborate findings for allometric trends common in South African handaxe production, where the covariation between tip and butt shape determine the balance of tool mass.

The Amanzi Springs Handaxes

When considering Amanzi Springs in the context of South African handaxe assemblages, a trend towards increased geometric size coupled with low variation in shape separates it from Cave of Hearths and Rietputs 15 (compare Figures 10 and 15). The results of the exploratory analysis show that Amanzi Springs handaxes are relatively larger and yet the variation is quite restricted across most length, breadth and thickness variables (see Table 1 and Figure 10). For a purported Late Acheulian assemblage, this is an unexpected result in terms of contradicting the general pattern of refinement (see Figure 8). On this point, the trend towards refinement from Early to Late Acheulian has been argued at length in Earlier Stone Age research (Hodgson, 2015; Klein, 2009; Kuman, 2007; Wynn, 1995, 1979; Wynn and Teirson, 1990). However, a number of studies have found that this principal is not ubiquitous of Late Acheulian assemblages, some of which show increased variability in handaxe forms (Li *et al.*, 2018; McNabb, 2009; McNabb *et al.*, 2004; McNabb and Cole, 2015). Possibly the clearest example of this is found in the southern African region. McNabb (2009; McNabb et al. 2004) found that handaxes from Cave of Hearths were highly variable in their overall shape. Li, et al. (2018) have also recently found that Cave of Hearths handaxes are more variable in shape than Rietputs 15 and that the refinement (B/Th) index does not discriminate these assemblages. They suggested that the overall coverage of flake scars, relating to primary and secondary flaking patterns to remove cortex and shape handaxes, are more abundant in the Cave of Hearths assemblage. While handaxes clearly show a general trend towards shape consistency, variability arises because of idiosyncratic circumstances on the individual knapper level, i.e. negotiating raw materials, package size and shapes, functional needs and general constraints on reduction intensity (McNabb *et al.* 2004; McNabb, 2009; Li *et al.*, 2018).

When comparing the variability in handaxe size and shape between Amanzi Springs, Cave of Hearths and Rietputs 15, there are several hypotheses that should be considered when interpreting results: 1) Amanzi Springs is possibly an Early Acheulian assemblage; and 2) these patterns represent an adaptation to the raw material availability and overall functional needs of the tool-makers. Deacon (1970) assigned Amanzi Springs to the Late Acheulian partly on his C^{14} dates of 60,600 ± 1,100 BP (GrN-4407) for the Riethuevel Member, which can be considered as an infinite age for the site, as well as the technological elements. Currently, there is no reason to doubt Deacon's hypothesis that Amanzi Springs is a Late Acheulian site, however reliable dating of the site is needed to understand where the assemblage fits into the Acheulian chronology.

Nonetheless, the second scenario presents a stronger case when viewing handaxe production from a practical perspective. This would argue that variability in size and shape are products of specific manufacturing processes including raw material selectivity and blank production, as well as discard patterns. It is difficult at present to evaluate the nature of deposition of the Amanzi Springs Acheulian artefacts. They occur in a distinct band within the Rietheuvel Member and then within the Pothole Fill of the Balmoral Member, although perhaps derived from the erosion of Rietheuvel. Deacon (1970) documented stone tools of all size grades, suggesting the Rietheuvel material does not represent size sorted, secondary deposition where smaller material has been winnowed away to leave larger handaxes. Given the springs are thermal, it also seems unlikely that the hominins who made them visited the site for water, especially given there are other freshwater springs ~7 km to the West. It was likely that the availability of Enon quartzite cobbles and boulders were in some part the attraction of the springs.

In terms of these materials, Deacon (1970) noted that the mechanical properties of Enon quartzites inhibit conchoidal fracture when compared to local silcrete materials that might have been available in Acheulian times. He described the material as comprised of large quartz grains with interstitial silica and a coarse, granular texture that caused irregular fracture patterns. Further, this material is very dense and requires increased percussive force to knap when compared to more isotropic materials such as chert or flint (pers. observ. MVC). When the overall size differences are considered from this perspective, it is possible that Acheulian hominins were selecting for larger blank materials to account for material constraints. Table 1 shows that the average handaxe length is over 16cm and 9cm in breadth, which suggests that boulder-sized, material packages were being exploited. Further, a variety of large flake-blank production techniques are present in the Amanzi Springs collections as stated above, which supports the notion that the Amanzi Springs tool-makers were well-adapted to negotiating the constraints of Enon quartzites. However, if this is the case then why would the Amanzi Springs collections exhibit a 'large and unstandardized' appearance if the hominins were adept at manipulating difficult raw materials? One possibility is that the Acheulian hominins were not concerned about the overall shape of handaxes and that the production of one or more useable cutting edges were acceptable given the material constraints. However, it seems likely that if tool-makers were not concerned about the extent of reduction in handaxes, the cortex percentages and flaks scar counts would be more skewed towards higher amounts of the former and lesser of the latter. Another possible answer is that this is a production site preserving handaxes that either were rejected and discarded due to production flaws while the more well-made tools were transported off Amanzi hill. In this sense, the overall larger size of Amanzi Springs handaxes reflects primary stages of production where large flakes and large clasts blanks were initially worked and discarded because of production complications. This may better account for the larger and unstandardized appearance of Amanzi Springs handaxes, which could relate to manufacturing failures and the timing of discard. However, conclusions on this matter remain tentative and future work with these collections aims to investigate this issue.

Conclusion

Handaxe 'Imperatives' in the South African Acheulian

The results discussed for three South African sites have found similar outcomes compared to Gowlett and Crompton's (1994; Crompton and Gowlett, 1993) multivariate analyses of Kilombe and Kariandusi. However, differences were detected that show some variation in allometric trends across the assemblages. The PCA results for Kilombe

summarized four basic trends: 1) PC1 accounts for size variation (60%) and does not represent allometric trends therein; 2) PC2 (15%) represented thickness variation linked with allometry; 3) PC3 (15%) represented planform variation linked with allometry; and 4) PC4 (10%) represented tip width variation linked with allometry (Crompton and Gowlett, 1993). The PCA results here deviated from this pattern slightly in that PC1 accounted for a larger percentage of variation (79%) with PC2 (7%) and PC3 (6%) capturing smaller proportions when compared to the assessments of Kilombe and Kariandusi (Crompton and Gowlett, 1993; Gowlett and Crompton, 1994). Further, length was strongly correlated with PC1 variance, which is not highlighted in Gowlett and Crompton's work. Nonetheless, the effects of size on the PCA used in this study could be skewed to some degree by the overall differences between Amanzi Springs and Cave of Hearths and Rietputs 15. In this sense, the larger proportions of Amanzi Springs handaxes drives size variation in multivatiate ordination tests, which is reflected in the DA as well.

Nontheless, PCs 2 and 3 display some interesting patterns in allometric trends that are different from Gowlett and Crompton's (1994; Crompton and Gowlett, 1993) results. The two major trends suggest that tip shape and butt thickness relative to the positioning of the point of maximum breadth are the most critical factors in maintaining size and shape proportions in South African handaxes. Here, butt thickness and tip shape are closely related, suggesting a tight balance between these variables as discussed above. This demonstrates that South African hominins were adept at controlling proportions of handaxes relating to the weight of these tools towards their upper and lower halves. Increasing or decreasing these variables at an uneven rate will cause exponential increases in mass towards one half or the other and significantly impact the balance of the tool.

While this trend is perhaps unique to South African handaxes, its end goal is similar across African Acheulian assemblages, which is to maintain the center of mass (CM) (Gowlett, 2006). The focus on breadth and thickness in the tip and butt ends of handaxes suggest a balancing of two ends, which directly correlates to the positioning of the CM. Recent studies have shown that shape variation and the positioning of CM is an important relationship in understanding the uniformity of handaxe forms (Grosman *et al*., 2008; Park *et al*., 2003; Saragusti *et al*., 2005). In fact, Grosman, et al. (2008) found that the position of CM relative to volume was consistent across Late Acheulian assemblages from the Middle East. This implies that CM is imperative for understanding covariation between handaxe size and shape and while tool-makers from different regions may have used diffent rule-sets, the results were similar.

The significance of this likely correlates to the use of these tools as cutting implements. The overall positioning of weight in tools is a critical aspect of their balance and efficiency. As such, maintaining tip and butt proportions in handaxes likely improved their efficiency. In fact, Key and Lycett (2016) found that mass and cutting efficiency correlated in a regression analysis, which showed that handaxes over a particular threshold of mass are more efficient in cutting activities than lighter (smaller) counterparts. They noted that handaxes ranging above 10cm correlated with cutting efficiency, which fit within the handaxe size range for assemblages analysed here and in Gowlett's work. In this sense, the positioning of mass within these tools likely aids in functionality and as such, Gowlett's (2006, 2013) imperatives argument for elongation and CM as 'true variables' that were important for handaxe production in Africa remains accurate.

In this context, Amanzi Springs represents an important assemblage for understanding the South African Acheulian in terms of morhological variation. As the analysis above demonstrates, handaxes form this site are comparatively larger in geometric size, yet tightly constrained in length, breadth and thickness dimensions (see Table 1 and Figure 10). However, Key and Lycett (2016) also found that elongation in handaxe size does not necessarily correlate to increasing efficiency, which then begs the question of why the Amanzi Springs handaxes

are so large when compared to Cave of Hearths and Rietputs 15. As mentioned above, one possibility for differences in size range may relate to the nature of these sites, where Amanzi Springs may preserve tools that were not shaped to their intended extent and rather are discarded pieces that failed during production. In this sense, Amanzi Springs may represent a production site, where the majority of these large and unstandardized tools are simply the 'handaxes that were left behind.' Further work is required to comfirm this tentative conclusion, although if this were the case, Amanzi Springs would be a rare site where production habits may provide further insight into both the varaition and constraints on handaxe size and shape.

Acknowledgments

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Tables

Table 1. Handaxe measurements (cm) for South African Acheulian assemblages.

Rietputs 15 (N= 57)	L	B	BA	BB	PMB	T	TA	TB	M	L/B	B/Th
Mean	12.71	8.09	4.60	6.70	4.73	4.51	2.39	3.78	458.23	1.57	1.84
S.D.	2.59	1.25	1.07	1.13	1.32	0.97	0.53	0.88	239.41	0.21	0.34
C.V.	20.38	15.39	23.32	16.86	27.82	21.52	22.29	23.33	52.25	13.47	18.23
Cave of Hearths (N= 64)											
Mean	14.10	8.29	4.82	7.20	4.99	4.44	2.19	3.63	418.97	1.70	1.91
S.D.	3.36	1.46	1.37	1.34	1.72	1.01	0.65	0.90	200.99	0.24	0.33
C.V.	23.82	17.59	28.41	18.64	34.48	22.71	29.60	24.69	47.97	14.35	17.14
Amanzi Springs (N= 57)											
Mean	16.63	9.55	7.37	8.74	6.52	5.71	3.69	4.37	887.07	1.76	1.71
S.D.	3.23	1.76	1.63	1.70	2.27	1.13	0.81	0.85	431.50	0.24	0.38
C.V.	19.40	18.47	22.05	19.44	34.76	19.80	22.05	19.44	48.64	13.40	21.91

Table 2. PC1 loadings and allometric coefficient scores by site.

	Rietputs		Cave of Hearths		Amanzi Springs	
	PC1	AC	PC1	AC	PC1	AC
L	0.12	0.74	0.14	0.93	0.12	0.80
B	0.09	0.56	0.08	0.55	0.11	0.77
BA	0.20	1.26	0.19	1.24	0.15	1.02
BB	0.08	0.48	0.08	0.52	0.12	0.85
PMB	0.24	1.49	0.29	1.90	0.31	2.13
T	0.17	1.08	0.14	0.91	0.08	0.56
TA	0.18	1.13	0.16	1.08	0.15	1.02
TB	0.20	1.26	0.13	0.88	0.12	0.85

Table 3. Cross-validated classification table for sites (75.1% correctly classified).

	RP15	CH	AS
RP15	66.7%	29.8%	3.5%
CH	29.7%	60.9%	9.4%
AS	3.4%	8.6%	87.9%

Figures
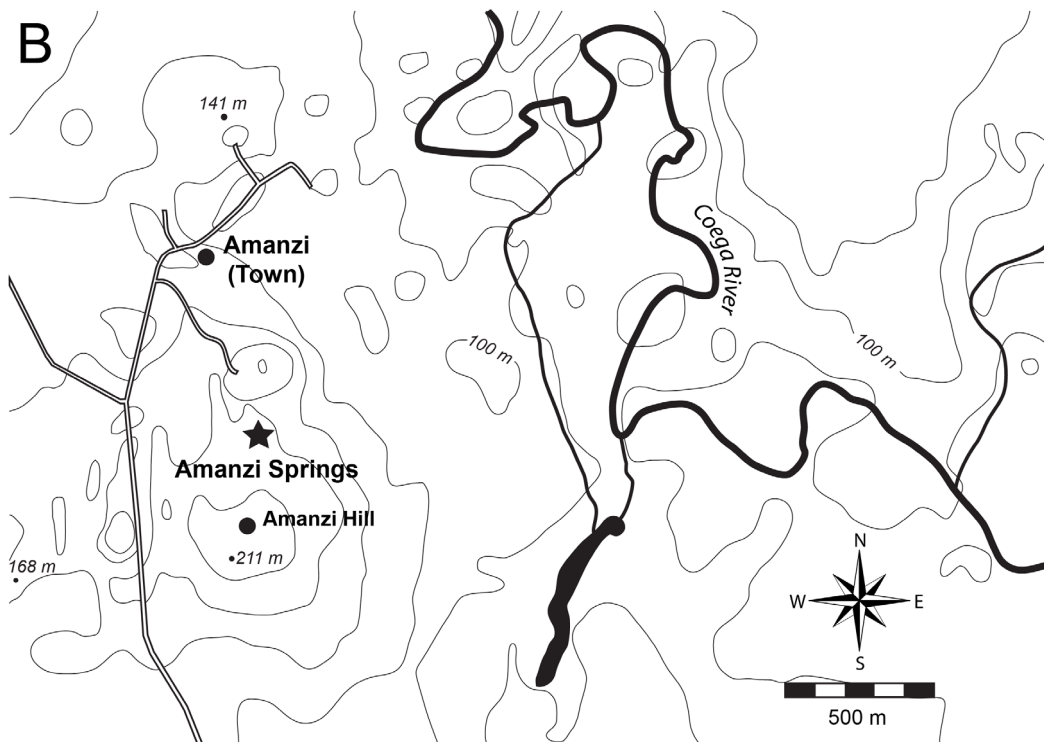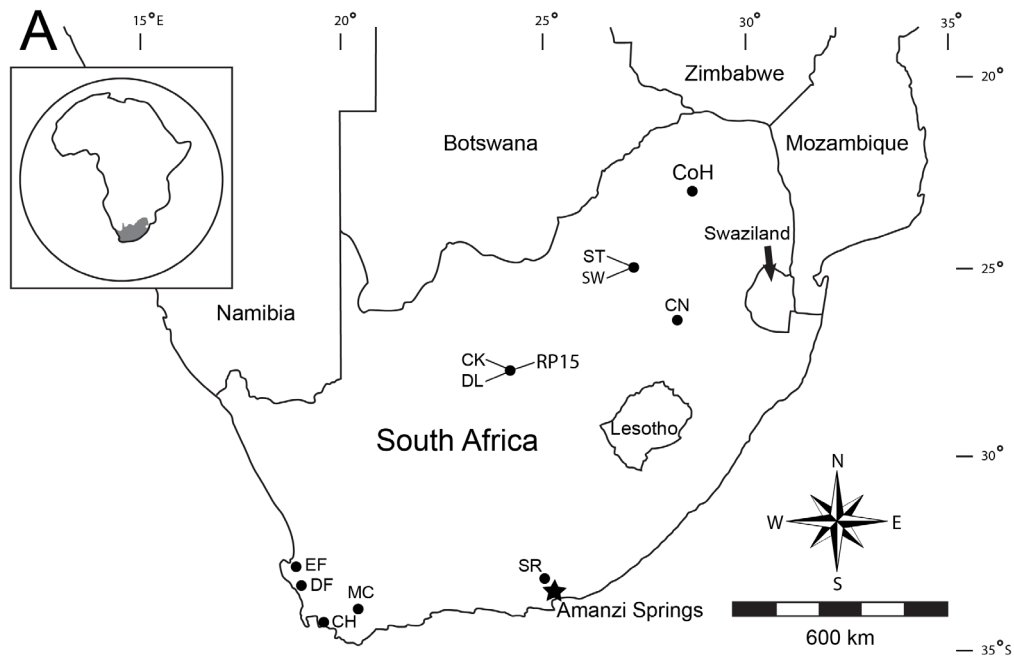
Figure 1. A. Geographical map of Amanzi Springs. A. Geographic positioning of Amanzi Springs within South Africa in relation to other important Acheulian sites. CK= Canteen Kopje, CH= Cape Hangklip, CoH= Cave of Hearths, CN= Cornelia-Uitzoek, DL= Doornlaagte, DF= Duinefontein 2, EF= Elandsfontein, MC= Montagu Cave, RP15 = Rietputs 15, SR= Sunday's River, ST= Sterkfontein Cave, SW= Swartkrans Cave. B. Topographic positioning of Amanzi Springs in relation to the Coega River valley.
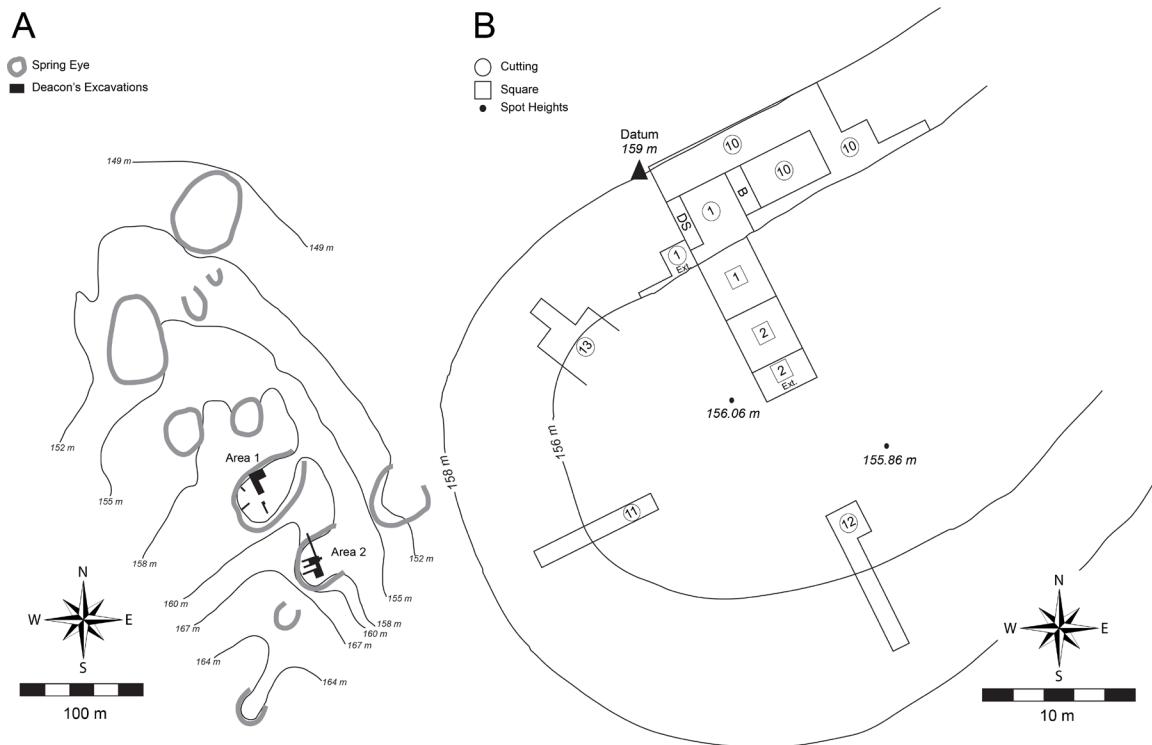
Figure 2. Map of H. J. Deacon's excavations at Amanzi Springs (Redrawn from Deacon 1970). A. The topographic positioning of the known spring eyes recorded by H. J. Deacon. B. Area 1 excavation map.
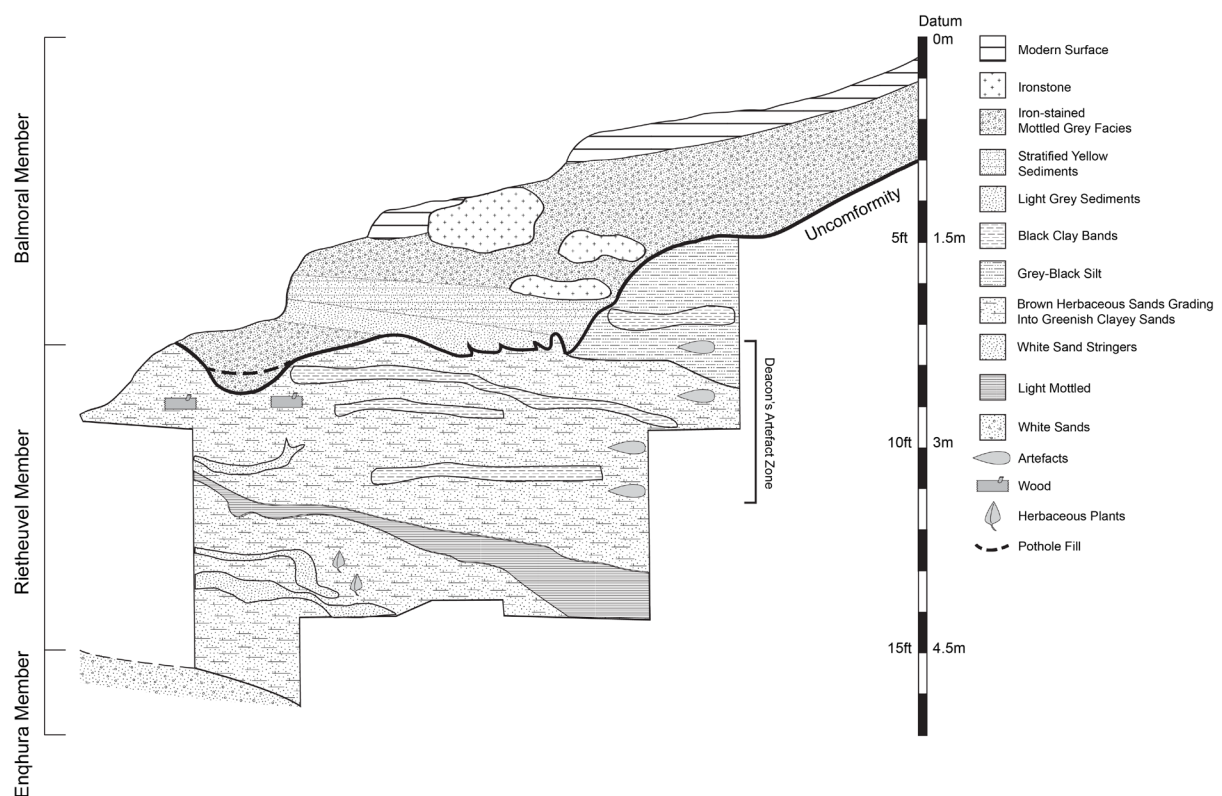
Figure 3. The Stratigraphy of Area 1 at Amanzi Springs (Redrawn from Deacon [1970]). This shows the complex relationship between the three members of the site: Balmoral, Rietheuvel and Enqhura.
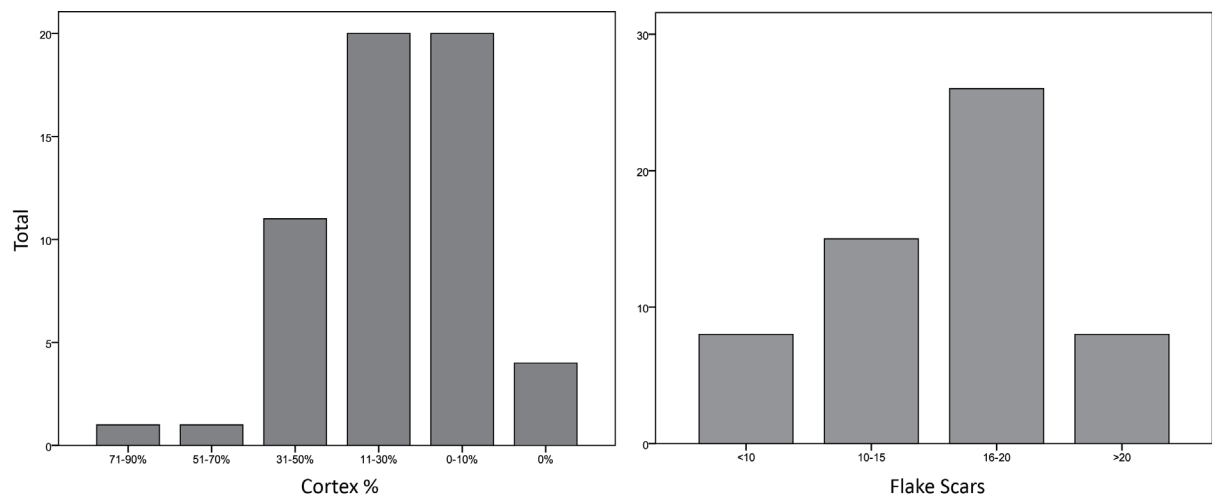
Figure 4. Bar graphs of handaxe attributes from Amanzi Springs (Area 1). A. Cortex percentage. B. Flake scar count.
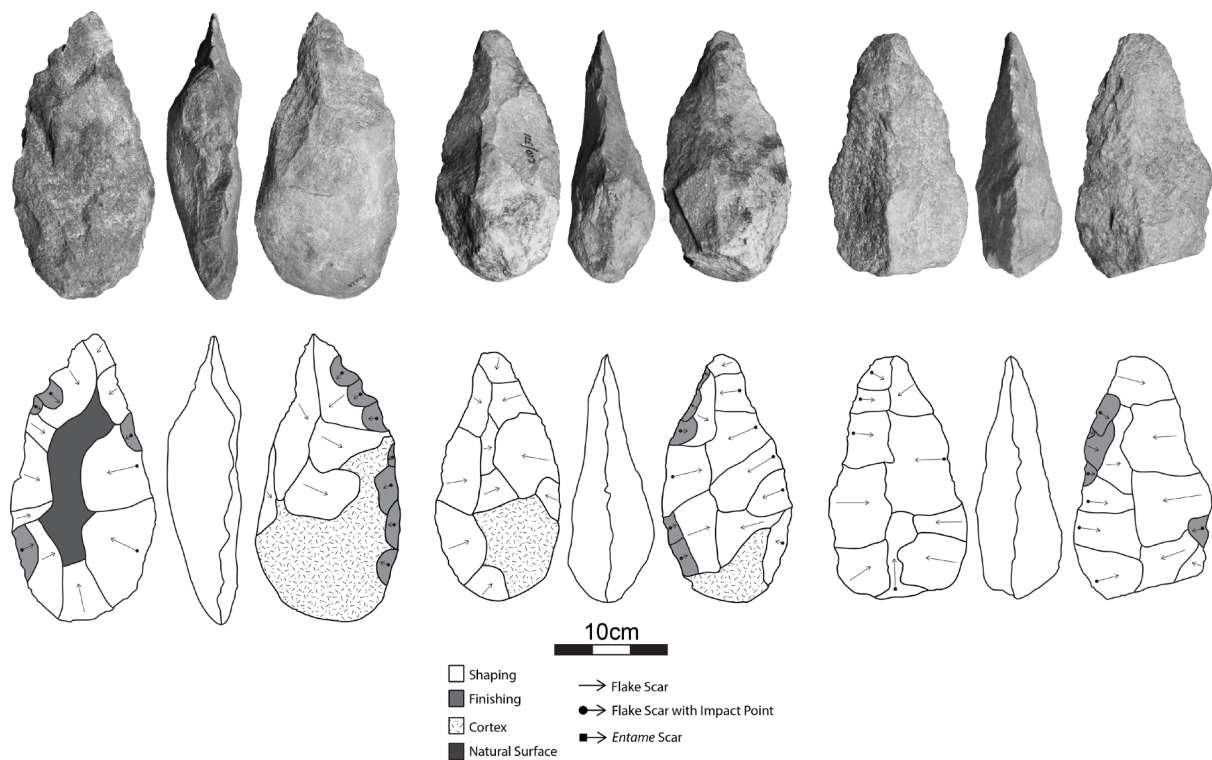
Figure 5. Handaxes from Amanzi Springs. Photographs (above) and schematic drawings (below) showing flaking patterns.
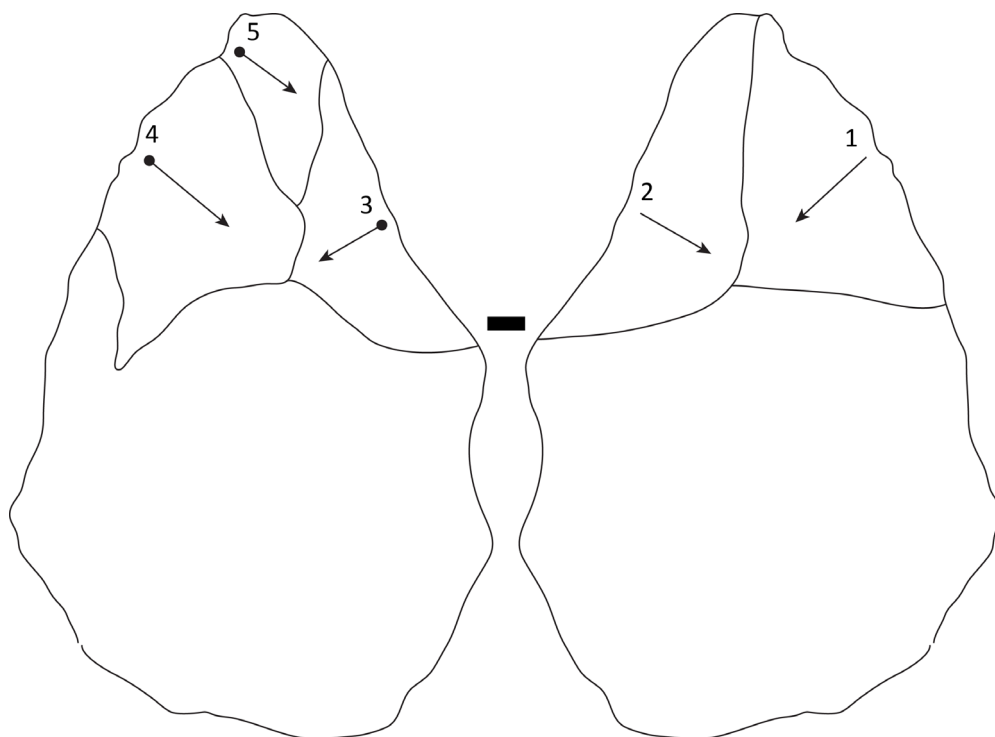
Figure 6. Simplified schematic of Deacon's (1970) "five flake pattern" of tip-shaping in handaxes.
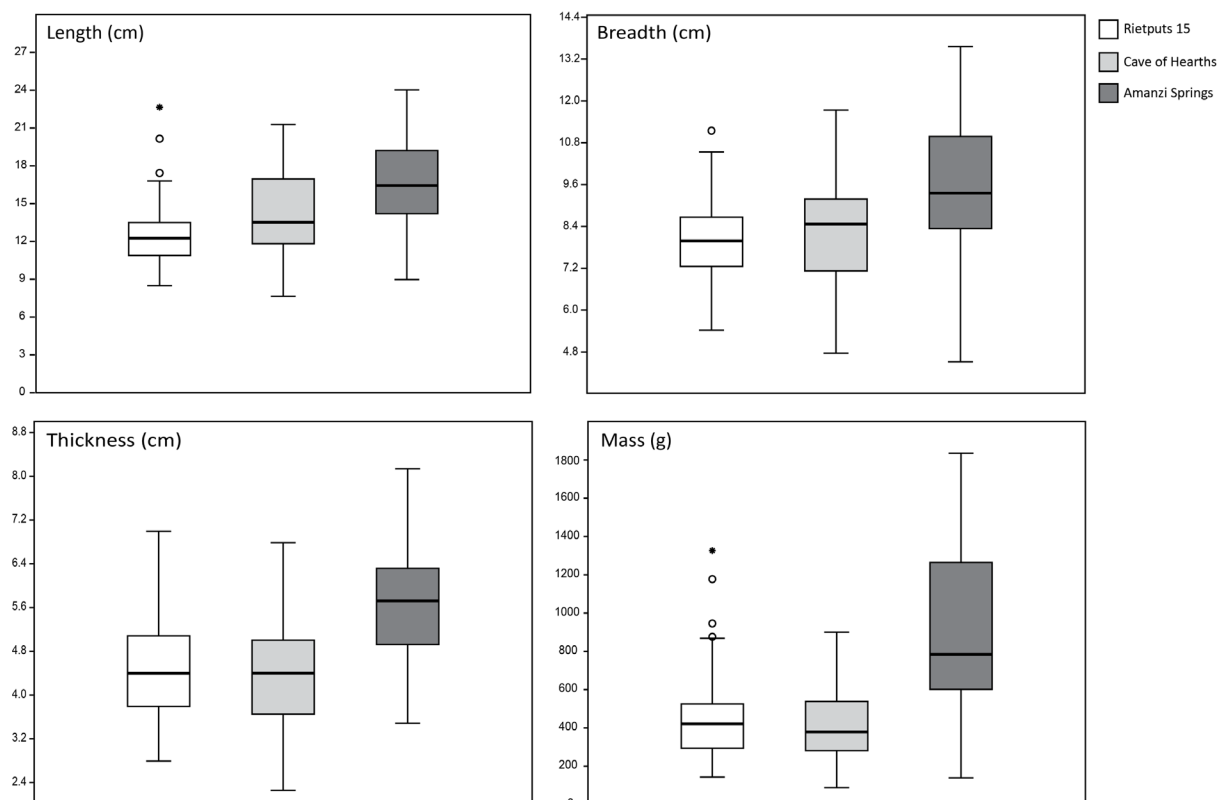
Figure 7. Comparison of basic metric measurements showing that Amanzi Springs handaxes are larger in size when compared to Cave of Hearths and Rietputs 15.
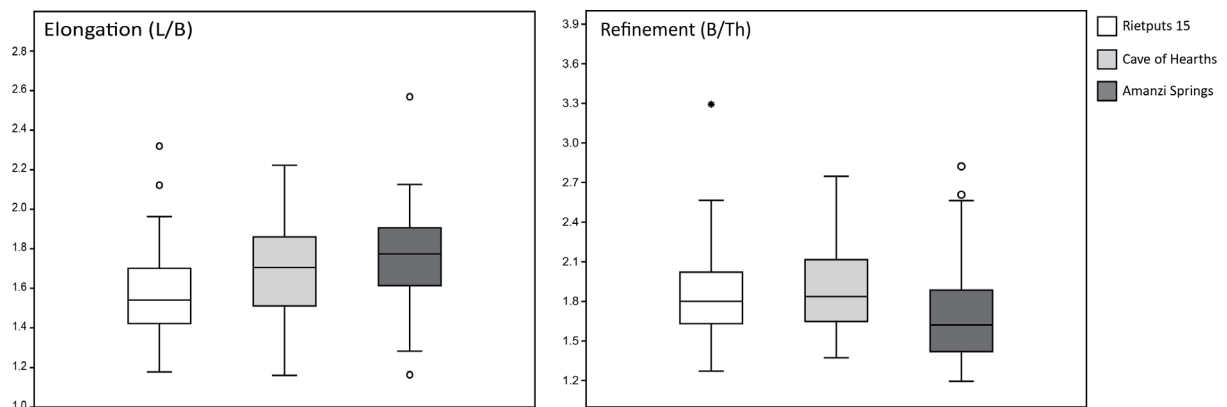
Figure 8. Comparison of elongation and refinement indices demonstrating that handaxes from Amanzi Springs are comparatively more elongated yet less refined.
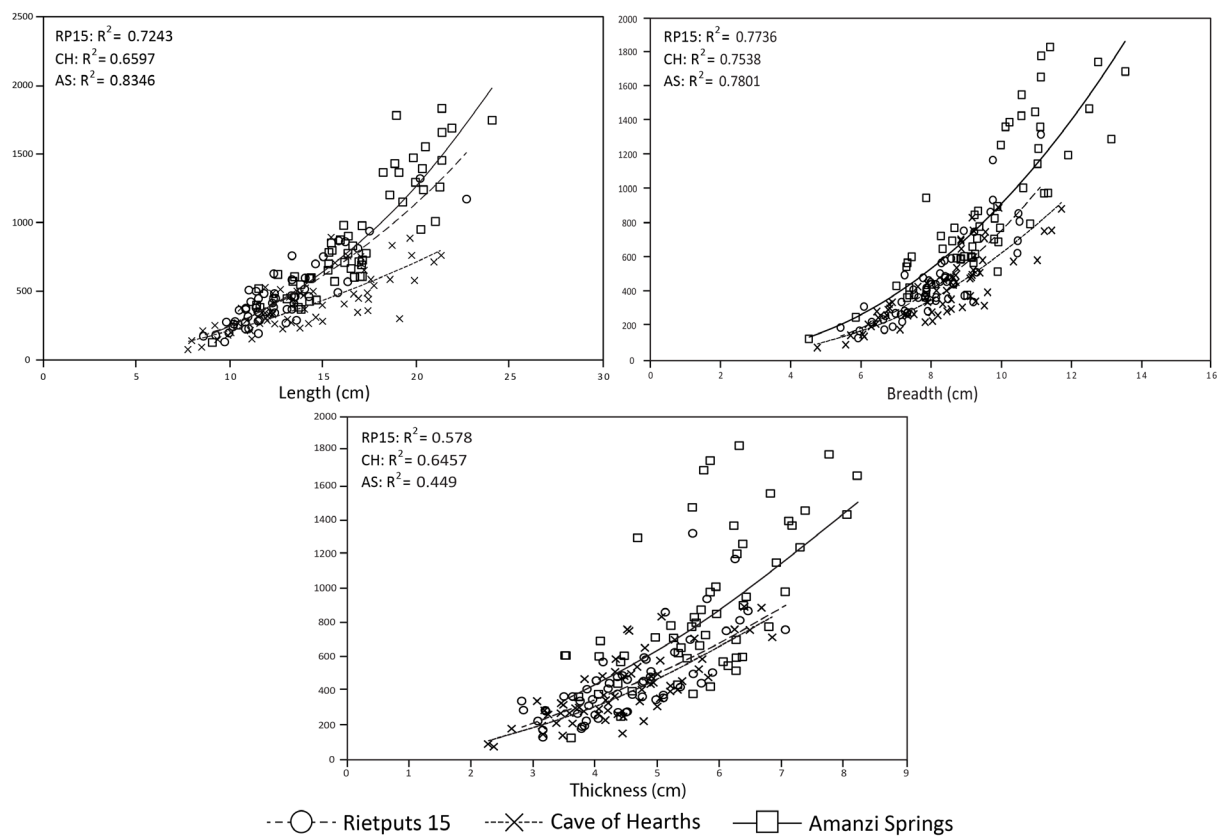
Figure 9. Regression of metric variables against mass (g) highlighting allometric trends.
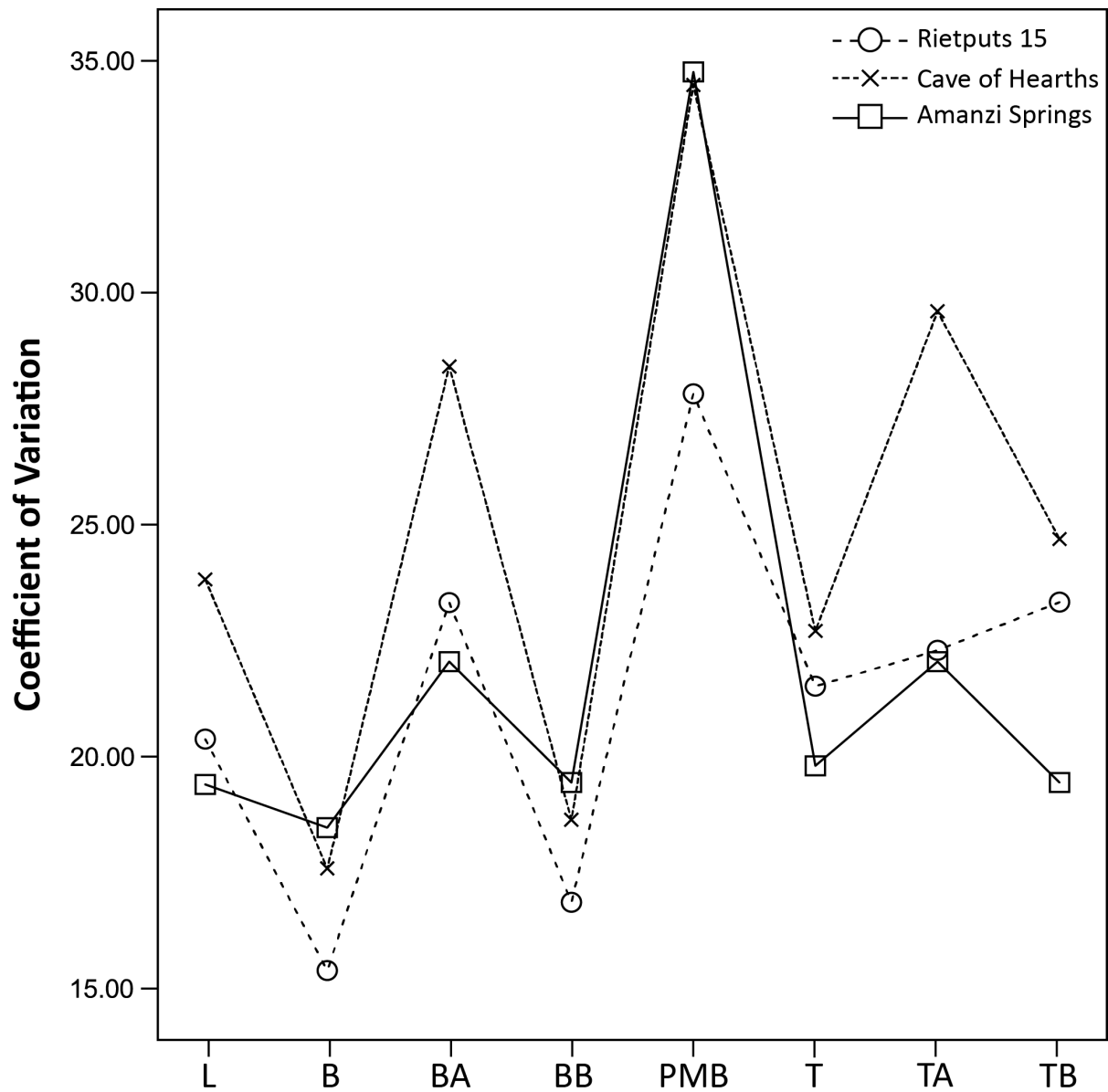
Figure 10. Coefficient of variation scores for variables used in the multivariate analysis, demonstrating differences in dimensional variation. L= Length, B= Breadth, BA= Breadth of Tip, BB= Breadth of Base, PMB= Point of Maximal Breadth, T= Thickness, TA= Tip Thickness, TB= Breadth of Base.
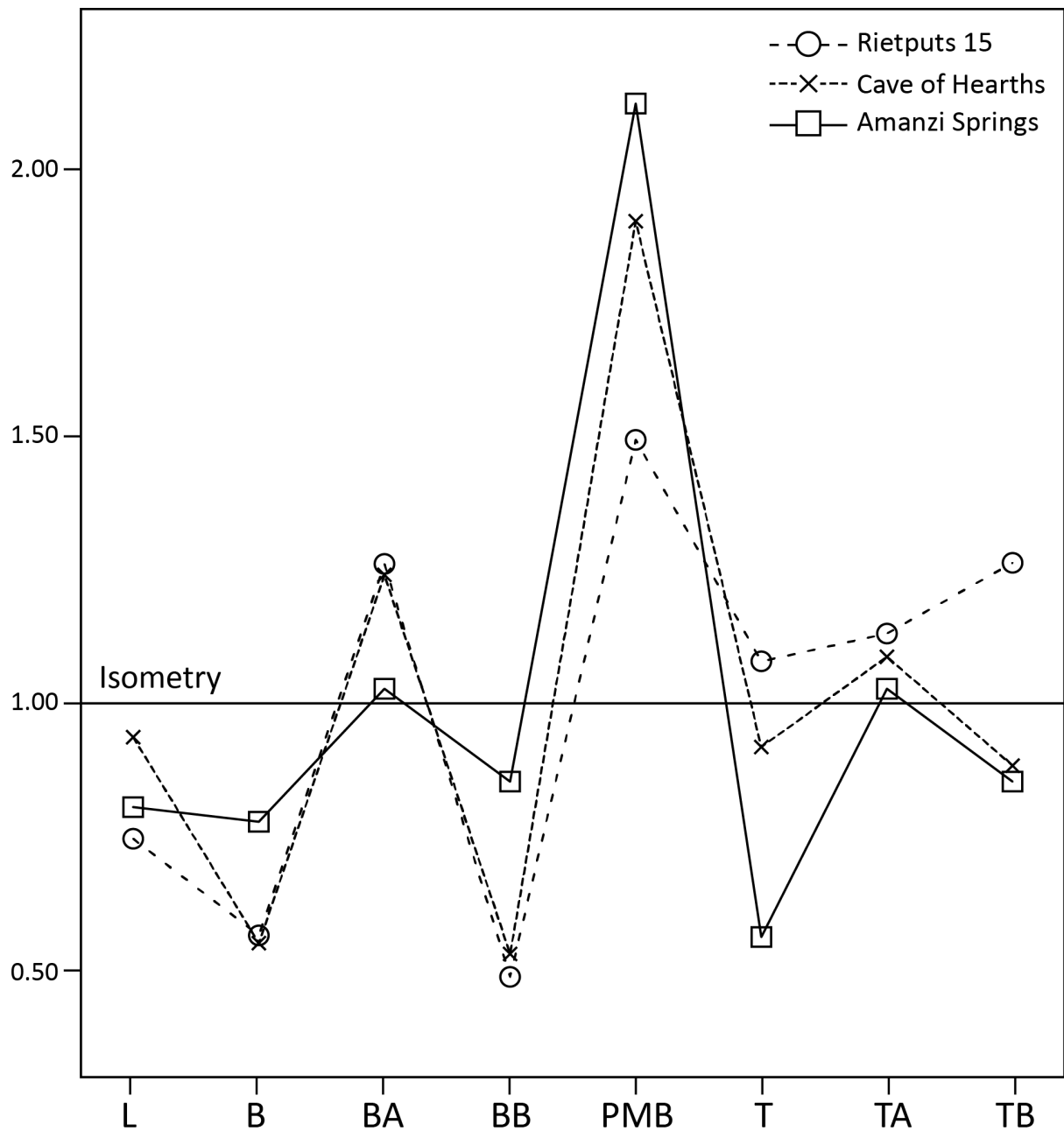
Figure 11. Allometric coefficients for variables used in the multivariate analysis demonstrating which variables are positively and negatively allometric. L= Length, B= Breadth, BA= Breadth of Tip, BB= Breadth of Base, PMB= Point of Maximal Breadth, T= Thickness, TA= Tip Thickness, TB= Breadth of Base.
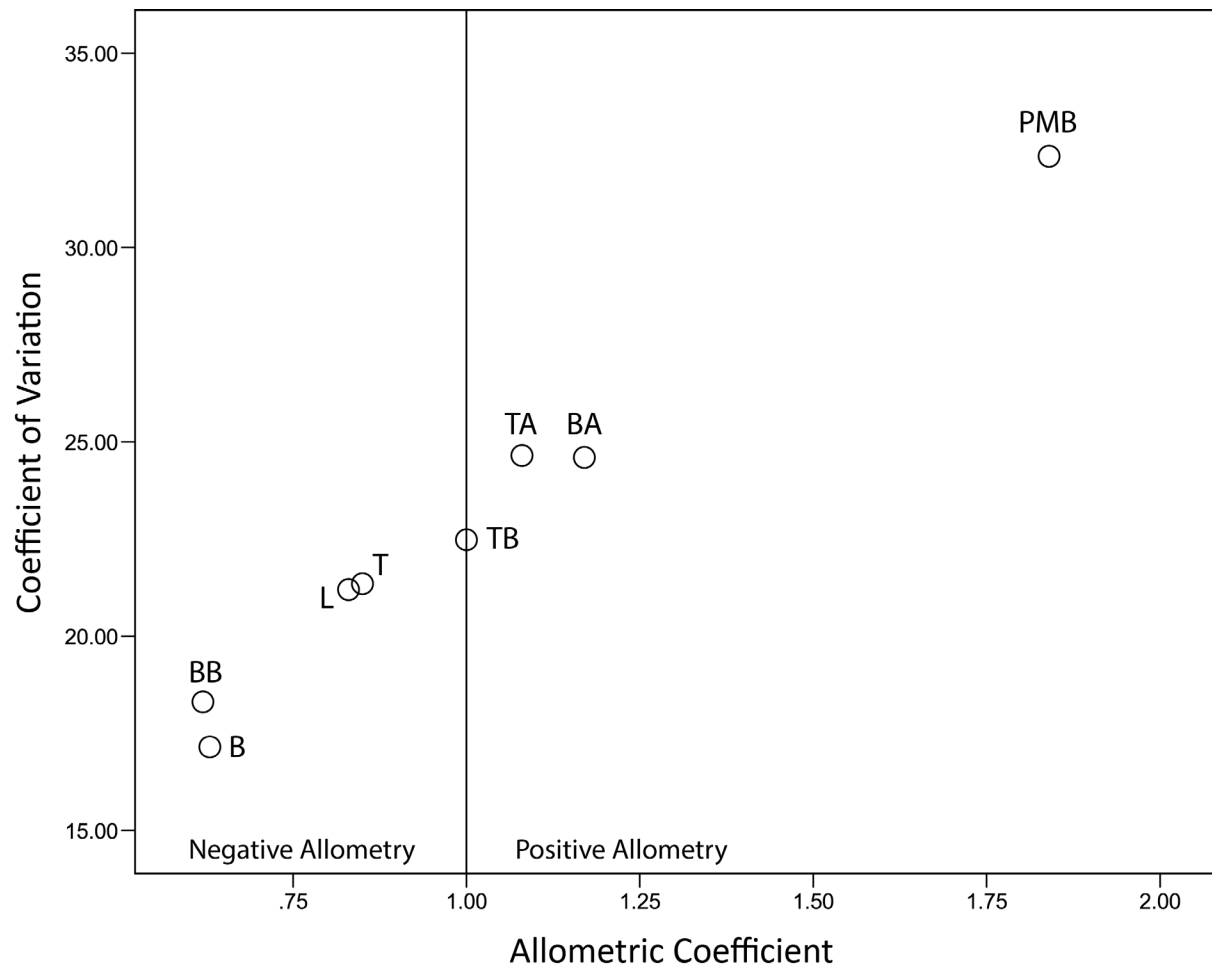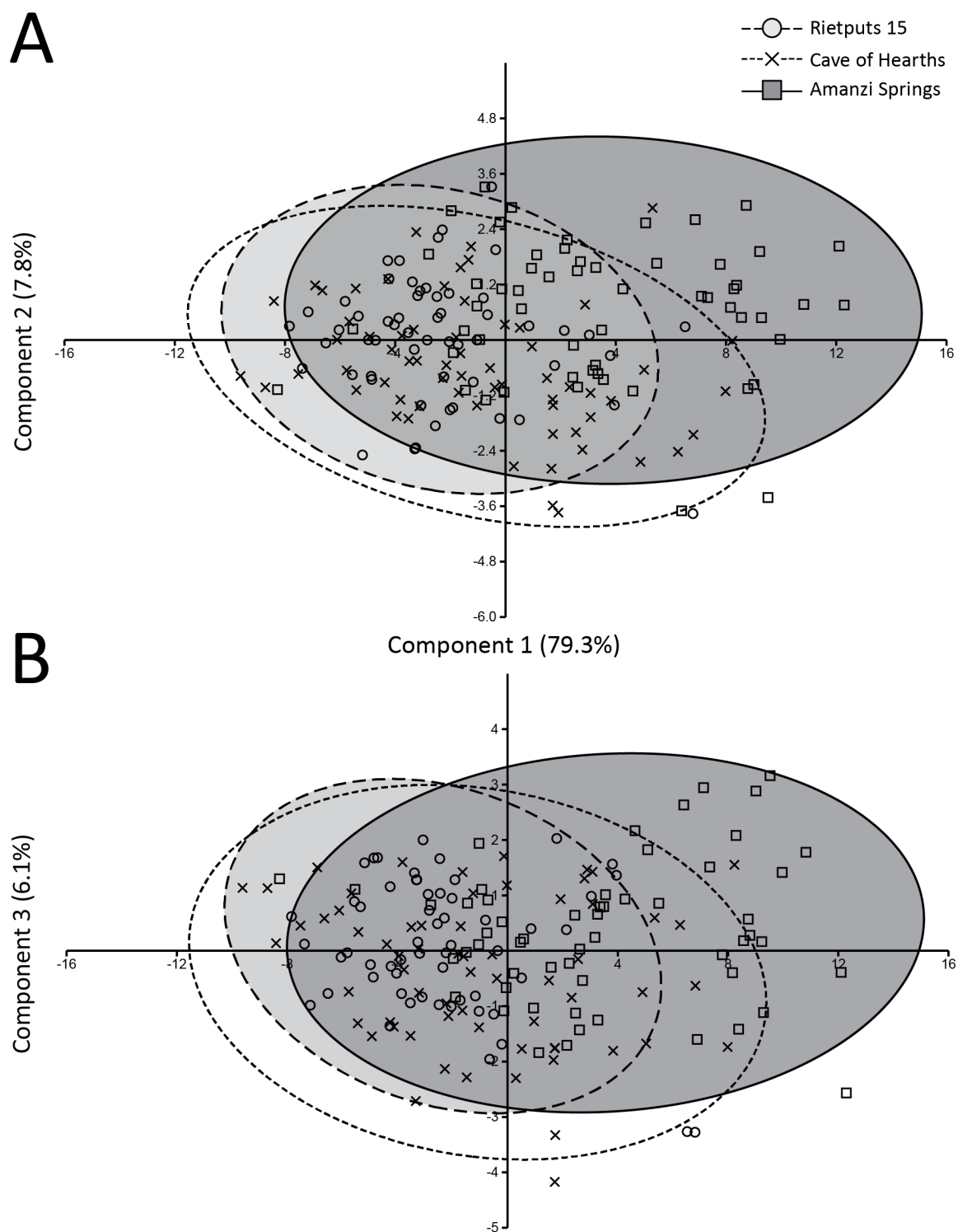
Figure 12. Bivariate plot of CV and AC scores for variables used in the multivariate analysis demonstrating how they group in terms of negative and positive allometric patterns. L= Length, B= Breadth, BA= Breadth of Tip, BB= Breadth of Base, PMB= Point of Maximal Breadth, T= Thickness, TA= Tip Thickness, TB= Breadth of Base.

Figure 13. Principal Component Graphs for Amanzi Springs, Cave of Hearths and Rietputs 15. A. PC1 and PC2. B. PC1 and PC3. Amanzi Springs scores load strongest onto PC1, which correlated to the overall size of handaxes (length).
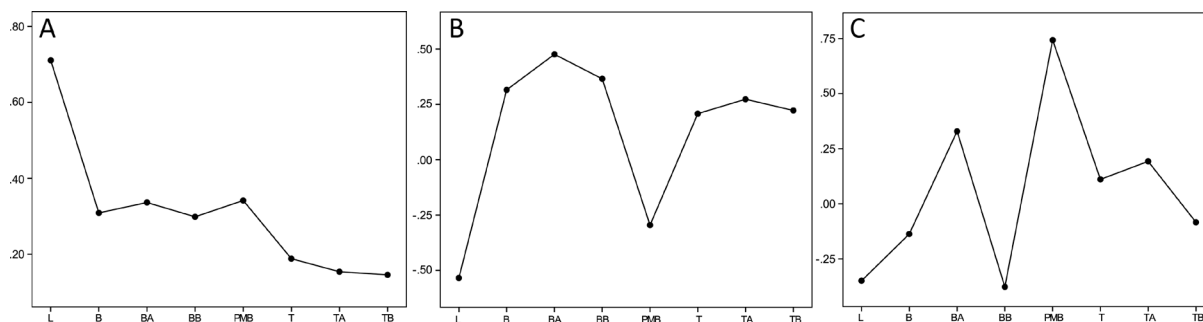
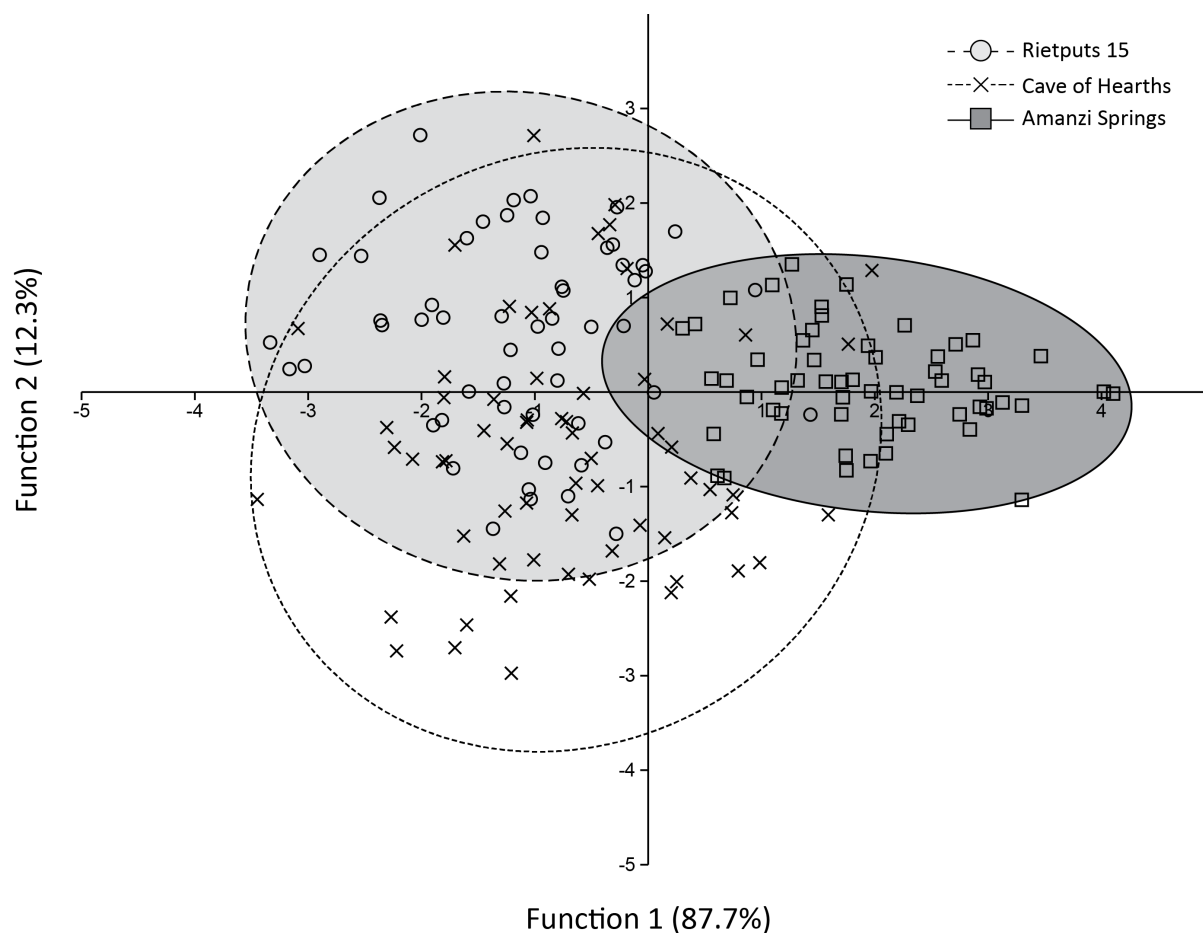Figure 14. Principal Component Loadings. A. PC1. B. PC2. C. PC3

Function 1 (87.7%)

Figure 15. Discriminant Analysis Graph for Amanzi Springs, Cave of Hearths and Rietputs 15. Amanzi Springs scores load strongest onto Function 1, which correlated to overall size (length and breadth).