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# Technological and geometric morphometric analysis of ‘post-Howiesons Poort points’ from Border Cave, KwaZulu-Natal, South Africa

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A B S T R A C T

Lithic assemblages immediately following the Howiesons Poort, often loosely referred to as the ‘post-Howiesons Poort’ or MSA III, have attracted relatively little attention when compared to other well-known phases of the South African Middle Stone Age (MSA) sequence. Current evidence from sites occurring in widely-differing environments suggests that these assemblages are marked by temporal and technological variability, with few features in common other than the presence of unifacial points. Here we present a technological and geometric morphometric analysis of ‘points’ from the new excavations of Members 2 BS, 2 WA and the top of 3 BS members at Border Cave, KwaZulu-Natal, one of the key sites for studying modern human cultural evolution. Our complementary methodologies demonstrate that, at this site, hominins adopted a knapping strategy that primarily produced non-standardised unretouched points. Triangular morphologies were manufactured using a variety of reduction strategies, of which the discoidal and *Levallois* recurrent centripetal methods produced distinctive morphologies. We find technological and morphological variability increases throughout the post-Howiesons Poort sequence, with clear differences between and within chrono-stratigraphic groups. Finally, we assess the suitability of the ‘Sibudan’ cultural-technological typology proposed for post-Howiesons Poort assemblages at Sibhudu, another KwaZulu-Natal site, and find similarities in the morphological axes characterising the samples, despite differences in the shaping strategies adopted. Overall, our work contributes to the growing body of research that is helping to address historical research biases that have slanted our understanding of cultural evolution during the MSA of southern Africa towards the Still Bay and Howiesons Poort technocomplexes.



## 1. Introduction

Border Cave is a key site for understanding modern human evolution in South Africa. It is unique in that the well-preserved and well-dated stratigraphic record documents key behavioural innovations across an extended timespan of 250,000 years (250 ka),

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yielding human remains and both organic and inorganic archaeological material (Backwell et al., 2018; Wadley et al., 2020a, b; Beaudet et al., 2022). Like other phases of occupation, the Middle Stone Age (MSA) sequence at Border Cave was originally divided into lithostratigraphic units by Beaumont (1978) based on geology, referred to as 'Members', as well as the recognition of layers attributed to different technocomplexes (Grün and Beaumont, 2001; Grün et al., 2003), including the Howiesons Poort, which, along with the Still Bay, is often believed to represent the emergence of 'behavioural modernity' (McBrearty and Brooks, 2000; Henshilwood and Marean, 2003; Henshilwood and Dubreuil, 2011; Henshilwood, 2012, but see Wadley, 2001; Shea, 2011).

Immediately overlying the Howiesons Poort layers at Border Cave are some referred to as post-Howiesons Poort (post-HP)/MSA III (Beaumont, 1978; Grün and Beaumont, 2001; Grün et al., 2003). This cultural phase throughout the South African MSA is particularly poorly understood because it apparently lacks the clear diagnostic technological and typological features that characterise other MSA technocomplexes and is, in addition, characterised by remarkable variability. Lombard and Parsons (2011) in an extensive review described how the lithic assemblages labelled 'post-HP' have been historically considered as lacking the signal of 'fully modern' behaviour, representing a "technology [that] is not very elaborate and [shows] no strong standardisation of the end-products" (Villa et al., 2005: 399). Yet evidence from across South Africa demonstrates that stone tools were made using highly structured and sophisticated technology during the post-HP (Wadley, 2005; Villa et al., 2005; Wadley and Harper, 1989; Soriano et al., 2007; Mackay, 2011; Conard et al., 2012; Porraz et al., 2013; Will et al., 2014; Bader et al., 2015; Will and Conard, 2018), with many aspects of continuity from earlier Howiesons Poort phases, such as the presence of backed pieces or bipolar knapping to produce microlithic blanks (de la Peña and Wadley, 2017; Will and Conard, 2018). These recent in-depth analyses of post-HP technological strategies have demonstrated that it is over-simplistic to assume that cultural evolution throughout the MSA involved a series of discrete innovative pulses.

We present here results of an investigation into the technological and morphological characteristics of lithic 'points' from the layers overlaying the members previously associated with the Howiesons Poort (Grün and Beaumont, 2001) at Border Cave, KwaZulu-Natal. From the technological assessment of the full lithic assemblage (de la Peña et al. this volume), triangular shapes were found to constitute 10% of the complete flakes, excluding the fragments (thus the true percentage is expected to be even higher). Although retouched points in the members considered in this study represent only 0.3% of all the lithic particles, there are only 24 retouched pieces in the whole assemblage, of which 11 are points (10 complete and one fragment), making them the most abundant category of the retouched tools. Additionally, the overall density of pieces per layer is extremely low, further highlighting the significance of the representation of triangular blanks in the post-HP assemblage at Border Cave.

### 1.1. What is the 'post-Howiesons Poort'?

The MSA is a crucial period in which modern humans are believed to have evolved, likely representing the origin of many of the cultural adaptations that emerged and spread with our own species, *Homo sapiens* (McBrearty and Brooks, 2000; Wadley, 2015; Scerri et al., 2018). Often linked to the emergence of 'modern human behaviour', the MSA sees the appearance of symbolic behaviours, such as personal ornamentation and ochre use, as well as innovation and increased complexity in the technological repertoire (Henshilwood, 2005; McBrearty and Brooks, 2000; Wadley, 2015). Within South Africa especially, cultural variability within the MSA has been historically organised into discrete 'technocomplexes' or 'industries' (e.g. Lombard et al., 2012), although the utility of this approach has more recently been questioned (Mackay et al., 2014; Wilkins, 2020). Perhaps the most well-researched of these technocomplexes are the Still Bay (~75–71 ka) and Howiesons Poort (~65–59 ka) (Wadley, 2007; Henshilwood, 2012; Wurz, 2013; de la Peña, 2020), the former recognised by the presence of foliate bifacial points and the latter characterised by the production of small blades retouched into segments and other backed pieces.

The assemblages before and after these technological traditions are sometimes loosely referred to as the 'pre-Still Bay' and 'post-HP', terms that were initially intended to group assemblages of similar periods without accorded cultural status (Wadley and Jacobs, 2006) but now are widely used across South Africa (Wurz, 2013; Wadley, 2015). The use of these cultural taxonomic labels, however, has attracted criticism (e.g., Conard et al., 2012). For example, it has been suggested that in certain cases the post-HP has been constructed to emphasise the distinctive innovations associated with the Still Bay and Howiesons Poort technocomplexes (Mellars, 2006; Jacobs et al., 2008). In the current context, an unsatisfactory situation exists in which pre-Still Bay and post-HP layers are often defined based on the *absence* of characteristic Still Bay or Howiesons Poort tool forms rather than the *presence* of particular diagnostic features (Conard et al., 2012; Mitchell, 2008). In order to avoid such uncertainty, an accurate characterisation of diversity among post-HP assemblages, involving in-depth investigation of technological, typological, and dimensional variation at contemporaneous sites is required. Such a characterisation would allow for more informative comparisons with preceding and succeeding industries, including testing of whether the term 'post-HP' as currently used in fact encompasses distinct regional cultural trajectories.

The term 'post-HP' has been used for almost five decades (e.g. Sampson, 1974), but is currently employed as a catch-all category to describe diverse and spatially disparate assemblages overlaying the Howiesons Poort, dating to between approximately 58–55 ka (Wadley, 2015) and sometimes referred to as the 'MSA III' (Volman, 1984). In this paper we retain the 'post-HP' label, though we recognise that it refers primarily to a chrono-stratigraphic period rather than to a coherent cultural entity but use it simply to refer to deposits immediately overlying Howiesons Poort layers. We attempt to shed light on recurrent features of post-HP assemblages by examining variation in the relevant levels at Border Cave and comparing these to documented variation at Sibhudu. The 'Sibudan' technocomplex at the latter site marks the first attempt to formally define post-HP assemblages based upon characteristic elements of lithic technology (Conard et al., 2012; Will et al., 2014; Will and Conard, 2018; Will, 2019). If similar elements are characteristic of the Border Cave material, it would suggest that the Sibudan nomenclature could be employed more widely. It would also enable archaeologists to move beyond the purely chrono-stratigraphic placement of these assemblages implied by use of the 'pre' or 'post' suffixes towards recognition of diagnostic cultural traits and their regional recognition.

### 1.2. The 'Sibudan' and it's diagnostic morphotypes

Sibhudu Cave, KwaZulu-Natal Province, has some of the most well-studied post-HP assemblages to date. Cochrane (2006, 2008) was one of the first to analyse tools from these layers and noted the presence of discoidal and *Levallois* flakes, bipolar knapping, and few retouched pieces. His initial conclusions were that there was an abrupt change in technological organization and raw material selection and use at the onset of the post-HP (Cochrane, 2008), in contrast to the sequence at Rose Cottage Cave where a gradual transition away from the Howiesons Poort was proposed (Soriano et al., 2007; Harper, 1997).

In a more recent technotypological analysis of Sibhudu lithics, Conard et al. (2012) identified four dominant types of tools present in all the layers studied, named the 'Tongati', 'Ndwedwe', 'naturally backed tools' and 'biseaux'. The newly identified tool types Tongati and Ndwedwe provided a novel framework for classifying assemblages rich in unifacial points. This classification scheme was subsequently revised (Will et al., 2014) to recognise asymmetric convergent tools (ACT) as an independent tool class, with the asymmetry of the distal end separating ACTs from Tongatis, under which category the majority of ACTs were originally classified.

Conard et al. (2012) proposed that the assemblages post-dating the Howiesons Poort at Sibhudu have the potential to become a post-HP template, and they argued for the reclassification of the post-HP as the 'Sibudan' technocomplex. However, they also stated that comparative studies are needed to consolidate Sibhudu as diagnostic for the region, and few studies have successfully applied the 'Sibudan' framework outside of the site. Porraz et al. (2013), for example, found evidence of the 'Tongati' techno-functional structure at Diepkloof Rock Shelter, Western Cape, but reported the absence of the other diagnostic features, thus rejecting the attribution of the assemblages to the 'Sibudan' technocomplex. Bader et al. (2015) also tried to apply the term to post-HP assemblages at nearby Holley Shelter and found some similarities in point morphotypes but also clear differences. Will et al. (2014) briefly compared the techno-typological characteristics of 'Sibudan' assemblages with post-HP assemblages at other sites, and found evidence for some 'Sibudan' characteristics at two: Rose Cottage Cave and Umhlatuzana. These authors suggest that perhaps the 'Sibudan' was geographically limited and restricted to within Marine Isotope Stage (MIS) 3, thus not encompassing the entire period following the Howiesons Poort.

Beyond Sibhudu, few unifying features among assemblages post-dating the Howiesons Poort have been established, and diachronic variability appears to characterise the phase (Mitchell, 2008; Will et al., 2014). The only consistent observation concerns the presence of unifacial points, argued to bear similarities to European Middle Palaeolithic Mousterian points, which are reported at numerous sites across South Africa in varying quantities (Villa et al., 2005; Wadley, 2005; Conard et al., 2012; Bader et al., 2015; Will and Conard, 2018). Yet, as we will demonstrate in this paper, the pointed products from post-HP assemblages at Border Cave are predominately unretouched, suggesting that point production strategies adopted during the post-HP were likely more varied than has been previously recognised.

### 1.3. Definition, function, and significance of MSA lithic 'points'

The establishment of the tripartite African Stone Age classificatory system by Goodwin and van Riet Lowe (1929) determined that "the typical implement throughout the Middle Stone Age is the worked point in a variety of forms" (Goodwin and Van Riet Lowe, 1929: 98). Points are therefore considered to be one of the hallmarks, or '*fossiles directeurs*', of the MSA, appearing almost simultaneously in the African record in regionally distinctive forms (Clark, 1982; McBrearty and Brooks, 2000; de la Peña et al., 2013; Taylor, 2016; Will and Conard, 2018; Sahle and Brooks, 2019; Douze et al., 2020, among others). The term 'point' is often used synonymously for 'projectile' due to the widespread belief that they were used in the MSA as hunting armatures (e.g., McBrearty and Brooks, 2000; Brooks et al., 2006). Such conflations between typology and functionality are reminiscent of the original classificatory systems developed for the European Palaeolithic, and arguably do not capture the extent of technological, typological, functional, and cultural diversity throughout the African Stone Age.

Recent definitions within the context of the MSA by Douze et al. (2020) have differentiated between non-pointed flakes that have been retouched to form a triangular shape ('typological' points) and those that are triangular flakes removed from a prepared core surface ('technological' points), representing different technological solutions to obtain tools with triangle-like shapes. Exactly what constitutes a 'point' is ambiguous and lacks consistency, often depending on the study region and period, and the specific tradition of research. Nonetheless, the different technological strategies adopted to produce pointed shapes, and their patterns of occurrence, have the potential to provide vital insight into adaptations to environmental pressures, convergence and reinvention, and social factors such as interaction between groups (McBrearty and Brooks, 2000; Wilkins, 2010).

Recently, the multidimensionality of MSA point function has been emphasised, with potential uses including throwing, cutting, sawing, and incising (e.g., Lombard, 2007a; Rots et al., 2011; de la Peña et al., 2013). Whilst Still Bay bifacial points (Lombard, 2006) and pre-Still Bay bifacial serrated points (Rots et al., 2017) demonstrate some of the clearest evidence of projectile functionality in the South African MSA toolkit, other evidence for points as composite projectile weaponry has been contested, such as at Kathu Pan 1, Northern Cape (Wilkins et al., 2012, 2015; Schoville et al., 2016 cf. Rots and Plisson, 2014). Attention has been drawn to the problematic use of certain traits to diagnose impact-related damage (Rots and Plisson, 2014), which complements evidence that apparent projectile tools were also used for other purposes (Lombard, 2006, 2007a,b; Tomasso and Rots, 2017). At Bushman Rock Shelter, Douze et al. (2020) conclude from use-wear and residue analysis that points were likely used for cutting and scraping, with little evidence for hafting. This corresponds with the evidence at Pinnacle Point B of edge damage distribution suggesting that points were cutting implements (Bird et al., 2007; Schoville, 2010). At Klasies River, pointed triangular flakes were hypothesized to have been used for short-distance weaponry based on their penetration potential (Shea, 2006; Sisk and Shea, 2011), whilst at Sibhudu, functional and residue analyses on quartz bifacial Howiesons Poort points suggest they were used as projectiles and, occasionally, for cutting tasks (de la Peña et al., 2013), as was also the case for Still Bay points (Lombard, 2006). This demonstrates that points were likely used to carry out a range of tasks within the MSA tool use repertoire.

Point designs during the MSA were likely constrained by the functional requirements of the tool, with the type and quality of raw material and reduction method used also influencing the range of shapes that could be produced (McBrearty and Brooks, 2000). Moreover, diversity in point production and style have also been argued to represent the underlying population structure of human populations during the MSA (Wilkins, 2010; Scerri et al., 2018). Distinctive Still Bay foliate points are widespread across southern Africa and are routinely argued as evidence for regional interaction and trade networks, and the geographic expansion of behaviourally 'modern' humans (Wadley, 2007; Lombard et al., 2010; Henshilwood and Dubreuil, 2011; Henshilwood, 2012; Mackay et al., 2014; though see Archer et al., 2016). Points have been argued to represent the single artefact category within MSA toolkits that most likely reflects group identity (McBrearty and Brooks, 2000; Wilkins, 2010). Ethnographically, projectile points are traded between interacting groups, with comparable designs among co-operating neighbours maintained to ensure that they can be used by several hunters (Yellen, 1977; Wiessner, 1983, 1985; Nicholas and Kramer, 2001). Nevertheless, interpreting point form solely in terms of 'style' or 'group identity' is reductionist, with strictly typological approaches tending to undervalue the constraints and parameters that condition point production, such as raw material quality, site type, technological strategy and patterns of use and reuse (Morales et al., 2015). Thus, the variable shape of MSA points through time was likely influenced by a combination of functional, technological, environmental, and socio-cultural factors, with interactions between factors influencing the final form of the tool.

### *1.4. Presenting a framework for investigating point production technology*

Here we present a technological and geometric morphometric (GMM) analysis of the post-HP points from Border Cave. We consider 'points' to be triangular-shaped flakes or flakes with a convergent distal end, achieved via "(1) the bifacial or unifacial shaping of undefined or non-pointed predetermined flakes into pointed forms—also called typological points; and (2) the production of triangular flakes—also called technological points—-from a prepared core surface, further retouched or not", following Douze et al. (2020: 127). This means that we include unifacial points within our sample, however, we do not limit ourselves to only those artefacts that have been retouched, allowing for a broader conception of 'points' than is typically considered during the post-HP. Moreover, unlike Douze et al. (2020), we do not restrict our definition of 'unretouched points' to only 'desired end-products'. This is because triangular points could also be a recurrent type of blank produced by specific knapping methods (*sensu* Inizan, 1999). Therefore, even if these triangular blanks are, in theory, incidental, they could be distinguishable in morphology as the knapping method essentially determines the volume of the core and thus consequently affecting to the form of the blanks produced.

This approach allows us to move away from previous typological classifications derived from the European Middle Palaeolithic and applied in southern Africa. For example, Volman's (1981:17–27) typology was based on that by Bordes (1961), both of which provide categories that are difficult to distinguish. In Volman (1981:17–27), the distinction between 'convergent sidescraper' and 'unifacial point' is subjective due to the similarity of the two categories; the precedent Bordes (1961) typology has a similar issue with 'Mousterian point' and 'convergent sidescraper'. Our approach attempts to avoid the potential bias that comes with using subjective definitions like 'unifacial point' and thus ensures a wide range of point production technology is captured.

Flaked tools are considered to be unstandardised and irregularly shaped in various post-HP assemblages, such as Rose Cottage Cave (Villa et al., 2005), Sibhudu (Cochrane, 2006) and Apollo 11 (Vogelsang et al., 2010). Our approach is therefore also likely to be more appropriate than arbitrarily selecting certain typological features in order to understand technological behaviours of post-HP populations.

Our broad definitions allows us to investigate unretouched and retouched pointed forms, following Douze et al. (2020), which has important implications in terms of the variety of technological strategies adopted during this period. The research history of South Africa has meant that morphological analyses of points have tended to be limited to within and between technocomplexes, involving artefact samples that are relatively standardised in form (e.g. Mohapi, 2012; Archer et al., 2015, 2016, though see Douze et al., 2020). Our approach is likely to be more insightful about the processes of cultural inheritance and learning than studying only those that conform to some extent in shape (Tostevin, 2019).

In this study, we focus on points due to their significance both within the post-HP assemblage at Border Cave and the MSA more generally. While the samples yielded from these layers at Border Cave are relatively small, this study represents the only composite technological and GMM analysis of post-HP points in South Africa, apart from the analysis of the full point sequence at Sibhudu by Mohapi (2012).

## 2. Brief background to the site

Border Cave is situated in northern KwaZulu-Natal about 365 m from the Eswatini border at 27°1′19"S, 31°59′24"E (Cooke et al., 1945) (Fig. 1). The site is located on a cliff within the Lebombo Mountains over 400 m above the Eswatini lowveld, some 2 km north of the Ngwavuma River gorge, and around 80 km from the Indian Ocean. Although it is usually referred to as a cave, the site is geomorphologically a large, semi-circular rock shelter approximately 50 m wide and 35 m long. The site has been excavated by various researchers throughout the 20th and 21st century. The data from this paper come from the Backwell excavations conducted since 2015 (Backwell et al., 2018 and this volume).

The sedimentary sequence of this archaeological site was divided into a succession of white ash (WA) and brown sand (BS) members, by Beaumont (1978) and by Butzer et al. (1978). Fig. 2 shows the stratigraphic divisions of the sequence. The latest revision of the stratigraphic sequence is synthesized by Stratford and colleagues (this volume and Table 1 of the supplementary material therein). The sequence at Border Cave covers several chronological episodes of occupation, between about 227 ka and 24 ka. Electron Spin Resonance (ESR) and radiocarbon ages imply that Members 5 WA, 5 BS, 4 WA, and 4 BS accumulated between 227 and 71 ka, Members 1 RGBS, 3 WA, and 3 BS between 82 ka and 56 ka, Members 2 WA, 2 BS Lower and Upper between 60 ka and 44 ka, and Members 1 WA and 1 BS Lower between 43 ka and 24 ka (Bird et al., 2003; Grün and Beaumont, 2001; Grün et al., 2003; Millard, 2006; d'Errico et al., 2012; Villa et al., 2012; Backwell et al., 2018). The most recent dating of the MSA sequence has been conducted by Tribolo et al. (this volume) using the luminescence method on sedimentary feldspar grains, and the results are in accordance with those obtained using ESR on teeth. Some of these chronological episodes are seldom represented in the southern African Middle Stone Age record, such as the basal layers corresponding to MIS 6 and 5. Moreover, the 'Early Later Stone Age' was defined in reference to the upper members of this sequence (Beaumont and Vogel, 1972; Beaumont, 1978; Beaumont et al., 1978). These two aspects make Border Cave a reference site not only in southern Africa but also across the continent.

The site is not only significant because of its long stratigraphic sequence but also because of its extraordinary organic preservation (d'Errico et al., 2012), particularly of palaeobotanical remains (Beaumont, 1978, Backwell et al., 2018; Wadley et al., 2020a, b; Zwane and Bamford, 2021). Besides this unusual characteristic, Border Cave has also yielded hominin remains (Beaumont, 1980; Beaudet et al., 2022), including a burial with an associated ornament in Member 1 RGBS, putatively associated with the Howiesons Poort technological tradition (d'Errico and Backwell, 2016). Other outstanding finds include an incised bone (Beaumont, 1978) interpreted as the earliest known system of notation (d'Errico et al., 2018), and the oldest evidence of bedding documented in prehistory (Wadley et al., 2020a; Sievers et al., 2022) and cooked starchy rhizomes at 170 ka (Wadley et al., 2020b).

We present an in-depth analysis of the unretouched and retouched points at Border Cave from the 2 BS, 2 WA and top of 3 BS members (see Fig. 2A–C). Beaumont (1978) described these members as lithostratigraphic units based on sediment characteristics, roof spall abundance, and vegetation and anthropic features (Beaumont, 1978). Butzer and Beaumont provided a more detailed

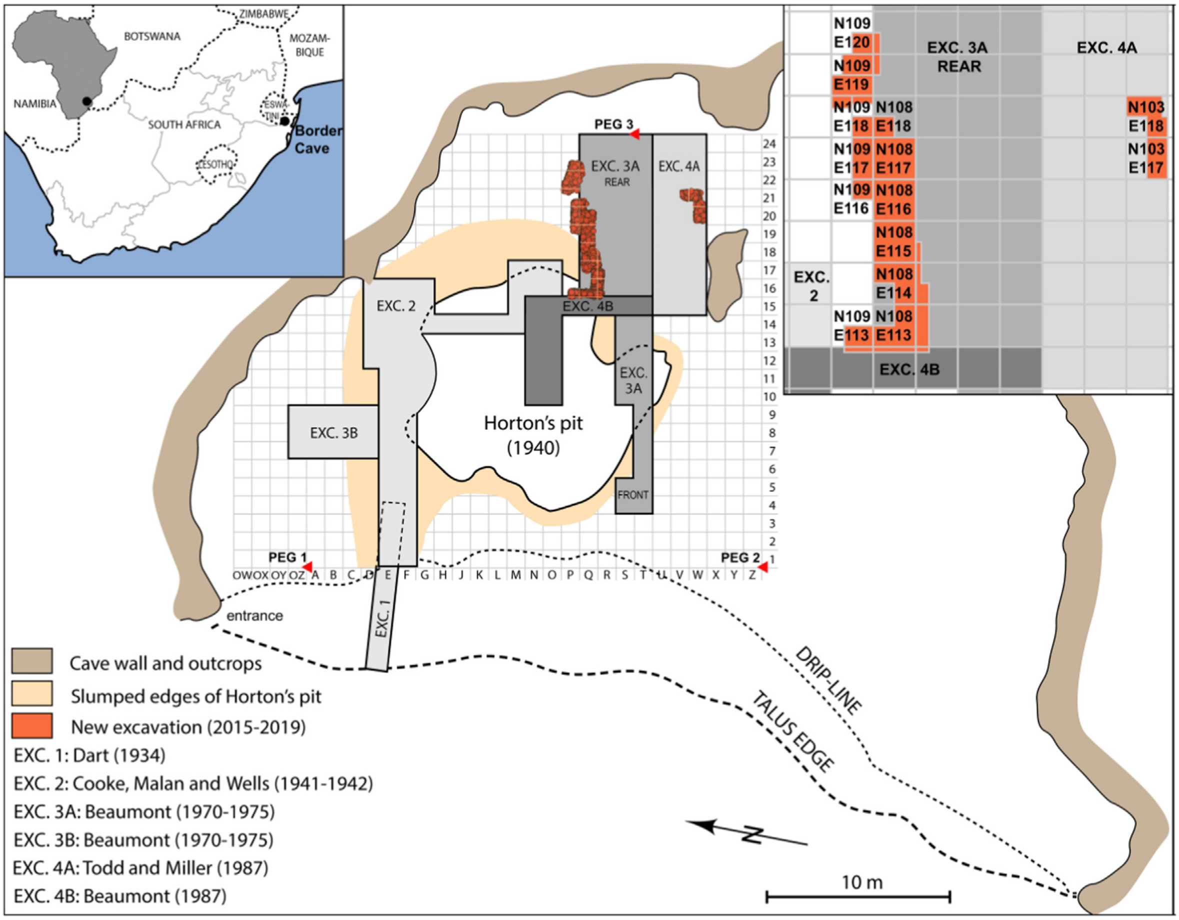


**Fig. 1.** Plan of the site showing the position of the various excavations from 1934 to 2019. The orange overlay shows the position of point-plotted artefacts in excavations conducted from 2015 to 2019 along the North wall of EXC. 3 A and South wall of EXC. 4 A. The insert provides the square names excavated according to North and East lines. The grid is the original one established by Cooke et al. (1945).

description considering additional methods of analysis (Butzer et al., 1978). Distinctions were proposed between the 2 BS Upper, 2 BS Lower A, 2 BS Lower B, 2 BS Lower C, 2 WA and 3 WA sedimentary units. The latest study by Stratford et al. (this volume) retains Beaumont's member distinction supplemented by an allostratigraphic approach to differentiate between the sedimentary units. In this technological and morphological analysis, we follow these latest distinctions. For a synthesis, see Stratford et al. (this volume) and Table 1 of the supplementary material therein. We also use the layer names and features defined during Backwell's excavations (Backwell et al. this volume), and our own relative stratigraphy.

### *2.1. Beaumont's work on the typology and technology of 'points' from members 2 BS, 2 WA and 3 BS*

The most detailed lithic analysis of Border Cave material is by Beaumont (1978, 1980; Beaumont et al., 1978). In his lithic analysis, he classified both retouched and unretouched material. Regarding point forms, he distinguished between retouched points ('trimmed points') and unretouched points. Among the retouched or trimmed points he further distinguished between 'trimmed points 1' (with an abrupt retouch), with three variants: a) 'defining', with retouch usually limited to the tip or a portion of one or both margins in order to improve point symmetry, b) 'convergent' and c) 'oblique'. 'Trimmed points 2' on the other hand have shallow invasive retouch. Within this second category, he distinguished between a) unifacial and b) bifacial points (Beaumont, 1978: 27–28). Regarding unretouched points, he labelled them simply as 'points', defining them as 'forms with triangular plan-forms' and 'convergent upon the distal end' of the piece. He distinguished between four subclasses (subclasses 1(a), 1(b), 2(a), 2(b), and also included a 'blade-points' subclass within his 'blades' category (see Supplementary Figure S1, which is modified after Beaumont, 1978, Fig. 20).

Regarding the lithic technology and typology of 2 BS and 2 WA, Beaumont framed it within MSA III and IV (Beaumont, 1978) and the 'post-Howiesons Poort complex'. He highlighted that, in this part of the sequence, blades 'grade with time from large and robust to short and squat forms', that triangular flakes were infrequent (but not absent), and that the lower levels often show 'butt reduction from the ventral surface to produce 'Emireh type points'. Indeed, he mentioned several times that these 'modified butts (points)' were confined to the '2 BS.LR C' and 2 WA units, except for one piece in Member 3 BS (Beaumont, 1978:136). He also identified two phases for the MSA III between 2 WA and 2 BS.UP: an early phase (2 WA and 2 BS.LR C) distinguished by the presence of modified butts and by low values for chalcedony and scaled pieces; and a late phase (2 BS.LR B and 2 BS.UP) classified by the absence of modified butts, and high values for chalcedony and scaled pieces. He also stressed how 2 BS.UP specifically had few points (Beaumont, 1978: 103). It is worth highlighting that he recorded the presence of 'backed pieces' with trapezoidal shapes within 2 BS.LR

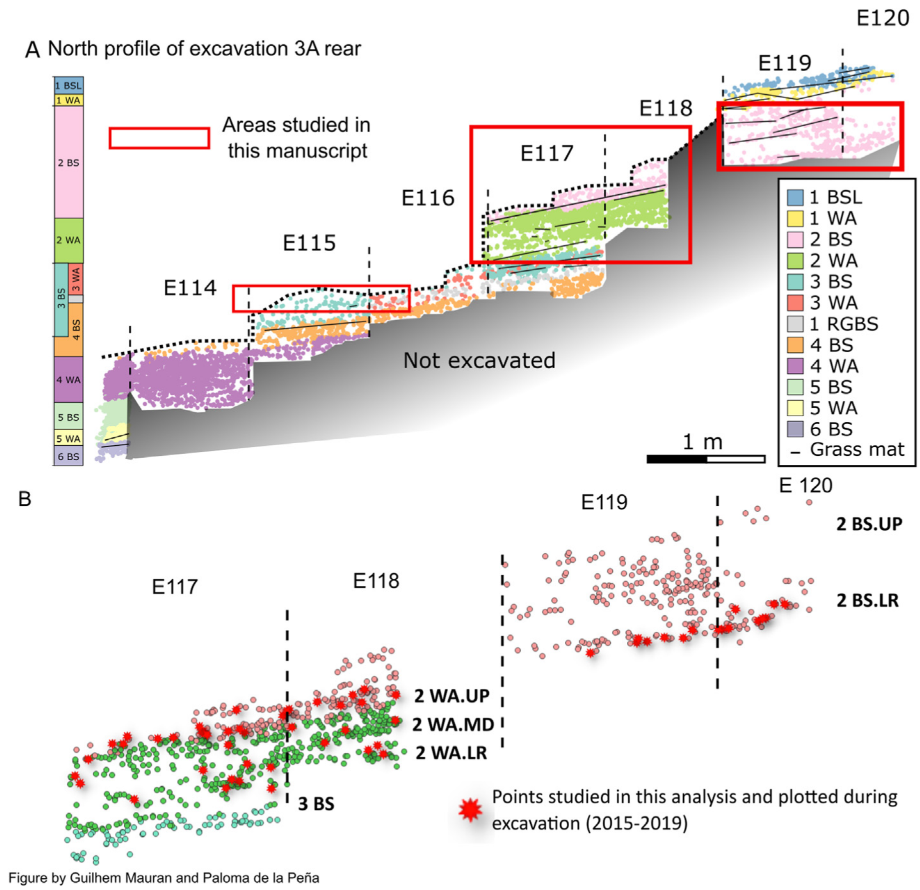


**Fig. 2.** A) North profile of excavation 3A rear showing the member system and areas studied in this manuscript framed in red. B) Points studied in the analysis plotted onto the stratigraphy. The members are separated by colour and the allostratigraphic names are given on the right-hand side of the squares.

and 2 WA (Beaumont et al., 1978: 412). Member 3 BS was initially associated with the ‘Epi-Pietersburg’ variant of the old ‘Second intermediate’ (later on referred to as ‘Howiesons Poort’, e.g. Grün and Beaumont, 2001) with abundant blades and a variety of backed elements, some of which resemble the *Châtelperron* or *Abri Audi* knives and pressure-flaked bifacial forms (Beaumont et al., 1978: 412).

Villa et al. (2012) also conducted a technological analysis of Members 2 WA and 2 BS in order to compare the post-HP to the Early Later Stone Age industries at Border Cave. In that study, 2 WA was characterised as mainly containing blades and elongated flakes with parallel sides ‘as the main objectives of the debitage’ (Villa et al., 2012: 13209). Finally, 2 BS.LR A and B were characterised as showing a decline in blade production and specifically by the disappearance of unifacial points, a drastic reduction of retouched pieces, and an increment in bipolar knapping. While there is a reference in that analysis to ‘unifacial points’ disappearing, there was no further description of these tools.

## 3. Materials

There are 54 pieces from the Backwell et al. (2018) excavation following our definition of ‘point’ outlined in Section 1.4. Table 1 summarises our sample, of which only 10 are retouched, and their stratigraphic position (also demonstrated in Fig. 2). The artefacts are curated at the Evolutionary Studies Institute at the University of the Witwatersrand in South Africa. Supplementary Materials S2 reports a preliminary assessment of the raw materials present in the sample – predominately, the points are manufactured using different varieties of rhyolite with the remaining likely being basalts and hornfels.

We only focussed on points that were complete or near complete so that each outline was both homologous and culturally significant for the GMM analysis. We also considered analyses of San arrowheads that found that tip angles were less than 99° (Clark, 1975), and thus discriminated based on this criterion. This constrained our selection to ensure that the triangular shapes corresponded roughly with that found ethnographically, whilst also enabling us to accurately record an orientation landmark on the tip, defined as the single homologous point where the lateral edges converge at the distal end. In some cases, the tip is slightly damaged, however, the use of harmonics (curves) to represent the shapes within an outline-based geometric morphometric (GMM) framework permits that the presence/absence of the end of the tip has little effect on the global shape of the artefact. For confirmation we ran the analyses with both the full sample (N = 54) and the sample with points with minimal tip damage removed (N = 39). This confirmed that minimal tip damage has very little effect on the results (Supplementary Online Materials S1). As such, we retained the artefacts with signs of tip damage and the orientation landmark for these points was positioned at the point closest to where the tip would have been.

## 4. Methods

We apply both technological analysis and two-dimensional (2D) GMM analysis to investigate technological and shape variability among post-HP points from Border Cave. Technological analysis

**Table 1**
A summary of the point sample from the post-Howiesons Poort layers at Border Cave, showing the stratigraphic position of each artefact. For technological and typological attributes and raw materials, see Supplementary Materials S2-3. Pieces with an asterisk (*) were not plotted, having been found among the sieved material. Relative stratigraphy was elaborated by grouping layers at similar depth (see Fig. 2) and giving each group a number from 1 to 16, with 1 being the youngest (uppermost) and 16 being the oldest (lowermost) layers.

| Artefact no. | Layer (Backwell et al. this vol) | Allostratigraphic unit (Stratford et al. this vol) | Relative stratigraphy | Retouch (Yes/No) |
|---|---|---|---|---|
| BC121* | 2 BS.UP | 2 BS.UP | 1 | N |
| BC123* | 2 BS.UP | 2 BS.UP | 1 | N |
| BC4082 | Dark Greyish Brown Cecil | 2 BS.LR | 2 | N |
| BC5155 | Cilla | 2 BS.LR | 2 | N |
| BC5406 | Cilla | 2 BS.LR | 2 | N |
| BC5408 | Cilla | 2 BS.LR | 2 | Y |
| BC5441 | Cilla | 2 BS.LR | 2 | N |
| BC5486 | Cilla | 2 BS.LR | 2 | N |
| BC5501 | Cilla | 2 BS.LR | 2 | N |
| BC5259 | Grass Mat Ceta | 2 BS.LR | 3 | N |
| BC5269 | Grass Mat Ceta | 2 BS.LR | 3 | Y |
| BC175* | Grass Mat Ceta | 2 BS.LR | 3 | N |
| BC4537 | Dark Yellowish Brown Chloe | 2 BS.LR | 4 | N |
| BC5344 | Clara | 2 BS.LR | 4 | N |
| BC5348 | Clara | 2 BS.LR | 4 | N |
| BC4536 | Dark Yellowish Brown Chloe | 2 BS.LR | 4 | N |
| BC442 | Orange silty | 2 BS.LR | 5 | Y |
| BC1222 | Grass Bed 2 within 2 BS.LR | 2 BS.LR | 6 | N |
| BC445 | Dark Greyish Brown | 2 BS.LR | 6 | N |
| BC543 | Dark Greyish Brown | 2 BS.LR | 6 | Y |
| BC647 | Grass Bed 1 | 2 BS.LR | 6 | N |
| BC691 | Grass Bed 2 | 2 BS.LR | 6 | N |
| BC811 | Grass Bed 2 | 2 BS.LR | 6 | N |
| BC1390 | Brown | 2 BS.LR | 7 | N |
| BC1488 | Brown | 2 BS.LR | 7 | N |
| BC1950 | Light Reddish Brown | 2 WA.UP | 8 | N |
| BC3300 | Dark Yellowish Brown Devo | 2 WA.UP | 8 | N |
| BC1396 | Brown Cathy | 2 BS.LR | 9 | N |
| BC1400 | Brown Cathy | 2 BS.LR | 9 | N |
| BC1405 | Brown Cathy | 2 BS.LR | 9 | N |
| BC1466 | Brown Cathy | 2 BS.LR | 9 | N |
| BC1483 | Brown Cathy | 2 BS.LR | 9 | N |
| BC1486 | Brown Cathy | 2 BS.LR | 9 | Y |
| BC2040 | Brown Sand Lower silty | 2 BS.LR | 9 | N |
| BC2295 | Brown Sand Lower silty | 2 BS.LR | 9 | N |
| BC2296 | Brown Sand Lower silty | 2 BS.LR | 9 | N |
| BC2297 | Brown Sand Lower silty | 2 BS.LR | 9 | N |
| BC2416 | Brown Sand Lower silty | 2 BS.LR | 9 | N |
| BC2936 | Brown with charcoal inclusions | 2 WA.UP | 9 | Y |
| BC3307 | Dabby | 2 WA.UP | 10 | N |
| BC2953 | Very Dark Greyish Brown | 2 WA.UP | 11 | N |
| BC4001 | Dark Brown Dijon | 2 WA.LR | 12 | N |
| BC4145 | Dark Brown Dijon | 2 WA.LR | 12 | N |
| BC4174 | Light Brown Dazy | 2 WA.UP | 12 | N |
| BC4273 | Dark Yellowish Brown Dino | 2 WA.MD | 12 | Y |
| BC4565 | Reddish Black Desmond | 2 WA.MD | 13 | Y |
| BC4710/BC5050 | Very Dark Brown Dudi-Dark Yellowish Brown or Brown Dossy | 2 WA.LR | 13 | Y |
| BC4827 | Dark Yellowish Brown Dossy | 2 WA.LR | 13 | N |
| BC5036 | Dark Yellowish Brown Dossy | 2 WA.LR | 13 | N |
| BC5505 | Dark Brown Dulce | 2 WA.LR | 14 | N |
| BC5506 | Dark Brown Dulce | 2 WA.LR | 14 | N |
| BC5518 | White Dubbin | 2 WA.MD | 14 | N |
| BC3224 | Very Dark Brown Ea | 3 BS | 15 | Y |
| BC3594 | Very Dark Brown Eba | 1 RGBS | 16 | N |

attempts to reconstruct the process of lithic manufacture through tracing the pattern of reduction. This reconstruction of the technological sequence and its subsequent use and abandonment (*chaîne opératoire*) provides insight into the fabrication, use, resharpening, and discard of any technological object (see Audouze and Karlin, 2017 for a recent review). GMM on the other hand allows for the characterisation and analysis of the form of the artefact (see Okumura and Araujo, 2018 and Matzig et al., 2021 for recent reviews), acting as an objective quantitative complement to technological analysis. Together, these methods have the potential to form a powerful tool for understanding lithic variability.

All statistical tests performed in the technological analysis were carried out using PAST (Hammer et al., 2001), while the GMM analysis was performed in the R software environment (R Core Team, 2020). For all statistical tests, we consider an alpha level of $<0.05$ to be statistically significant.

### 4.1. Technological analysis

Technological investigation of the sample involves an attribute analysis following previous lithic methodological studies (Bernaldo de Quirós et al., 1981; Inizan, 1999; Pelegrin, 1995; Tostevin, 2012; de la Peña, 2015) that has been adapted for this collection. Our analysis applied the *chaîne opératoire* concept and associated technological approaches (Karlin et al., 1991; Pelegrin, 1995; Inizan, 1999), however, we tried to control the subjectivity of this approach through univariate and multivariate analyses, as proposed elsewhere (e.g., Rios et al., 2012; Soto-Sebastián, 2014; de la Peña, 2015; Scerri et al., 2016). These included normality tests (Shapiro-Wilk), t-tests and Mann-Whitney tests, which were applied to the typometrical attributes, and a series of correspondence analyses on the qualitative attributes grouping different technological aspects of triangular blank manufacture. A full technological analysis of the lithics from members 2 BS, 2 WA, and a small sample of 3 BS and 1 RGBS from the new excavations from Border Cave (Backwell et al. this volume) is presented elsewhere (de la Peña et al. this volume); following this, we attempted to associate each point to a knapping reduction strategy ('knapping methods' *sensu* Inizan, 1999). As most of the reduction varieties in de la Peña and colleagues study are attributed to centripetal 'core-prepared' strategies, we have followed the work of Boëda (1993), Boëda (1993) and Meignen (2019). Regarding core reduction strategies, we also group the different varieties into the core classification system of Conard et al. (2004), as it has been used in several recent technological analyses of South African Middle Stone Age assemblages (e.g., Conard et al., 2012, Douze et al., 2020).

Our technological analysis involved recording both typometrical and technological attributes. The variables measured were raw material type, presence of cortex, length, breadth, thickness, weight, type of platform, platform length, platform width, external platform angle, number of dorsal scars, cross section, dorsal scar pattern, blank curvature, knapping accidents, heating stigmas, residues (for a more detailed description, see Supplementary Material S3 and Supplementary Figures S2-S3). As a novelty, we also incorporated the attribute 'ridges and nodes' which consisted of counting the points of intersection of dorsal flake negatives or, instead, if there were no intersections between flake scars, the number of ridges (Supplementary Figure S3). This variable was designed to explore the intensity of recurrence in the knapping process. As a specificity of the points studied here, we recorded if there was proximal dorsal scar removal as a gesture to eliminate the overhang between the striking platform and the knapping surface (a qualitative trait also defined elsewhere, e.g., Pelegrin, 1995). To aid comparisons between Border Cave and the recent Middle Stone Age point study at Bushman Rock Shelter, we also used two attributes defined by Douze et al. (2020, see Fig. 7.1. and Supplementary Figure S3), specifically their classification regarding the 'organization of dorsal scars' and the 'orientation of the tip with regard to the striking axis'. The first attribute was applied because it seems a simplified version of our attribute 'number of scars', and the latter one to monitor the tips.

### *4.2. Outline-based geometric morphometrics (GMM)*

GMM methods can be split into two categories: landmark-based approaches that require the presence of homologous points in 2D or 3D space, and outline-based methods that use geometric descriptions of whole homologous outlines or surfaces through the analysis of harmonics and eigenshapes (Okumura and Araujo, 2018). Following the recent assessment of the pertinence of these two methods by Matzig et al. (2021), we employed outline-based 2D GMM in this analysis. Whilst landmark-based approaches have their utility, especially for examining questions about shape without random noise, outline-based methods have several advantages for non-biological structures such as knapped lithics, as they avoid many of the potential issues of homology through the arbitrary positioning of landmarks, allowing the analysis, rather than the researcher, to determine the important aspects of shape variation at the outset. This benefits our analysis since our samples include non-standardised and asymmetric forms, making the definition of comparative landmarks particularly difficult and subjective.

#### *4.2.1. Data collection and preparation*

We performed 2D GMM on photographs of the points, taken by P. de la Peña, which were generated following protocols designed by Timbrell (2022) for lithic photography. These use a number of steps to optimize the photos for outline-based GMM. We created images of the dorsal face of each specimen with a Canon EOS 700D camera with a 2.8 mm macro lens. The resulting images have a resolution of 3456 × 5184 pixels. We placed a scale in each photograph to ensure a measure of size is recorded within the image and to remedy issues of lens distortion (fisheye).

To process the photographs in preparation for analysis, we binarized each image using the object detection tool in Adobe Photoshop. This helps to facilitate the automatic extraction of the outline by increasing the contrast between the background and the artefact. We then synthesized all of the images into a single thin-plate spline (.tps) file using tpsUtil. Outline extraction was performed in tpsDig2, with each artefact represented by an average of 4615 equidistant points, and the data were scaled by specifying the pixel:metric ratio for each image. We saved the data as (x,y) coordinates within the.tps file, and then imported it into the R software environment for analysis (R Core Team, 2020).

#### *4.2.2. Outline generation and standardisation*

Here we performed elliptic Fourier analysis (EFA), a common method of closed outline shape analysis, using the 'Momocs' package in R (Bonhomme et al., 2014). As briefly outlined by Hoggard et al. (2019), EFA boasts several advantages over other Fourier based methodologies, such as coordinate-point eigenshape and Fourier radius variation, including that it does not require each outline to have the same number of points, or that they be evenly spaced, allowing for the analysis of complex 2D edges.

To standardise the outlines following Bonhomme et al. (2017), all specimens were normalised to a common centroid, scaled using their centroid size and rotated according to the orientation landmark, which was placed using Momocs (Bonhomme et al., 2014) to ensure that the points were aligned along the same axis. We performed an automatic outlier detection procedure with a conservative confidence level of 99% and found no significant outliers. We then selected the number of appropriate harmonics necessary to efficiently capture point shape, deemed to be 99% harmonic power. Harmonics are a series of repeating trigonometric functions that decompose a closed outline to best represent the shape (Caple et al., 2017) (see Supplementary Figure S4 for a visualisation of this process). For 99% harmonic power, we retained 11 harmonics.

#### *4.2.3. Statistical analyses*

To explore the potential drivers of shape variability within the post-HP point sample, we applied a range of statistical techniques. First, we performed a Principal Components Analysis (PCA) to reduce the dimensionality of the data. To assess the relationship between centroid size and the most heavily weighted principal components (PCs), as well as length and width metrics established in the technological analysis, we performed correlation and linear regression analyses. To estimate the extent to which the factor variables could be predicted by the PCs representing 95% of the total variance, we applied linear discriminant analysis (LDA). Sample sizes were established *a priori* and used as prior group probabilities for the LDA, which estimates the classification of each individual into a group based on the shape data, and a jackknife procedure was employed to reduce the re-substitution errors that can lead to overestimates of the accuracy of LDA. We also performed regression on the shape variables and the relative stratigraphy, representing an ordinal measure of chronology (Table 1). Finally, we performed multivariate analysis of variance (MANOVA), analysis of variance (ANOVA) and Tukey's Honestly Significant Difference (HSD) tests on the PC scores to further assess the statistical significance of differences between the groups.

#### 4.2.4. Preliminary comparative study

Finally, to explore whether the 'Sibudan' morphotypes defined by Conard et al. (2012) and refined by Will et al. (2014) are reflected in the variability observed at Border Cave, we conducted a preliminary GMM study of the published Sibudan point morphotypes that Conard, Will and colleagues named Tongati (N = 27), Ndwedwe (N = 7) and asymmetric convergent tools (ACT) (N = 10).

Border Cave and Sibhudu are at a distance of approximately 350 km apart, and 2 BS has a similar chronology to the Sibudan, which dates to around 58 ka, providing a point of interest for understanding spatial patterns of variability in the eastern part of South Africa. However, a major difference between the Sibhudu and Border Cave points is that the Tongati, ACT and Ndwedwe tools are heavily retouched and resharpened, whereas at Border Cave few show signs of secondary modification, with only 5.4% retouched. Additionally, they are defined by the specific way in which they are continuously re-shaped through a reduction process, and therefore their typology is considered to be dynamic rather than static. To aid comparison between the sites, we therefore included a sample of unretouched points from Sibhudu (N = 15). At Sibhudu, unretouched blanks comprise the most abundant category of stone artefacts from each post-HP layer, which are produced via parallel, platform and discoidal reduction (Will et al., 2014). We used the 'outlineR' package and associated protocols by Matzig (2021) to extract the lithics in Figs. 5–7 and 10-11 in Conard et al. (2012), Figs. 3–4 in Will et al. (2014) and Figs. 6 and 13 in Conard and Will (2015).

The 'Sibudan' morphotypes contain a range of geometries within each category as they are defined based on techno-functional characteristics rather than being purely typological. We therefore performed an initial PCA to establish whether these morphotypes actually differ from each other in terms of their outline shape. We note, however, that a bias may exist in that this subset of artefacts were used in figures to highlight differences between and within types (i.e. different stages of their life history), and thus further investigation with the full Sibudan sample is ultimately required, though this consists of 348 unifacially retouched points alone.

Then, we projected the morphotypes onto the PCs from Border Cave using the 'rePCA' function in Momocs (Bonhomme et al., 2014). The rePCA function reapplies the PCA rotation from an initial sample in order to plot the PC scores of new observations on the existing morphological axes (i.e. the new observations are plotted according to the established coefficients, but do not contribute to the calculation of those coefficients). We also performed this analysis in reverse, to project the Border Cave sample into the shape space created by the PCA of the Sibhudu material. This unique approach is the most appropriate for our exploration, as the samples being compared are technologically different, therefore PCA projection allows us to understand how the Sibhudu points plot onto axes that describe the variation at Border Cave (and vice versa) without performing a direct comparison; for example, plotting the Border Cave material onto the Sibhudu axes provides an indication of the extent to which the shapes of the 'Sibudan' tool types are also present in the Border Cave assemblage.

## 5. Results

In this section, we report the results from our technological and GMM analyses, finishing with a preliminary investigation into the relevance of the 'Sibudan' morphotypes at Border Cave using GMM. We draw attention to the fact that our sample is small, though this is a reflection of the general low density of lithics from these layers (de la Peña, this volume). Our results should nonetheless be interpreted as demonstrating trends that should be confirmed in future analyses with larger samples. Supplementary Data File S1 reports the attribute data for each point, the variables of which are listed in Supplementary Materials S3. The outline data, and code used to analyse it, can be downloaded from the GitHub repository for the project at: https://github.com/lucytimbrell/post-HP_points.

### 5.1. Technological analysis

Before describing the technological characteristics of the point sample, some additional context regarding the full lithic assemblage must be presented. The general analysis of all the *debitage*, retouched pieces and chips from the new Backwell collection for 2 BS, 2 WA and a small sample of 3 BS and 1 RGBS is presented in detail in de la Peña et al. (this volume). The most abundant types of cores present are parallel (*Levallois*-like) varieties, followed by inclined (discoid cores) and platform cores (Conard et al., 2004). The parallel variant represented seems to be *Levallois* recurrent in 2 BS and 2 WA.UP (as defined by Boëda (1993)), whereas a bi-directional (two-opposed platform) variety is seen in 2 WA.LR and the top of 3 BS; this was deduced by the presence of plunging flakes, rather than cores (see de la Peña et al. this volume). This modality of knapping was also proposed by Villa et al. (2012) for this assemblage and is probably a variant of *Levallois* reduction. The most complete inclined core type seems to follow Boëda's (1993) definition of discoidal, although there are other examples and several fragments that could be classified in what Terradas (2003) called 'multi-facial discoidal'. There are at least three examples (2 BS.LR and 2 WA.MD) of small platform cores with residual scars from the production of bladelets. Additionally, there are clear technological examples of what Boëda (1993) defines specifically as 'chordal flakes' and '*Levallois* flakes' (*vide infra* explanation of these blanks through different examples in de la Peña et al. this volume).

#### 5.1.1. Unretouched points and knapping modalities

Most of our 'point' sample consists of unretouched triangular blanks (44/54). Some of these blanks fall into well-known *chaîne opératoire* schemas, such as *Levallois* recurrent/parallel and discoid/inclined (Boëda, 1993; Conard et al., 2004; Terradas, 2003), matching the cores and core-related by-products documented in the rest of the assemblage (de la Peña, this volume). In this regard, among our unretouched point sample, there are 'chordal flakes', originally defined by Boëda (1993), and characterised by knapping reduction along the chordal orientation of the core, resulting in the technological axis oblique to the morphological axis of the point. There are two types of chordal flakes: "the ones that have a distal point created by the intersection of two either unilineal or crossed removals opposite the 'back' (core edge), referred to as a "pseudo-*Levallois* point" by Bordes (1961), while the other type (also called *éclat débordant*) has a lateral back oriented along the technological axis of the flake that is opposite one or two edges" (Faivre et al., 2017: 118). These technological pieces can be produced through parallel and inclined reduction, and both appear in our sample (Fig. 3).

Furthermore, there are some unretouched flakes that could be associated with a recurrent centripetal *Levallois* reduction due to their facetted platforms, multidirectional scar patterns and the


**Fig. 3.** Different examples of triangular blanks that could come from an inclined – discoid reduction sequence. B, D and H are pseudo-*Levallois* points, one of the types of chordal flakes defined by Boëda (1993). All the pieces have been oriented according to their morphological axis. The white arrow in some of the pieces indicates the percussion point. All scales = 1 cm.

angle of the knapping surface-striking platform (Fig. 4). Although this last characteristic does not always denote a 'parallel' removal of the *Levallois* flake, as in our sample, there are several examples with angles over 60°.

There are several pieces in our assemblage that fall under the definition of *Levallois* point (typical or atypical) blanks (Fig. 5), as exemplified by the ones at Kebara (Boëda, 1993; Meignen, 2019). It is unclear if the Border Cave points were produced in specific reduction sequences targeting this variety of blanks, such as a unidirectional convergent modality at Kebara (Meignen, 2019), however, it seems plausible that the production of these unretouched points could have been integrated within a recurrent centripetal *Levallois* reduction strategy (or other *Levallois* variants) and they were not the exclusive goal of the *Levallois* reduction. In Fig. 4E and F, we have produced a hypothesized reconstruction of the production of a triangular blank after the scar pattern of a *Levallois* flake (coming from a *Levallois* recurrent centripetal schema). This is to show that this scenario of alternating the production of sub-quadrangular blanks and triangular blanks seems plausible.

Finally, there is a possibility that, in these layers, there was also a specific knapping reduction targeting elongated triangular blanks, highlighted by the refitted example of BC5050 and BC4710 (Fig. 6C), and the piece BC4827 (Fig. 6J) that show a rectilinear profile and a scar pattern not conforming to a centripetal recurrent *Levallois* knapping surface. In addition to these pieces, in 2 WA.LR, there are a few core-related by-products that denote knapping reduction from two-opposed platform cores, and angles of <60° between the striking platform and the knapping surface. These pieces could derive from two opposed platform *Levallois* cores as shown in Fig. 6.

Following our technological analysis, it appears that most of the unretouched points do not come from specific reduction sequences targeting triangular blanks, but from reduction sequences that produce, incidentally, a large number of triangular elements (such

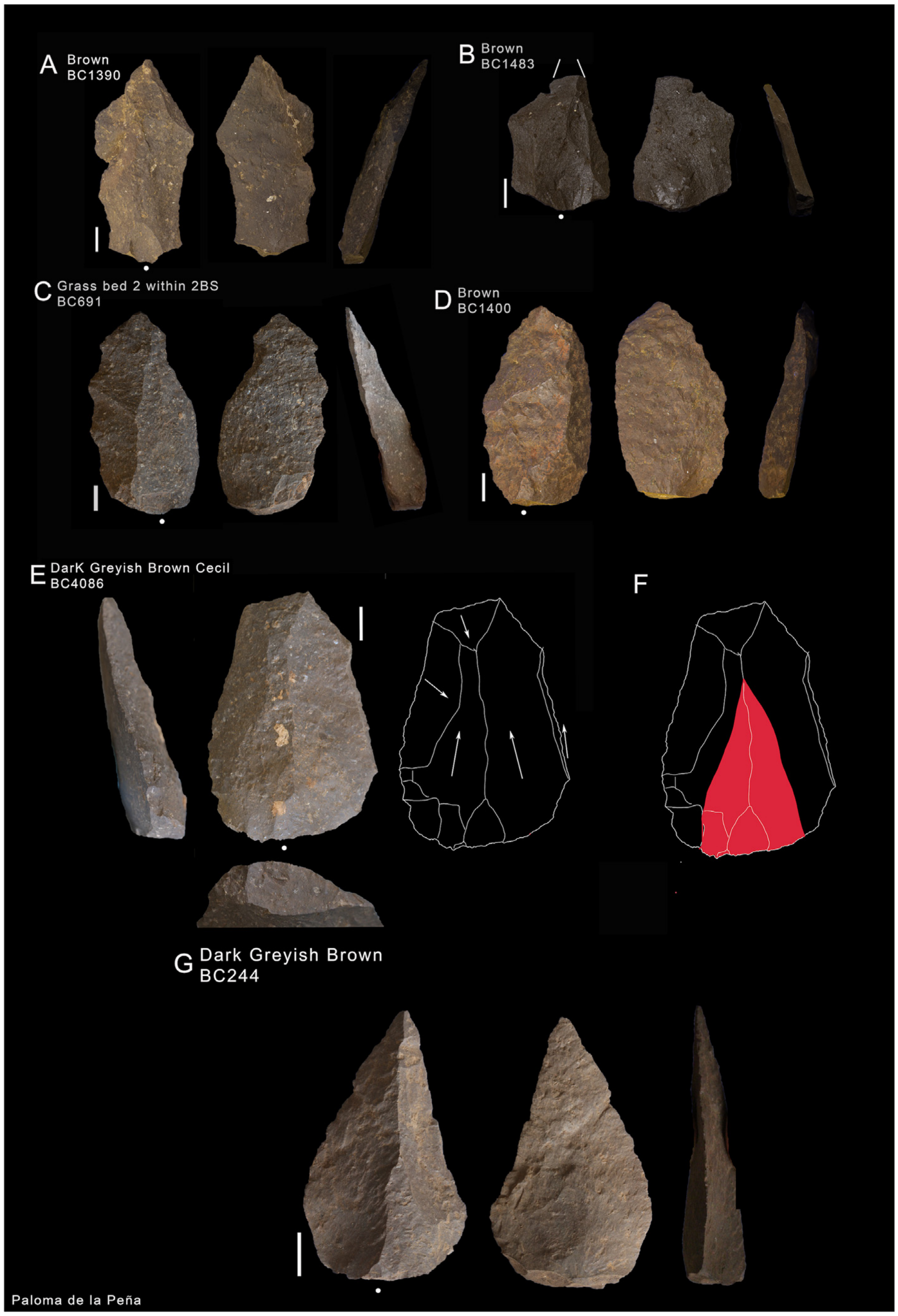


**Fig. 4.** Some examples of unretouched points that could come from a parallel/*Levallois* recurrent reduction (A, B, C, D, G). E is a *Levallois* flake (not a point) that serves to illustrate how appointed/convergent forms could actually come from *Levallois* recurrent cores. F is a hypothetical reconstruction of a point removal based on the blank in E. G is very similar to the point hypothesized in F. All scales = 1 cm.

as in discoidal and *Levallois* recurrent centripetal schemas). Moreover, there are artefacts that could point to specific *Levallois* modalities targeting triangular blanks, such as the atypical *Levallois* points (Fig. 5), maybe from a unidirectional convergent modality or from alternating a recurrent centripetal *Levallois* modality with the production of triangular elements (Fig. 4). In addition, the pieces BC4728 and the refitting of BC5050 and BC4710 could come from *Levallois* cores with two opposed platforms as shown in Fig. 6, and as highlighted in the extended technological analysis through core-related by-products in 2 WA (de la Peña et al. this volume).

Overall, we propose that most of our sample falls into inclined and parallel varieties. However, within *Levallois* reduction, we acknowledge the possibility of at least two distinct variants (recurrent centripetal and two opposed platforms) and potentially three (unipolar convergent *Levallois*) due to the presence of atypical *Levallois* points. We *tentatively* classified all of the points techno-typologically based on this assessment into four knapping schemas, as well as an indeterminate category where the classification was ambiguous. The four modalities are discoidal (D), *Levallois* recurrent centripetal (L), two opposed platforms *Levallois* (2OP) and *Levallois* points (LP) (although, as explained before, unipolar convergent scar patterns could be integrated in other parallel/*Levallois* reduction schemas) (see Fig. 7 for a synthesis of knapping modalities identified in the assemblage and Supplementary

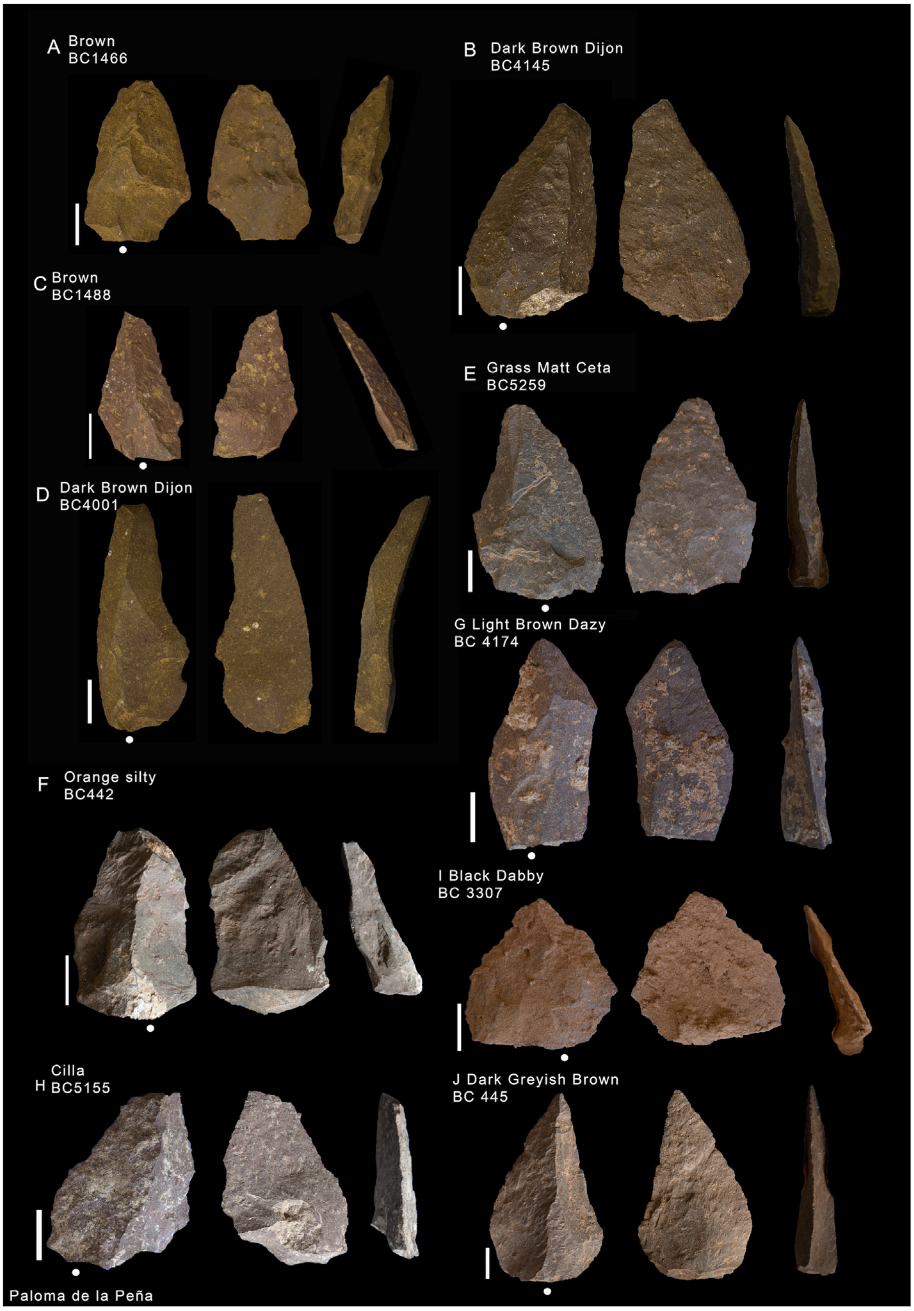


**Fig. 5.** Different examples of triangular blanks or 'points'. Some of these examples could be classified as atypical *Levallois* points (A, B, C, D, E). All scales = 1 cm.

Table S1 for knapping modalities according to allostratigraphic members). The characteristics for tentatively assigning the points to knapping modalities are summarised in Table 2. We acknowledge that the discoidal flakes, which are mainly chordal flakes, could be related to a *Levallois* recurrent centripetal reduction too (i.e, to the preparation stages of the recurrent Levallois reduction or the amendment of these cores). However, we decided to associate chordal flakes to the discoidal modality because these types of flakes tend to be more abundant in discoidal reduction sequences.

### *5.1.2. Retouched points*

Typological (retouched) points account for only 5.4% (N = 10) of our point sample, with some having evidence of macro-wear indicative of potential use and/or trampling (de la Peña and Witelson, 2018, Fig. 8D–F). There are several aspects worth noting in this small sample. Firstly, the two *fossiles directeurs* that Beaumont (1978) highlighted - *Châtelperron/Abri Audi* knives and trimmed points – are present in our sample. In Very Dark Brown Ea (3 BS), BC3224 fits the description by Beaumont of '*Châtelperronian*' points, with an abrupt direct retouch to the lateral left (unique in this sample) and a plain platform (Fig. 8I). The refitting of BC5050 and BC4710 (Fig. 8H) is probably the best example of the 'trimmed points' that Beaumont observed at the base of 2 WA, with the base being shaped through an inverse simple retouch. BC4728 (Fig. 8J) from Dark Yellowish Brown Dino apparently shows a similar 'template', as the retouch is identical to the refitting, and the dorsal face presents a single ridge; the refitting is a '1 Node' (1 N) piece, whereas BC4728 is a '1 Ridge' (1 R) piece. Due to the small sample

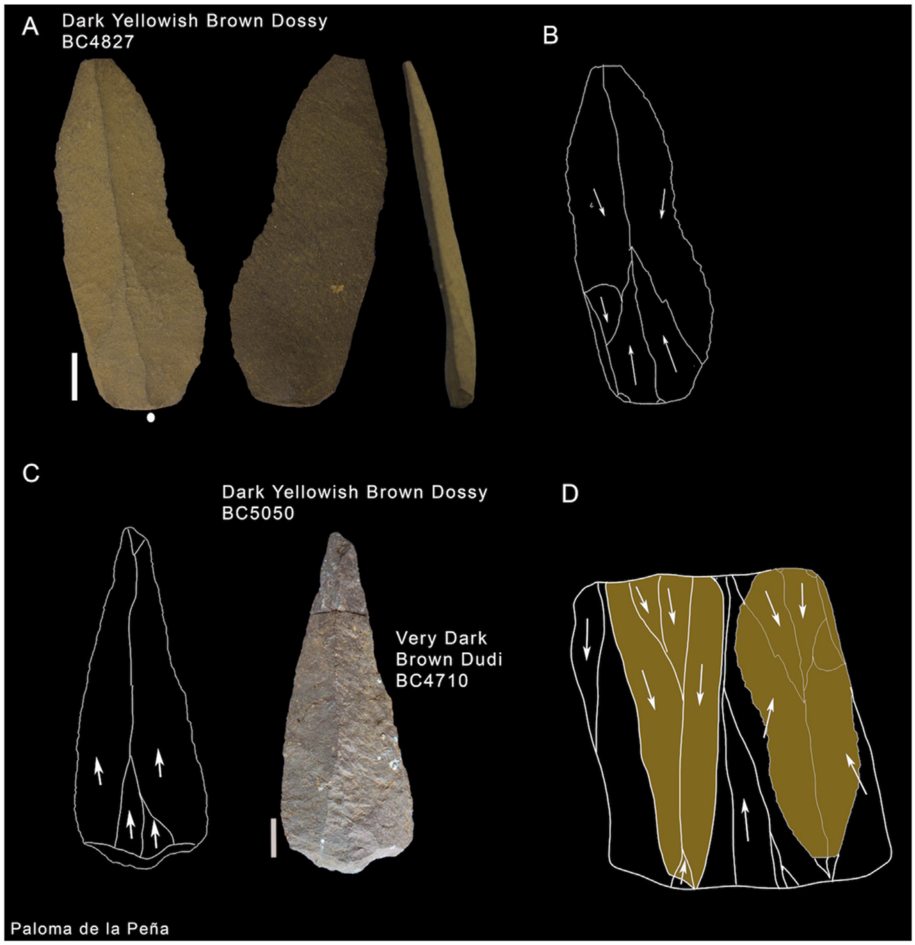


**Fig. 6.** *Levallois*-like blades with bi-directional scar pattern probably coming from a two opposed platform core. On the bottom right we have made a hypothetical core reconstruction using the two archaeological points in a two opposed platform core. All scales = 1 cm.

size and the fact that retouch has led to the elimination of the platform, it is purely speculative to propose a knapping method for these two points. However, it is plausible that both could fit a *Levallois* point reduction scheme specifically targeting elongated blanks with one central ridge (even if the refitting is 1 N, more than 3/4 of the pieces in the sample are 1 R).

In 2 BS.LR, there are three retouched points where the platform has been removed (BC543, BC5209, BC1222; Fig. 8A, B and E). This could be to facilitate hafting, although BC5209 (Fig. 8B) presents bladelet-like scars that could be directed to the production of blanks (maybe a core on flake). However, use-wear analysis is necessary to support any functional interpretation.

BC2936 (Fig. 8F) probably derived from discoidal reduction as it was found in association with large discoidal flakes. BC4565 (Fig. 8G) unintentionally mimics what in the literature is known as a *Levallois* point (Bordes, 1961), as the smallest scar appears to be a hinge accident (i.e., not a 'desired removal'); the knapper managed to produce a triangular shape blank through an inner percussion (meaning far from the overhang, see Soriano et al., 2007), thus producing typological characteristics of a *Levallois* point. This piece has clear macro scars on the tip.

### *5.1.3. Univariate and multivariate analyses*

We found that the three sub-members of 2 WA have similar ranges for overall length, width, thickness and weight, though to conclude anything meaningful from 2 WA.MD is impossible due to the small sample size (N = 3). All groups from 2 WA are nested within the range of variability for 2 BS for all variables (Fig. 9a-d). We then grouped points into two members (2 BS and 2 WA) and found statistically significant differences in thickness ($p = 0.002$) and weight ($p = 0.0032$), but not length and width (see Supplementary Table S2), highlighting how points from 2 BS tend to be thicker and heavier than those in 2 WA.

Regarding the length and width of the platforms of points from Members 2 WA and 2 BS, Fig. 9e-f demonstrates that the distribution of 2 WA similarly falls within that of 2 BS for both variables. T-tests found that the two members show no significant differences (Supplementary Table S3). Over half of the 2 BS sample has platforms measuring over 1 cm thick, which is indicative of an inner percussion (following Soriano et al., 2007), probably with a hard mineral hammer as there are very well-developed percussion bulbs, and all the percussion features are visible (such as *lancettes*), which is diagnostic of mineral percussion in flint (Pelegrin, 2000) (Supplementary Figure S5).

In terms of the type of platforms, 2 BS.LR has more variability than the rest of the sub-members and is the only one with facetted platforms (Supplementary Figure S6). Plain platforms dominate in all the sub-members. Some of the points show preparation of the dorsal proximal area or removal of the overhang (Supplementary Figures S2 and S5). This knapping 'gesture' (Pelegrin, 1995) could be adopted either to avoid knapping accidents such as hinge/step removals or to pre-prepare the point to have a smaller platform, perhaps in anticipation of hafting activities.

For the attribute 'ridges and nodes', 2 BS.LR has higher

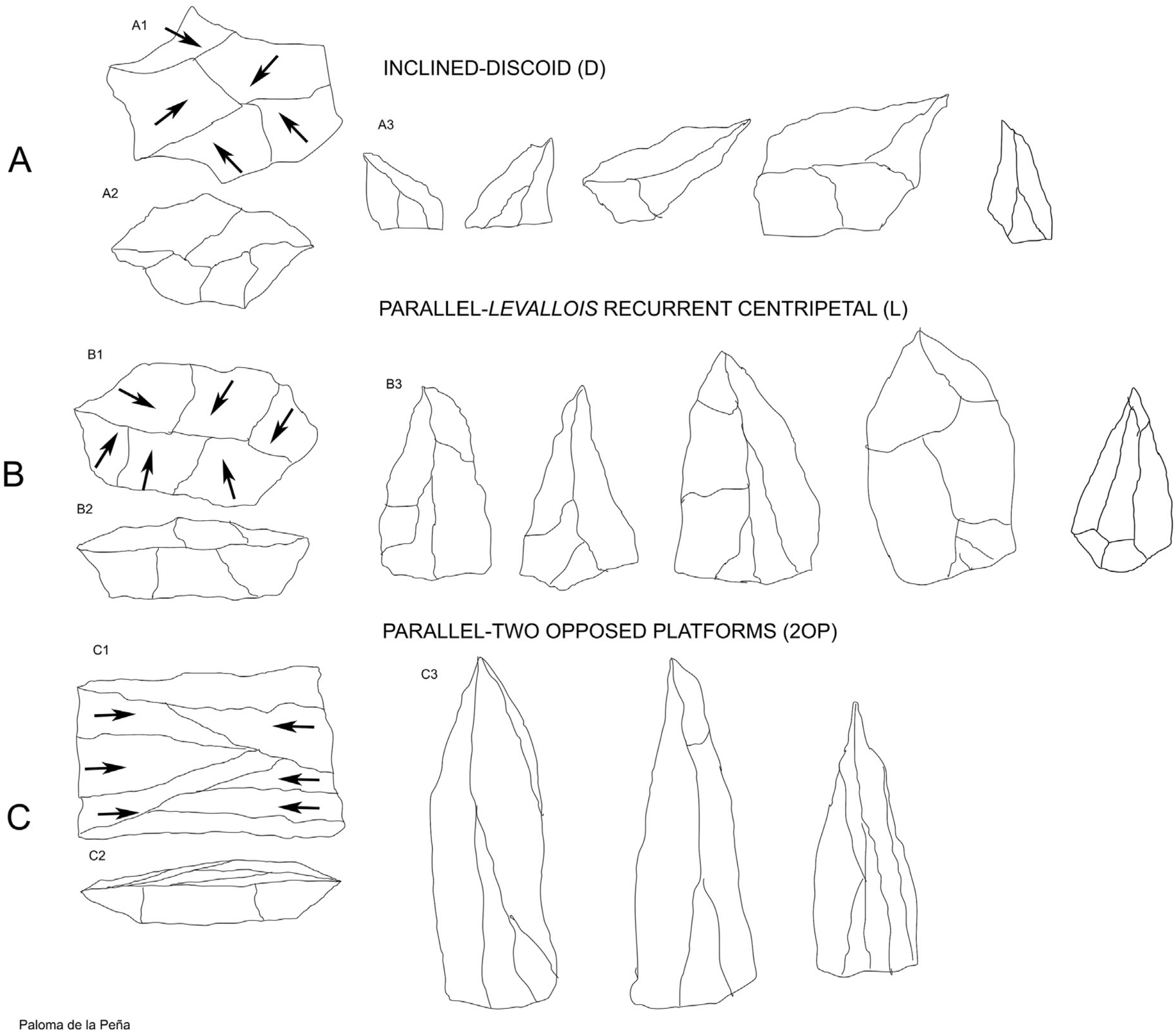


**Fig. 7.** A schema showing different knapping modalities identified in the point assemblage. A. Inclined–Discoid (D) (A1 - Knapping surface, A2 - Section of the core, A3 - Hypothesized blanks from this modality of knapping). B. *Levallois* recurrent centripetal (L) (B1 - Knapping surface, B2 - Section of the core, B3 -Hypothesized blanks from this modality of knapping) C. Parallel-*Levallois* two opposed platforms (2OP) (C1 - Knapping surface, C2 - Section of the core, C3 - Hypothesized blanks from this modality of knapping). The *Levallois* points (LP) shown in Fig. 4 could come from any of these knapping modalities or from a unidirectional convergent modality, but there is not enough evidence to suggest an independent knapping method for those types of blanks.

**Table 2**
Summary of the knapping modalities identified in the technological analysis.

| | | |
|---|---|---|
| Inclined-Discoid (D) (n = 18) | | • <4 dorsal scars<br>• Striking platform and knapping surface angle between 40 and 70°<br>• Thick plain or dihedral platforms<br>• 'Chordal flakes' (*vide supra*) |
| Parallel | Parallel-*Levallois* recurrent centripetal **(L)** (n = 8) | • Multidirectional scar pattern<br>• >4 scars<br>• Striking platform-knapping surface angle 40−70°<br>•Facetted platforms (although this is not a discriminant characteristic) |
| | Parallel-*Levallois* points (typical and atypical) **(LP)** (n = 15) | • ≤4 dorsal scars<br>• Unidirectional convergent scar pattern<br>• Facetted or dihedral platforms (although this is not a discriminant characteristic) |
| | Parallel-Two opposed platforms **(2OP)** (n = 2) | • Unipolar convergent or bi-directional scar pattern<br>• Striking platform-knapping surface angle <60° |
| Indeterminate (Ind) (n = 11) | | Not displaying any or only some diagnostic characters |

recurrence in knapping than the other sub-members (more scores of >2 N) and is the only group with ridges that could indicate a blade-like (laminar) knapping surface scar pattern (Supplementary Figure S6). For the scar pattern, multidirectional are dominant in the sample, following Tostevin (2013) and Douze et al.'s (2020) simplified classifications (Supplementary Figure S6). More than half of the sample has a centred orientation of the tip following Douze et al. (2020).

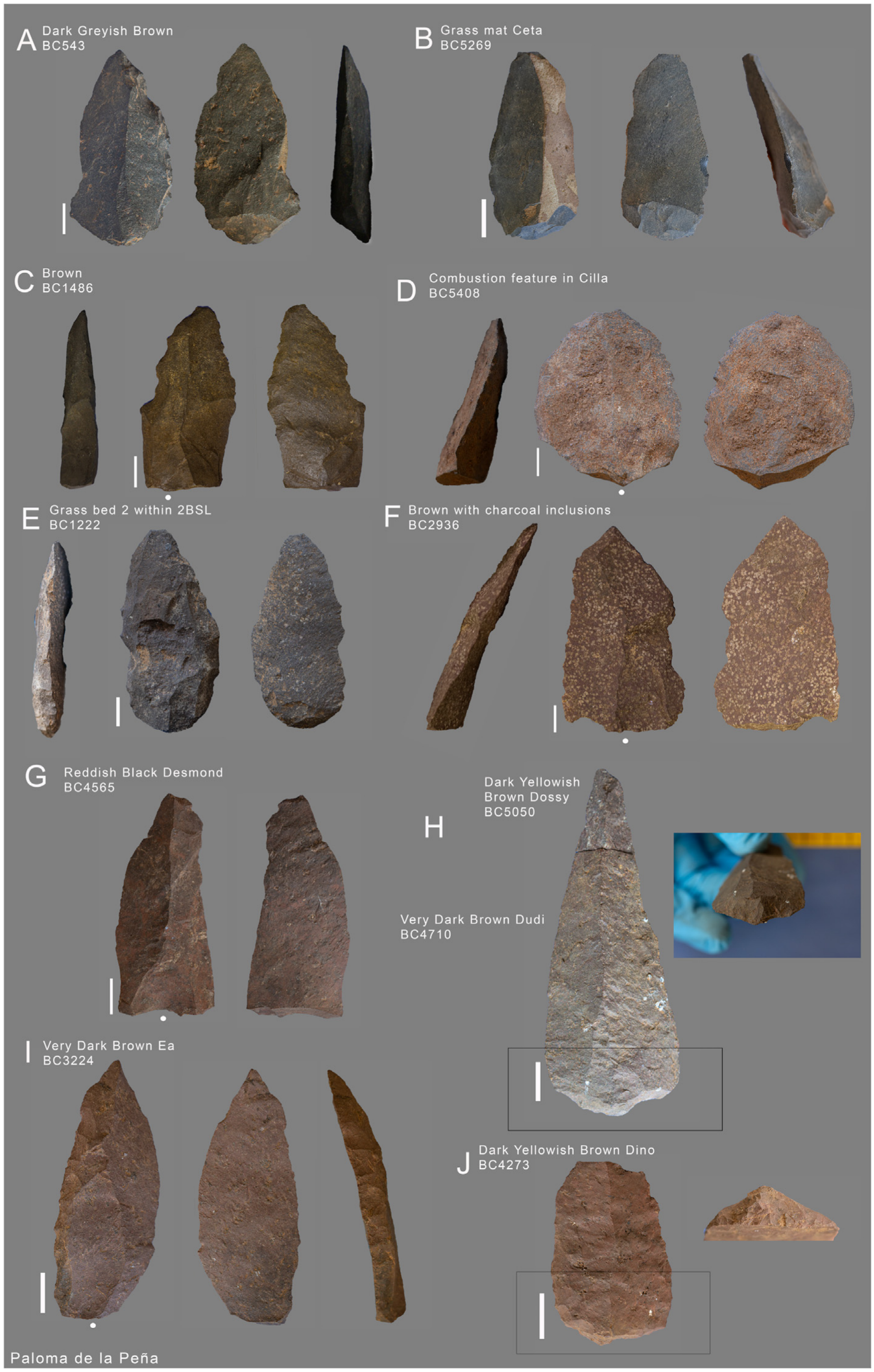


**Fig. 8.** Points from Members 2 BS, 2 WA and 3 BS that are retouched (A, B, C, H, I, J), and bear macro-traces of possible use or trampling (D, F, G). Piece E is covered with potlids. Piece G is a lookalike *Levallois* point. Piece I from Member 3 BS could be identified as what Beaumont called a '*Châtelperron* point', and pieces H, I, J are what he termed 'trimmed points'. All scales = 1 cm.

To explore the relationship between the qualitative variables, we next performed three different correspondence analyses considering different technological aspects of triangular blank manufacture of these unretouched pieces. The eigenvalue and the contribution of each axis (%) is reported in Supplementary Materials S4. Fig. 10 presents the results of the correspondence analyses.

Firstly, we explored the platform type (which reflects the technique of knapping, *sensu* Inizan, 1999; Pelegrin, 2000), the ridges and node system (indicative of the recurrence of knapping or how much a knapping surface is exploited), the scar pattern (which tells us about the organization of the cores and the knapping methods (*sensu* Inizan, 1999)) and finally the section (a qualitative description of the morphology of the piece beyond its triangular shape, though this is tackled quantitatively in the GMM section). We chose these variables as they give an overview of all the characteristics of the blanks. The results demonstrate that 2 WA.UP

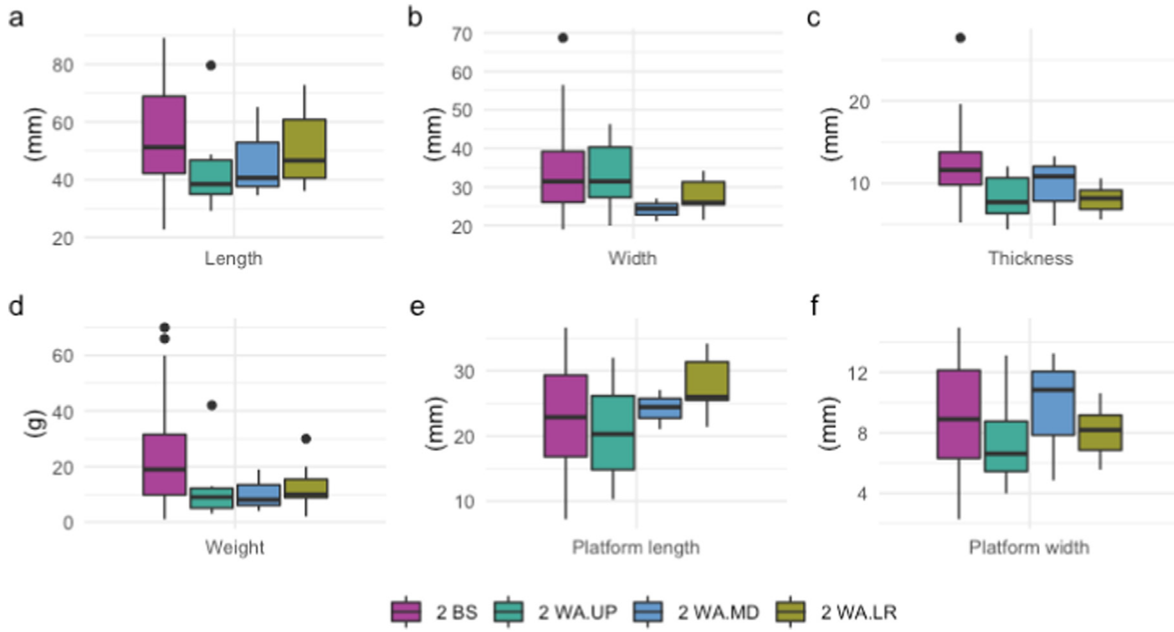


**Fig. 9.** Boxplot of a) length, b) width, c) thickness, d) weight, e) platform length and f) platform width of the points from Members 2 BS, 2 WA.UP, 2 WA.MD and 2 WA.LR.

differs notably from 2 BS.LR, whereas the difference between 2 BS.LR and 2 WA.LR and 2 WA.MD is less acute. Within 2 WA, 2 WA.LR and 2 WA.UP show the biggest differences, predominantly in the second axis which explains about 34% of the variability (Supplementary Materials S4 Table S1).

We next performed a correspondence analysis of the attributes relating to the knapping technique (Pelegrin, 2000). We considered again the platform, the angle between the striking platform and the knapping surface (we grouped the platform angles in three groups: 60, 60–80 and > 80, see Supplementary Materials S3) and the removal of the overhang (*vide supra*). In this case, 2 BS.LR and 2 WA.MD are the most different, whilst 2 WA.UP and 2 WA.MD are very similar in the factorial space. 2 WA.LR falls in-between the other sub-members along the first axis (86% of the variability), though closer to the two other groups from 2 WA. Despite appearing differentiated from 2 WA.UP and 2 WA.MD along the second axis, as this axis only explains 11% of the variability, the difference between the 2 WA members is minimal (Supplementary Materials S4 Table 2).

Finally, we performed a correspondence analysis considering the Douze et al. (2020) classification (Supplementary Materials S4 Table 3), specifically their 'organization of dorsal scars' and the 'orientation of the tip with regards to the striking axis' attributes. In this case, we obtained a slightly different picture, with 2 BS and 2 WA.LR points being the most different within the factorial space. In this last case, as in the first multivariate analysis, 2 BS.LR and 2 WA.UP are the most far apart. In addition, the three 2 WA sub-members differ in the vertical second axis (which in this case explains around 24% of the variability).

In synthesis, from these results, the allostratigraphic sub-members within 2 WA always separate from 2 BS.LR. The differences between 2 WA sub-members are less acute. Furthermore, 2 WA.UP and 2 WA.MD fall very close to each other in two of the cases considered.

### 5.2. Geometric morphometric analyses

We next used GMM analyses to investigate shape variability in our sample. PCA found that the first 8 PCs represent 95% of the cumulative variance in the outline data (see Supplementary Figure S7), however, here we discuss the first three principal components (PCs) representing 82% cumulative variance (Fig. 11). PC1 represents 63% of the variance in the data and highlights an axis of elongation. PC2 represents 12% of the total variance and represents symmetry and relative basal width. PC3 also represents 12% of the total variation and mirrors this pattern in terms of asymmetry and with increased emphasis on standardisation of the margin in terms of triangularity. This means that left-leaning artefacts with convexity on the left lateral side have high PC2 and low PC3 values.

#### 5.2.1. Allometry

To assess allometric relationships in the data we used Pearson's correlation and regression analysis (see Supplementary Figure S8). Length ($r = -0.43, p = 0.004, adj.\ r^2 = 0.16, F = 9.284$) but not width ($r = 0.23, p = 0.10, adj.\ r^2 = 0.03, F = 2.737$) demonstrated a statistically significant relationship with centroid size. This suggests that elongated points tend to be smaller. When investigating allometric relationships between centroid size and the PCs, PC1 was found to be highly statistically significant ($r = 0.98, p < 0.001, adj.\ r^2 = 0.96\ F = 1137$), whereas PC2 ($r < 0.001, p = 0.99, adj.\ r^2 = -0.01, F < 0.001$) and PC3 ($r = 0.01, p = 0.94, adj.\ r^2 = -0.01, F < 0.01$) have no correlation with size, confirming the above pattern.

#### 5.2.2. Chronology and raw materials

We next explored shape variability among the broad lithostratigraphic Members 2 BS, 2 WA and 3 BS, demonstrated in Fig. 12. Along PC1, 2 WA is more variable than 2 BS, especially towards the positive end of the axis (wider shapes). Member 2 BS, however, is more variable along PC2, falling more positively than 2 WA. Along PC3, 2 WA tends to fall more negatively than 2 BS – as PC2 and PC3 are reflections of the same axis of asymmetric variation, the separation of the groups along PC2 and PC3 shows that 2 BS tends to have points with asymmetric lateral convexity towards the distal end whilst 2 WA tends to have points with asymmetric lateral convexity towards the proximal end. Both points from 3 BS fall within the range of variability for 2 WA and 2 BS. We find that member affiliation can be accurately predicted using the PCs (*CV*

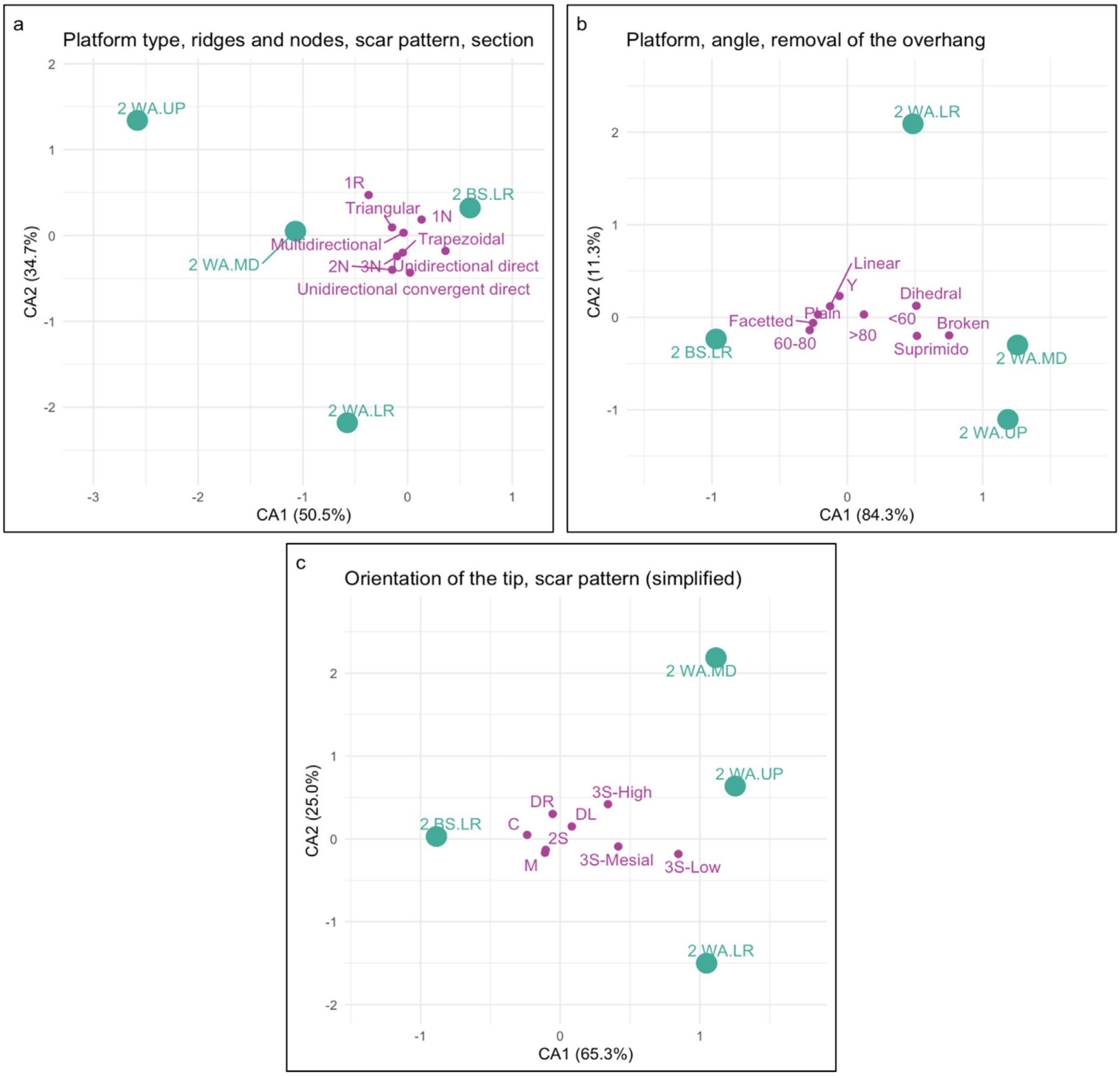


**Fig. 10.** Correspondence analysis considering a) type of platform, ridges and nodes, scar pattern and section, b) platform, angle striking platform-knapping surface and removal of overhang and c) 'organization of dorsal scars' and the 'orientation of the tip with regards to the striking axis' following a simplified version of the categories defined by Douze et al. (2020).

*correct* = *66%*), however, this result is driven purely by the larger sample size of 2 BS (*2 BS* = *88%*, 2 WA = *25%*, *3 BS* = *0%*). Nonetheless, neither ANOVA nor MANOVA found significant differences between the overall morphology of points from the different members (*PC1: p* = *0.526, PC2: p* = *0.408, PC3* = *0.09; MANOVA: p* = *0.89*).

We then used the revised sub-member system of Stratford et al. (this volume) and relative stratigraphy as more fine-grained interpretations of diachrony at the site (see Table 1). As demonstrated by Supplementary Figure S9, along PC1 there is a pattern of increasing elongation through time, with the youngest sub-members tending to have higher values of PC1 than the oldest groups. Ordinal regression of the relative stratigraphy confirms this by finding a weak but significant negative relationship between PC1 and chronology ($r = -0.27$, $p = 0.05$, adj. $r^2 = 0.05$, $F = 4.04$; see Supplementary Figure S10). Nonetheless, ANOVA finds no significant differences in overall shape between the sub-members along the first three PCs (*PC1* = *p* = *0.602, PC2* = *0.383, PC3* = *0.304*), which was confirmed by a MANOVA (p = 0.67).

As a potential influence over artefact shape (Andrefsky, 1994; Manninen and Knutsson, 2014; cf. Eren et al., 2014), we tested for differences between raw material types and found no significant differences (*PC1: p* = *0.3, PC2: p* = *0.12, PC3* = *0.82, MANOVA: p* = *0.7*), though this is expected due to the homogeny of the sample (see Supplementary Materials S2).

### 5.2.3. Technological attributes

Next we investigated the effects of the technological attributes (Supplementary Materials S3) on point shape. We found that only reduction method, degree of retouch and orientation of tip demonstrated significant results. Supplementary Materials S5 reports the results for the remaining attributes.

Our results demonstrate that *Levallois* points (LP) are highly variable along PC1, whilst discoidal tend to fall positively, having wider morphologies (Fig. 13). The two points with two opposed platforms (2OP) fall very negatively along PC1, as they are elongated compared to the rest of the points. Along PC3, discoidal (D) points tend to fall more positively than the other groups, particularly

**Table 3**
Tukey HSD results for PC1 and PC3 of the geometric morphometric data for the reduction methods (D = discoidal, Ind = indeterminate, L = *Levallois* recurrent centripetal, LP = *Levallois* point, 2OP = two opposed platforms). Statistical significance highlighted at p < 0.05 (*) or p < 0.01 (**).

| | | difference | lower | upper | p-adj |
|---|---|---|---|---|---|
| PC1 | D-2OP | 0.121 | 0.002 | 0.239 | 0.043* |
| | Ind-2OP | 0.066 | −0.056 | 0.188 | 0.542 |
| | L-2OP | 0.090 | −0.036 | 0.215 | 0.271 |
| | LP-2OP | 0.115 | −0.004 | 0.234 | 0.064 |
| | Ind-D | −0.054 | −0.115 | 0.006 | 0.100 |
| | L-D | −0.031 | −0.099 | 0.036 | 0.688 |
| | LP-D | −0.006 | −0.061 | 0.050 | 0.998 |
| | L-Ind | 0.023 | −0.050 | 0.097 | 0.898 |
| | LP-Ind | 0.049 | −0.014 | 0.112 | 0.201 |
| | LP-L | 0.025 | −0.044 | 0.095 | 0.838 |
| PC3 | D-2OP | 0.006 | −0.036 | 0.047 | 0.995 |
| | Ind-2OP | −0.005 | −0.048 | 0.038 | 0.997 |
| | L-2OP | −0.021 | −0.065 | 0.023 | 0.647 |
| | LP-2OP | 0.002 | −0.040 | 0.044 | 0.999 |
| | Ind-D | −0.011 | −0.0312 | 0.011 | 0.614 |
| | L-D | −0.027 | −0.051 | −0.003 | 0.017* |
| | LP-D | −0.004 | −0.023 | 0.016 | 0.983 |
| | L-Ind | −0.016 | −0.042 | 0.009 | 0.388 |
| | LP-Ind | 0.007 | −0.015 | 0.029 | 0.896 |
| | LP-L | 0.0233 | −0.001 | 0.0460. | 0.065 |

*Levallois* recurrent centripetal (L). Reduction methods can be used to predict point shape with an accuracy of 44%, with discoidal and *Levallois* recurrent centripetal being the most distinguishable (*D = 55%, Ind = 37%, L = 54%, LP = 33%, 2OP = 0%*). MANOVA at 95% confidence confirmed that there are statistically significant differences in shape between the reduction methods, with ANOVA on PC1 and PC3 (Table 3) highlighting how there are significant differences between D and 2OP points along PC1 ($p = 0.043$) and L and D points along PC3 ($p = 0.017$), though we draw attention to the small sample sizes here.

We also investigated shape variation between technological (unretouched) and typological (retouched) points. We grouped points that demonstrate macroscars into a third category. Although there are many more unretouched points in the sample than retouched and those with macroscars, clear differentiation is visible in the PCA scatter plots (Fig. 14). Unretouched (U) points are more variable along all three PCs. Retouched (R) points fall as a tight cluster negatively on PC1, around the mean on PC2 and around the mean of PC3 – together this suggests that, as a group, retouched points tend to be more symmetrical, standardised and elongated when compared to unretouched points. Despite being a small group like retouched points, those with macroscars (M) are more variable along the PCs than retouched, though their variability is not as pronounced as that of unretouched points. Due to the unequal sample sizes of the groups, LDA was unable to accurately classify points based on degree of retouch (*mean = 77%, M = 0%, R = 0% and U = 98%)*. However, ANOVA and Tukey HSD of the PCs found that along PC1, unretouched and retouched points show statistically significant differences (Table 4), highlighting the distinction between typological and technological points in terms of elongation, though MANOVA did not find a statistically significant relationship between retouch and shape (p = 0.53).

We finally explored whether the tip orientation according to the striking platform had an influence on point morphology. Fig. 15 demonstrates the scatterplots of the points in relation to tip orientation along PC1-PC3; along PC1, the groups overlap considerably, with *déjeté* right (DR) points showing the least variability, and centred (C) points the most variability. Along PC2, *déjeté* left (DL) have pieces that fall more positively, whilst along PC3 there are DR points that fall towards the negative extreme. This could suggest that DL points tend to have the bulge on the right towards the base, whilst DR points tend to have the bulge on the lateral left towards the distal end. However, DL and DR points overlap substantially, demonstrating that the direction of tip orientation in relation to the striking platform has little relationship with overall shape when the points are aligned along their morphological axis. LDA could accurately differentiate between points of different tip orientation, particularly C points (overall classification accuracy = 59%; C = 79%, DL = 16%, DR = 38%) using the PCs. ANOVA of the first three PCs found that along PC3 there are statistically significant differences

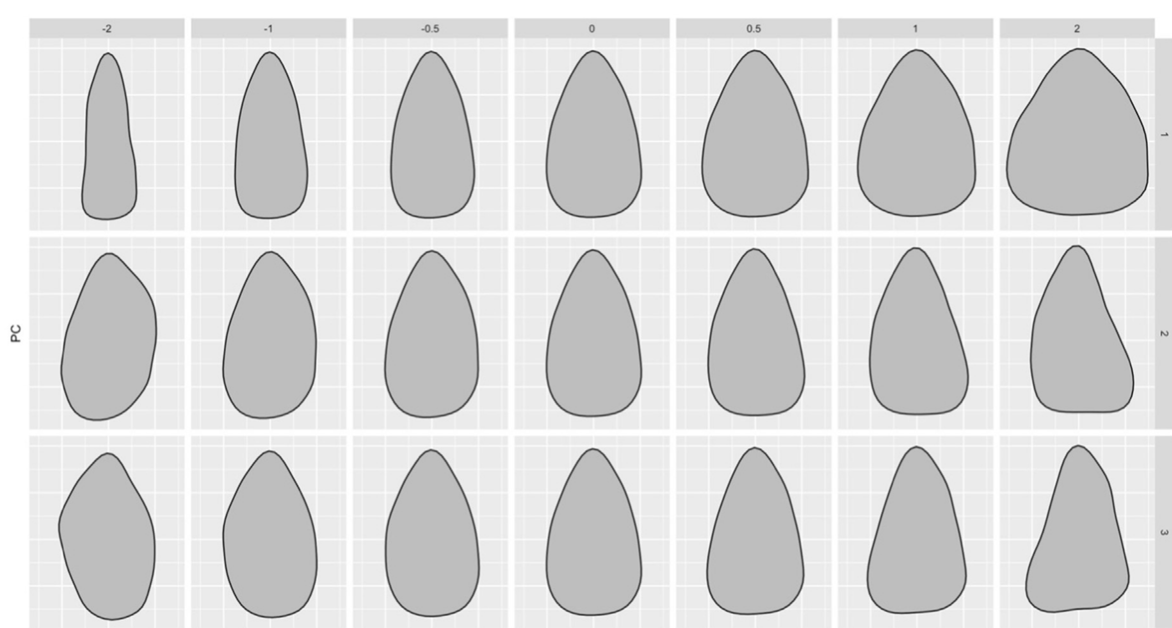


**Fig. 11.** Principal component (PC) contributions demonstrating the mean and standard deviation of shape change along PC1 (top), PC2 (middle) and PC3 (bottom). These three axes of variation characterise 82% of the morphological variability within the point sample.

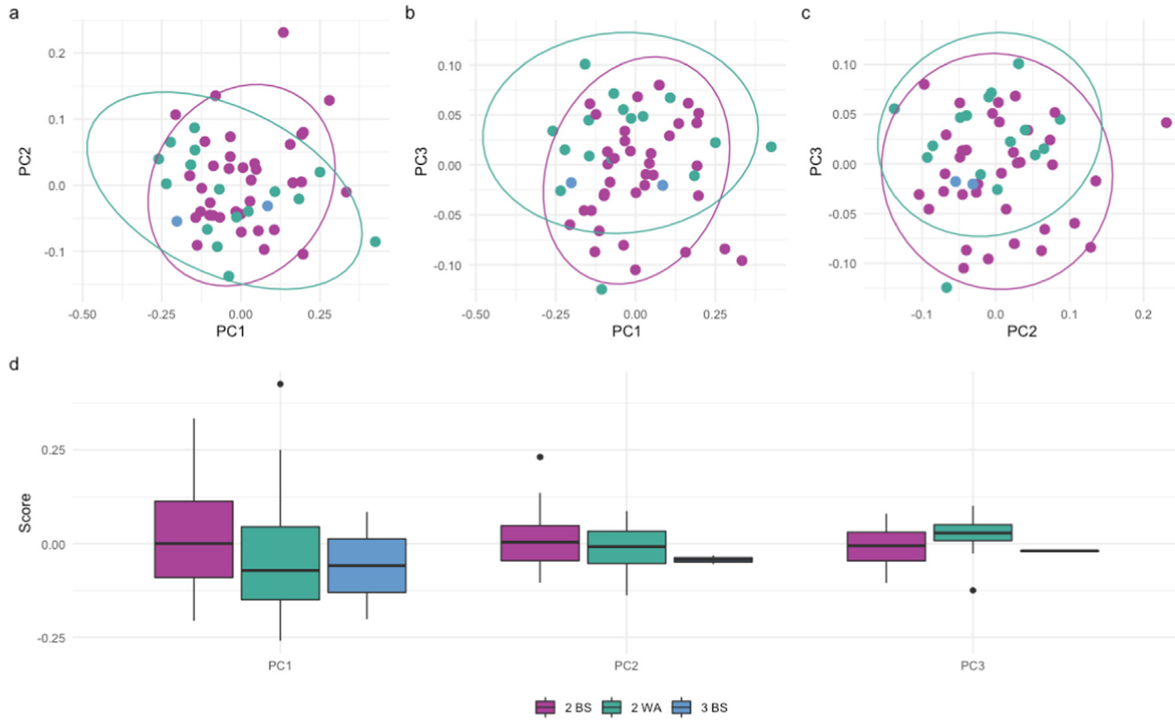


**Fig. 12.** Principal component analysis in relation to the member divisions by Beaumont (1978), as recognised in the new excavations. Scatterplots (a–c) highlight variation along principal components (PCs) 1–3. The boxplots (d) visualize the differences between the groups along these first three PCs. Refer to Fig. 11 for shape extensions along the PCs.

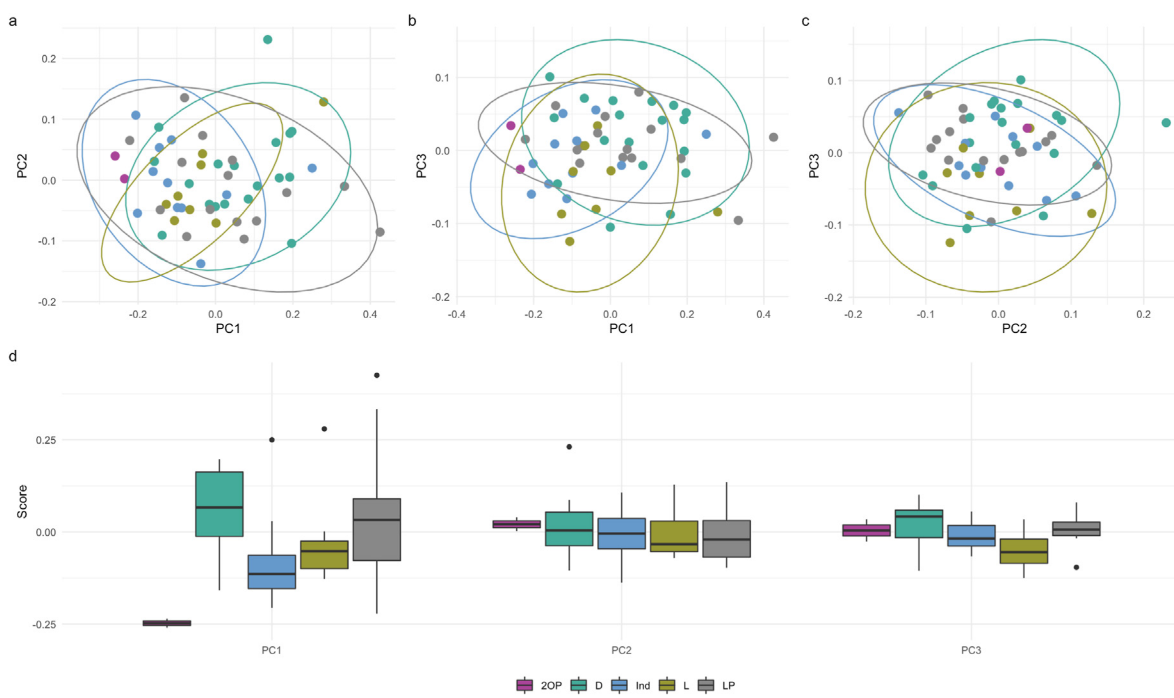


**Fig. 13.** Principal component analysis in relation to reduction methods (2OP = 2 opposed platforms, D = discoidal, L = *Levallois* recurrent centripetal, LP = *Levallois* points, Ind = indeterminate). Scatterplots (a–c) highlight variation along principal components (PCs) 1–3. The boxplots (d) visualize the differences between the groups along these first three PCs. Refer to Fig. 11 for shape extensions along the PCs.

between the groups ($p = 0.043$), which was confirmed by a MANOVA ($p < 0.01$), though post-hoc Tukey HSD suggests no significant pair-wise differences along PC1-3.

### 5.3. *Preliminary investigation of 'Sibudan' morphotypes at Border Cave*

As previously mentioned, one of the main questions regarding the post-HP is whether the 'Sibudan' point morphotypes defined by

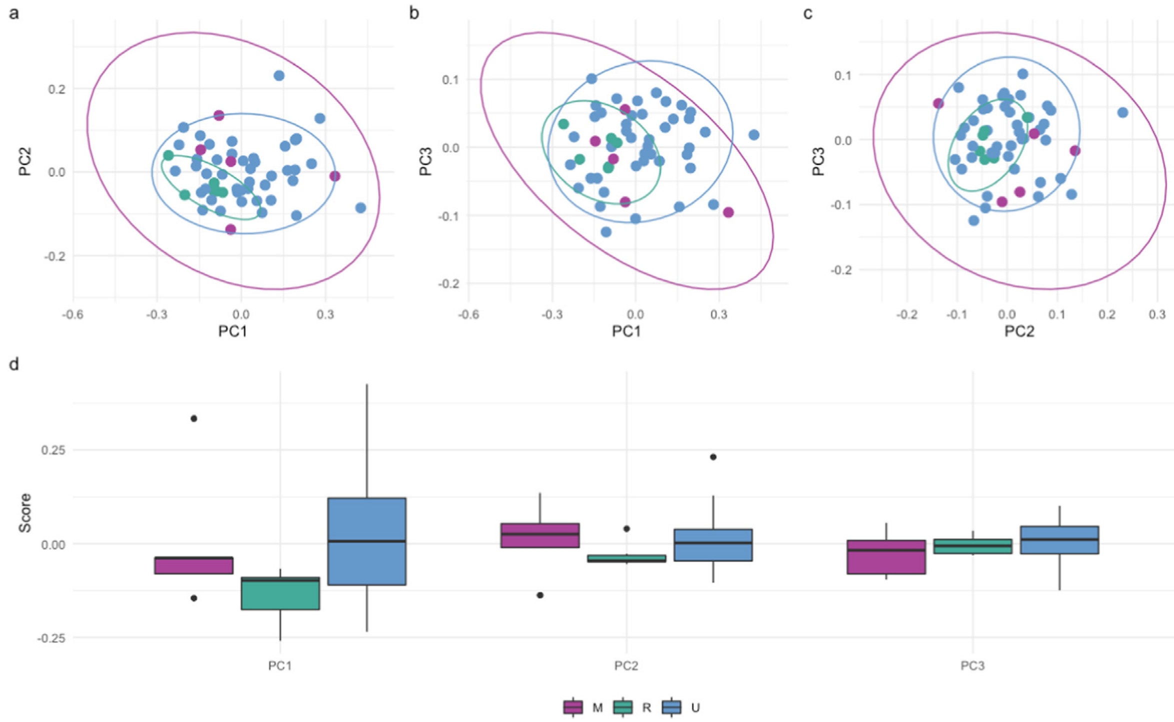


**Fig. 14.** Principal component analysis in relation to degree of retouch (M = macroscars, R = retouched, U = unretouched). Scatterplots (a–c) highlight variation along principal components (PCs) 1–3. The boxplots (d) visualize the differences between the groups along these first three PCs. Refer to Fig. 11 for shape extensions along the PCs.

**Table 4**
Tukey HSD results for PC1 of the reduction methods (M = macroscars, R = retouched, U = unretouched). Statistical significance highlighted at p < 0.05 (*) or p < 0.01 (**).

| | difference | lower | upper | p-adj |
|---|---|---|---|---|
| R-M | −0.057 | −0.143 | 0.0230 | 0.262 |
| U-M | 0.005 | −0.063 | 0.0721 | 0.985 |
| U-R | 0.061 | −0.000 | 0.124 | 0.054* |

Conard et al. (2012) and refined by Will et al. (2014) are found elsewhere in South Africa and can thus be considered as diagnostic of the post-HP (see Supplementary Figure S11 for the 'Sibudan' morphotypes considered in this analysis).

Fig. 16 demonstrates that, despite being dynamic in nature, the Tongati, ACT and Ndwedwe morphotypes and unretouched Sibudan points exhibit formal differences that are reflected in the outline of the artefact. Across the shapespace (see Supplementary Figure S12 for visualisation of shape change along PC1-3), the Ndwedwe tools form a discrete cluster, which separates almost entirely from the Tongatis, particularly along PC2 *(p = 0.003)* and PC3 (*p = 0.020*). This was confirmed by LDA which found that Ndwedwe and Tongati could accurately be distinguished (*86% CV correct and 89% CV correct respectively*). The ACTs are less coherent in terms of shape and overlap with both the Ndwedwes and, more closely, the Tongatis, and could not accurately be distinguished from the other types using LDA (*0% CV correct*). Unretouched points are variable along the PCs, though statistically significant differences occur with the Tongatis along PC1 (*p = 0.01*), and Ndwedwes along PC2 (*p = 0.003*) and PC3 (*p = 0.05*). This shape difference is anticipated in the model of reduction presented by Conard et al. (2012: Fig. 8, pp. 189). Under this model the shape changes as the piece is progressively retouched on the distal part. This is most evident in PC1 (see Supplementary Figure S12), where many of the Tongatis occupy more of the positive shapespace, which is produced by the narrowing of the stone through retouch, especially at the tip. MANOVA confirms there are statistically significant differences between the morphotypes ($p < 0.001$).

This GMM confirmation of the existence of discrete shape types in the post-HP layers at Sibhudu (above) allows us to ask to what extent these shapes were also present at Border Cave. Despite major differences between the sites in terms of retouching, we find that the morphological axes at Border Cave (Fig. 17) can be used to differentiate some of the Sibudan morphotypes. Fig. 16a-c shows the morphotypes projected into the Border Cave shape space, using the rePCA function in Momocs (Bonhomme et al., 2014). The shape differences reported between unretouched and Tongati points at Sibhudu in Fig. 17 are also retained along PC1 of Border Cave, though the differences lack statistical significance. Tongati and Ndwedwe points were found to be significantly different along PC2 (*p = 0.03*) within the Border Cave shape space.

Fig. 17d-f positions the Border Cave points on the Sibudan morphological axes, reversing the projection. It shows that the Border Cave points predominantly cluster in the middle of the Sibhudu shape space. This central overlap could result from the use of similar reduction sequences at both sites producing similarly shaped blanks. Differentiation in shape then appears through retouch, with Tongatis, Ndwedwes and ACTs displaying greater spread along the PC1 axis, which describes narrowing of the point through retouch. The Border Cave points have a greater spread along PC2 (asymmetry), which may reflect the selection of regular, symmetrical, and triangular blanks at Sibhudu to produce Tongati and Ndwedwe morphotypes, as suggested in the reduction cycles of these tools (Conard et al., 2012). Overall, the Border Cave sample contains a greater variety of point shapes and does not display the regular pattern of tip narrowing seen at Sibhudu.

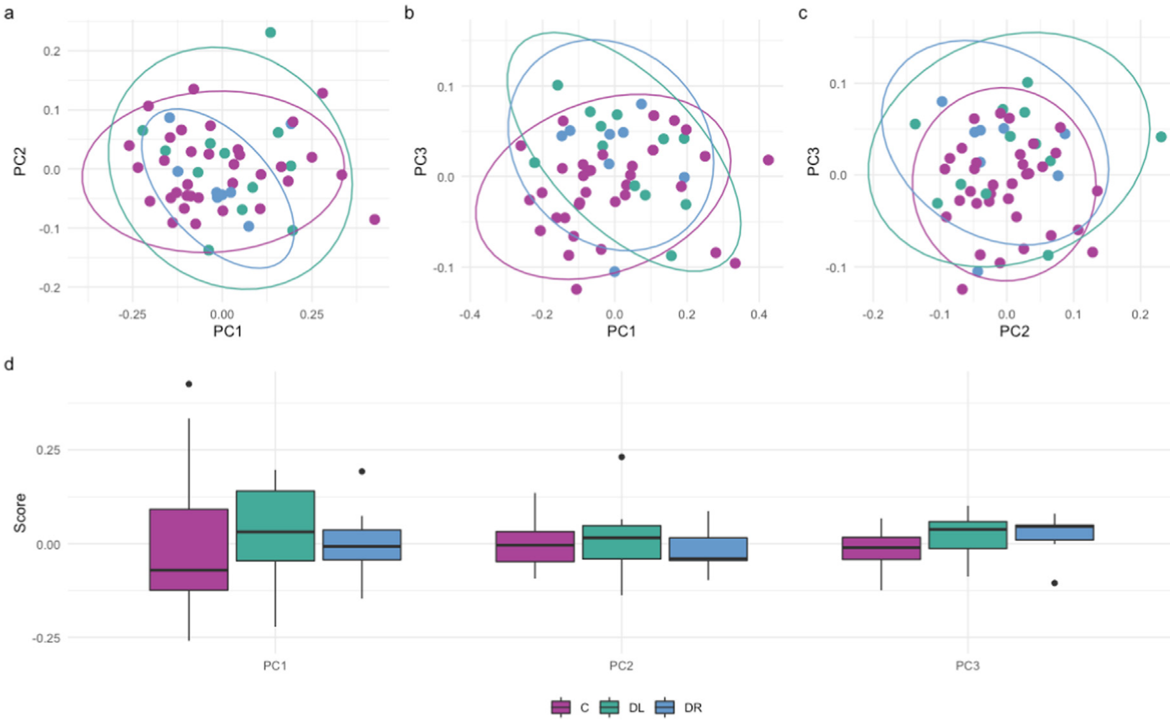


**Fig. 15.** Principal component analysis in relation to tip orientation (C = centred, DL = *Déjeté* left, DR = *Déjeté* right). Scatterplots (a–c) highlight variation along principal components (PCs)1–3. The boxplot (d) visualizes the differences between the groups along these first 3 PCs. Refer to Fig. 11 for shape extensions along the PCs.

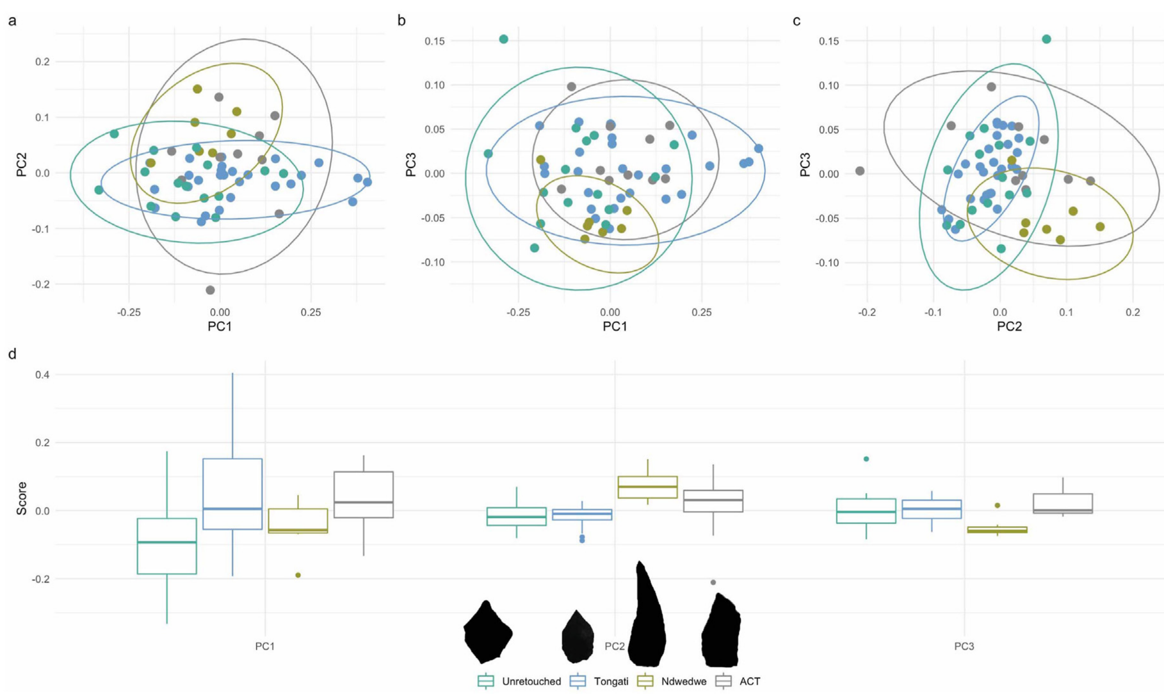


**Fig. 16.** Scatterplots of principal component (PC) scores for Tongati, Ndwedwe and asymmetric convergent tools (ACT) and unretouched points, representing a) PC1 against PC2, b) PC1 against PC3, c) PC2 against PC3 with d) boxplots of the PC scores along PC1, PC2 and PC3. Outlines in this analysis were extracted from artefact drawings in Conard et al. (2012), Will et al. (2014) and Conard and Will (2015) with an example of each morphotype shown here (all outlines for the morphotypes are shown in Supplementary Figure S10). Refer to Supplementary Figure S11 for shape extensions along the PCs.

## 6. Discussion

In this study, we present a combined technological and GMM approach for analysis of knapped lithic artefacts. This integrated methodology allows us to investigate several hypotheses related to the technology and typology of post-HP points and the potential relationships between the two. GMM and technological analysis capture different but complementary aspects of variation within

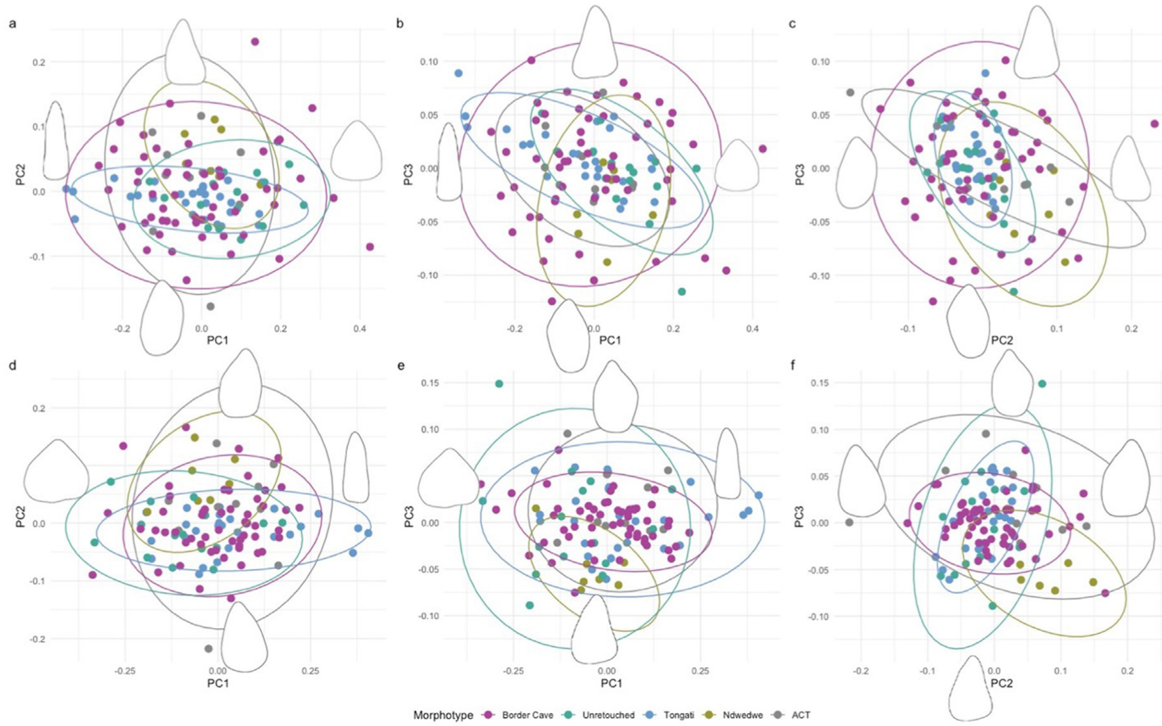


**Fig. 17.** Comparison of Border Cave and Sibudan point types (Ndwedwe, Tongati, ACT and unretouched) using principal component analysis (PCA) projection. The top row shows principal components (PCs) defined by the Border Cave sample a) PC1 and PC2, b) PC1 and PC3, c) PC2 and PC3. The bottom row uses PCs defined by the Sibhudu sample d) PC1 and PC2, e) PC1 and PC3 f) PC2 and PC3. Shape extensions along the PCs for Border Cave (see Fig. 10) and Sibhudu (see Supplementary Figure S11) have been superimposed to aid visualisation of the shape differences.

stone tool assemblages – the overall shape is captured through the outline and reflects the broad design space configuration of the artefact, yet it is the artefact's technological attributes that provide information regarding the dynamics of cultural transmission and method of production (Matzig et al., 2021). We explored several established technological attributes that we independently qualify and qualitatively assess, including a new technological attribute ‘ridges and nodes’ that provides a quantifiable measure of the recurrence of knapping. We then investigated these attributes under the scope of overall morphology through GMM, providing new insights into the relationship between tool manufacture and shape.

### 6.1. *A combined technological and geometric morphometric approach*

In this study, we combined the *chaîne opératoire* method with a multivariate analysis and univariate statistics. Despite our small sample, we preliminarily propose that at Border Cave post-HP points were produced using a variety of core reduction methods, as is also reported in the post-HP layers at Diepkloof (Porraz et al., 2013). Discoidal triangular blanks appear differentiated in shape when compared to points made via *Levallois* recurrent centripetal and with two-opposing platforms. Reduction strategies have been argued to influence lithic form, yet the exact morphological consequences of knapping modality are far from well-defined, primarily because flakes from different methods converge in shape and size (Rezek et al., 2011). Several studies have aimed to morphologically identify some of these reduction methods through GMM approaches, with variable success (Clarkson et al., 2006; Eren and Lycett, 2012, 2016; Picin et al., 2014). Recently, machine learning has also been used to differentiate between discoidal and centripetal *Levallois* methods and found statically significant differences between them (González-Molina et al., 2020). Our results contribute to this body of work by highlighting that, at Border Cave, unretouched points produced from discoidal cores tend to be wide and asymmetrical, likely reflecting the lack of pre-determination in flake removal.

Whilst GMM methods have been used to explore technological diversity (Rezek et al., 2011; Bretzke and Conard, 2012; Picin et al., 2014; Morales et al., 2015; Chacón et al., 2016), our study is the first to explore the effects of such a wide range of technological attributes on point morphology. We found that most of the technological attributes studied did not influence the overall form of the artefact, however, knapping modality, degree of retouch and orientation of the tip were found to have significant effects on artefact shape. The latter two attributes could be argued to have a more obvious impact on point morphology – retouch affords a high degree of shape control with reduction narrowing the artefact, and a *déjéte* tip infers a tip that is orientated at an angle to the striking platform. Interestingly, our results suggest that the *direction* of tip orientation has little effect on the overall morphology of the point when the piece is rotated along its morphological axis, though *déjéte* points appear differentiated from centred points in their ranges of asymmetry. This is likely because *déjéte* points fall under the same technological principle, regardless of the direction of tip orientation, while those that are centred in relation to the striking platform tend to have more balanced shapes. In addition, it is interesting that we can delineate statistically significant differences in shape between knapping modalities; this requires future examination with larger samples. Overall, GMM methods provide a quantified and objective complement to the qualitative observations derived from technological analyses, together allowing for a comprehensive understanding of technological diversity.

### 6.2. Point production strategies

One of the many features we studied in this paper was Douze et al.'s (2020) distinction between technological (unretouched) and typological (retouched) points. This classification echoes earlier work by Migal (2007) who proposed two schemas of point production for the Final Palaeolithic in the Central European Lowlands: 1) serial blade production where points are secondarily modified by retouching and 2) points that are pre-determined by shaping of the striking surface of a core in order to achieve a pointed morphology of the final blank, referred to as a 'preferential point'. In this sense, a 'preferential' or 'technological' point is a tool characterised by morphological features important to the knapper, as the point is readily functional once removed from the core. While generic blanks could be retouched into multiple tool forms, 'preferential' or 'technological' reduction suggests that the aim of point production is established much earlier in the knapping sequence. This difference has major implications with regards to the technological sequence performed by the knapper and the degree of control over the form of the final product, though both require the projection of a triangular shape in the mind according to Douze et al. (2020).

However, we note a key distinction from this binary system in that unretouched triangular shapes can be produced via blank reduction where points are not necessarily the goal of knapping, as opposed to a scenario classified as 'technological points' where the mental template of the piece is projected onto the surface of a prepared core ('preferential points' —Migal, 2007). Our technological analysis found that most of the post-HP points at Border Cave probably do not come from specific point production sequences, but rather from various reduction sequences that tend to produce triangular elements. These points bear morphological features that differ from those on retouched pieces, characterised by narrower and more standardised and balanced shapes.

#### 6.2.1. Why is there an absence of retouch during the post-HP at Border Cave?

Our sample consists primarily of unretouched triangular elements, as also seen at Bushman Rock Shelter (Douze et al., 2020) and Mwulu's Cave (de la Peña et al., 2019). We hypothesise four potential reasons for such limited secondary modification during the post-HP at Border Cave, though we caution that this exercise is highly speculative and based on an analysis of only 54 artefacts.

Firstly, the lack of retouch could suggest that the points were readily functional, and no further modification was needed after the flake was removed from the core (Migal, 2007) as has been noted ethnographically (Gould et al., 1971; Hiscock, 2004). Hiscock (2004) found that retouched artefacts were usually those which did not come off the core in the desired shape, and thus required subsequent reshaping. A technological strategy that does not require additional shaping could be highly productive and more time efficient. Binford (1973) suggested that low-cost expedient technologies tend to be manufactured via variable production strategies with little investment in the form of the artefact. In this sense, manufacture, use and discard of these types of artefacts are all likely to occur within the same immediate context (Vaquero and Romagnoli, 2018). This could also suggest that post-HP assemblages at Border Cave represent ephemeral, low intensity occupations, particularly compared to Sibhudu where there is abundant retouch debitage and re-tooling, which is likely evidence of the intense residential use of the site.

An absence of secondary modification may also be related to the abundance of raw material at Border Cave (Beaumont, 1978). Border Cave has abundant local rocks from which knappers could produce tools, as shown by the homogeneous raw material types and points that were produced primarily from rhyolite, basalts, chalcedonies/agates and quartz. All these materials appear in areas relatively nearby, and one of the preferred rhyolite varieties is found along the path accessing the site (in secondary context) in the form of small slabs. Distance decay theory posits that retouch increases with distance from source, with retouch and resharpening associated with reuse of a tool becoming more pertinent in areas of raw material scarcity (Iovita, 2011). Sholts et al. (2017) in an analysis of Pleistocene North American points suggested that, to conserve raw materials in areas far from quarry sites, the most skilled knappers were probably the primary producers of stone tools to reduce the chance of mistakes, reflected by their production of more symmetric points. Therefore, non-standardised point production during the post-HP at Border Cave could reflect an increase in knapping experimentation due to the decreased pressure for tool conformity, as is also suggested at Klein Kliphuis Rockshelter (Mackay, 2011). This could have led to a decrease in the group's reliance on specialists and an increase in the proportion of the group having knowledge about lithic production. Moreover, the lack of standardisation may reflect the fact that raw material abundance afforded knappers the liberty of producing additional blanks as opposed to having to retouch less suitable ones. However, Sibhudu also has abundant raw materials surrounding the site, yet demonstrates very high retouch frequencies in some but not all layers (Will et al., 2014), suggesting raw material availability was likely not an influential factor in determining point retouch intensity.

The lack of retouch could indicate the ways in which these tools were used. McBrearty and Brooks (2000) pointed out that the overall morphology of a point, particularly its hafted end (typically the base), is constrained by the functional requirements of the tool. Small narrow points have been found to be aerodynamic as they have low resistance to the air, whilst symmetrical designs do not wobble when thrown and distribute the load evenly upon impact, reducing the probability of tool failure (Cotterell and Kamminga, 1990). Yet symmetry does not necessarily equate to a solely projectile function; for example, Kuman (1989) concluded that the heavily retouched points from ≠Gi, Botswana, likely performed a variety of functions, including both throwing and cutting. This MSA site provides a useful contrast to Border Cave as, despite a similar discoidal knapping strategy, shaping was used at ≠Gi to produce broadly symmetrical shapes, interpreted as an attempt to compensate for the asymmetry and mass imbalance that occurs through discoidal reduction (Brooks et al., 2006). A hand-held function may be more appropriate for the unretouched post-HP elements at Border Cave, as has been suggested for some of the quartz Howiesons Poort bifacial points at Sibhudu (de la Peña et al. (2013) and for lithics from Northeast African MSA sites (Rots et al., 2011). Together, the evidence suggests that triangle-shaped forms could have performed a variety of functions within the post-HP toolkit at Border Cave and should be explored further with functional analyses.

Finally, when compared to point production strategies adopted at Sibhudu, the lack of retouch is a major point of difference with Border Cave. This could suggest that, as opposed to this technological strategy being adaptive, there was a period after the Howiesons Poort of cultural drift (Shennan, 2011), producing cultural regionalisation in knapping and shaping strategies. Technological variability arising from random drift may explain why post-HP assemblages do not appear to form a culturally homogenous unit when compared to the Still Bay and Howiesons Poort phases. Overall, the relative scarcity of retouch at Border Cave compared to Sibhudu could reflect a combination of differences in site use intensity, function, and potentially higher levels of mobility within a relatively small region of South Africa.

### 6.3. Assessing the post-Howiesons Poort through time and space

Using univariate and multivariate analyses, we found notable chronological variation throughout the post-HP sequence at Border Cave. In the typometrical analyses, 2 WA and 2 BS (particularly 2 BS.LR) show significant differences, with 2 BS tending to have more variable platform types and a higher number of ridges and nodes, probably because *Levallois* reduction produces more scars on the dorsal surface. Although we found no significant differences in the overall shape of the pieces, 2 WA tends to have wider points than 2 BS, a trend of elongation through time that is confirmed by a weak but significant relationship in the relative chronology. Member 2 BS is also more variable in terms of the basic dimensions of the points, with weight and thickness showing statistically significant differences compared to 2 WA. These two typological characteristics are not reflected in the 2D outline of the artefacts, which likely explains why the GMM analysis did not find statistically significant differences between the mean shapes of points from the different members. This highlights the strength of combining technological analysis with GMM analysis, as relying solely on either one can overlook key aspects of cultural variability.

Thus far, the quantitative analysis of post-HP points has been primarily limited to a single site, Sibhudu, with certain morphotypes being suggested as potentially diagnostic for the period (Conard et al., 2012; Will et al., 2014; Conard and Will, 2015; Bader et al., 2015; Will and Conard, 2018; Will, 2019). Triangular blanks at Sibhudu are produced using similar reduction methods to those we have reported at Border Cave (Will et al., 2014). However, clear differences in point density and retouch strategies can be observed at the sites. Nonetheless, our evaluation of the 'Sibudan' through GMM shows that the distinct tool types present at Sibhudu are reflected somewhat in the shape space of points from Border Cave, which we hypothesise demonstrates that the use of similar reduction methods produced similarly shaped triangular blanks, with the more regular blanks being selected for further modification through retouch and resharpening at Sibhudu to form the distinct morphotypes.

Our findings demonstrate many other notable parallels with what is known of the post-HP throughout South Africa. At Diepkloof (Porraz et al., 2013), flakes from the post-HP layers appear more morphologically variable than in preceding layers. This is consistent with our finding that the unretouched points at Border Cave are asymmetrical and diverse. At Diepkloof the excavators noted several unifacial points with short triangular distal ends, similar to Tongati tools (Conard et al., 2012). At Rose Cottage Cave, typological and technological diversity is found to be higher in the post-HP than in the underlying Howiesons Poort (Soriano et al., 2007). A lack of tool standardisation and high levels of technological diversity thus appears to be a theme for the period (Villa et al., 2005; Soriano et al., 2007; Conard et al., 2012; Porraz et al., 2013). Such variability could relate to the high number of tasks being conducted during this period, as demonstrated both by diversity in tool production strategies reported at Border Cave here and in the literature (Villa et al., 2012; Backwell et al., 2018) and the general lack of technological consistency across post-HP assemblages.

## 7. Conclusion

Overall, we concur that the post-HP marked a period of technological variability, as shown through the non-standardised technological strategy adopted at Border Cave to produce primarily irregular triangular-shaped blanks. Post-HP points at Border Cave were manufactured using a variety of reduction methods, of which some produced distinctive shapes, and that knappers primarily took advantage of the natural morphology of the pieces produced by these different core reduction technologies. This could indicate a potentially diverse range of functions for pointed forms at Border Cave during this period. We found that the post-HP points from Border Cave, whilst somewhat similar in shape, are technologically unlike those from the post-HP at Sibhudu. We therefore propose that elements of the 'Sibudan' technocomplex likely occur at other post-HP sites in southern Africa, however the package as a whole does not, supporting the contention that post-HP assemblages are characterised by technological diversity. Overall, our composite investigation of the shape and technology of non-standardised triangular forms from a period outside of the well-known South African technocomplexes has allowed for an unbiased assessment of cultural variability and contributes to our understanding of human behaviour throughout the MSA sequence.

## Author contributions

LT, MG, AW, PP: Conceptualization, LT, AW, MG, CH, PP: Methodology, PP: Data curation, LT, MG, AW, CH, LW, FD, LB, PP: Writing, editing and reviewing manuscript.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data has been uploaded onto a GitHub repository with a link in the manuscript

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## Appendix A. Supplementary data

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