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# Backed Pieces and Their Variability in the Later Stone Age of the Horn of Africa


Alice Leplongeon  • Clément Ménard •  
Vincent Bonhomme • Eugenio Bortolini


**Abstract** Backed pieces became widespread in the Upper Pleistocene and Holocene and are part of the classic definitions for the Later Stone Age in many parts of Africa. However, the association of backed pieces with Later Stone Age is not clear in the Horn of Africa. These pieces are present in both Middle Stone Age (MSA) and Later Stone Age (LSA) contexts. To what extent was the “backing phenomenon” homogeneous or diverse between and within the two periods? Here, we start with a review of the literature on backed pieces in the Horn of

Africa, noting the lack of terminological consensus and the absence of a shared typology in the region. We then describe the variability of backed pieces using two complementary approaches: (1) multivariate statistical analysis on a set of 28 attributes of 188 artifacts from eight securely dated contexts and (2) 2D geometric morphometric analyses on the same dataset. The two approaches provide complementary results, which allow us to identify and discuss the chronological trends in backing technology and morphology, without

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introducing a new terminology or proposing a new formal “descriptive” typology.

**Résumé** Les pièces à dos abattu deviennent omniprésentes au Pléistocène récent et à l’Holocène, et sont donc partie intégrante des définitions classiques du Later Stone Age. Cependant, l’association des pièces à dos abattu avec le Later Stone Age est peu claire dans la Corne de l’Afrique. En effet, elles se retrouvent à la fois dans des assemblages Middle Stone Age ou Later Stone Age. Dans quelle mesure le « phénomène des pièces à dos abattu » est-il homogène ou relève de processus différents entre et au sein de ces deux périodes? Dans cet article, nous présentons une synthèse critique de la littérature mentionnant les pièces à dos abattu dans la Corne de l’Afrique, et soulignons l’absence d’un consensus sur l’usage d’une terminologie ou d’une typologie commune dans la région. Nous décrivons ensuite la variabilité des pièces à dos abattu en s’appuyant sur deux approches complémentaires: (1) une analyse statistique multivariée en reposant sur 28 variables de 188 pièces provenant de huit contextes datés de façon absolue, et (2) une analyse de géométrie morphométrique en 2D. Les deux approches ont livré des résultats complémentaires, qui permettent d’identifier et de discuter les tendances chronologiques affectant les pièces à dos, sans avoir à introduire de nouvelles dénominations ni à proposer une nouvelle typologie « descriptive ».

**Keywords** Backed pieces · Horn of Africa · Later Stone Age · Lithic variability

## Introduction

The lack or inadequacy of comparable assemblages is a significant challenge that we face when trying to interpret the African regional or multiregional lithic record. This challenge is aggravated by the need to reconcile the different approaches, methods, and typologies that lithic analysts have used to describe the assemblages across the continent. During the 1960s–1970s, researchers tried to develop a uniform terminology and typology for describing lithic artifacts (Clark and Kleindienst 1974; Merrick 1975; Nelson 1973), following the recommendations of the Burg-Wartenstein symposium on “Systematic Investigation of the African Later Tertiary and Quaternary” (Bishop and Clark 1967; Clark et al. 1966).

The typology developed by Nelson (1973) had a strong influence on the research conducted in Eastern Africa during the 1970s–1980s (see Ambrose 1984a; Brandt 1982; Kurashina 1978; Mehlman 1989). But it was soon superseded by a multitude of individual variants and site-dependent typologies. In addition, Nelson’s typology was never much in use in the Horn of Africa (for a review of the situation in Eastern Africa, see Shea 2020, chapters 4 and 5). Nowadays, there is little agreement among lithic analysts on the use of a common typology on a multiregional/continental scale, and we are far from achieving the objective of a unified terminology of forms and types in the Later Stone Age studies. A few LSA typologies exist for different regions of the continent, but their usage lacks consensus among archaeologists. A notable exception, however, is the typology of Tixier (1963, 1974), widely used for the North African Epipaleolithic, which we will hereafter refer to as Later Stone Age (LSA), in agreement with recent usage (e.g., Barton et al. 2019).

In the Horn of Africa (HoA), researchers are well aware of the limitations caused by the lack of consensus on typological definitions and the very nature of the LSA (see discussions in Brandt et al. 2012; Leplongeon et al. *in press*). Backed pieces, which are often considered a hallmark (or *fossile directeur*) of the LSA, remain poorly known. This paper aims to contribute to a better understanding of the emergence and spread of backed pieces in the region by:

1. Reviewing the literature on the occurrences of backed pieces in the HoA during the Upper Pleistocene and Holocene;
2. Providing a detailed comparative attribute analysis of backed pieces from several sites in the HoA and identifying the possible patterns of variability (e.g., in shape or size) across time and space.

Our objective in this exercise is not to propose a new typology. Hence, we shall use a very general definition in the analysis in order to include most of the categories that previous researchers have used, such as geometrics, microliths, and backed blades. A backed piece is, therefore, defined here as a product with at least one edge, or part of an edge, modified by an abrupt to semi-abrupt continuous retouch. This definition allows us to include a wide variety of backed or partially backed pieces, regardless of their size or shape.

Our analysis is based on materials from different sites in Ethiopia (discussed below). These artifacts were previously analyzed thoroughly by two of us (Leplongeon 2013; Ménard 2015). To compensate for the lack of shared terminology in the previous descriptions of these assemblages, we shall implement two complementary approaches: multivariate statistical analyses and 2D geometric morphometrics. These will allow us to quantify, describe, and test differences in shape variability of backed pieces in the region without having to resort to the introduction of new terms.

### **Backed Pieces and the Later Stone Age: Disentangling a Complex Relationship**

Backed pieces can be defined, according to Tixier (1963, p. 26, 1974, p. 4), as *retouched* pieces, with at least one edge blunted by an abrupt retouch. A prominent group of French specialists of the Mesolithic (including Tixier) proposed that a backed edge (*bord abattu* in French) could be defined as a retouch not producing a new sharp (i.e., acute) edge (G.E.E.M. 1969, p. 356). The underlying assumption, though not systematically supported by functional analyses (e.g., Honegger 2009; Wadley and Mohapi 2008), is that backed edges correspond to hafted parts and that backed pieces are stone inserts in composite tool technology, usually linked to projectile technology.

We use the term “backed pieces” because it is the most inclusive among existing categories and types. “Backed pieces” is an unbiased term and does not entail a specific size or type of blank (flake, blade, bladelet). Of course, this category, like any other, may sometimes fall short of representing the complexity and diversity of lithic remains. Moreover, it emphasizes the importance of a simple way of modifying artifact edges, which is only one possible solution among others and does not account for the unretouched artifacts for which we have evidence of hafting and use (e.g., Villa et al. 2012).

#### **When Did Backed Pieces Occur?**

Backed pieces were identified in various southern African contexts as early as the later Middle Pleistocene in the Lupemban assemblages of Twin Rivers and Kalambo Falls (Barham 2002). They were present in numerous Upper Pleistocene assemblages attributed to the Howiesons Poort (e.g., Brown et al. 2012; Delagnes

et al. 2006; Igreja and Porraz 2013; Lombard and Phillipson 2010; McBrearty and Brooks 2000), and it is likely that they were intermittently used during later periods in the region (Deacon 1984; Porraz et al. 2016; Wadley 1993). They eventually became widespread in the Holocene industries (Goodwin and Van Riet Lowe 1929; Mitchell 1997). In Eastern Africa, backed pieces appeared later during Marine Isotope Stage (MIS) 3 (e.g., Ambrose 2002; Shipton et al. 2018; Tryon 2019).

#### **Are Backed Pieces a Hallmark of the LSA?**

Classic definitions for the LSA generally include a shift towards the production of smaller artifacts and bladelets, increased use of the bipolar technique, and the generalized occurrence of “microliths” (e.g., Phillipson 2005). Backed microliths, in particular, are often considered as the hallmark of the LSA. This is the case for “iconic” LSA industries such as the Wilton in Southern Africa (Goodwin and Van Riet Lowe 1929; Mitchell 1997). It is also true of the aggregated industries such as the Iberomaurusian in the Maghreb (e.g., Barton et al. 2019; Lubell 2001; Tixier 1963). However, the pattern varied across the continent. There are LSA assemblages without backed pieces, and there are others with large numbers of backed pieces. In addition, we have MSA assemblages with backed pieces (see review in Ambrose 2002). Then, to what extent can backed pieces be considered a hallmark of the LSA?

In most LSA contexts, it seems that the trend towards smaller tools or the production of smaller blanks is more significant than the presence of backed pieces. LSA assemblages are often characterized by small tool types, such as “backed microliths,” “crescents,” and “backed blade/lets” (e.g., Clarkson et al. 2018; Leakey 1931; Leakey 1943; Leplongeon 2014; Merrick 1975; Phillipson 2005; Tixier 1963). However, there is a lack of a consensus over the definition of microliths (e.g., Pargeter et al. 2017). In Eastern Africa for example, most researchers tend to use the definition of small backed pieces for microliths, but what “small” means varies widely (when a limit is given, it ranges from 25 to 30 mm or even 50 mm in length (e.g., Clark 1985; Diez-Martin et al. 2009). To overcome this problem, several recent papers have aimed to set clear definitions and discuss what is behind the terms such as microliths, microlithization, and miniaturization (Elston and Kuhn 2002; Leplongeon 2014; Pargeter 2016; Pargeter et al. 2017; Pargeter and Shea 2019; Porraz 2009).

Backed pieces may appear independently in different regions and contexts and may not be part of the same phenomenon as small blank production and bladelet technology (e.g., Ambrose 2002; Leplongeon 2014). Clarkson et al. (2018), in a recent review of backed-microlithic technology, argue for convergence in the appearance of backing technology on a multiregional scale, based on evidence for an asynchronous appearance of this technology in Eastern Africa, Southern Africa, Arabia, South Asia, and Australia. They highlight several selective advantages of the adoption of backing technology (e.g., reliability, maintenance, ease of manufacture, and standardization) that may explain why convergence is the most likely scenario at this multiregional scale.

Even if (small) backed pieces are sometimes considered part of the classical definition of the LSA, they cannot be considered as a *fossile directeur* of the LSA on a continental scale. For example, backed pieces occur in Howiesons Poort, an MSA industry. It is observed, however, that backed pieces became much more frequent at the end of the Pleistocene in Africa (e.g., Ambrose 2002; Phillipson 2005). Systematic regional comparative analyses are needed to understand the processes behind the adoption of backed tools in different parts of the continent.

### The Later Stone Age in the Horn of Africa

The Upper Pleistocene (~126–11.7 ka) in Africa is characterized by important technological innovations, economic changes, diversification of subsistence strategies (e.g., fishing), and increase in nonutilitarian objects such as ornaments (e.g., ostrich eggshell or marine shell beads). The preponderance of these behavioral traits has been argued to be a marker of the Middle Stone Age (MSA) to LSA transition (see McBrearty and Brooks 2000 for details). In Eastern Africa, there is limited evidence to discuss this transition, but the available data suggest that its timing and expression vary regionally. The shift towards LSA technologies appears to be very gradual and nonlinear (Leplongeon et al. 2017; Ménéard et al. 2014; Ranhorn and Tryon 2018; Shipton et al. 2018; Tryon 2019; Tryon and Faith 2016). In the HoA, in particular, there is limited information on the emergence of the LSA. This is due to the very small number of sites with well-dated sequences spanning the MSA/LSA transition. Also, most of these sequences document a sedimentological and

chronological gap broadly corresponding to MIS 2 (Brandt et al. 2017; Ménéard and Bon 2015; Tribolo et al. 2017). The archaeological record for the Upper Pleistocene in the HoA is thus very fragmentary (Leplongeon et al., *in press*). The available data reveal a complex picture, with the occurrence of LSA traits (e.g., small backed pieces) in MSA assemblages (e.g., at Mochena Borago, Brandt et al. 2012), or the co-occurrence of MSA traits (e.g., Levallois cores or retouched points) and LSA traits (small backed pieces) very late in the Holocene, e.g., ~6–8 ka cal BP at Goda Buticha (Leplongeon et al. 2017). Large backed pieces were indicative of the earliest LSA industries at Lake Besaka (Brandt 1982, 1986), while the recently published Late Glacial and Early Holocene LSA industries of the Ziway-Shala basin are characterized by both large and small backed pieces with a great diversity of shapes, and some assemblages do not present any backed pieces (Ménéard et al. 2014).

Comparisons between published accounts are made particularly difficult by the co-existence of diverse terminologies. For example, backed pieces are classified using diverse typologies, depending on whether the researchers aim to highlight the size, i.e., “microliths”; the general shape of the backed piece, i.e., “crescents,” “segments,” and “geometrics”; or the shape of the back, i.e., “curved- or straight-backed pieces.” This variability in naming backed pieces means that it is impossible to know whether the same type of artifact is being compared. Therefore, systematic and thorough interassemblage comparisons are often not possible. These artifacts may also encompass a great functional variability, although functional analyses on such kinds of tools are still in their infancy in the HoA (there have been only two published accounts during the last 40 years: Beyin 2010; Clark and Prince 1978).

The previous studies highlight some possible trends in the production of backed pieces in the HoA. They offer hypotheses that remain to be tested through systematic comparisons at a regional scale:

1. A trend towards the production of smaller backed pieces through time (Brandt 1982; Ménéard et al. 2014).
2. A trend towards the production of more symmetrical pieces through time, possibly illustrated by a shift from nongeometric to geometric pieces (Arthur et al. 2019; Brandt 1982; Leplongeon 2014).
3. Variations in the shape of backed pieces may correspond to different geographical or chrono-cultural entities (Ménéard et al. 2014).

## Backed Pieces in the Horn of Africa

Despite the importance of the HoA in the history of research on the LSA (Brandt 1986; Clark 1954; Graziosi 1940), there are very few sites securely dated to MIS 3–1 featuring backed pieces (Fig. 1, Table 1). Published sites and contexts with dates older than MIS 1 (i.e., more than 14.8 ka) and featuring backed pieces are few. These are Porc-Épic (Pleurdeau 2003, 2004), Mochena Borago (Brandt et al. 2012), Goda Buticha, units IID-IIF (Leplongeon 2014; Leplongeon et al. 2017; Pleurdeau et al. 2014), FeJx4 near Lake Besaka (Brandt 1982), and Laga Oda (Kurashina 1978). The 30 backed pieces found in MSA levels at Porc-Épic (Pleurdeau 2003, 2004) are, however, of dubious origin. Almost all of them come from a 1933 excavation and may have originated from mixed archaeological levels, including the topmost LSA layer at the site. Backed pieces are absent from assemblages excavated in 1975–1976 (Leplongeon 2014; Pleurdeau 2005). At the remaining sites, backed pieces from pre-MIS 1 levels (Upper Pleistocene) occur in very small numbers. They mostly consist of fragments at Mochena Borago; only one was found at Goda Buticha IID-IIF (Leplongeon 2014; Leplongeon et al. 2017), five fragments at FeJx4 Lower Horizon (Brandt 1982; Behailu Habte, pers. comm.), and only one at Laga Oda (Kurashina 1978). Except at Mochena Borago, their occurrence in the Upper Pleistocene levels may result from occasional vertical transport from the backed piece-rich Holocene upper levels. In the HoA, several late MSA or “transitional” industries were defined, which included the presence of backed pieces in association with MSA features (e.g., Stillbay, Magosian, Hargeisan; Clark 1954). Most of these terms are now abandoned, but the idea of an early presence of backed pieces in the HoA record still persists. Our review shows, however, that evidence from well-dated contexts is needed to understand the patterns and significance of the occurrence of backed pieces in pre-MIS 1 levels in the HoA.

Evidence for MIS 1 occurrence of backed pieces in a well-dated context is more numerous. Table 1 summarizes the corpus of the main published assemblages containing backed pieces from stratigraphic units/layers directly dated to MIS 1 in the HoA. Backed pieces are present in both open-air and cave sites, in different ecological regions, and throughout the very end of the Pleistocene and the Holocene. However, it should be noted that only one site is dated to the Early Holocene (DW2s1/DW2s3). A second remark is that,

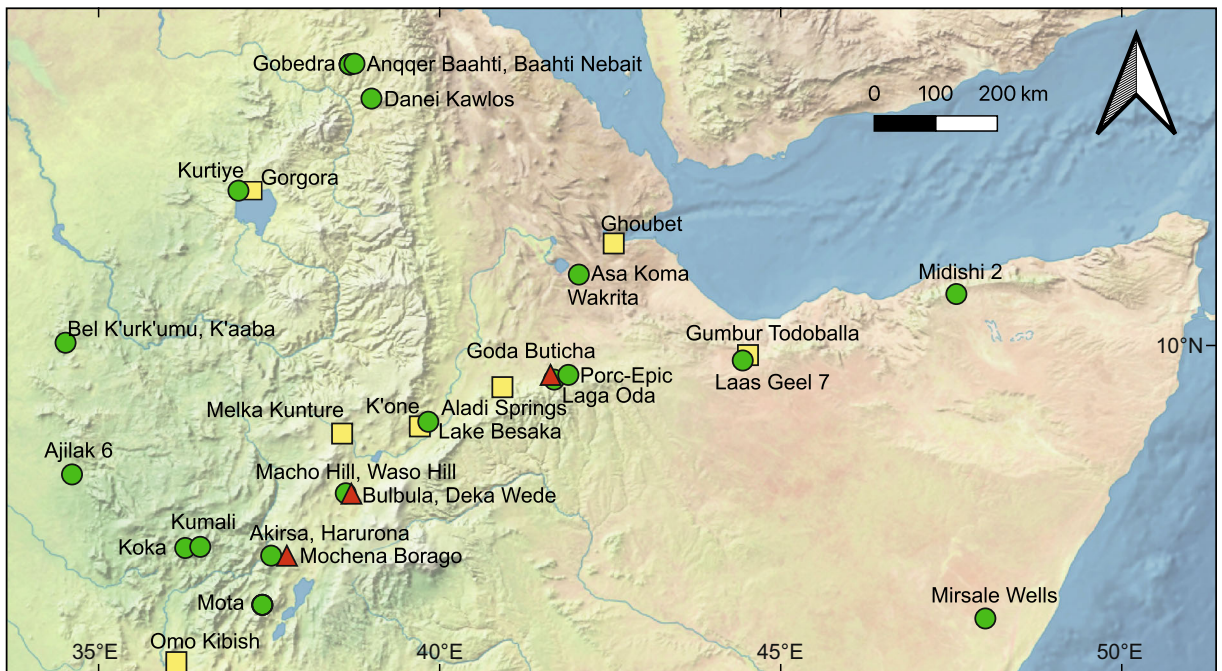
even during the Middle and Late Holocene, backed pieces are not always the most predominant tools, which may relate to a diversity of site function and length of occupation. These are important factors that need to be taken into account when interpreting patterns of variability in backed pieces.

## Materials and Methods

To identify patterns of variability in backed pieces from the HoA over time and overcome the challenges of the diverse typologies, we adopted a multivariate approach that uses attribute analysis to quantify similarities and differences between assemblages. We explored variability using principal component analysis (PCA), multiple correspondence analysis (MCA), and 2D geometric morphometric (GM) analysis. All statistical analyses were performed using R v.4.0 (R Core Team 2020), RStudio v.1.3 (RStudio Team 2015), and FactoMineR for multivariate PCA and MCA analyses (Husson et al. 2017; Lê et al. 2008); Momocs v 1.3.0 for morphometric analysis (Bonhomme 2020; Bonhomme et al. 2014); and ggplot2 (Wickham 2009) and factoextra (Kassambara and Mundt 2017) for generating graphics for all the abovementioned analyses. The list and description of the variables used, the complete database, illustrations of the dorsal views of artifacts, and the R project used to perform the analyses and generate the figures in this article are available in the Electronic Supplemental Materials (ESM 1–4, <https://doi.org/10.6084/m9.figshare.7825607>), so that scholars interested in this topic can test the reproducibility of these methods in other contexts (e.g., Marwick 2017).

## The Data

Because the evidence for pre-MIS 1 occurrence of backed pieces in well-dated contexts is very limited in the HoA (see review above), this comparative study focuses on artifacts attributed to MIS 1 only. The backed pieces used for this analysis originated from eight archaeological stratigraphic units—Goda Buticha I (GBI), Mochena Borago Spit 7 (MB7), Mochena Borago US 3010 (MB3010), Goda Buticha IIC (GBIIC), DW2s1/3, DW2s2, B1s1 Upper, and B1s1 Lower—and from four different sites—Goda Buticha, Mochena Borago, DW2, and B1s1 (see Table 1 and Figs. 2, 3, 4, and 5). These samples were drawn from different types of sites (cave



**Fig. 1** The Horn of Africa, showing archaeological sites with backed pieces attributed to MIS 3–1: circles (sites directly dated); triangles (sites analyzed in this study); squares (other sites). Made with Natural Earth Data

and open-air sites), environmental settings, and technological contexts (flake and bladelet production). Detailed technological and typological analyses of these assemblages are presented elsewhere (Leplongeon 2014; Leplongeon et al. 2017; Ménard 2015; Ménard et al. 2014). A summary of these characteristics can be found in Table 2. For comparative purpose, the sites will hereafter be grouped into four main chronological periods based on radiocarbon dating: (1) Late Glacial (14.8–11.7 ka), corresponding to GS-1 and GI-1 (Rasmussen et al. 2014); (2) Early Holocene (11.7–8.2 ka); (3) Middle Holocene (8.2–4.2 ka); and (4) Late Holocene (younger than 4.2 ka). The Holocene subseries are rounded after the International Union of Geological Sciences boundaries (Walker et al. 2018).

We recorded attributes on a total of 188 complete and partially complete backed pieces. Partially complete refers to pieces missing small fragments (not exceeding 1/10th of total length), for which original shape and size could be confidently reconstructed. We conducted 2D GM (outline) analyses using elliptical Fourier transforms and curve analyses using discrete cosine transform on a subset of 164 pieces only (see Dommergues et al. 2007; Ferson et al. 1985; Giardina and Kuhl 1977). Unfortunately, we had to remove certain fragments from the analysis. These are damaged artifacts that were

potentially used and feature impact scars (Fisher et al. 1984). This possibly introduced bias and a possible over-representation of rough-outs and unused artifacts over the used ones.

### Multivariate Analysis

Twenty-eight attributes were defined to describe the contextual, morphometrical, and technological aspects of backed pieces (see ESM 1 and 2). The variables belong to three main domains: morphometrical (dimensions, symmetry); variables linked to blank selection (curvature, twisting, and morphology of opposed edge); and types of blank transformation (removal of bulb or butt, type, extent, and location of retouch). The significance of differences in the distribution of continuous variables across assemblages was assessed using pairwise Mann–Whitney tests for independent study design. The effects of multiple testing were controlled by applying Bonferroni correction to the obtained  $p$  values.

Multivariate analyses efficiently summarize the overall variability recorded in the dataset by redistributing it across a lower number of linear combinations of original variables, therefore considerably reducing data dimensionality and facilitating data ordination. PCA and MCA are well-suited methods to explore variability in

**Table 1** Assemblages analyzed in this study (in bold) and other published assemblages with backed artifacts from sites with multiple MIS 1 direct dates (stratigraphic units with > 100 artifacts and > 10 backed pieces only)

| Chronology      | Archaeological unit                | Age (cal BP) <sup>a</sup> | N assemblage       | Retouched tools |              | Backed pieces <sup>b</sup> |             | References                                  |
|-----------------|------------------------------------|---------------------------|--------------------|-----------------|--------------|----------------------------|-------------|---|
|                 |                                    |                           |                    | N               | % assemblage | N                          | % retouched |   |
| Late Holocene   | Laas Geel 705                      | 0.5–1.5 ka                | 104                | 13              | 13%          | 12                         | 92%         | Gutherz et al. 2014                         |
|                 | <b>Goda Buticha I<sup>c</sup></b>  | 0.5–4 ka                  | 350                | 30              | 9%           | 18                         | 60%         | Leplongeon et al. 2017; Tribolo et al. 2017 |
| Middle Holocene | Laga Oda 40–50                     | 0.5–4 ka                  | 2,837              | 92              | 3%           | 85                         | 92%         | Kurashina 1978                              |
|                 | Mota Cave, early pottery period    | 1.5–2.5 ka                | 697                | 38              | 5%           | 23                         | 61%         | Arthur et al. 2019                          |
|                 | <b>Mochena Borago Spit 7</b>       | 2–2.5 ka                  | 418                | 98              | 23%          | 92                         | 94%         | Ménard 2015                                 |
|                 | Mota Cave, prepottery period       | 3.3–4.5 ka                | 1,306              | 214             | 2%           | 139                        | 55%         | Arthur et al. 2019                          |
|                 | Asa Koma                           | 4–4.5 ka                  | 21,247             | 342             | 2%           | 252                        | 74%         | Diaz 2017                                   |
|                 | <b>Mochena Borago US 3010</b>      | 4.5–5 ka                  | 901                | 117             | 13%          | 105                        | 90%         | Ménard 2015                                 |
| Early Holocene  | <b>Goda Buticha II<sup>c</sup></b> | 6–8 ka                    | 1,259              | 111             | 9%           | 32                         | 29%         | Leplongeon et al. 2017; Tribolo et al. 2017 |
|                 | Laas Geel 708                      | 9–10 ka                   | 314                | 19              | 6%           | 10                         | 53%         | Gutherz et al. 2014                         |
|                 | Laas Geel 706                      | 4–13.5 ka                 | 617                | 22              | 4%           | 15                         | 68%         | Gutherz et al. 2014                         |
|                 | <b>DW2s1/DW2s3<sup>d</sup></b>     | 11–12 ka                  | 702                | 142             | 20%          | 129                        | 91%         | Ménard 2015; Ménard et al. 2014             |
| Late Glacial    | <b>DW2s2<sup>e</sup></b>           | 11–13 ka                  | 395                | 24              | 6%           | 11                         | 8%          | Ménard 2015; Ménard et al. 2014             |
|                 | <b>B1s1 Upper</b>                  | 13–13.5 ka                | 2,600 <sup>f</sup> | 144             | 6%           | 52                         | 36%         | Ménard et al. 2014                          |
|                 | <b>B1s1 Lower</b>                  | 13–13.5 ka                | 6,900 <sup>f</sup> | 342             | 5%           | 25                         | 7%          | Ménard et al. 2014                          |

The bold values refer to the assemblages analysed in this study

<sup>a</sup> Rough calibrated intervals rounded to the nearest 0.5 ka, GB intervals are partly based on OSL ages

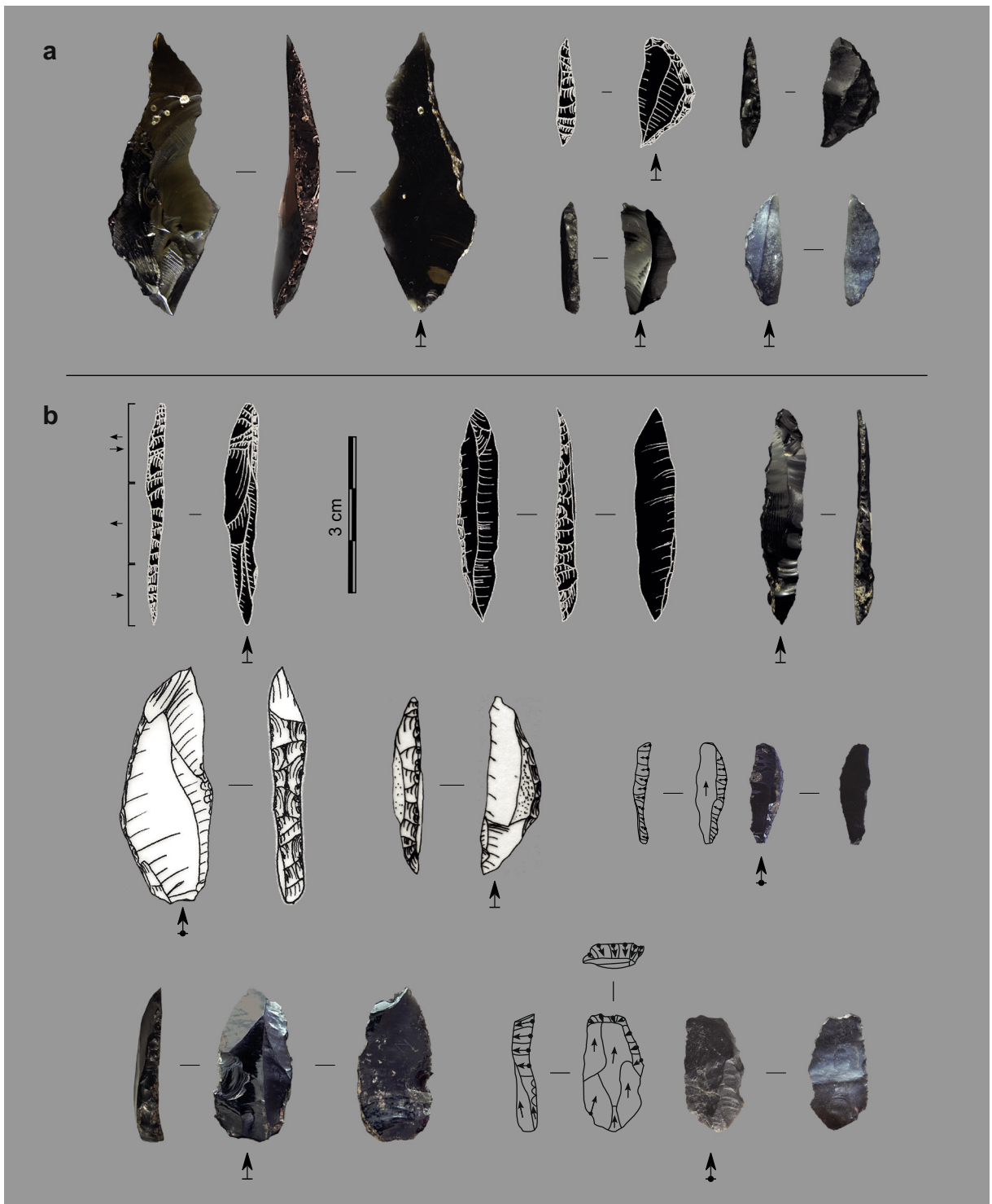
<sup>b</sup> Global inventories include fragmented pieces, studied samples include only complete and subcomplete pieces

<sup>c</sup> Data from one square (B1)

<sup>d</sup> Counts from DW2s1 only, studied pieces from DW2s3 only

<sup>e</sup> Counts from locus A only, studied pieces from locus A and B

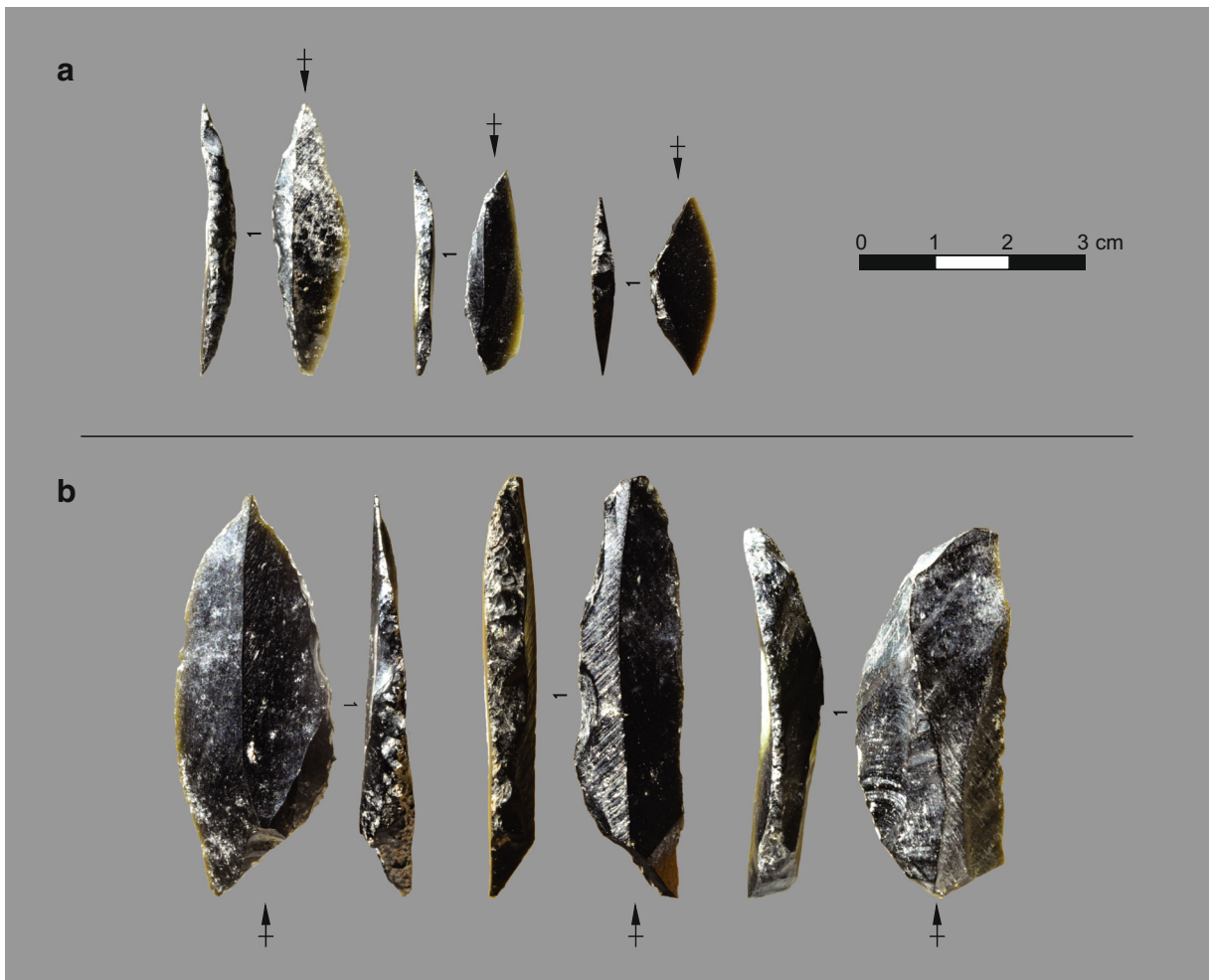
<sup>f</sup> Estimate



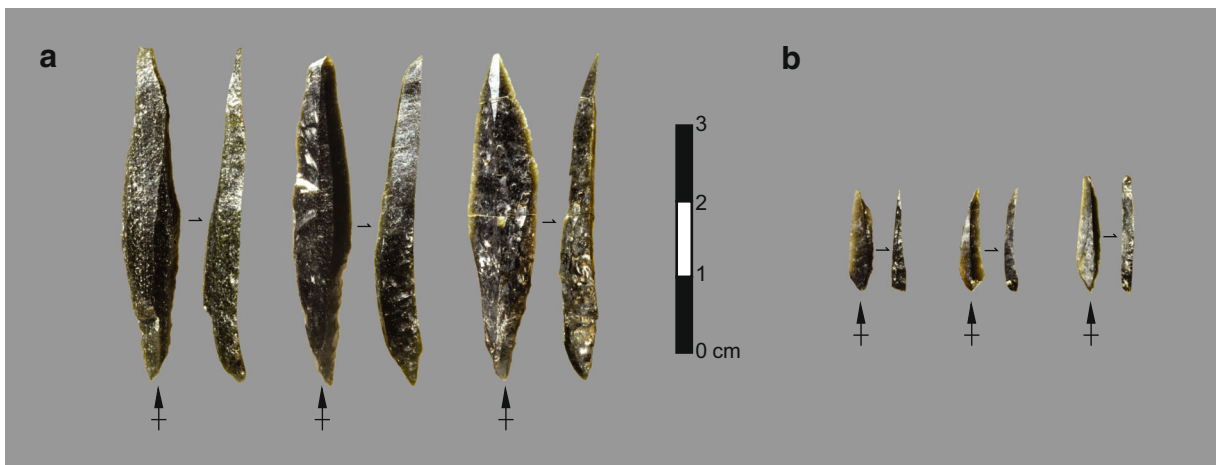
**Fig. 2** Backed artifacts from Goda Buticha. **a** Unit I (GBI). **b** Unit IIC (GBIIC). Photos and drawings: A. Leplongeon

quantitative and qualitative variables observed in lithic assemblages (e.g., Scerri et al. 2014), especially because

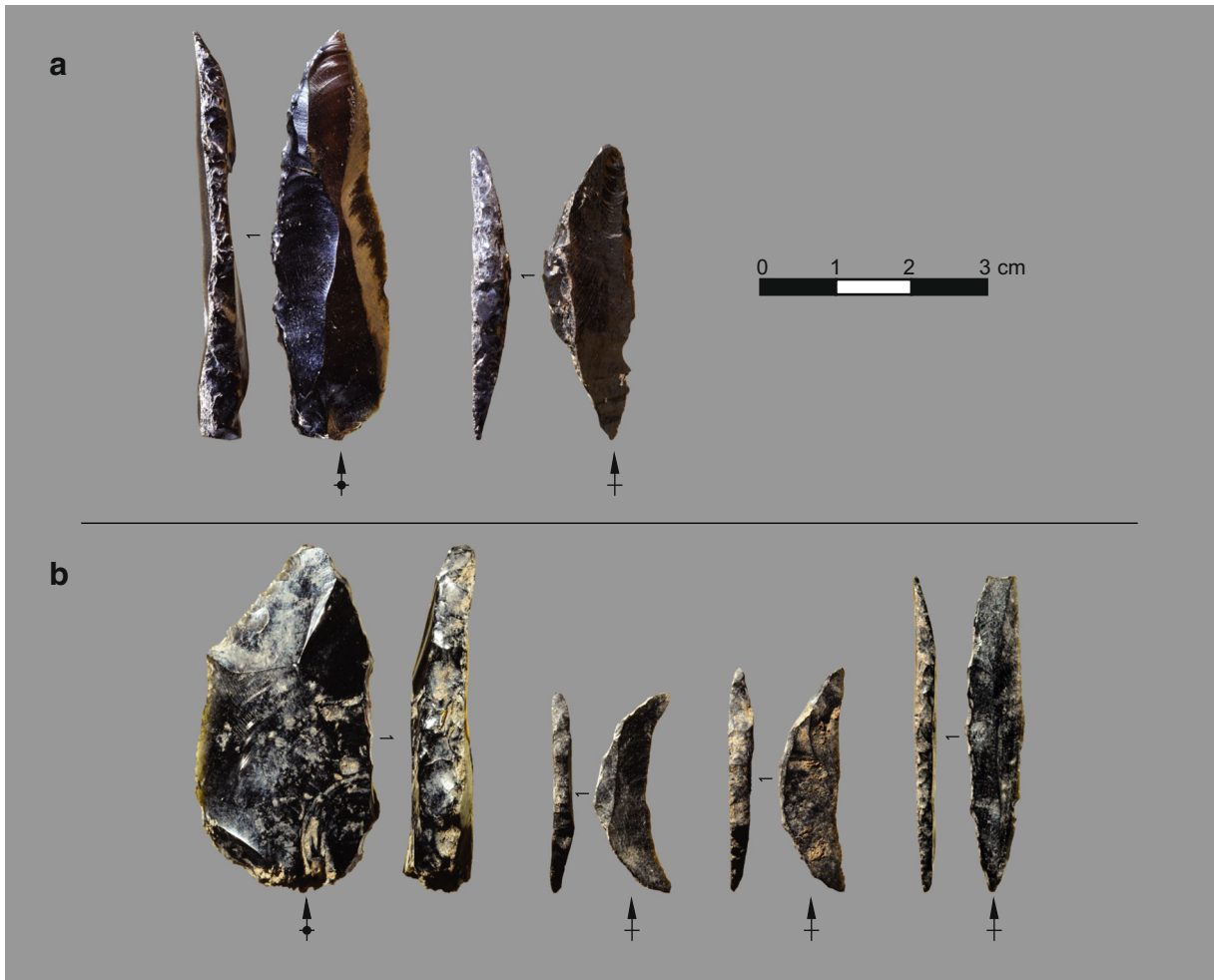
of the considerable number of attributes (and their interaction) used to systematically describe and study lithic



**Fig. 3** Backed artifacts from Bulbula 1 sector 1. **a** Upper units (B1s1 Upper). **b** Lower units (B1s1 Lower). Photos: C. Ménard



**Fig. 4** Backed artifacts from Deka Wede 2. **a** Sector 2 (DW2s2). **b** Sector 1 (DW2s1; tool types similar to DW2s3). Photos: C. Ménard



**Fig. 5** Backed artifacts from Mochena Borago. **a** Spit 7 (MB7). **b** Unit 3010 (MB3010). Photos: C. Ménard

materials. Here, we apply PCA to five quantitative variables and MCA to seven qualitative variables recorded in our backed pieces dataset. For example, we applied PCA to assess the relationship between length and various morphometric indices, as well as to evaluate the relative contribution of weight (mass) or elongation to the overall variability. At the same time, we used MCA to explore potential correlations between pairs of qualitative variables, for example between the presence or removal of the butt, and the presence or absence of transversal symmetry, and to obtain a comparison for PCA results. To interpret the results of PCA and MCA, we used the outputs given by the FactoMineR package (Lê et al. 2008). The relative contribution of an active variable to the construction of each component (i.e., axis in the graph) is given by reporting its correlation coefficient (in the case of quantitative variables) or R2

coefficient (in the case of qualitative variables) on each component (or dimension). Only the variables with a significant ( $p$  value  $< .05$ ) contribution to the construction of each component are reported. In the case of qualitative variables, the nature of the link between the variable and the component is further analyzed by studying the centroids of groups of individuals belonging to the same modality of the variable on the PC. Only the modalities with a significant  $p$  value are indicated in the results (Lê et al. 2008).

Finally, the intraassemblage diversity, in terms of the temporal qualitative variables, was explored using the Gini–Simpson diversity index ( $D = 1 - \sum_{i=1}^S p_i^2$ ; Jost 2006) calculated using the function H in the vegetarian package. The dissimilarity between pairs of temporally subsequent assemblages was calculated for each qualitative variable as the inverse of Morisita–Horn overlap

**Table 2** General characteristics of the analyzed assemblages

|                           | Age<br>(cal BP) | General characteristics       |        |           |        | Backed pieces        |           |   |
|---------------------------|-----------------|-------------------------------|--------|-----------|--------|----------------------|-----------|---|
|                           |                 | Raw materials                 | Blades | Bladelets | Flakes | Raw materials        | Blanks    | Original typological attributions                                 |
| Goda Buticha I            | 0.5–4 ka        | Chert (+),<br>obsidian<br>(+) | +      | +         | ++     | Obsidian<br>(mostly) | Bladelets | Crescents   |
| Mochena Borago Spit<br>7  | 2–2.5 ka        | Obsidian                      | –      | –         | +++    | Obsidian             | Flakes    | Circle segments   |
| Mochena Borago<br>US 3010 | 4.5–5 ka        | Obsidian                      | –      | –         | +++    | Obsidian             | Flakes    | Circle segments (mostly)  |
| Goda Buticha IIC          | 6–8 ka          | Chert (++)<br>obsidian<br>(+) | +      | +         | ++     | Chert<br>(mostly)    | Elongated | Curved, rectilinear   |
| DW2s1/3                   | 11–12 ka        | Obsidian                      | +      | ++        | –      | Obsidian             | Bladelets | Slightly convex backed<br>micro-bladelets with<br>triangular base |
| DW2s2                     | 11–13 ka        | Obsidian                      | ++     | +         | –      | Obsidian             | Blades    | Lozenge shape tanged<br>points                                    |
| B1s1 Upper                | 13–13.5 ka      | Obsidian                      | ++     | ++        | –      | Obsidian             | Bladelets | Curved backed bladelets   |
| B1s1 Lower                | 13–13.5 ka      | Obsidian                      | ++     | ++        | –      | Obsidian             | blades    | Large backed pieces   |

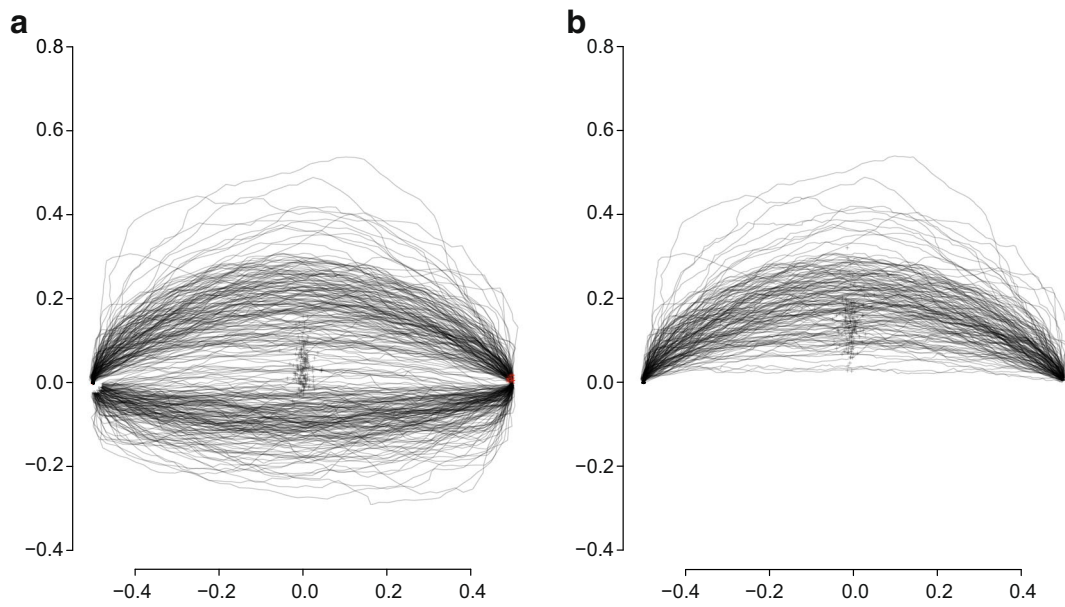
index computed through the function `sim.table` in the same package. Both values are bound between 0 (maximum homogeneity) and 1 (maximum diversity/dissimilarity) and are based on the sum of the squared relative frequency of pieces exhibiting each mode of the categorical variables. Low diversity (or higher homogeneity) suggests the dominance of one particular modality over the other ones. High diversity is instead generated by an almost even distribution of pieces across variants. The Gini–Simpson diversity index is one of the most common and basic measures of intrasite diversity that can be easily replicated and compared across sites. It is appropriate for the present case as it is based on squared variant frequencies, i.e., it is a diversity of order 2 (Jost 2006, p. 364; Legendre and Legendre 1998, p. 242) like the index used to ascertain interassemblage dissimilarity (Morisita–Horn index; Jost 2007). The Morisita–Horn index was chosen because it is independent of sample size (Wolda 1981). For this reason, it has been used to investigate processes of culture change in archaeological contexts (Crema et al. 2014; Maiorano et al. 2020).

## 2D Geometric Morphometrics

The 2D geometric morphometric (GM) analysis allows for a comparison of shapes independent of metric attributes. It is a powerful tool for comparing stone tools

regardless of the incidental variables that may have been introduced during stone tool production or originated as bias linked to external constraints (e.g., raw materials). Over the last decade, GM has been widely used in archaeology, particularly to identify and describe variations in material culture and lithic artifacts (Cardillo 2010; MacLeod 2018; Okumura and Araujo 2018). Most of the published analyses conducted on lithics have focused on landmarks and semi-landmarks (Webster and Sheets 2010) for comparing artifacts and assemblages (e.g., Buchanan et al. 2014; Cardillo et al. 2016). A similar kind of analysis on materials studied here would be limited to only two landmarks (only proximal and distal tips can be defined as homologous points) and is likely to be inefficient. Therefore, we use the elliptical Fourier analysis (Rohlf 1990), which has been successfully applied to describe variations of lithic artifacts (Iovita 2009, 2010, 2011; Iovita and McPherron 2011; Lipo et al. 2016).

Photographs of dorsal views from each artifact were treated with Adobe Photoshop CC in order to generate the data for GM analysis. The images were scaled and rotated (retouched edges were all put on the left side), and their contrast was enhanced (Levels tool). Then the artifacts were isolated from the background (Quick Selection tool), their outlines were filled in with black, and the results were exported to .jpg files (ESM 3). The outlines



**Fig. 6** Stacked outlines of **a** the backed artifacts selected for outline analysis after treatment and **b** open curves (backed edges) of the same artifacts (backed edges on top)

of these samples were digitized and analyzed with Momocs package v1.3.0 (Bonhomme 2020). The number of harmonics retained was chosen using harmonic power and analyses resulting in five harmonics (20 coefficients) for outlines and six harmonics (14 coefficients) for curves, in both cases 95% of the harmonic power was retained (see Bonhomme et al. 2014; Dommergues et al. 2007 for more details concerning these approaches and their calibration). Outlines were normalized (subsamped to 360 points, centered, and aligned) (Fig. 6a, b). Two landmarks were manually defined at the top and bottom of each artifact (proximal and distal ends, respectively). In the case of orthogonal terminations (e.g., quadrangular shapes), the landmarks were set towards the left (i.e., at

the nearest point from the retouched edge). Outlines were then sliced to retain the parts left of the landmarks (open curves) corresponding to retouched edges (Fig. 6b). This method has some limitations: retouched parts can extend beyond the landmarks, and the curves produced often encompass unretouched parts.

## Results

Below are the results of the analyses of the quantitative and qualitative variables and the shape of the backed pieces.

**Table 3** Variables used in the PCA

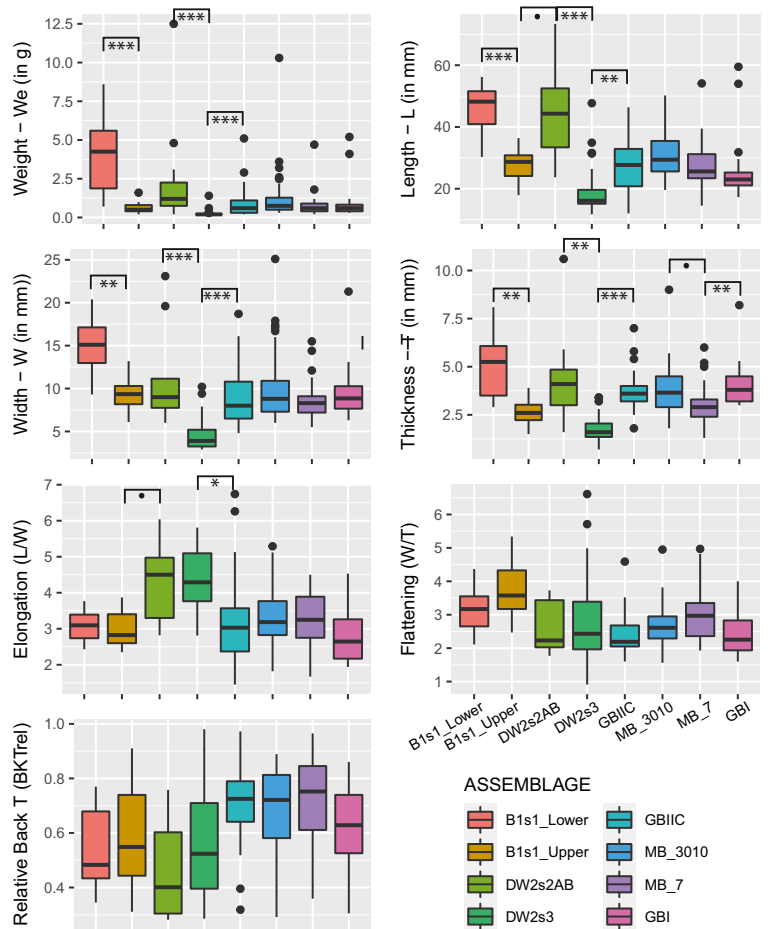
|                                     |   |        |
|-------------------------------------|---|--------|
| Active quantitative variables       |   |        |
| Length                              | Maximal length in mm (morphological axis)   | L      |
| Weight                              | Weight in g   | We     |
| Elongation                          | Ratio of length/width   | LW     |
| Robustness                          | Ratio of width/thickness  | WT     |
| Relative thickness of the back      | Ratio of the mean of the thickness of the back/thickness of the piece   | BKTrel |
| Supplementary qualitative variables |   |        |
| Provenance                          | Layer   | PROV   |
| Raw material                        | Obsidian, chert, chalcedony, basalt   | RM     |
| Chronology                          | Late Glacial (14.8–11.7 ka), Early Holocene (11.7–8.2 ka),<br>Mid-Holocene (8.2–4.2 ka), Late Holocene (< 4.2 ka) | CHRONO |

**Table 4** Summary of main dimensions of backed artifacts (extreme values in bold)

| Grouping            | B1s1_Lower   | B1s1_Upper  | DW2s2AB      | DW2s3        | GBIIC       | MB_3010     | MB_7        | GBI          |
|---------------------|--------------|-------------|--------------|--------------|-------------|-------------|-------------|--------------|
| nb pieces           | <b>10</b>    | <b>24</b>   | <b>11</b>    | <b>27</b>    | <b>21</b>   | <b>46</b>   | <b>33</b>   | <b>16</b>    |
| We—mean (mm)        | <b>4.02</b>  | 0.60        | 2.52         | <b>0.27</b>  | 1.11        | 1.24        | 0.77        | 1.10         |
| We—st dev           | <i>2.53</i>  | <i>0.32</i> | <i>3.57</i>  | <i>0.24</i>  | <i>1.19</i> | <i>1.58</i> | <i>0.78</i> | <i>1.42</i>  |
| L—mean (mm)         | <b>45.91</b> | 27.78       | <b>44.79</b> | <b>19.36</b> | 27.95       | 31.26       | 27.39       | 27.01        |
| L—st dev            | <i>8.02</i>  | <i>5.22</i> | <i>15.68</i> | <i>8.27</i>  | <i>9.25</i> | <i>7.93</i> | <i>7.48</i> | <i>12.21</i> |
| Width—mean (mm)     | <b>15.15</b> | 9.33        | 10.99        | <b>4.57</b>  | 9.30        | 10.07       | 8.64        | 9.68         |
| Width—st dev        | <i>3.38</i>  | <i>1.65</i> | <i>5.44</i>  | <i>1.91</i>  | <i>3.89</i> | <i>4.03</i> | <i>2.21</i> | <i>3.55</i>  |
| Thickness—mean (mm) | 5.06         | <b>2.60</b> | 4.37         | <b>1.83</b>  | 3.82        | 3.79        | 3.02        | 4.15         |
| Thickness—st dev    | <i>1.79</i>  | <i>0.65</i> | <i>2.40</i>  | <i>0.72</i>  | <i>1.18</i> | <i>1.22</i> | <i>0.98</i> | <i>1.31</i>  |
| LW—mean             | 3.09         | 3.00        | <b>4.33</b>  | <b>4.33</b>  | 3.29        | 3.30        | 3.23        | 2.81         |
| LW—st dev           | <i>0.43</i>  | <i>0.48</i> | <i>1.04</i>  | <i>0.87</i>  | <i>1.36</i> | <i>0.77</i> | <i>0.71</i> | <i>0.74</i>  |
| WT—mean             | 3.19         | 3.72        | 2.68         | 2.81         | 2.44        | 2.68        | 3.01        | 2.39         |
| WT—st dev           | <i>0.71</i>  | <i>0.74</i> | <i>0.79</i>  | <i>1.41</i>  | <i>0.70</i> | <i>0.65</i> | <i>0.83</i> | <i>0.64</i>  |
| BKTrel—mean         | <b>0.54</b>  | 0.59        | <b>0.47</b>  | <b>0.54</b>  | 0.70        | 0.68        | 0.72        | 0.62         |
| BKTrel—st dev       | <i>0.16</i>  | <i>0.19</i> | <i>0.18</i>  | <i>0.18</i>  | <i>0.16</i> | <i>0.15</i> | <i>0.16</i> | <i>0.16</i>  |

Italic values correspond to standard deviations (st dev)

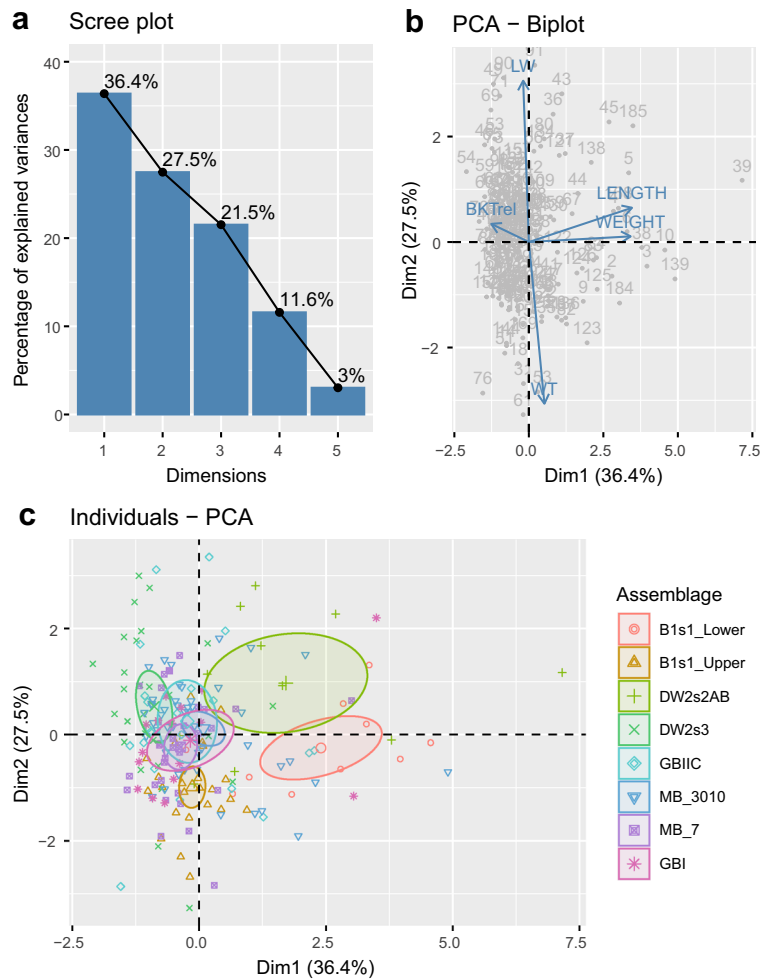
**Fig. 7** Boxplots of the main dimensions and ratios of backed pieces. Stars indicate instances of significant Mann–Whitney tests after Bonferroni correction.  $p$  value <0.05, \*  $p$  value <0.025, \*\*  $p$  value <0.01, \*\*\*  $p$  value < 0.001 [assemblages are arranged in chronological order from the oldest (left) to the most recent (right)]



**Table 5** FactoMineR outputs for the first three components of the PCA analysis

| Dimension 1                                  |             |           | Dimension 2                                  |             |           |
|--|-------------|-----------|--|-------------|-----------|
| Quantitative variables with $p$ value < 0.05 |             |           | Quantitative variables with $p$ value < 0.05 |             |           |
|  | Correlation | $p$ value |  | Correlation | $p$ value |
| LENGTH                                       | 0.9236      | < 0.001   | LW   | 0.816       | < 0.001   |
| WEIGHT                                       | 0.9115      | < 0.001   | LENGTH                                       | 0.1734      | 1.73E-02  |
| BKTrel                                       | - 0.3367    | < 0.001   | WT   | - 0.8179    | < 0.001   |
| Qualitative variables with $p$ value < 0.05  |             |           | Qualitative variables with $p$ value < 0.05  |             |           |
|  | R2          | $p$ value |  | R2          | $p$ value |
| PROV   | 0.3444      | < 0.001   | PROV   | 0.1772      | < 0.001   |
| CHRONO                                       | 0.1768      | < 0.001   | CHRONO                                       | 0.0631      | 0.0073    |
| Category                                     | Estimate    | $p$ value | Category                                     | Estimate    | $p$ value |
| B1s1_Lower                                   | 2.1015      | < 0.001   | DW2s2AB                                      | 0.9345      | 0.0045    |
| 1-Late-Glacial                               | 0.9603      | < 0.001   | 2-Early-Holocene                             | 0.491       | 0.0111    |
| DW2s2AB                                      | 1.4087      | < 0.001   | DW2s3  | 0.4925      | 0.0111    |
| 2-Early-Holocene                             | - 0.8046    | < 0.001   | CHAL   | 1.2244      | 0.0132    |
| DW2s3  | - 1.1859    | < 0.001   | 1-Late-Glacial                               | - 0.3826    | 0.0237    |
|  |             |           | B1s1_Upper                                   | - 1.0242    | < 0.001   |
| Dimension 3                                  |             |           |  |             |           |
| Quantitative variables with $p$ value < 0.05 |             |           |  |             |           |
|  | Correlation | $p$ value |  |             |           |
| BKTrel                                       | 0.8573      | < 0.001   |  |             |           |
| WEIGHT                                       | 0.2889      | < 0.001   |  |             |           |
| WT   | - 0.2935    | < 0.001   |  |             |           |
| LW   | - 0.4113    | < 0.001   |  |             |           |
| Qualitative variables with $p$ value < 0.05  |             |           |  |             |           |
|  | R2          | $p$ value |  |             |           |
| CHRONO                                       | 0.2403      | < 0.001   |  |             |           |
| PROV   | 0.2648      | < 0.001   |  |             |           |
| RM   | 0.0453      | 0.0358    |  |             |           |
| Category                                     | Estimate    | $p$ value |  |             |           |
| 3-Mid-Holocene                               | 0.5407      | 1.00E-04  |  |             |           |
| 4-Late-Holocene                              | 0.5106      | 0.0049    |  |             |           |
| CHERT  | 0.6337      | 0.0089    |  |             |           |
| MB_3010                                      | 0.4033      | 0.0102    |  |             |           |
| GBIIC  | 0.5533      | 0.0214    |  |             |           |
| MB_7   | 0.4319      | 0.0243    |  |             |           |
| B1s1_Upper                                   | - 0.3462    | 0.0389    |  |             |           |
| OBS  | - 0.2178    | 0.0095    |  |             |           |
| DW2s2AB                                      | - 0.7287    | 0.0089    |  |             |           |
| 1-Late-Glacial                               | - 0.2269    | 0.0047    |  |             |           |
| 2-Early-Holocene                             | - 0.8245    | < 0.001   |  |             |           |
| DW2s3  | - 0.9148    | < 0.0010  |  |             |           |

**Fig. 8** Results of the PCA for the first and second components, showing (a) scree plot, (b) biplot, and (c) plot of the individuals for the first two components of the PCA

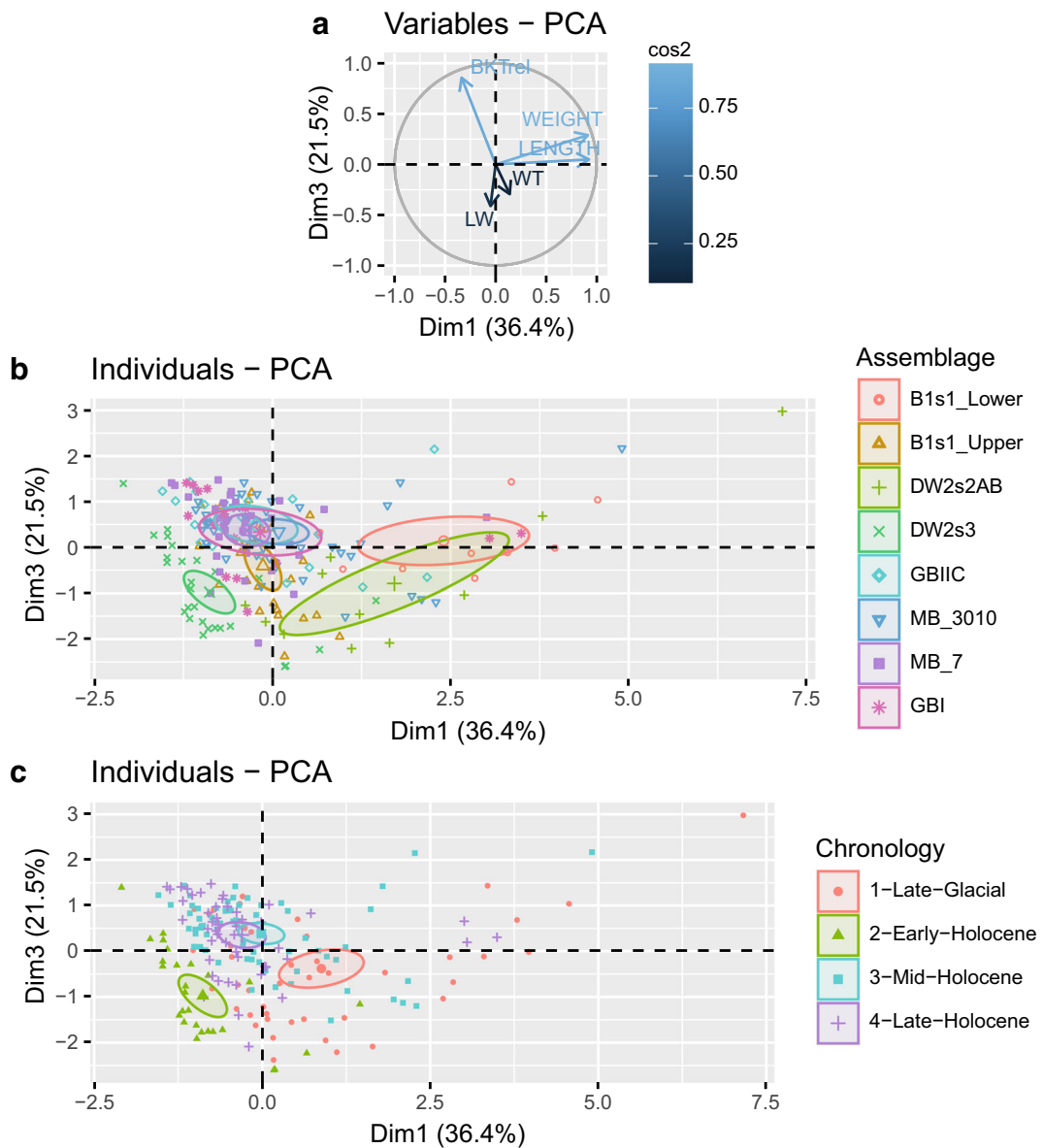


## Quantitative Variables and Principal Component Analysis

Five quantitative variables and three supplementary qualitative variables were used in the PCA (Table 3). Table 4 and Fig. 7 describe the main characteristics of the backed pieces. When variables are taken independently of each other, no general trend is observed over time (Fig. 7). However, except for the variable “thickness,” pair-wise Mann–Whitney tests (see ESM 5) only show significant differences between the earliest assemblages. These indicate a greater degree of variability in the earlier assemblages compared with the more recent ones (from GBIIC, i.e., from the Middle Holocene onward).

The results of the PCA are summarized in Table 5 and Fig. 8. They show that the first three dimensions (or

components) have eigenvalues higher than 1, and altogether express more than 85% of the total inertia. The first two dimensions represent more than 60% of the variance in the dataset. The graphs (Fig. 8a, b) show that the length and weight variables are highly correlated (as expected) and that the elongation is inversely correlated to the robustness of the piece. The first axis opposes heavy and light backed pieces, while the second axis opposes elongated and relatively thick pieces, and short and relatively thin pieces. The results show that the variance summarized by the first two dimensions is mainly explained by the provenience (“grouping”) and, to a lesser extent, by the chronology (Table 5). Backed pieces from B1s1 Lower and DW2s2 are longer and heavier than backed pieces from the other sites. The first dimension seems to indicate a change towards smaller backed pieces from the Late Glacial (B1s1

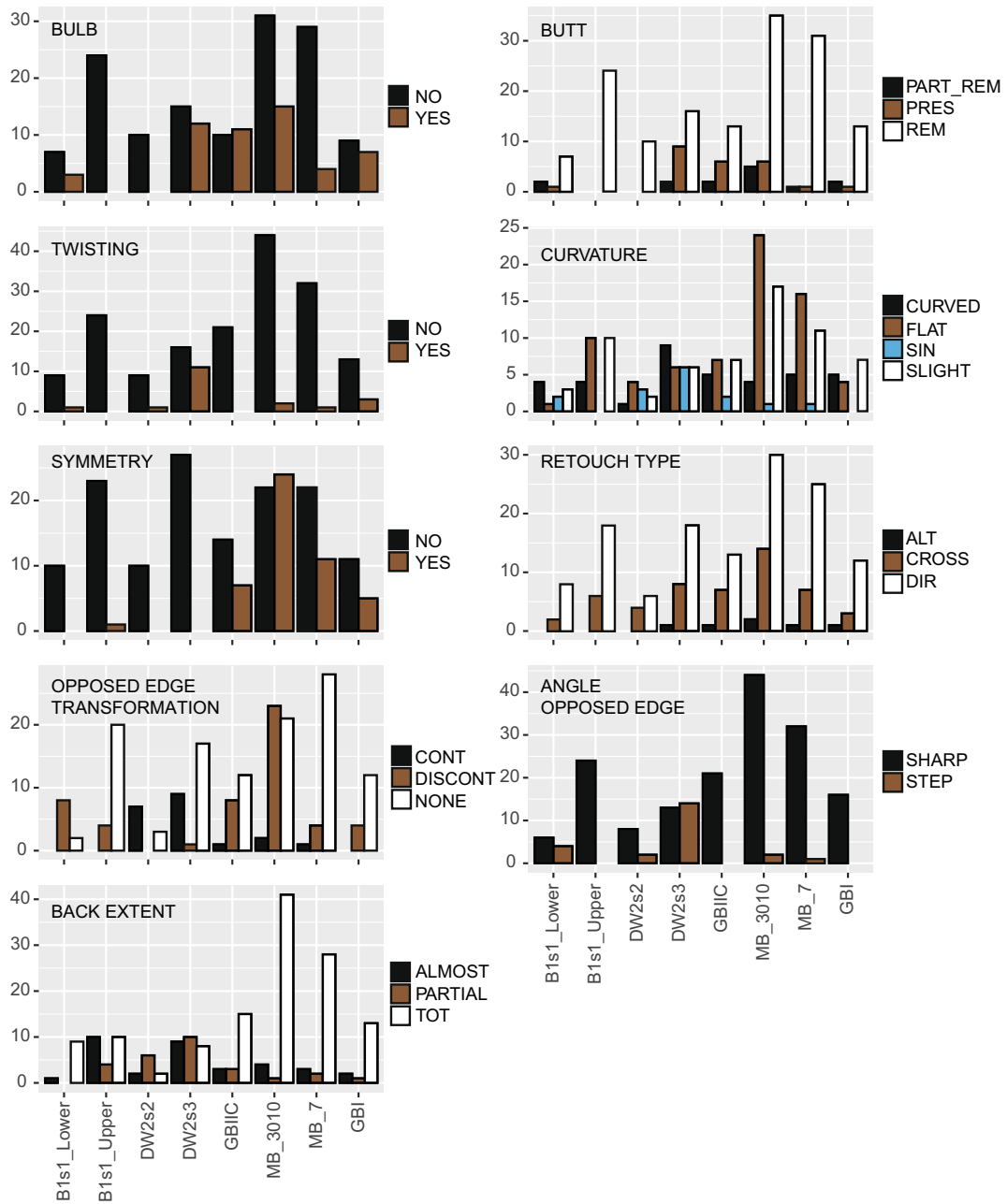


**Fig. 9** Results of the PCA for the first and the third components

Lower and DW2s2) to the Early Holocene (DW2s3) (Fig. 8c). However, this should be nuanced by the fact that there are no significant differences within Holocene sites and that the variance of B1s1 Upper (Late Glacial) is included in one of the Holocene sites (Table 5).

The second dimension opposes B1s1 Upper, characterized by backed pieces with a low elongation index, to DW2s2 and DW2s3 with a high elongation index. No general chronological trend can be observed, as B1s1 Upper and DW2s2 are both dated to the Late Glacial.

The third dimension expresses more than 20% of the variance and opposes backed pieces with a thick back (i.e., the back corresponds to the maximum thickness of the piece) and those with a thin back (Fig. 9a). The variance observed can be partly explained by the variable “grouping” and the variable “chronology” (Fig. 9b, c). In particular, the backed pieces can be divided into two groups: backed pieces from DW2s2, DW2s3, and B1s1 Upper are characterized by a relatively thin back, compared with the other group of sites (GBI, GBIIC, MB3010, and MB7)

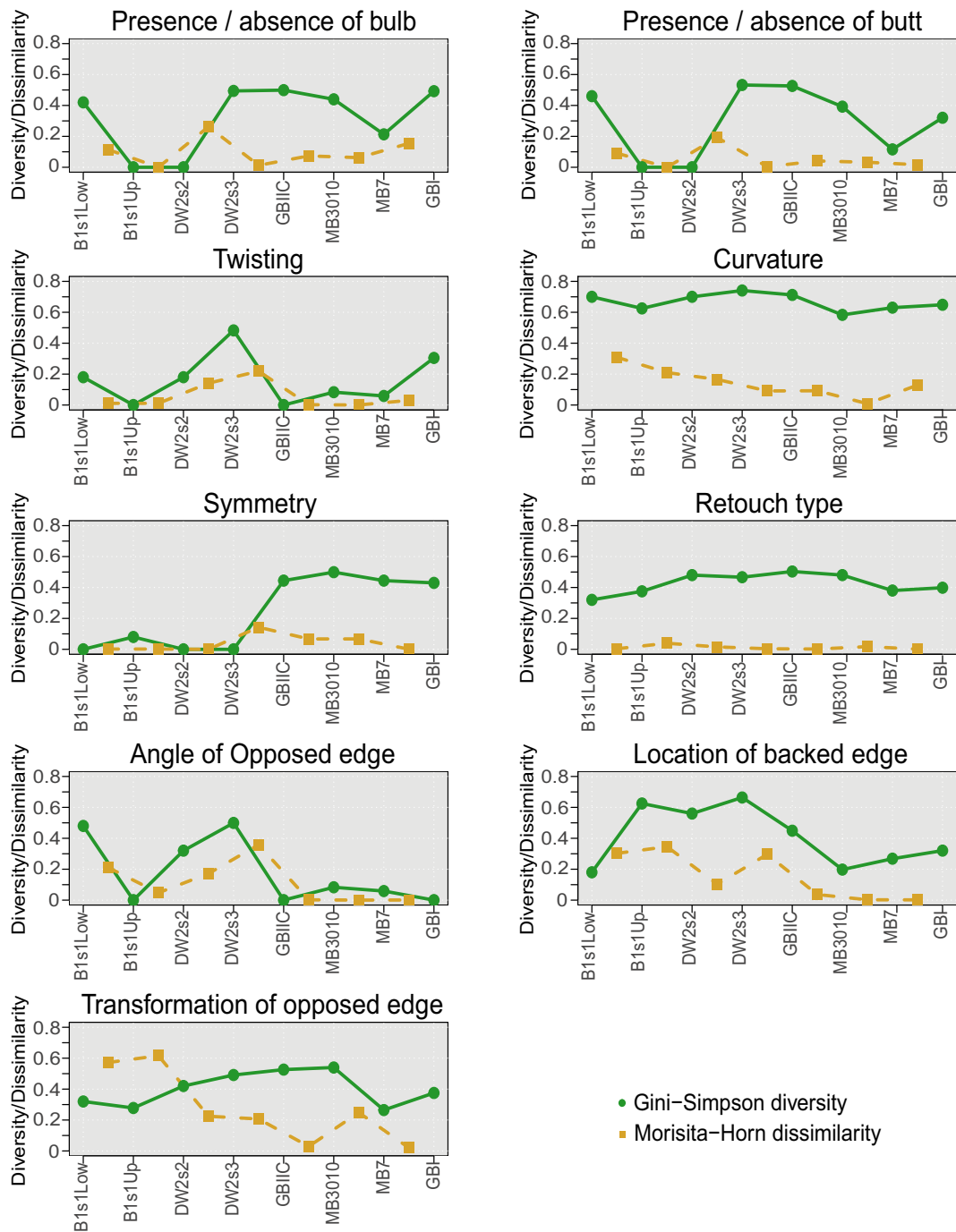


**Fig. 10** Barplot showing the counts of pieces exhibiting the main qualitative traits in each assemblage

with thick back. Therefore, there appears to be a trend towards thicker back over time, between the Late Glacial-Early Holocene and the Middle-Late Holocene. This trend is, however, not linear as there is also a significant difference between DW2s3 (Early Holocene) and the Late Glacial assemblages (B1s1 Lower and Upper, and DW2s2), in that the backed pieces at DW2s3 have even thinner backs compared with the Late Glacial backed pieces.

### Qualitative Variables and Multiple Correspondence Analysis

Nine qualitative variables were retained for the analysis. These variables relate to blank transformation (removal of the proximal part, and the type and location of the retouch), blank selection (twisting, curvature, angle of opposed edge), the symmetry of the piece, and the



**Fig. 11** Plots of Gini-Simpson diversity and Morisita-Horn dissimilarity values for each qualitative variable

degree of transformation observed on the edge that is opposed to backing (Figs. 10 and 11; ESM 1).

The exploration of intraassemblage diversity and interassemblage distance based on qualitative variable counts highlight specific trends for each variable:

- Both values are stable over time for curvature, retouch type, and transformation of the opposed edge.
- The bulb and butt variables act in a very similar way (as expected) and indicate a higher variability in the

presence/absence of bulb and butt in the more recent periods.

- DW2s3 and, to a lesser extent, DW2s2 differ from the other assemblages by higher diversity in the variables—“twisting” and “angle of the opposed edge,” which corresponds to higher frequencies of twisted blanks and a steep angle of the edge opposed to the back.
- Symmetrical pieces make their appearance in the present sample from GBIIC (Middle Holocene) onwards.
- A decrease in the diversity relating to the location of the backed edge suggests that the backing affecting the whole edge becomes dominant from MB3010 (Middle Holocene) onwards.

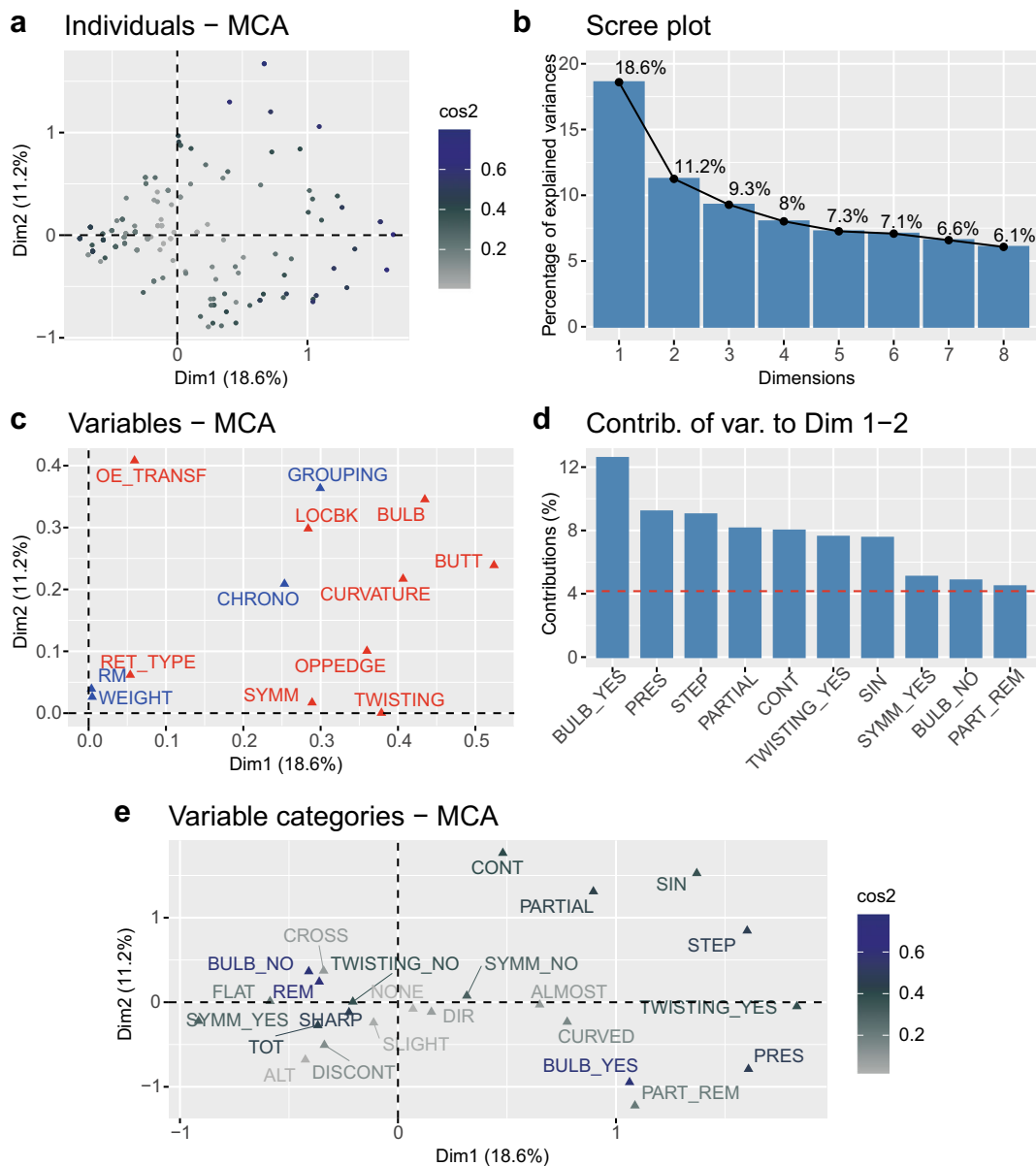
Although backed pieces from the present sample exhibit a high variability, these data suggest a shift towards more symmetrical pieces and change in backing location during the Middle Holocene. To understand the link between these variables and further explore variability in backed pieces, a multiple correspondence analysis (MCA) was performed using these seven qualitative variables, three supplementary qualitative variables, and one supplementary quantitative variable (weight) (Table 6). The supplementary quantitative

variable was chosen because the PCA above already showed that it was the quantitative variable explaining most variability (along with length to which it is highly correlated).

The two first dimensions express nearly 30% of the variation of the backed pieces (Fig. 12a–c and Table 7). The first axis (22%) opposes backed pieces with the proximal part present (bulb and partial or complete butt) and a twisted lateral profile to symmetrical backed pieces with the proximal part removed. The second axis summarizes 11% of the total variation in the dataset. Positive values on the second axis correspond mostly to backed pieces with the proximal part removed, or pieces characterized by a partial backing, a sinuous longitudinal profile, or a steep angle of and a continuous transformation of the opposed edge. On the contrary, negative values on the second axis correspond mostly to backed pieces with the proximal part preserved, a backing affecting the whole edge or a sharp angle of the opposed edge, the latter showing discontinuous transformation (Fig. 12d, e). In general, the first axis opposes backed pieces with the minimal transformation of the blank to backed pieces with the heavy transformation of the blank (proximal part removed and back located on the whole edge). The first axis also seems to show a correlation between these variables and the presence/

**Table 6** Variables used in the MCA

|  |   |                           |
|--|---|---------------------------|
| Active qualitative variables               |   |                           |
| Bulb                                       | Present/removed   | YES, NO                   |
| Butt                                       | Present/removed/partially removed   | PRES, REM, PART_REM       |
| Twisting                                   | Yes/no  | YES, NO                   |
| Curvature                                  | Flat/slightly curved/curved/sinuous   | FLAT, SLIGHT, CURVED, SIN |
| Transversal symmetry (SYMM)                | Symmetry observed from an axis perpendicular to the largest dimension   | YES, NO                   |
| Retouched type (RET TYPE)                  | Type of backing: alternate, crossed, direct   | ALT, CROSS, DIR           |
| Angle of opposed edge (OPP. EDGE)          | Angle of the edge opposed to the back   | SHARP, STEEP              |
| Transformation of opposed edge (OE TRANSF) | Continuous/discontinuous/none   | CONT, DISCONT, NONE       |
| Location of the back (LOC BK)              | Whole edge/partial (proximal or distal part only)/almost on the whole edge                                    | TOT/PARTIAL/ALMOST        |
| Supplementary qualitative variables        |   |                           |
| Provenance                                 | Assemblage  | PROV                      |
| Raw material                               | Obsidian, chert, chalcedony, basalt   | RM                        |
| Chronology                                 | Late Glacial (14.8–11.7 ka), Early Holocene (11.7–8.2 ka), Mid-Holocene (8.2–4.2 ka), Late Holocene (<4.2 ka) | CHRONO                    |
| Supplementary quantitative variables       |   |                           |
| Weight                                     | Weight in g   | W                         |



**Fig. 12** MCA plots for the two first components

absence of symmetry and angle of the opposed edge. The second axis is mostly related to characteristics of the edge opposed to the back and thus may relate to different functions/ways of hafting backed pieces. It is also interesting to note that it is, to some extent, inversely correlated to the supplementary quantitative variable “weight.”

DW2s3 (Early Holocene) and, to a lesser extent, DW2s2 are different from the other sites by having positive values on both components (Fig. 13a). This creates a separation between Late Glacial and Early Holocene sites on the one hand and Middle and Late

Holocene sites on the other hand (Fig. 13b). DW2s2 and DW2s3 are thus characterized by backed pieces with a lower rate of blank transformation, perhaps related to the specific bladelet technology identified at these sites, which would have allowed the production of specific blanks (Ménard et al. 2014). The characteristics of their opposed edge may suggest different functional and hafting properties different from the backed pieces in the other sites.

The plane of the third and fourth components summarizes almost 20% of the total variability (Table 8 and

**Table 7** FactoMineR outputs for the PC1 and PC2 of the MCA

| Dimension 1   |          |           | Dimension 2   |          |           |
|---|----------|-----------|---|----------|-----------|
| qualitative variables with $p$ value < 0.05                 |          |           | qualitative variables with $p$ value < 0.05                 |          |           |
|   | R2       | $p$ value |   | R2       | $p$ value |
| BUTT  | 0.5241   | < 0.001   | OE_TRANSF   | 0.4081   | < 0.001   |
| BULB  | 0.4347   | < 0.001   | BULB  | 0.3453   | < 0.001   |
| TWISTING  | 0.3786   | < 0.001   | GROUPING  | 0.3635   | < 0.001   |
| CURVATURE   | 0.4065   | < 0.001   | LOCBK   | 0.2982   | < 0.001   |
| OPPEDGE   | 0.3599   | < 0.001   | BUTT  | 0.239    | < 0.001   |
| SYMM  | 0.2889   | < 0.001   | CURVATURE   | 0.217    | < 0.001   |
| LOCBK   | 0.2838   | < 0.001   | CHRONO  | 0.2089   | < 0.001   |
| CHRONO  | 0.2532   | < 0.001   | OPPEDGE   | 0.1005   | < 0.001   |
| GROUPING  | 0.2995   | < 0.001   | RET_TYPE  | 0.0617   | 0.0029    |
| OE_TRANSF   | 0.0593   | 0.0036    | WEIGHT  | -0.1616  | 2.71E-02  |
| RET_TYPE  | 0.0539   | 0.0061    |   |          |           |
| Categories of supplementary variables with $p$ value < 0.05 |          |           | Categories of supplementary variables with $p$ value < 0.05 |          |           |
|   | Estimate | $p$ value |   | Estimate | $p$ value |
| Early-Holocene  | 0.5773   | < 0.001   | DW2s2AB   | 0.7553   | < 0.001   |
| DW2s3   | 0.6127   | < 0.001   | Early-Holocene  | 0.238    | 1.00E-04  |
| Late-Holocene   | -0.2526  | 0.0158    | DW2s3   | 0.2371   | 1.00E-04  |
| Mid-Holocene  | -0.2325  | 0.0078    | Late-Glacial  | 0.1582   | 1.00E-04  |
| MB_7  | -0.2909  | 0.0065    | GBIIC   | -0.2581  | 2.42E-02  |
| MB_3010   | -0.2732  | 0.0018    | GBI   | -0.2928  | 2.30E-02  |
|   |          |           | MB_3010   | -0.2519  | 4.00E-04  |
|   |          |           | Mid-Holocene  | -0.2529  | < 0.001   |

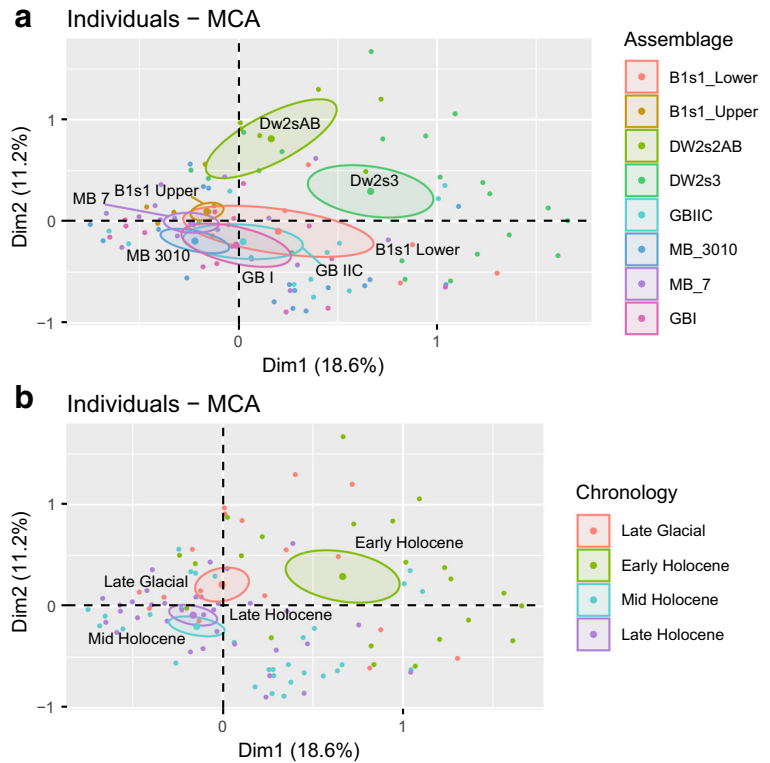
Figs. 14 and 15). The third dimension corresponds to the degree of “investment” put into the backing. It opposes pieces that have a continuous backed edge characterized by cross retouch to partially backed pieces defined by the use of direct or alternate retouch. The fourth dimension contrasts (1) longitudinally flat or slightly curved pieces with a discontinuous transformation of the edge opposed to backing to (2) longitudinally curved backed pieces without any visible transformation of the edge opposed to backing.

Only a limited part of the variability represented by the third and fourth dimensions can be explained by differences in assemblages, with a significant difference only between the two levels of B1s1 (Lower and Upper) (Table 8). This shift in the degree of investment in backing at B1s1 correlates with the shift towards smaller dimensions of the toolkit between B1s1 Lower and Upper. This difference is still unexplained given that both units are chronologically very close (it is estimated that a maximum of 300 years separated them) and that

they share the same technological attributes and most probably the same economic context and site function (i.e., dominant exploitation of bovinds; Lesur et al. 2016; Ménard et al. 2014).

The MCA highlights a high variability that can only be partially explained by differences in assemblage composition or chronology. Overall, we observe a separation between Late Glacial and Early Holocene backed pieces on the one hand and Middle and Late Holocene on the other hand. The latter is characterized by the more systematic removal of the proximal part, a backing technique affecting the total length of the piece, and higher symmetry. At the assemblage scale, DW2s3 appears to be distinct from all the other sites based on the presence of partial backing, a proximal part that is left intact, and a twisted profile. Backed pieces from DW2s3 correspond to a particular type described by one of us as “pointed backed micro-bladelets with triangular bases (fusiform points?)” (Ménard et al. 2014, p. 65) and previously unmentioned in the literature concerning the

**Fig. 13** Individual plots of the two first components of the MCA



studied region. The fact that they can be easily discriminated in our study corroborates the use of our method,

which allows us to identify differences without using any kind of typology.

**Table 8** MCA backed pieces outputs for components 3 and 4

| Dimension 3   |          |           | Dimension 4                                 |        |           |
|---|----------|-----------|---|--------|-----------|
| Qualitative variables with $p$ value < 0.05                 |          |           | Qualitative variables with $p$ value < 0.05 |        |           |
|   | R2       | $p$ value |   | R2     | $p$ value |
| LOCBK   | 0.4354   | < 0.001   | CURVATURE                                   | 0.4324 | < 0.001   |
| RET_TYPE  | 0.3148   | < 0.001   | OE_TRANSF                                   | 0.3732 | < 0.001   |
| OE_TRANSF   | 0.1899   | < 0.001   | BUTT  | 0.1937 | < 0.001   |
| BUTT  | 0.1689   | < 0.001   | TWISTING                                    | 0.0816 | 0.0001    |
| OPPEDGE   | 0.0938   | < 0.001   | SYMM  | 0.0396 | 0.0063    |
| TWISTING  | 0.0724   | 0.0002    | RET_TYPE                                    | 0.0513 | 0.0079    |
| CURVATURE   | 0.0805   | 0.0015    | BULB  | 0.0218 | 0.0437    |
| GROUPING  | 0.1026   | 0.0064    | WEIGHT                                      | 0.2329 | 0.0013    |
| SYMM  | 0.0332   | 0.0125    |   |        |           |
| WEIGHT  | 0.2036   | 0.0052    |   |        |           |
| Categories of supplementary variables with $p$ value < 0.05 |          |           |   |        |           |
|   | Estimate | $p$ value |   |        |           |
| B1s1_Lower  | 0.2772   | 0.0173    |   |        |           |
| MB_3010   | 0.0884   | 0.0496    |   |        |           |
| B1s1_Upper  | -0.2595  | 0.0008    |   |        |           |

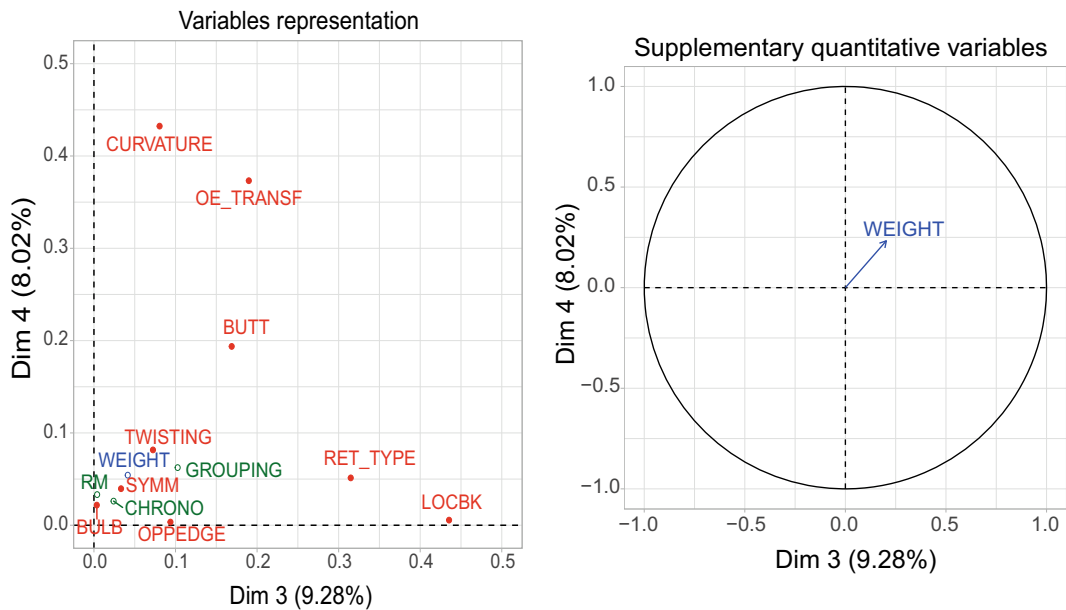


Fig. 14 Graphs of the qualitative and supplementary variables of the MCA for components 3 and 4

## 2D Geometric Morphometric Analyses

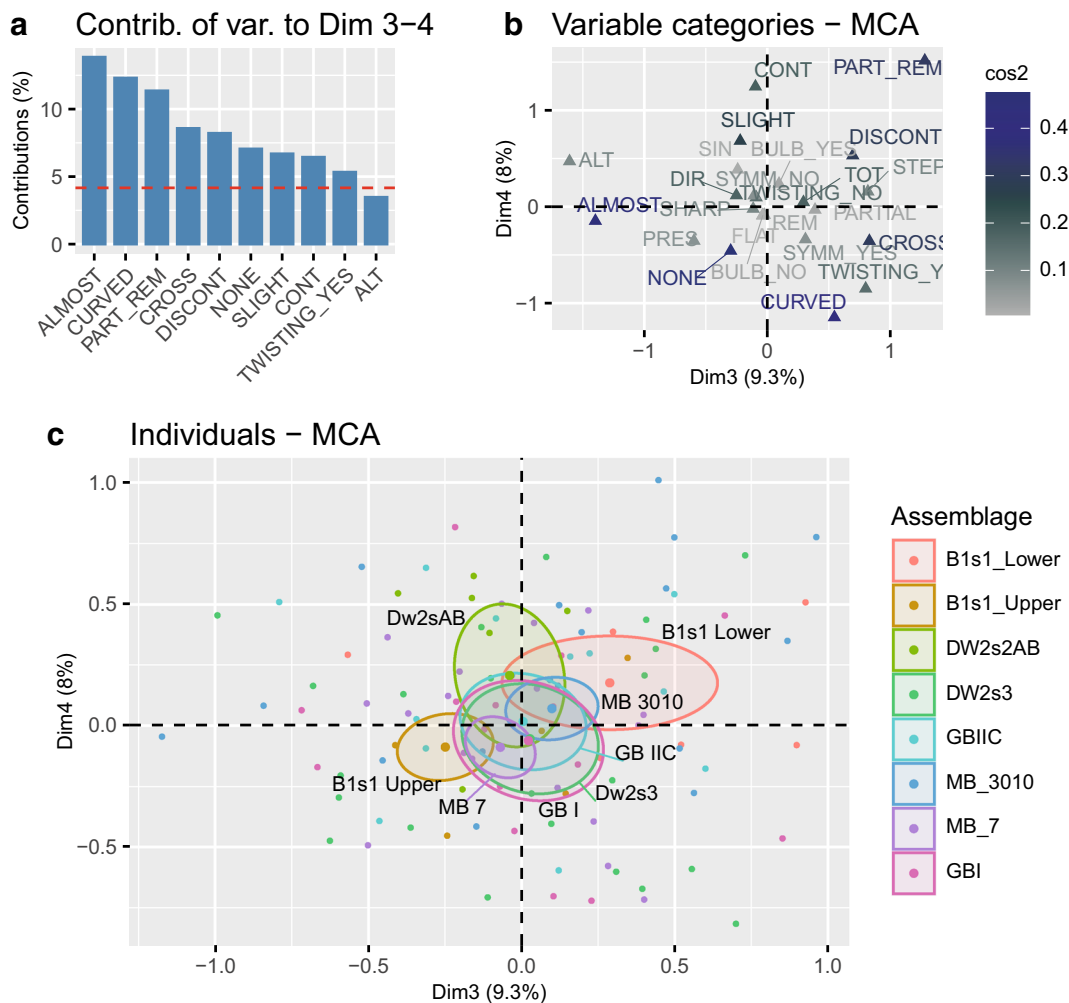
The variability of both the outlines and open curves (backed edges) were systematically observed and tested to assess the influence of the morphology of the opposed edge on the analyses. We kept the pieces with bilateral retouches, such as the ones from DW2s2, for open curve analysis. Unless indicated otherwise, results of analyses conducted on the outlines are in close agreement with the ones on open curves, showing a limited influence of the opposed edge morphology on the analysis. A PCA of the outlines demonstrates that the first two components capture most of the variance of the dataset (79.8%). If we consider only the backed edges, the first two dimensions express 85.7% of the variance (PC1, 74.6%; PC2, 11.1%). PC1 captures “triangularity” (or edge convexity of the shape), while PC2 captures “squareness” (Fig. 16).

Confusion matrices were used to visualize linear discriminant analysis (LDA) results (Fig. 17). The model on outlines (Fig. 17a) does not perfectly discriminate between assemblages; in other words, some of the assemblages present overlapping shapes. Nevertheless, prediction worked well for some assemblages (correctness above 50%): DW2s3, DW2s2, and MB3010. Predictions also denote the proximity between the two assemblages from Mochena Borago, with a good share of artifacts from one assemblage predicted as coming from the other one. Results for DW2s2 have to be considered with caution given

the small sample size. The model on open curves (backed edges; Fig. 17b) is less helpful. The prediction is accurate only for DW2s3 and Mochena Borago, probably as a result of the heterogeneity of retouched edges morphology in the samples analyzed. A model with chronological periods (Fig. 17c) provides a clearer picture and allows us to distinguish each period more easily, except for the Late Holocene (which we must again consider with caution given the relatively small size of samples from Late Glacial and Early Holocene in comparison with later periods). The model on open curves (Fig. 17d) is again less helpful.

To better ascertain the presence of significant differences between the analyzed assemblages and the different LSA periods, we ran permutational multivariate analysis of variance (PERMANOVA) on distance matrix (using the Adonis in the Vegan package; Oksanen et al. 2019). The analysis tests whether centroids (means) and within-group dispersions are homogeneous across all groups. The test is nonparametric, as it does not assume normality, and significance is calculated via permutation of observations across groups (in the present case, 999 iterations). Results on both the outlines and open curves, both at the assemblage and chronological level, all indicate dissimilarities ( $\text{Pr}(> F)$  smaller than 0.001; see ESM 6).

These analyses and the multivariate ones conducted above indicate differences between assemblages and a chronological trend towards transverse symmetry (i.e., “geometric” morphologies during the Early and Middle



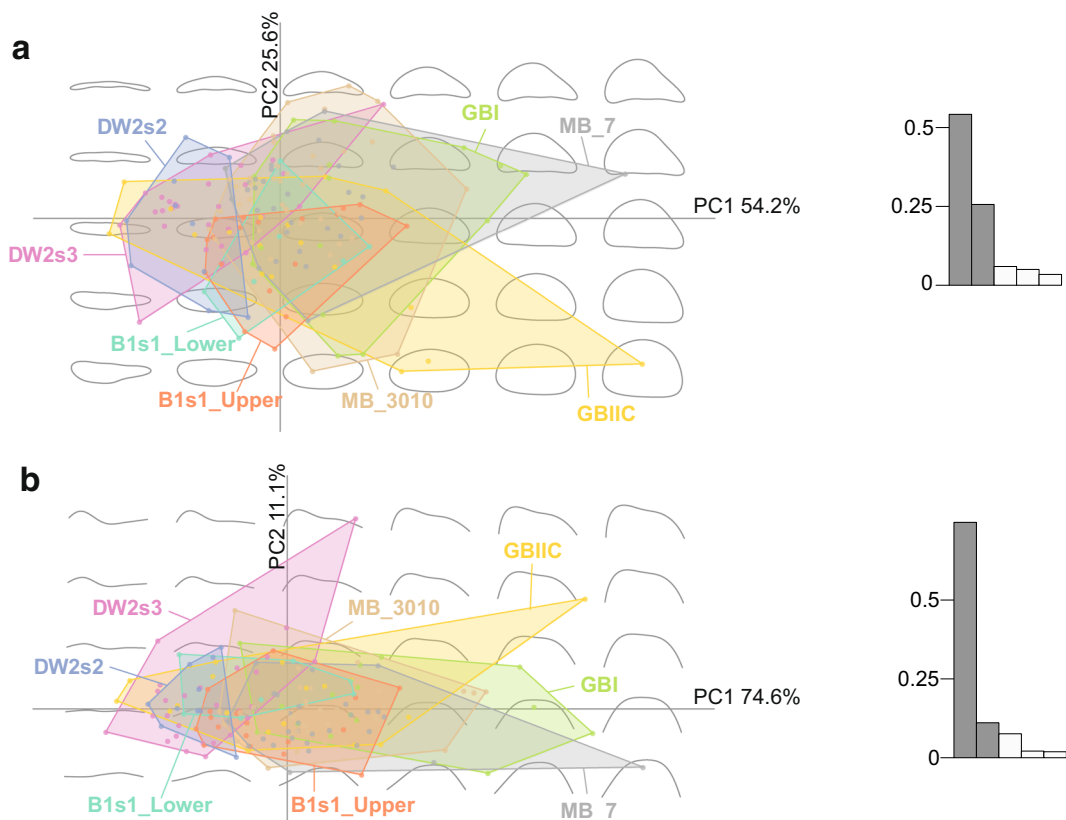
**Fig. 15** Graphs of the variable categories and of the individuals on components 3 and 4 of the MCA

Holocene). This can be summarized through the graphic representation of mean shapes or “ideal types” of backed pieces for each period (Fig. 18). Assemblage variability, assessed through a paired samples Wilcoxon test on a bootstrapped dataset, confirms that the only assemblages which are similar come from the same site (Goda Buticha, Mochena Borago) and in the proximity of B1s1 and DW2s3. A similar test at the chronological period level again indicates dissimilarities between each pair except for the Middle-Late Holocene one.

## Discussion

The review of the Upper Pleistocene and Holocene archaeological record in the Horn of Africa shows that there is only limited evidence for backed pieces before the end of

MIS 2 and the beginning of MIS 1 in the HoA. However, a large part of the late Upper Pleistocene, broadly corresponding to MIS2, remains undocumented in the HoA. In other words, no site can currently be confidently attributed to MIS2 in the HoA. It is not clear yet whether this is due to a research bias or archaeological reality (e.g., see discussions in Leplongeon et al. *in press*, 2017; Ménard and Bon 2015; Tribolo et al. 2017). Nonetheless, in the current state of knowledge, the importance of backed pieces in the HoA’s Upper Pleistocene MSA contexts seems to have been overstated in the past. Their occurrence may have resulted from mixing with more recent levels (e.g., Porc-Épic) or was in limited numbers (e.g., Goda Buticha unit IId–IIf, Mochena Borago). For these reasons, the analysis conducted on MIS 1 materials only enables us to answer the following questions: (1) is there a trend towards the production of smaller backed pieces over



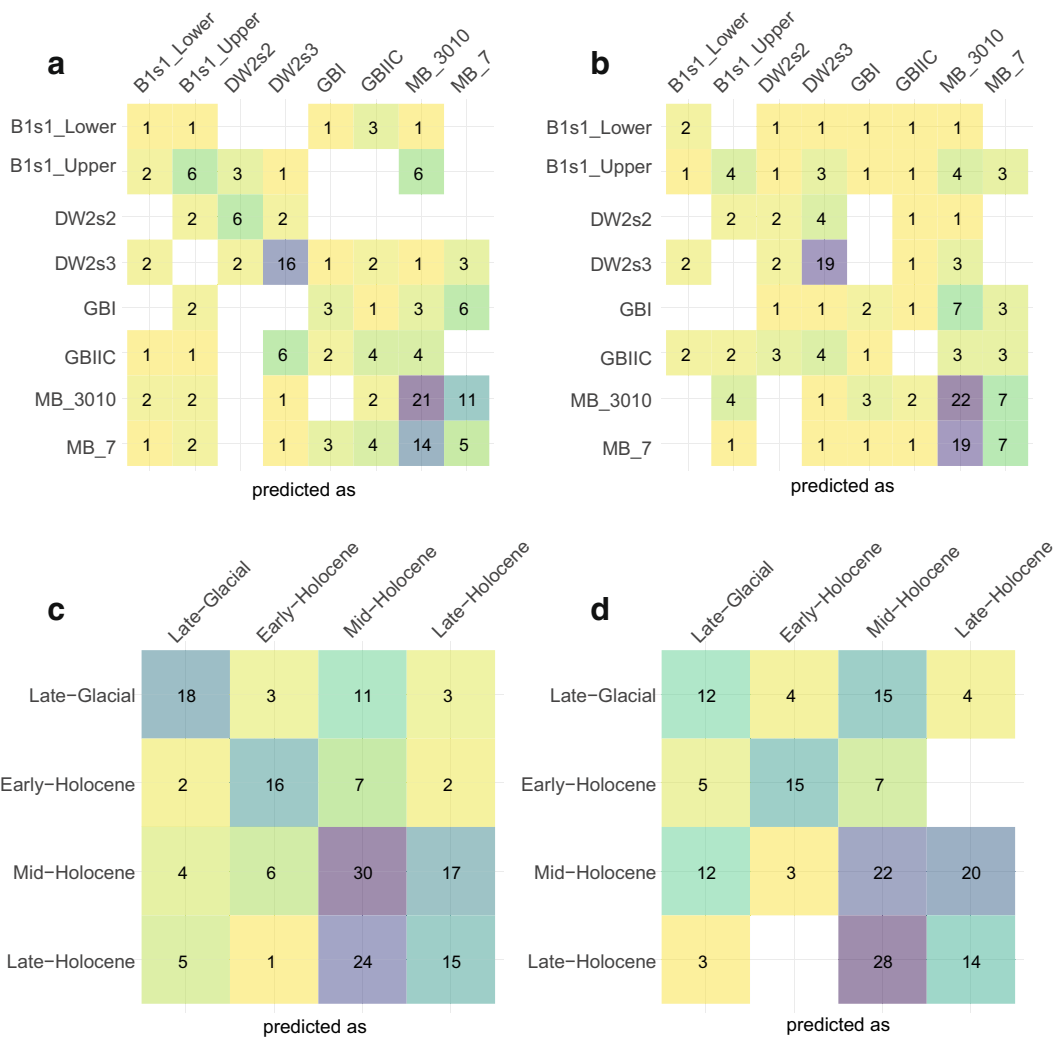
**Fig. 16** Results of the PCA for the first and the second components on outlines (a) and open curves (b)

time? (2) Is there a trend towards an increase in symmetry over time? And do the observed variations in shape correspond to chrono-cultural entities?

For the first question, our results suggest that rather than a trend towards the production of smaller backed pieces over time, we observe a high variability in size during the Late Glacial and Early Holocene. In contrast, from the Middle Holocene onwards, backed pieces are consistently of smaller dimensions (see Fig. 7). In response to the second question, only backed pieces from the Middle Holocene onwards present a transversal symmetry (see Figs. 10 and 11). Multivariate analyses show that this correlates with relatively thicker back (i.e., the back corresponds to the maximum thickness of the piece) (see Fig. 9), and a transformation of the blank due to the removal of the proximal part (butt and bulb), continuous backing retouch on the whole edge, and a possible selection of blanks with flat profiles (see Figs. 11, 12, and 13). During the Middle and Late Holocene, backed pieces are more symmetrical than in the previous periods, and this may be in part due to a greater modification/selection of the original blank shape. However, this does not imply the

standardization of backed pieces. The outline analysis points to the great intraassemblage variability in the samples, regardless of the period considered (see Fig. 16).

Regarding the third question, the results from the univariate, multivariate, and GM analyses highlight the presence of two general groups: the first one is composed of backed pieces from the earliest assemblages (i.e., Late Glacial and Early Holocene) and is characterized by a higher diversity in shape, size, blank characteristics, location and extent of the backing, and characteristics of the opposed edge. The four assemblages from this first group are all located in the Ziway-Shala basin, and come from three different sites, spatially and temporally close to one another. Nonetheless, the diversity observed in the backed pieces from these assemblages echoes their overall technological and functional diversity (Ménard et al. 2014). Faunal assemblages, in particular, indicate strong differences in site function and/or paleoenvironmental context (Lesur et al. 2016; Ménard et al. 2014). Functional diversity may, therefore, better explain the variety of backed pieces than their association with specific and distinct chrono-cultural entities.

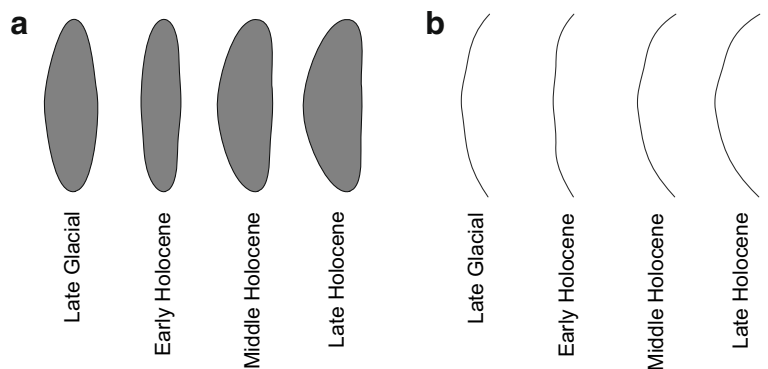


**Fig. 17** Confusion matrices of outlines LDA (a), open curves LDA (b) for assemblages, outlines LDA (c), and open curves LDA (d) for chronology

On the contrary, the second group, corresponding to later assemblages (i.e., Middle and Late Holocene), shows

a greater overall homogeneity, and have higher frequencies of symmetrical pieces. Nevertheless, these do not imply a

**Fig. 18** Mean shapes of outlines for each chronological period—plan views, main retouched edge to the left (a), and open curves (b)



lower rate of intraassemblage variability (see Fig. 11) or standardization of forms (see results of the GM analyses). The datasets for the second group come from two shelter/cave sites (Mochena Borago and Goda Buticha) located ca. 700 km from each other in distinct environmental settings. All levels are associated with a faunal assemblage suggesting a subsistence strategy based on hunting. The technological characteristics of the lithic assemblages present some similarities (e.g., high frequency of flake production) as well as some differences. These differences include a higher frequency of bladelet production between Goda Buticha and Mochena Borago and between levels at Goda Buticha and different compositions of the lithic assemblages, especially lower frequencies of backed pieces at Goda Buticha. All of these do not favor grouping them under the same chrono-cultural entities. However, some similarities in the morphometrical characteristics of the samples may reflect a higher-order relationship, such as functional convergence and the regional adoption of this type of tool.

The presence of backed pieces is usually associated with major changes in technical behaviors, such as hafting, or hunting/fishing techniques. But several use-wear and comparative analyses have highlighted the need to exercise caution in assuming that they were all hafted to serve as projectiles or that they were part of the same technological “phenomenon” (e.g., Ambrose 2002; Clarkson et al. 2018; Groman-Yaroslavski et al. 2020; Lewis et al. 2014; Wadley and Mohapi 2008; Wurz and Lombard 2007). The results presented here suggest that the backed pieces had a higher level of variability in the Late Glacial and Early Holocene, compared with the later periods. The influence of raw material type and distance on these patterns is certainly limited, as most backed pieces in our sample are obsidian, and the sites are located in very close proximity to obsidian sources. However, an exception is Goda Buticha, where obsidian sources near the site have been reported, but their suitability for knapping remains to be confirmed (Leplongeon et al. 2017, p. 209). Whether the variability observed in our study reflects a greater functional variability still has to be tested, but this will have to be based on a larger sample of sites and in combination with use-wear analyses. If we accept that these artifacts were replaceable inserts that were rapidly discarded without being rejuvenated, we can at least rule out the possibility that their morphology changed throughout their use, such as for other kinds of tools (Dibble 1987; Iovita 2009, 2010).

## Conclusion

The HoA is a large and diverse geographic unit, and the backed lithic tools from this region offer great potentials of comparison with the ones from comparable regions of similar size, such as East Africa (Tryon 2019, p. 271). However, our data in this paper come only from Ethiopia. We recognize that the inclusion of assemblages and backed pieces from Somalia and Somaliland might have produced a more complex picture, not to mention other specific kinds of shaped tools present there (e.g., Brandt 1986; Clark 1954; Graziosi 1940). We should stress that the materials we have presented do not account for all the regional diversity and that we had to limit our study to the few assemblages for which we have a good stratigraphic and chronological control. Our paper offers the first quantified multi-site comparisons for the backed pieces in the HoA, and a larger dataset from across the region may build on the framework we have outlined here.

Comparisons between the HoA and East Africa are not easy, especially because of the diversity of industries in these regions. A growing body of evidence tends to show that these two regions, sometimes grouped together, actually reflect two distinct regional cultural trajectories (e.g., Leplongeon et al. *in press*; Shea 2020; Tryon 2019). In addition, East Africa faces the same lack of consensus regarding the nomenclature of LSA industries as the HoA (e.g., Wilshaw 2016). Comparisons are generally limited to the mean metrics for given types of tools. Such data are likely to produce inconclusive results because of competing definitions for different sub-categories of backed pieces, strong intraassemblage variability, and significant overlap between variables like length and width. We believe that the methods presented here would prove efficient in making comparisons between regions with rich assemblages of backed pieces, as in East Africa where nonlinear patterns of evolution have already been identified (e.g., Ambrose 1984b, 1998; Wilshaw 2012).

One important result of this study is that attribute and geometric morphometric analyses enable us to identify diverse groups of backed pieces in a replicable manner and without the use of any subjective typology. For example, our analysis sets the specific backed pieces from DW2s1/s3 apart from the other backed pieces in our sample, which is consistent with previous observations mentioning that they did not have any equivalent in the literature (Ménard et al. 2014). The approach adopted here, therefore, adds to the growing number of studies showing that attribute analysis can be used to highlight

morphometric patterns in backed pieces in a more objective and reproducible way than the use of “classic” typologies. This is a pilot study to understand the patterns of backed piece variability in the HoA over time and their significance in the LSA technology. Whereas our study relies on a limited number of assemblages, further analysis including data from other dated contexts and integrating high-resolution paleoenvironmental data will help to detect and explain other patterns of variation in backed pieces during the LSA.

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### Compliance with Ethical Standards

**Conflict of Interest** The authors declare that they have no conflict of interest.

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