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Backed pieces and their variability in the Later Stone Age of the Horn of Africa

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Country and region discussed: Horn of Africa

Backed pieces and their variability in the Later Stone Age of the Horn of Africa

Abstract

Backed pieces, although already present in earlier periods, became widespread in the Upper Pleistocene and Holocene, and are part of the classic definitions for the Later Stone Age. However, the association of backed pieces with Later Stone Age appears less clear in the Horn of Africa than in other regions. These pieces are present in both Middle Stone Age and Later Stone Age contexts, and the homogeneity of the "backing phenomenon" in the Horn of Africa can be questioned. Here, we first critically review the literature on backed pieces in the Horn of Africa and, given the lack of terminological consensus and the absence of a shared typology in the region, we describe the variability of backed pieces using two complementary approaches: multivariate statistical analysis on a set of 28 attributes of 188 artefacts coming from 8 securely dated contexts, and 2D geometric morphometrics analyses on the same dataset. The two approaches provided complementary results which allowed us to identify and discuss chronological trends (*e.g.,* the apparent absence of miniaturization across different temporal intervals, the increase in the number of geometric shapes during the Middle and Late Holocene) without either resorting to new terminology or proposing a new formal "descriptive" typology.

Keywords: Backed pieces, Horn of Africa, Later Stone Age, lithic variability

Résumé

Les pièces à dos abattu, bien que déjà présentes à des périodes plus anciennes, 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 semble moins claire dans la Corne de l'Afrique que dans d'autres régions. En effet, elles se retrouvent à la fois dans des assemblages Middle Stone Age ou Later Stone Age et l'homogénéité du « phénomène des pièces à dos abattu » peut être questionné dans la Corne de l'Afrique. Dans cet article, nous présentons une synthèse critique de la littérature mentionnant les pièces à dos abattu dans la Corne de l'Afrique. En l'absence d'un consensus sur l'usage d'une terminologie ou d'une typologie commune dans la région, nous décrivons la variabilité des pièces à dos abattu en s'appuyant sur deux approches complémentaires : une analyse statistique multivariée en reposant sur 28 variables de 188 pièces provenant de 8 contextes datés de façon absolue, et une analyse de géométrie morphométrique en 2D. Les deux approches ont livré des résultats complémentaires, qui permettent d'identifier et de discuter de tendances chronologiques (*e.g.,* l'apparente absence de miniaturisation au cours du temps, l'augmentation de formes géométriques à partir de l'Holocène moyen et récent) sans avoir à introduire de nouvelles dénominations ni à proposer une nouvelle typologie « descriptive ».

Mots-clés : Pièces à dos abattu, Corne de l'Afrique, Later Stone Age, variabilité lithique

1. Introduction

One of the most important challenges and long-standing debates we face when trying to interpret the African regional or multi-regional lithic record is the lack of comparability of assemblages, which is partly due to the different approaches, methods and typologies used by lithic analysts working in Africa. During the 1960s-1970s, for the purpose of making inter-site comparisons and 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), researchers tried to rationalize the terminology and typology they would use for describing stone artefacts (including backed pieces) and made explicit descriptions of the different terms they used (Clark and Kleindienst 1974; Merrick 1975; Nelson 1973). The typology developed by Nelson had initially a strong influence on research conducted in eastern Africa during the 1970s-1980s (see Ambrose 1984a; Brandt 1982; Kurashina 1978; Mehlman 1989) but was soon superseded by a multitude of individual variants and site-dependent typologies; it was also never much in use in the Horn of Africa (for a review of the situation in eastern Africa see Shea 2020, Chapters 4 & 5). Nowadays, few lithic analysts agree on the use of a common typology on a regional scale, let alone on a multi-regional/continental scale, and we are far from achieving the objective of a "unified nomenclature of forms and types and a terminology of techniques in the field of African Pre- and Protohistory" (Clark et al. 1966, p. 117). A notable exception is however the typology of Tixier (1963, 1974), widely used for the North African Epipaleolithic, which we will hereafter refer 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. critically reviewing all occurrences of backed pieces in the HoA during the Upper Pleistocene and Holocene and discuss their presence with regards to their general context.
2. performing a detailed comparative attribute analysis on backed pieces from several sites from the HoA and identify possible patterns of variability (e.g., in shape or size).

Because our objective is not to propose a new typology, here we shall use a very general definition, which aims to be as inclusive as possible, and can encompass most of the categories in use including geometrics, microliths, and backed blades. A backed piece is therefore 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 key assemblages which were previously analysed thoroughly by two of us (Leplongeon 2013; Ménard 2015). To compensate for a lack of shared terminology we shall try to implement two complementary approaches: multivariate statistical analyses and 2D geometric morphometrics, which 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.

2. Backed pieces and the Later Stone Age: disentangling a complex relationship

2.1. What are backed pieces?

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 (which included Tixier) has once proposed, a bit tautologically, 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, unfortunately not systematically supported by functional analyses, is that backed edges correspond to hafted parts and that backed pieces are stone inserts in composite tool technology, usually linked to projectile technology but not only (e.g., Honegger 2009; Wadley and Mohapi 2008).

As indicated above, we found this term to be 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, as any other, falls short of representing the complexity and diversity of lithic remains, and some artefacts with similar functions may be excluded from our analysis. Moreover, it over-emphasizes the importance of a simple way of modifying artefact edges, which is only one possible solution among others and does not account for the unretouched artefacts for which we have evidence of hafting and use (e.g., Villa et al. 2012).

2.2. 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 or absent during later periods in the region (Deacon 1984; Porraz et al. 2016; Wadley 1993), although they eventually became widespread in later 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). Interestingly, the very presence of backed pieces in these assemblages is usually a strong argument for attributing them to the LSA.

2.3. Are backed pieces a hallmark of the LSA?

Classic definitions for the LSA generally include a shift towards the production of smaller artefacts and bladelets, often associated with an increased use of the bipolar technique, and the generalised occurrence of "microliths" (e.g., Phillipson 2005). Backed microliths in particular are often considered as the hallmark of the LSA. This is for example the case for "historic" LSA industries such as the Wilton in Southern Africa (Goodwin and Van Riet Lowe 1929; Mitchell 1997), but also aggregated industries such as the Iberomaurusian in the Maghreb (e.g., Barton et al. 2019; Lubell 2001; Tixier 1963). However, on a continental scale, there are LSA assemblages without backed pieces, or with large backed pieces and MSA assemblages with backed pieces as well (see review in Ambrose 2002). To what extent backed pieces are considered a hallmark of the LSA?

In many cases, in 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 in the assemblage – what matters is that they are small and definitions for LSA assemblages include references to "backed microliths", "crescents" or "backed blade/lets" (e.g., Clarkson et al. 2018; Leakey, L.S.B., 1931, Leakey, M.D., 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 or even 50 mm in length; (e.g., Clark 1985; Diez-Martin et al. 2009) despite several recent papers aiming to set clear definitions and/or discuss what is behind terms such as microliths, microlithisation/miniaturisation (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 in different contexts, and may not be part of the same phenomenon as small blank production and bladelet technology (e.g., Ambrose 2002; Leplongeon 2014). Clarkson and colleagues (2018) in a recent review of backed-microlithic technology argue for convergence in the appearance of backing technology on a macro-regional 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, maintainability, ease of manufacture and standardization), that may explain why convergence is the most likely scenario at this macroregional scale.

Even if (small) backed pieces are sometimes considered part of the classical definition of the LSA or some LSA industries, they cannot be considered as a *fossile directeur* of the LSA on a continental scale: the Howiesons Poort industry is a good example. What is observed however is that they become much more frequent at the end of the Pleistocene in Africa. Systematic regional comparative analyses are needed to better understand mechanisms behind the adoption of backed tools.

3. The Later Stone Age in the Horn of Africa

The Upper Pleistocene (~126-11.7 ka) in Africa is characterised by important technological innovations and economic changes with the diversification of subsistence strategies (e.g., fishing) and the increased evidence for non-utilitarian objects such as ornaments (e.g., ostrich eggshell or marine shell beads). The progressive emergence of such items is generally referred to as 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 non-linear (Leplongeon et al. 2017; Ménard 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. In addition, most of these sequences document a sedimentological and chronological gap broadly corresponding to MIS 2 (Brandt et al. 2017; Ménard 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 otherwise 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 characterised by both large and small backed pieces with a great diversity of shapes, and some assemblages do not present any backed pieces (Ménard et al. 2014).

Comparisons between published accounts is made particularly difficult by the co-existence of diverse terminologies; 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”, “geometrics” or the shape of the back, i.e., “curved- or straight- backed pieces”. This variability in naming backed pieces is such that systematic and thorough inter-assemblage comparisons are often not possible, as it is impossible to make sure that the same type of artefact is being compared. These artefacts 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 forty years: Beyin 2010; Clark and Prince 1978).

These studies highlight some possible trends in the production of backed pieces through time in the HoA, 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; Ménard et al. 2014);

2. A trend towards the production of more symmetrical pieces through time (possibly illustrated by a shift from non-geometric to geometric pieces through time (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 (Ménard et al. 2014).

4. Backed pieces in the Horn of Africa

Using the definition for backed pieces presented above, we conducted a review of published assemblages, as well as direct observations. Despite the importance of the region 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).

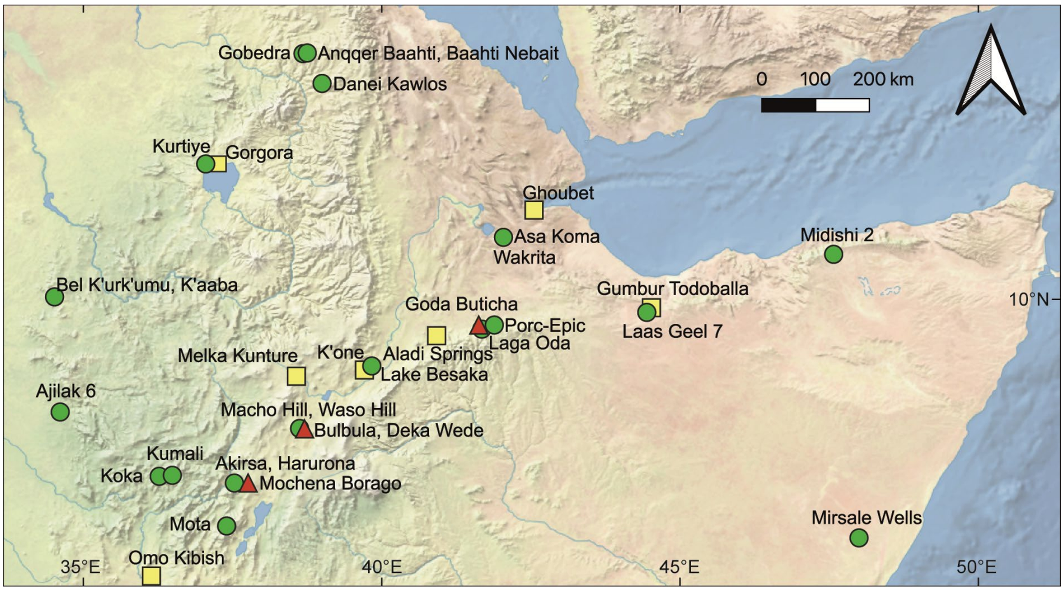

Fig. 1 Map of the Horn of Africa (between 5°N-15°N only) with main archaeological sites with backed attributed to MIS 3-1. Circles, sites directly dated; Triangles, sites analysed in this study; Squares, other sites. Made with Natural Earth Data

Published sites with levels with direct dates older than MIS 1 (i.e., older than 14.8 ka) and featuring backed pieces can be counted on the fingers of one hand: they 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 the 1933 excavation, and may have resulted from mixing between archaeological levels, including the topmost LSA layer at the site. Backed pieces are absent from assemblages excavated solely in 1975-76 (Leplongeon 2014; Pleurdeau 2005). At the remaining sites, backed pieces from pre-MIS 1 levels occur in very small numbers. They mostly consist of fragments at Mochena Borago (pers. obs.); only two were 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 was found at Laga Oda (Kurashina 1978). All of them occur in a context where later levels are rich in backed pieces. Except at Mochena

Borago, they consist of very few pieces and the hypothesis that their occurrence in Upper Pleistocene levels result from occasional vertical transport cannot therefore be excluded. This short review shows that the evidence for pre-MIS 1 occurrence of backed pieces in well-dated contexts is very limited in the HoA. This is important to stress given the fact that, in the region, several late MSA or "transitional" industries were defined, most of them now abandoned, but which included in their definition the presence of backed artefacts (e.g., Stillbay, Magosian, Hargeisan; Clark 1954).

Table 1 Assemblages analysed in this study (in bold) and other published assemblages with backed pieces from sites with multiple MIS 1 direct dates (stratigraphic units with >100 artefacts and >10 backed pieces only). * rough calibrated intervals rounded to the nearest 0.5 ka, GB intervals are partly based on OSL ages; ** global inventories include fragmented pieces, studied samples include only complete and subcomplete pieces; *** data from one square (B1); **** counts from DW2s1 only, studied pieces from DW2s3 only; ***** counts from locus A only, studied pieces from locus A and B; $^{(e)}$ estimate

Chronology	**Archaeological unit**	**Age (cal BP)***	**N assemblage**	**Retouched tools**		**Backed pieces****			**References**
				N	% assemblage	N	% retouched	N studied	
Late Holocene	Laas Geel 705	0.5-1.5 ka	104	13	*13%*	12	*92%*		Gutherz et al. 2014
	Goda Buticha I* **	**0.5-4 ka**	**350**	**30**	***9%***	**18**	***60%***	**16**	Leplongeon et al. 2017; Tribolo et al. 2017
	Laga Oda 40-50	0.5-4 ka	2837	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
	Mochena Borago Spit 7	**2-2.5 ka**	**418**	**98**	***23%***	**92**	***94%***	**33**	Ménard 2015
	Mota Cave, pre-pottery period	3.3-4.5 ka	1306	214	*2%*	139	*55%*		Arthur et al. 2019
Middle Holocene	Asa Koma	4-4.5 ka	21,247	342	*2%*	252	*74%*		Diaz 2017
	Mochena Borago US 3010	**4.5-5 ka**	**901**	**117**	***13%***	**105**	***90%***	**46**	Ménard 2015
	Goda Buticha IIC* **	**6-8 ka**	**1259**	**111**	***9%***	**32**	***29%***	**21**	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
Early Holocene	**DW2s1/DW2s3 **** **	**11-12 ka**	**702**	**142**	***20%***	**129**	***91%***	**27**	Ménard 2015; Ménard et al. 2014
Late Glacial	**DW2s2***** **	**11-13 ka**	**395**	**24**	***6%***	**11**	***8%***	**11**	Ménard 2015; Ménard et al. 2014
	B1s1 Upper	**13-13.5 ka**	**2600$^{(e)}$**	**144**	***6%***	**52**	***36%***	**24**	Ménard et al. 2014
	B1s1 Lower	**13-13.5 ka**	**6900$^{(e)}$**	**342**	***5%***	**25**	***7%***	**10**	Ménard et al. 2014

In the current state of knowledge, more evidence from well-dated contexts is needed in order to discuss the significance of the occurrence of backed pieces in pre-MIS 1 levels in the HoA. In addition, their number is too small to be analysed in the frame of this comparative study and we will therefore only analyse materials from MIS 1 deposits here.

Table 1 summarises the corpus of the main published assemblages containing backed pieces from stratigraphic units/layers directly dated to MIS 1 in the HoA (Table 1). 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 tool, which may relate to a diversity of site function/length of occupation.

5. Materials and methods

To identify patterns of variability in backed pieces from the HoA over time and avoid the use of typologies, we adopted a multivariate approach based on an attribute analysis to quantify similarities and differences between assemblages. We further explored variability using Principal Component Analysis (PCA), Multiple Correspondence Analysis (MCA) and 2D geometric morphometrics (GM). All statistical analyses were performed using R v.4.0 or younger (R Core Team 2020) and RStudio v.1.3 (RStudio Team 2015), using packages FactoMineR for multivariate analyses (Husson et al. 2017; Lê et al. 2008), Momocs v 1.3.0 for everything morphometrics (Bonhomme 2020; Bonhomme et al. 2014), ggplot2 for most graphics (Wickham 2009) and factoextra (Kassambara and Mundt 2017). The list and description of the variables used, the complete database, illustrations of the dorsal views of artefacts, as well as the R project used to perform the analyses and generate the figures of the paper, so that the analyses are reproducible (e.g., Marwick 2017), are all made accessible online (ESM1- 4).

5.1. Corpus

The backed pieces analysed here come from eight archaeological stratigraphic units, from four different sites. For comparative purpose, the sites will hereafter be grouped into four main chronological periods based on available radiocarbon dating: Late Glacial (14.8-11.7 ka), Early Holocene (11.7-8.2 ka), Middle Holocene (8.2-4.2 ka) and Late Holocene (younger than 4.2 ka) (Table 1 and Figs 2-5; Late Glacial corresponding to GS-1 and GI-1, Rasmussen et al. 2014; Holocene subseries rounded after International Union of Geological Sciences boundaries, Walker et al. 2018). Because there is no significant evidence for backed pieces dated to an older period of the Upper Pleistocene in the HoA (see above), we focused on artefacts attributed to MIS 1 only.

We sampled different types of sites (cave sites and open-air sites), environmental settings and technological contexts (flake or bladelet production), following in depth technological and typological analyses that are presented in detail elsewhere (Leplongeon 2014; Leplongeon et al. 2017; Ménard 2015; Ménard et al. 2014). A summary of these characteristics can be found in Table 2.

Table 2 General characteristics of analysed assemblages

		General Characteristics				**Backed pieces**		
	Age (cal BP)	**Raw materials**	**Blades**	**Bladelets**	**Flakes**	**Raw materials**	**Blanks**	**Original typological attributions**
Goda Buticha I	0.5-4 ka	chert (+), obsidian (+)	+	+	++	obsidian (mostly)	bladelets	crescents
Mochena Borago Spit 7	2-2.5 ka	obsidian	-	-	+++	obsidian	flakes	circle segments
Mochena Borago US 3010	4.5-5 ka	obsidian	-	-	+++	obsidian	flakes	circle segments (mostly)
Goda Buticha IIC	6-8 ka	chert (++), obsidian (+)	+	+	++	chert (mostly)	elongated	curved, rectilinear
DW2s1/3	11-12 ka	obsidian	+	++	-	obsidian	bladelets	slightly convex backed micro-bladelets with triangular base
DW2s2	11-13 ka	obsidian	++	+	-	obsidian	blades	lozenge shape tanged 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

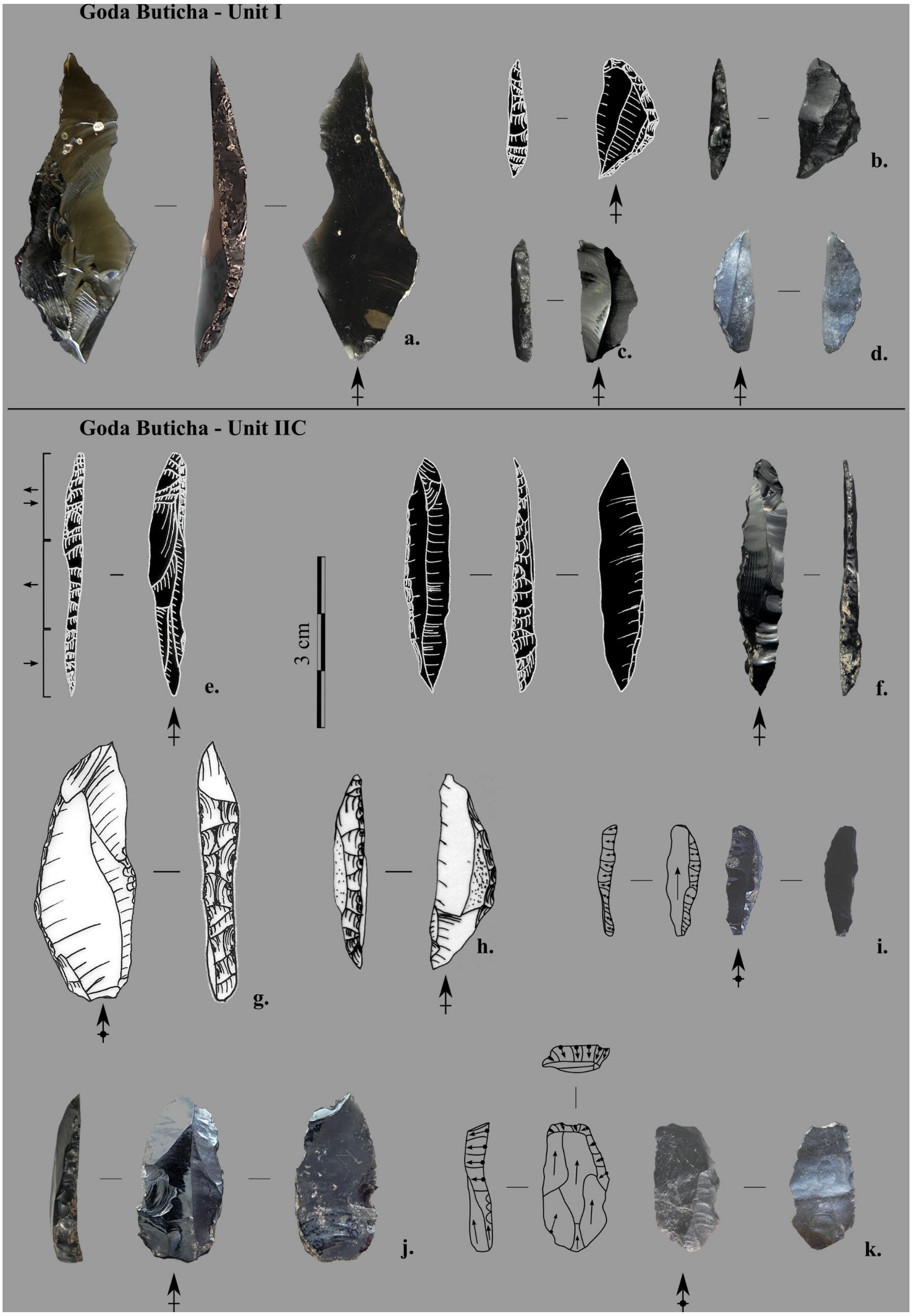

Fig. 2 Backed pieces from Goda Buticha. A. Unit I (GBI); B. Unit IIC (GBIIC). Photos and drawings: A. Leplongeon

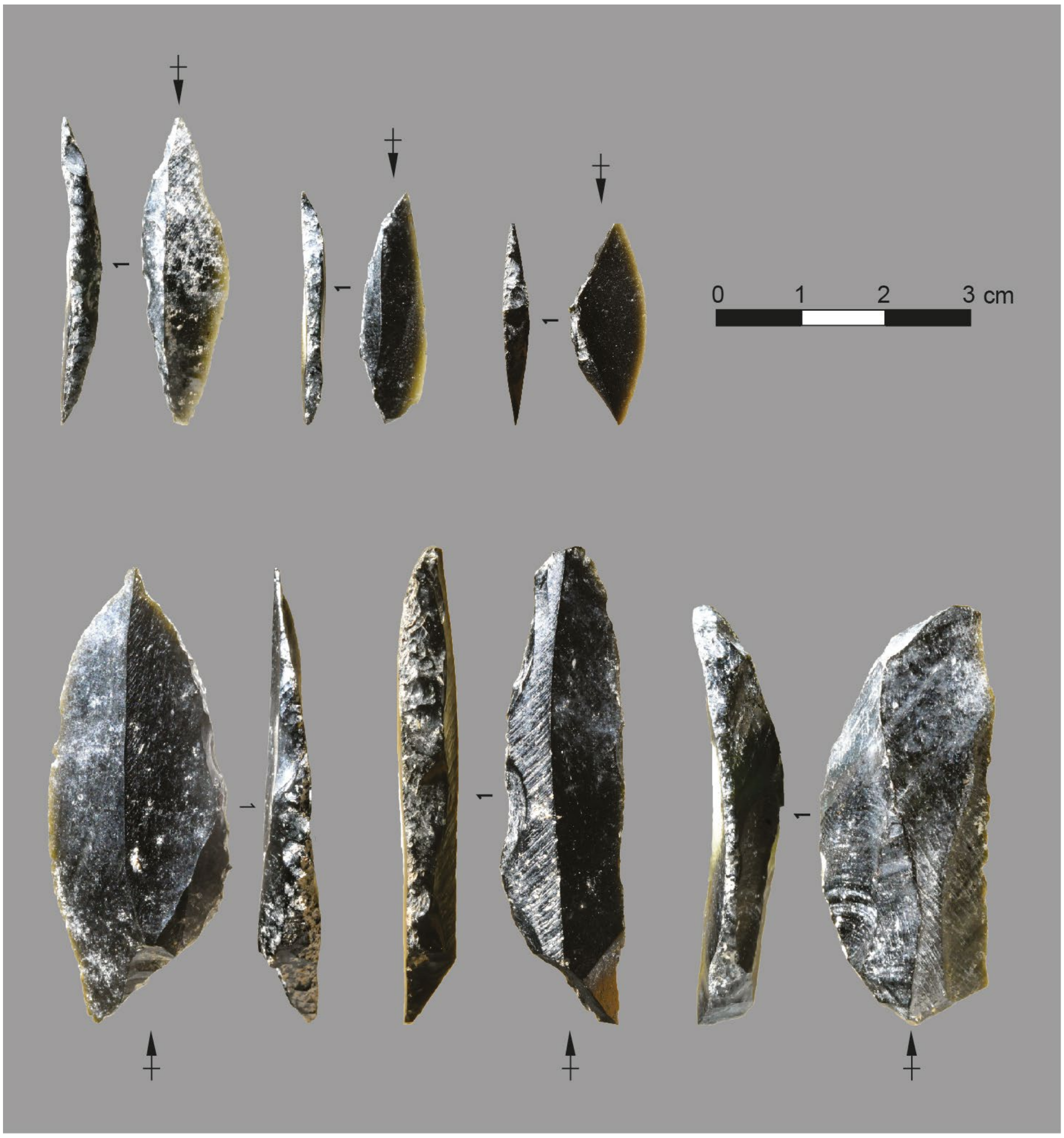

Fig. 3 Backed pieces from Bulbula 1 sector 1. A. Upper units (B1s1 Upper); B. Lower units (B1s1 Lower).
Photos: C. Ménard

Fig. 4 Backed pieces from Deka Wede 2. A. Sector 2 (DW2s2); B. Sector 1 (DW2s1; tool types similar to DW2s3).
Photos: C. Ménard

Fig. 5 Backed pieces from Mochena Borago. A. Spit 7 (MB7); B. Unit 3010 (MB3010).
Photos: C. Ménard

We recorded attributes on a total of 188 complete (or subcomplete) backed pieces. Subcomplete (or virtually complete) refers to pieces with small fragments missing for which original shape and size could be confidently reconstructed (with a missing part not exceeding 1/10th of total length). We conducted 2D GM, namely outline analyses using elliptical Fourier transforms (Ferson et al. 1985; Giardina and Kuhl 1977) and curve analyses using discrete cosine transform (Dommergues et al. 2007) analysis on a subset of 164 pieces only. We unfortunately had to remove fragments from the analysis, including damaged artefacts which were potentially used and featured impact scars (Fisher et al. 1984). This possibly introduced a bias, and a possible over-representation of rough-outs and unused artefacts over used ones.

5.2. Multivariate analysis

Twenty-eight attributes were defined to describe the contextual, morphometrical and technological aspects of backed pieces (see SM 1 & 2 and tables below). The variables can be divided into three main domains: morphometrical (dimensions, symmetry), variables linked to blank selection (curvature, twisting, morphology of opposed edge), or types of blank transformation (removal of bulb or butt, type, extent and location of retouch).

The presence of differences in the distribution of continuous variables across assemblages was tested through 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 a 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 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 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 formally assess the relationship between length and various morphometric indices, as well as to weight 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 such as 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, intra-assemblage diversity over time in the distribution of 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. Dissimilarity between pairs of temporally subsequent assemblages was instead calculated for each qualitative variable as the inverse of Morisita-Horn overlap 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) suggest 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 intra-site diversity which 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 inter-assemblage dissimilarity (Morisita-Horn index; Jost 2007). The latter was chosen because it is independent from sample size (Wolda 1981) and for this reason has been already used to investigate processes of culture change in archaeological contexts (Crema et al. 2014; Maiorano et al. 2020).

5.3. 2D Geometric Morphometrics

2D Geometric Morphometrics (GM) allow for comparison of shapes independently of metric attributes; it is a powerful tool to compare stone tools regardless of variables that can be uncontrolled during stone tool production or bias linked to external constraints (like raw materials). Over the last decade, GM have been widely used in archaeology, and particularly to identify and describe variations in material culture and lithic artefacts (Cardillo 2010; MacLeod 2018; Okumura and Araujo 2018). Most of the published analysis conducted on lithics have focused on landmarks and semi-landmarks (Webster and Sheets 2010) for comparing artefacts and assemblages (e.g., Buchanan et al. 2014; Cardillo et al. 2016). A sole landmark-based analysis on backed pieces such as the ones investigated here is likely to be inefficient (there can hardly be more than two landmarks unequivocally defined, corresponding respectively to proximal and distal tip on such kinds of pieces), here we will focus instead on Elliptical Fourier Analysis (Rohlf 1990) which have been successfully used to describe variations of lithic artifacts (Iovita 2011; Iovita 2009, 2010; Iovita and McPherron 2011; Lipo et al. 2016).

Photographs of dorsal views from each artefact were treated with Adobe Photoshop CC: they were scaled, rotated (retouched edges were all put on the left side) and their contrast was enhanced (Levels tool), artefacts were isolated from the background (Quick Selection tool), their outlines were filled in with black, and the results were exported to .jpg files. We unfortunately had to remove 24 pieces formerly categorized as subcomplete, the corpus being thus significantly reduced compared to the one used for multivariate analysis (n=164/188).

Outlines were digitized and analysed with Momocs package v1.3.0 (Bonhomme 2020). The number of harmonics retained was chosen using harmonic power and analyses resulting in 5 harmonics (20 coefficients) for outlines, and 6 harmonics (14 coefficients) for curves, in both cases 95% of the harmonic power was retained. See Dommergues and colleagues (2007) and Bonhomme and colleagues (2014) for more details concerning these approaches and their calibration. Outlines were normalized (they were subsampled to 360 points, centred, and aligned). Two landmarks were manually defined at the top and bottom of each artefact (respectively proximal and distal ends). In 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 sliced to retain the parts left of the landmarks (open curves) corresponding to retouched edges. This method has some limitations: retouched parts can extend beyond the landmarks and the curves produced often encompass unretouched parts.

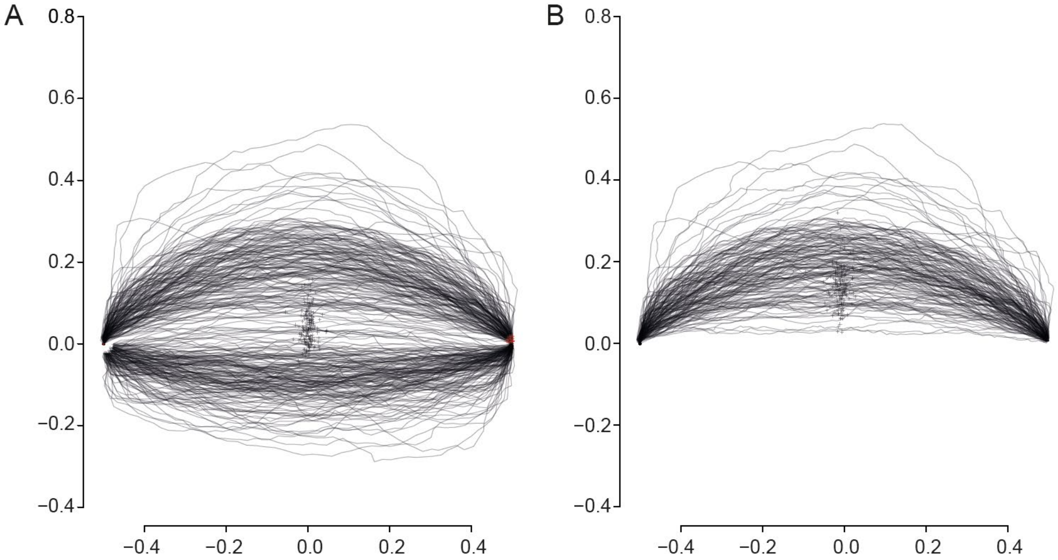

Fig. 6 A. Stacked outlines of the backed pieces selected for outline analysis after treatment; B. stacked open curves (backed edges) of the same artefacts. Backed edges on top

6. Results

The analyses provided results on three different aspects of our dataset; (1), on the quantitative variables, (2), on the qualitative variables, and (3), on the shape of backed pieces.

6.1. Quantitative variables and Principal Component Analysis

Five quantitative variables and three supplementary qualitative variables were used in the PCA (Table 3).

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), Mid-Holocene (8.2-4.2 ka), Late Holocene (< 4.2 ka)	CHRONO

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 SM5) only show significant differences between the earliest assemblages, which would indicate a greater degree of variability in the earlier assemblages compared to the more recent ones (from GBIIC, i.e., from the Middle Holocene onward).

Table 4 Summary of main dimensions of backed pieces. Values in bold indicate extreme values.

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

Results of the PCA are summarised in Table 5 and Fig. 8 and show that the first three first dimensions have eigenvalues higher than 1, and taken together express more than 85% of the total inertia.

The two first dimensions express more than 60% of the variance in the dataset. The graph of the variables (Fig. 8) shows 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. Results show that the variance summarised by the first two components is first explained by the provenience (“grouping”) and to a lesser extent by the chronology. 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 Lower and DW2s2) to the Early Holocene (DW2s3). 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 the one of the Holocene sites.

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

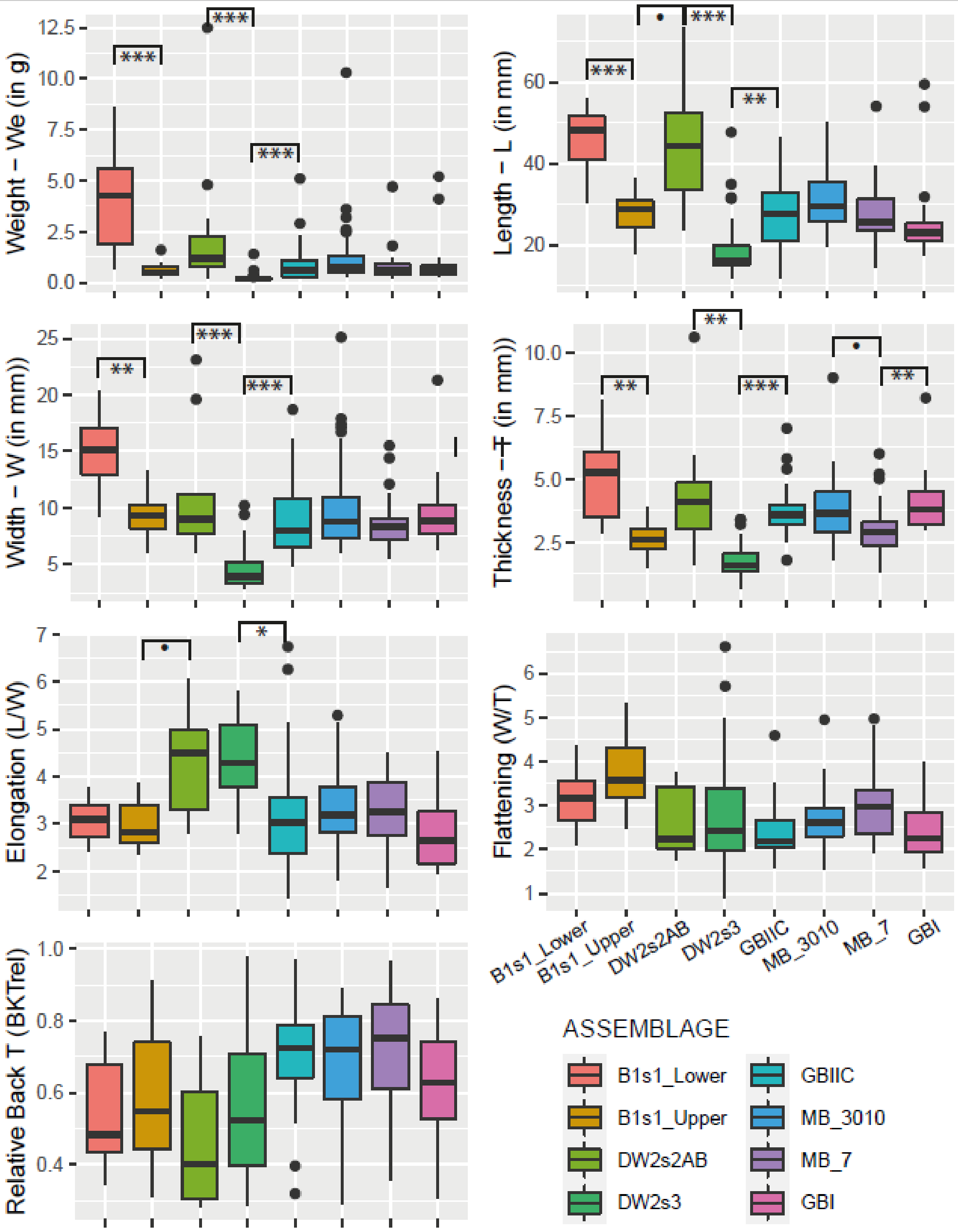

Fig. 7 Boxplots of the main dimensions and ratios of backed pieces. Stars indicate instances of significant Mann-Whitney tests after Bonferroni correction: . p-value <.05, * p-value <.025, ** p-value <.01, *** p-value <.001. For detailed results, see SM5.
NB: assemblages are arranged in chronological 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	<.001	**LW**	0.816	<.001
WEIGHT	0.9115	<.001	**LENGTH**	0.1734	1.73E-02
BKTrel	-0.3367	<.001	**WT**	-0.8179	<.001
qualitative variables with p-value <0.05			qualitative variables with p-value <0.05		
	R2	**p.value**		**R2**	**p.value**
PROV	0.3444	<.001	**PROV**	0.1772	<.001
CHRONO	0.1768	<.001	**CHRONO**	0.0631	0.0073
category	*Estimate*	*p.value*	*category*	*Estimate*	*p.value*
B1s1_Lower	2.1015	<.001	*DW2s2AB*	0.9345	0.0045
1-Late-Glacial	0.9603	<.001	*2-Early-Holocene*	0.491	0.0111
DW2s2AB	1.4087	<.001	*DW2s3*	0.4925	0.0111
2-Early-Holocene	-0.8046	<.001	*CHAL*	1.2244	0.0132
DW2s3	-1.1859	<.001	*1-Late-Glacial*	-0.3826	0.0237
			B1s1_Upper	-1.0242	<.001
Dimension 3					
quantitative variables with p-value <0.05					
	correlation	**p.value**			
BKTrel	0.8573	<.001			
WEIGHT	0.2889	<.001			
WT	-0.2935	<.001			
LW	-0.4113	<.001			
qualitative variables with p-value <0.05					
	R2	**p.value**			
CHRONO	0.2403	<.001			
PROV	0.2648	<.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	<.001			
DW2s3	-0.9148	<.0010			

PC3 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 backed pieces with a thin back (Fig. 9). The variance observed can be partly explained by the variable “grouping” and the variable “chronology” (Fig. 9). In particular, the backed pieces can be divided into two groups: backed pieces from DW2s2, DW2s3 and B1s1 Upper are characterised by a relatively thin back, compared to the other group of sites (GBI, GBIIC, MB3010 and MB7). There thus appears to be a trend towards thicker backs 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 to the Late Glacial backed pieces.

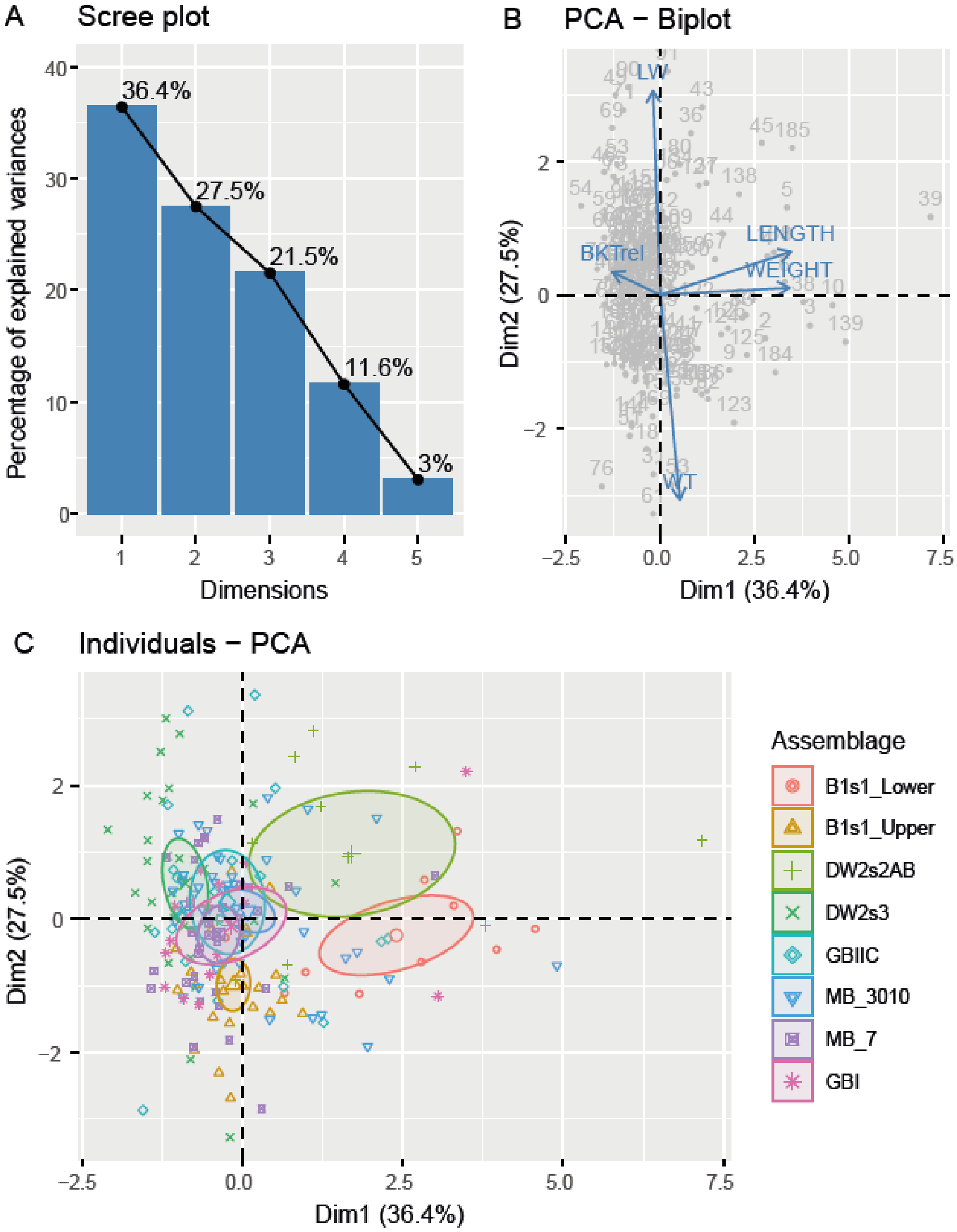

Fig. 8 A. Scree plot, B. biplot and C. plot of the individuals for the first two components of the PCA

Backed pieces do tend to be smaller and lighter over time, but in a non-linear way. This is only true between the Late Glacial and the Holocene. There is a trend towards a backing retouch that concerns the maximum thickness of the piece from the Middle and Late Holocene, while backed pieces from earlier sites tend more frequently to have a partial backing.

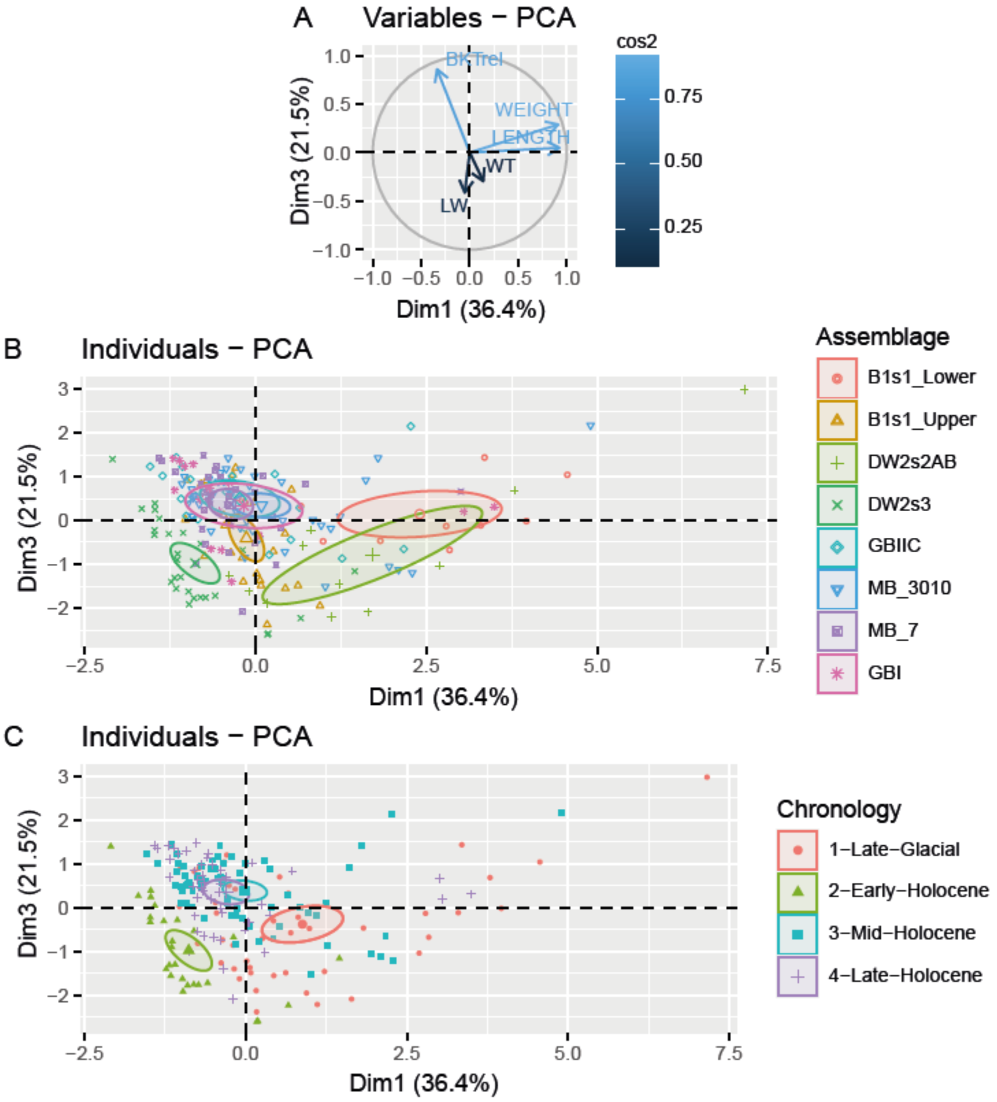

Fig. 9 Results of the PCA for the 1st and the 3rd component

6.2. Qualitative variables and Multiple Correspondence Analysis

Nine qualitative variables were retained for the analysis, which correspond to variables related to blank transformation (removal of the proximal part, type and location of the retouch), to blank selection (twisting, curvature, angle of opposed edge), to the symmetry of the piece and the degree of transformation observed on the edge opposed to backing (see section above, Figs. 10, 11 and SM1).

The exploration of intra-assemblage diversity and inter-assemblage 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 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 diversity for the location of the backed edge, suggesting that the backing affecting the whole edge becomes dominant from MB3010 (Middle Holocene) onwards.

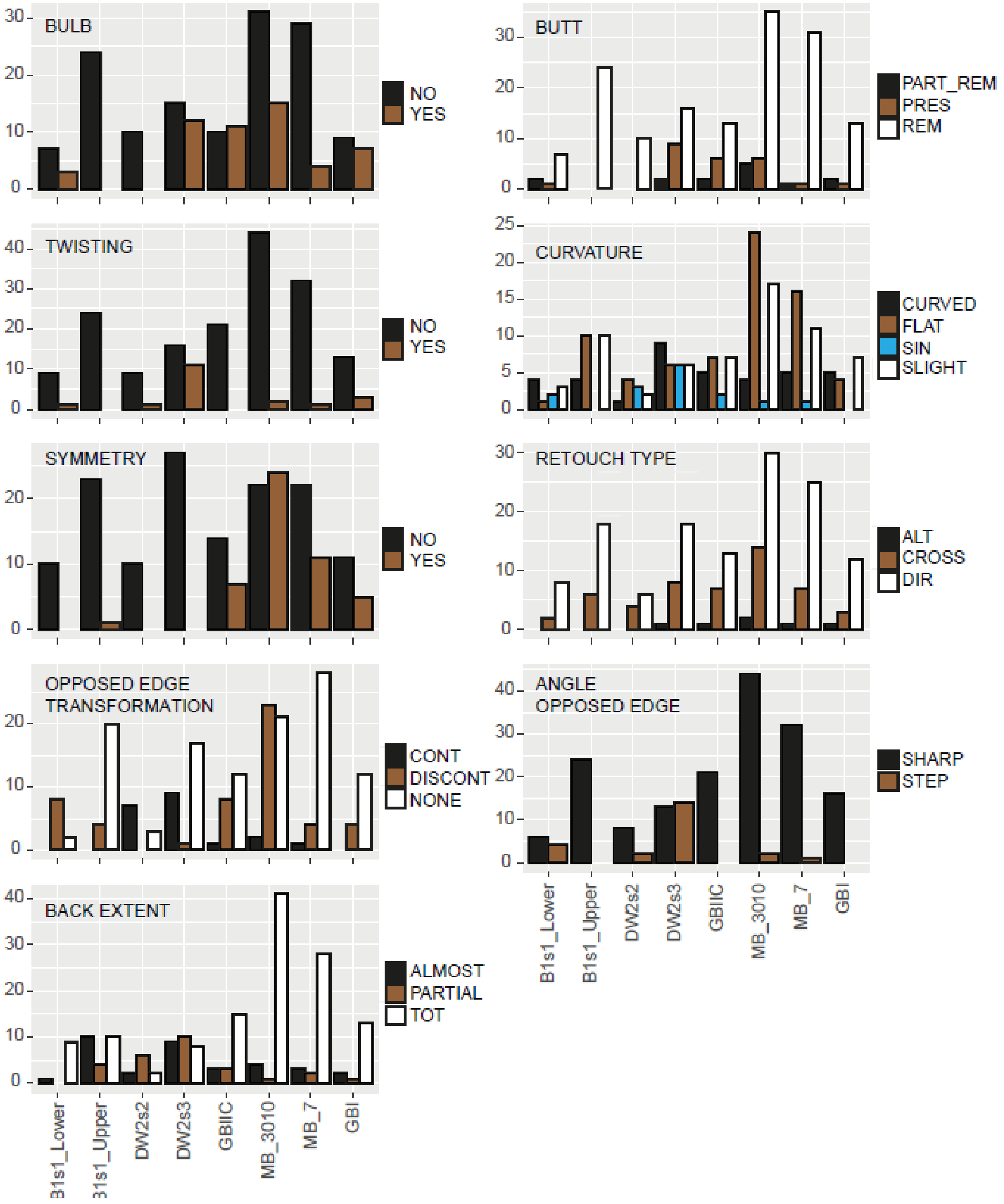

Fig. 10 Barplot showing the counts of pieces exhibiting the main qualitative traits in each assemblage

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.

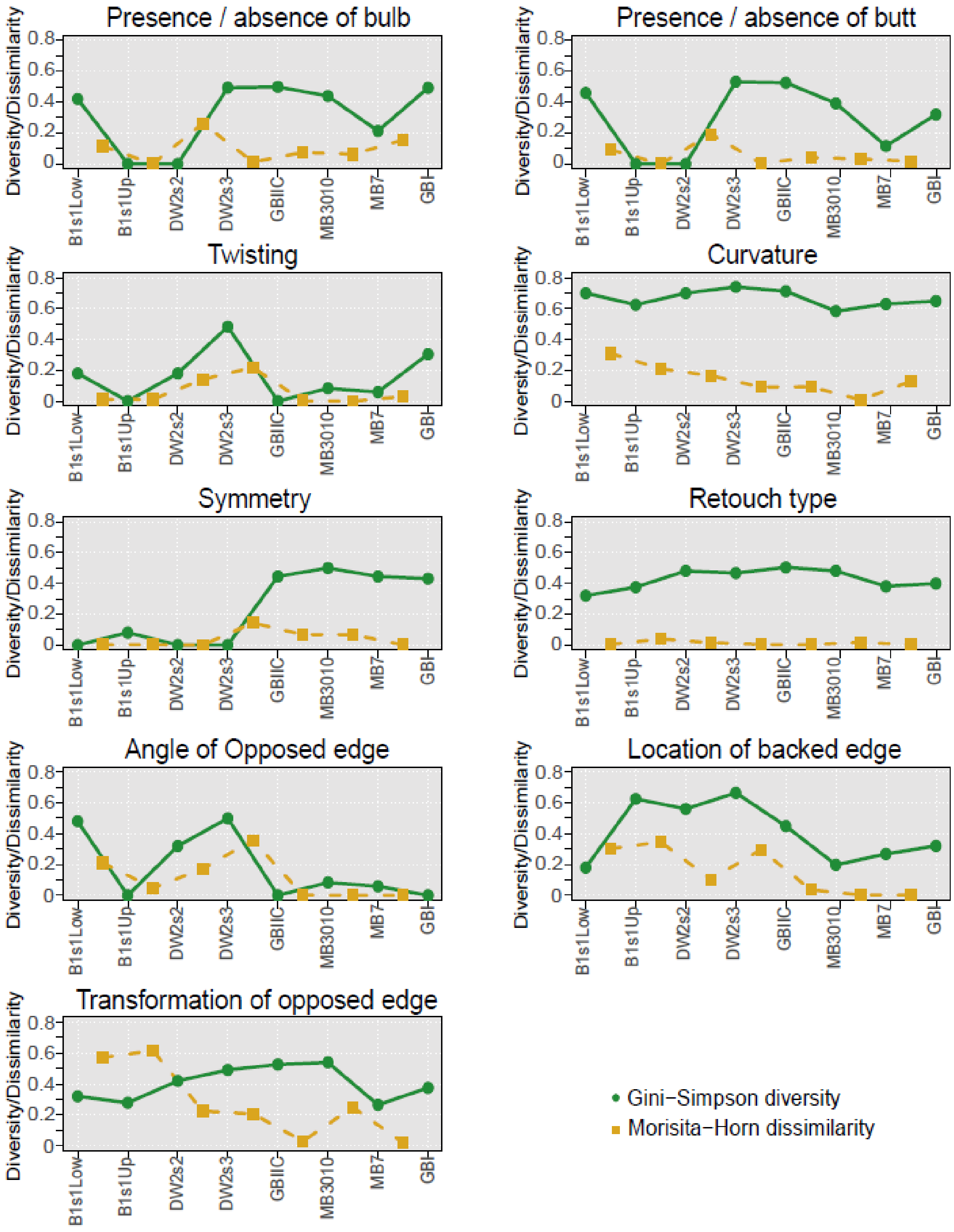

Fig. 11 Plots of Gini-Simpson diversity and Morisita-Horn dissimilarity values for each qualitative variable

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). This supplementary variable was chosen as the PCA above 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 summarises 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 characterised 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 minimal transformation of the blank to backed pieces with 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/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".

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

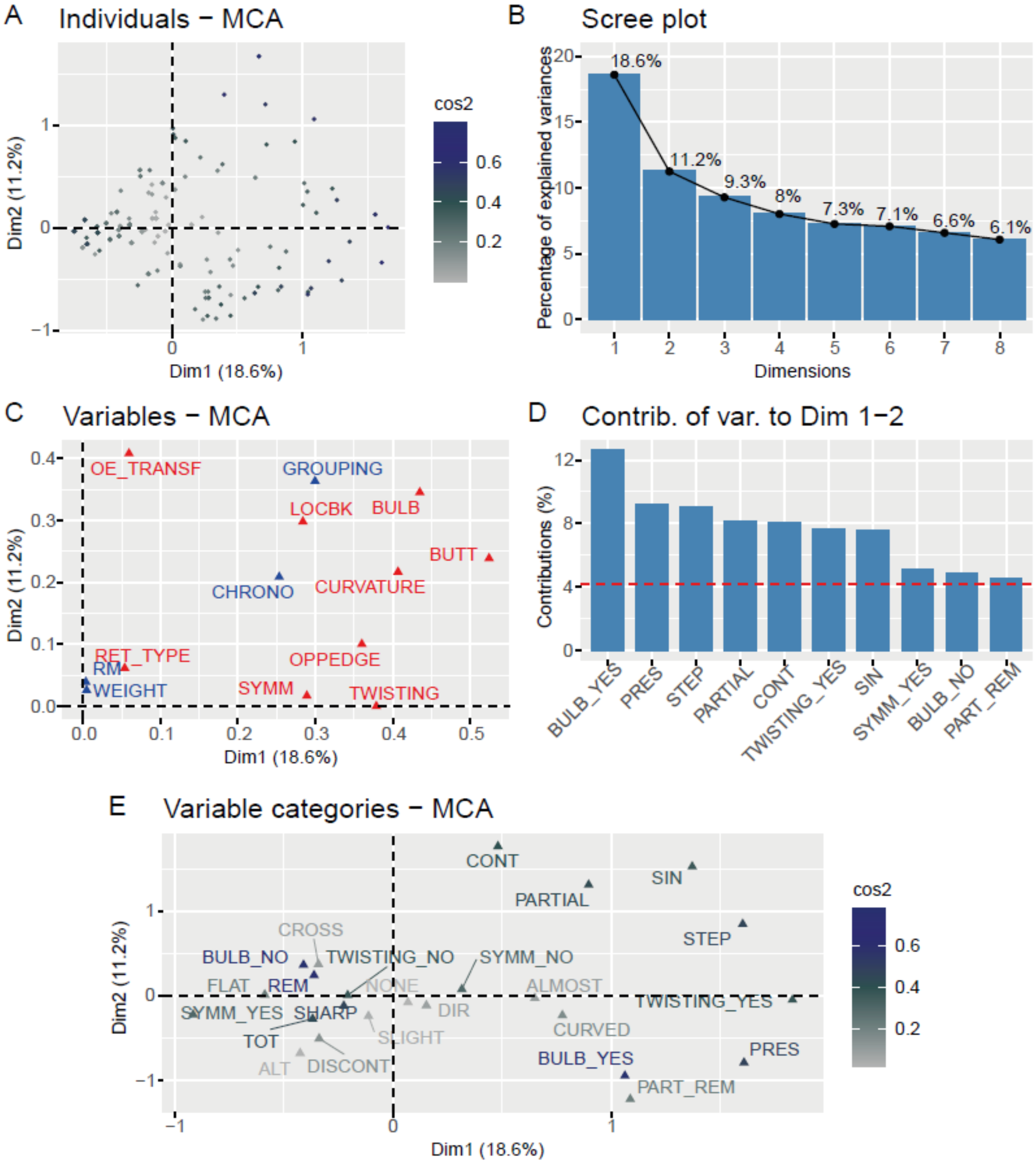

Fig. 12 MCA plots for the two first components

DW2s3 (Early Holocene), and to a lesser extent DW2s2, are separated 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. DW2s2 and DW2s3 are thus characterised 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/or hafting properties different to backed pieces from the other sites, which may also relate to their microlithic size (significant correlation with the supplementary variable “weight”).

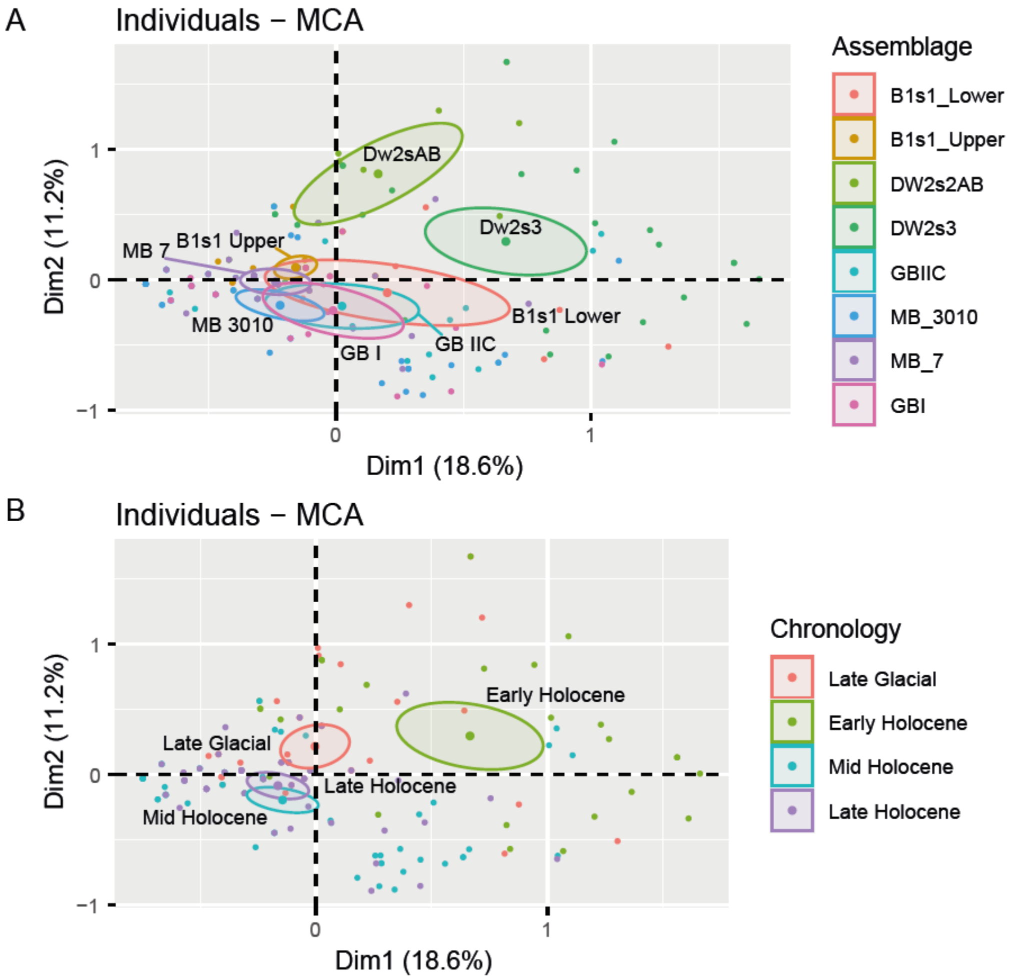

Fig. 13 Individual plots of the two first components of the MCA

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	<.001	OE_TRANSF	0.4081	<.001
BULB	0.4347	<.001	BULB	0.3453	<.001
TWISTING	0.3786	<.001	**GROUPING**	**0.3635**	<.001
CURVATURE	0.4065	<.001	LOCBK	0.2982	<.001
OPPEDGE	0.3599	<.001	BUTT	0.239	<.001
SYMM	0.2889	<.001	CURVATURE	0.217	<.001
LOCBK	0.2838	<.001	**CHRONO**	**0.2089**	<.001
CHRONO	**0.2532**	<.001	OPPEDGE	0.1005	<.001
GROUPING	**0.2995**	<.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 <.05***		
	Estimate	**p.value**		**Estimate**	**p.value**
Early-Holocene	0.5773	<.001	*DW2s2AB*	0.7553	<.001
DW2s3	0.6127	<.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	<.001

The plane of the third and fourth components summarises almost 20% of the total variability (Table 8 and Figs. 14-15). The third component corresponds to the degree of "investment" put into the backing, opposing pieces with backing affecting the whole edge with a cross retouch. It opposes pieces that have a continuous backed edge characterised by cross retouch to partially backed pieces characterised by the use of direct or alternate retouch. The fourth component opposes longitudinally flat or slightly curved pieces with a discontinuous transformation of the edge opposed to backing, to 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 components 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 a 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 separate them), and that they share the same technological attributes and most probably the same economic context and site function (i.e., dominant exploitation of bovids; Lesur et al. 2016; Ménard et al. 2014).

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	<.001	CURVATURE	0.4324	<.001
RET_TYPE	0.3148	<.001	OE_TRANSF	0.3732	<.001
OE_TRANSF	0.1899	<.001	BUTT	0.1937	<.001
BUTT	0.1689	<.001	TWISTING	0.0816	0.0001
OPPEDGE	0.0938	<.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			

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 characterised by a 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 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 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.

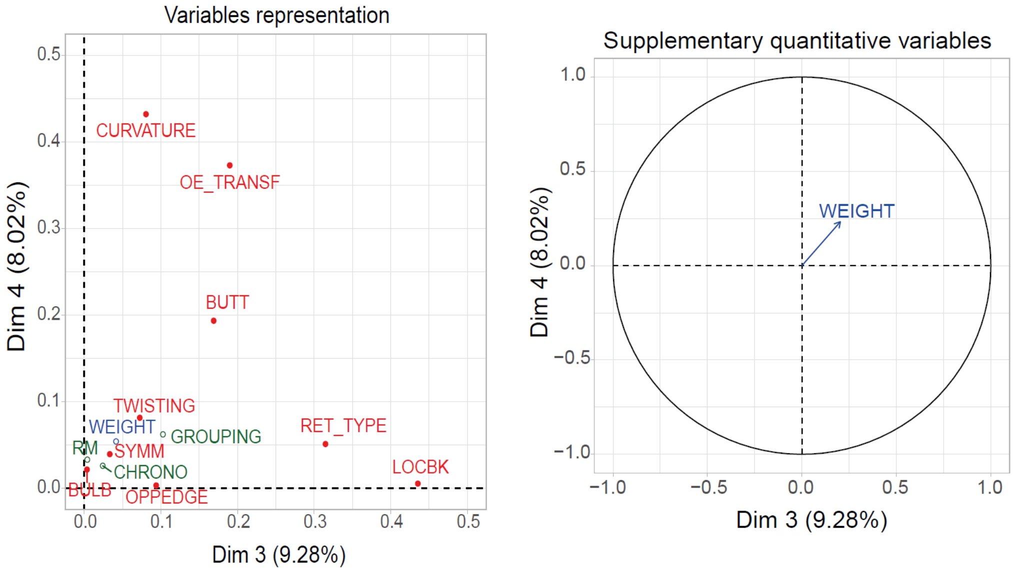

Fig. 14 Graphs of the qualitative and supplementary variables of the MCA for components 3 & 4

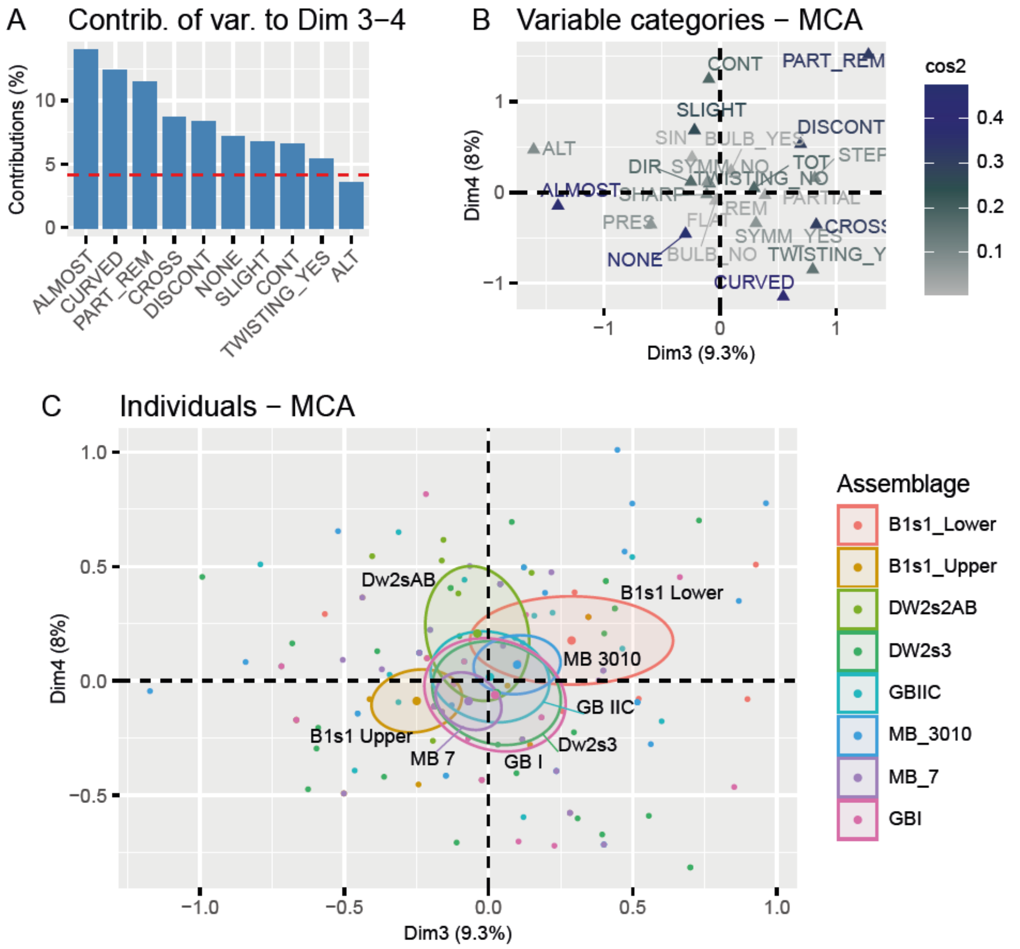

Fig. 15 Graphs of the variable categories and of the individuals on components 3 & 4 of the MCA

6.3. 2D Geometric Morphometrics 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 for the open curves analysis pieces with bilateral retouches such as the ones from DW2s2, which is somehow artificial. Unless indicated otherwise, results of analyses conducted on the outlines are in close agreement with the ones on open curves, indicating a limited influence of the opposed edge morphology on the analysis.

A PCA of the outlines indicates 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).

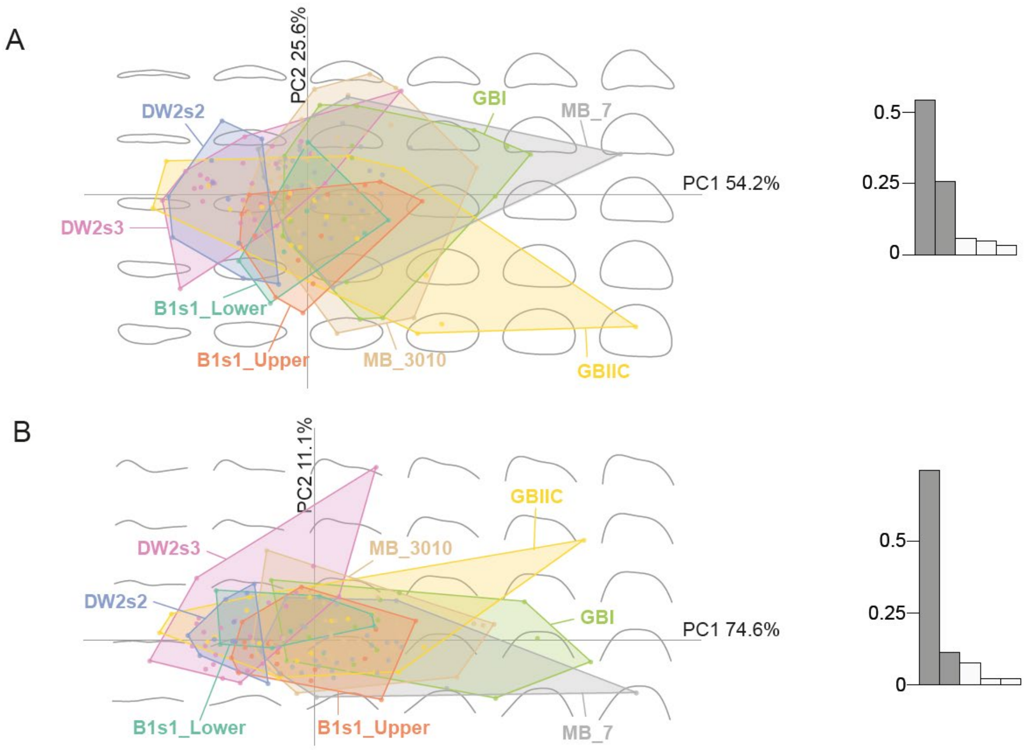

Fig. 16 A. Results of the PCA for the 1st and the 2rd component on outlines; B. on open curves

Confusion matrices were used to visualize Linear Discriminant Analysis (LDA) results (Fig. 17). The model on outlines (Fig. 17A) is not perfectly discriminating 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 size of the sample. The model on open curves (backed edges; Fig. 17B) is less helpful with correct prediction only for DW2s3 and Mochena Borago, probably as a result of a great heterogeneity of retouched edges morphology among the samples analysed.

A model with chronological periods (Fig. 17C) provides a clearer picture and allows 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.

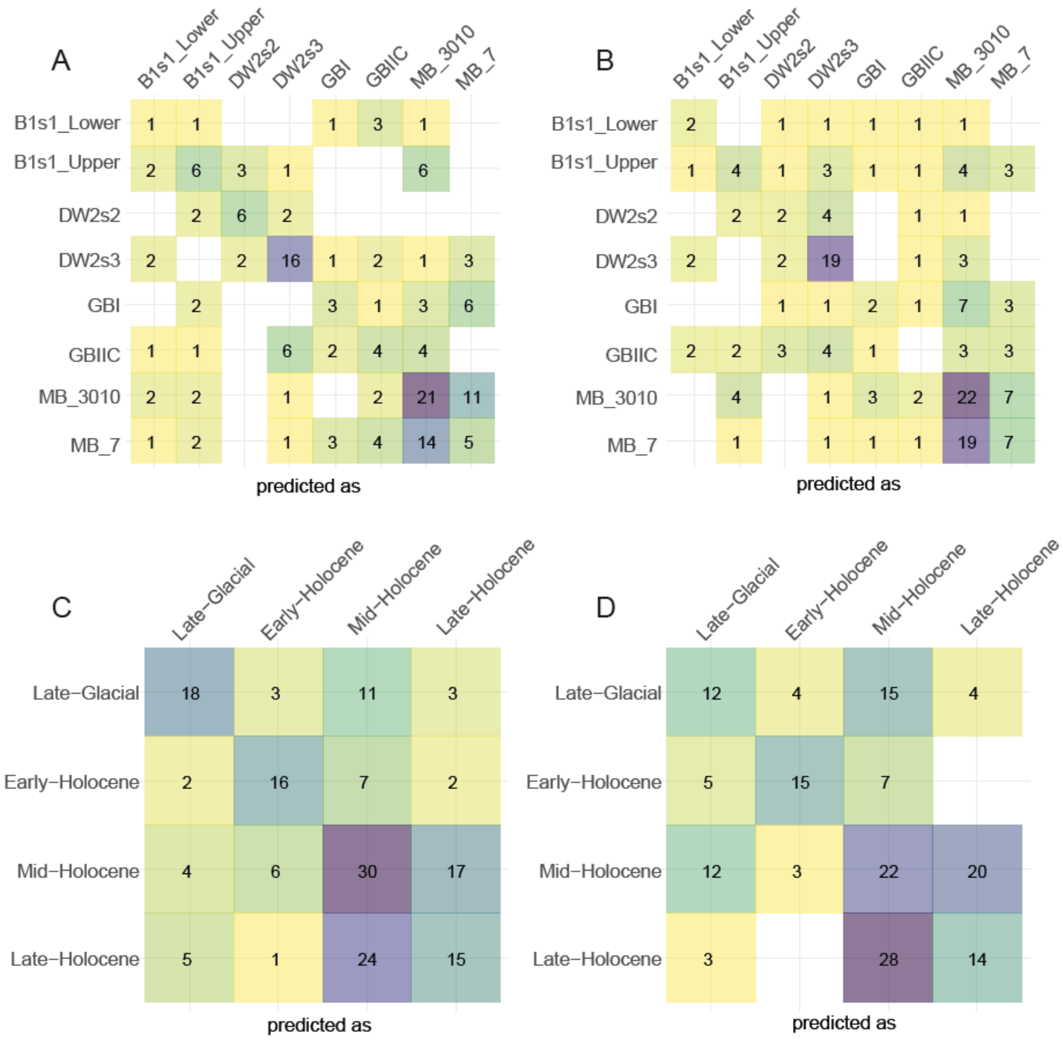

Fig. 17 A. Confusion matrices of outlines LDA, B. of open curves LDA (assemblages). C. Confusion matrices of outlines LDA, B. of open curves (chronology)

To better ascertain for the presence of significant differences between the analysed assemblages and/or chronological periods we ran Permutational Multivariate Analysis of Variance (PERMANOVA) on distance matrix (using the function adonis in the vegan package; Oksanen et al. 2019). The latter tests whether centroids (means) and within-goup dispersions are homogeneous across all groups. The test is non-parametric 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 (Pr(>F) smaller than 0.001; see SM6).

These different analyses are in close agreement with multivariate analyses indicating differences between assemblages and a chronological trend towards transverse symmetry (i.e., “geometric” morphologies during the Early and Middle

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 interestingly the proximity of B1s1 and DW2s3, which had not been identified before. A similar test at the chronological period level again indicates dissimilarities between each pair except for the Middle-Late Holocene one.

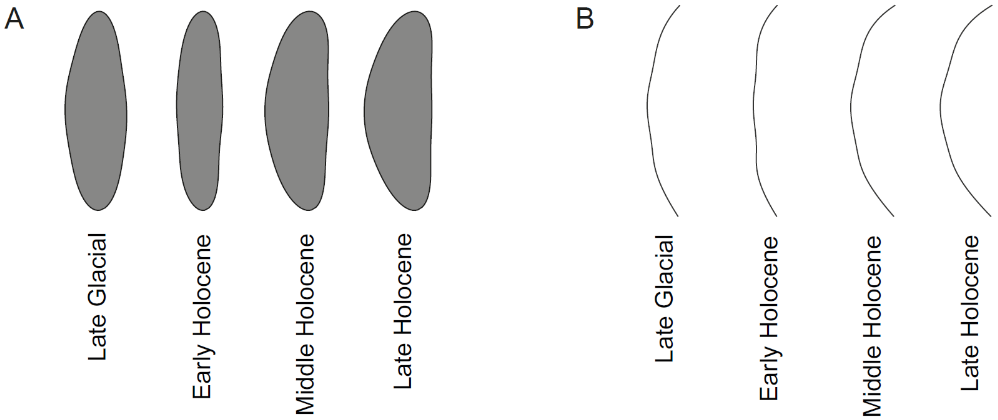

Fig. 18 A. Mean shapes of outlines for each chronological period (plan views, main retouched edge to the left); B. on open curves.

7. Discussion

Our short review of sites well dated to the end of the Pleistocene and Early Holocene in the HoA shows that there is only limited evidence for backed pieces before the end of MIS 2/beginning of MIS 1. However, a large part of the end of the Upper Pleistocene, broadly corresponding to MIS2, remains undocumented in the HoA, as 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 in Upper Pleistocene MSA contexts (ex-transitional industries) seems to have been somewhat overstated in the past. Their occurrence may result from mixing with more recent levels (e.g., Porc-Épic), or were appearing in limited numbers (e.g., Goda Buticha unit IId-IIf, Mochena Borago).

This paper aimed to systematically compare backed pieces from several sites of the region and in doing so test several trends that have been proposed during previous studies (see above). In particular, these were:

- Is there a trend towards the production of smaller backed pieces over time?
- Is there a trend towards an increase in symmetry over time?
- Do the observed variations in shape correspond to chrono-cultural entities?

7.1. Are backed pieces smaller over time in the Horn of Africa during MIS 1?

Our results suggest that rather than a trend towards the production of smaller backed pieces over time, we observe a high variability in size at the beginning of the period (Late Glacial and Early Holocene) while from the Middle Holocene onwards backed pieces are consistently (with less variance) of smaller dimensions (Fig. 7).

7.2. Are backed pieces more symmetrical over time in the Horn of Africa during MIS 1?

Only backed pieces from the Middle Holocene onwards present a transversal symmetry (Figs. 10-11). Multivariate analyses show that this correlates with a backing retouch affecting the maximum thickness of the pieces (Fig. 9) as well as with a transformation of the blank involving the removal of the proximal part (butt and bulb), a continuous backing retouch on the whole edge, and a possible selection of blanks with flat profiles (Figs. 11-13). 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 standardisation of backed pieces as the outline analysis points to the great intra-assemblage variability in the samples, regardless of the period considered (Fig. 16).

7.3. Do observed morphometrical variations correspond to chrono-cultural entities?

The results from the univariate, multivariate and GM analyses conducted on our sample 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 characterised 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 actually come from three different sites, spatially and temporally close to each other. 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 palaeoenvironmental context (Lesur et al. 2016; Ménard et al. 2014). Functional diversity may therefore better explain the diversity of backed pieces than their association with specific and distinct chrono-cultural entities.

On the contrary, the second group, corresponding to later assemblages (i.e., Middle and Late Holocene) shows a greater overall homogeneity for these general characteristics, and have higher frequencies of symmetrical pieces but these however do not imply a lower intra-assemblage variability (see Fig. 11) nor a standardisation in shape (see results of the GM analyses). They 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 (e.g., higher frequency of bladelet production between Goda Buticha and Mochena Borago, and between levels at Goda Buticha, different compositions of the lithic assemblages, in particular lower frequencies of backed pieces at Goda Buticha), that do not allow to group them under the same chrono-cultural entities. However, some similarities in the morphometrical characteristics may reflect a higher-order relationship such as functional convergence and/or the regional adoption and spread of this type of tool.

The presence of backed pieces is usually associated with major changes in technical behaviours, such as hafting, or hunting/fishing techniques. But several use-wear (e.g., Groman-Yaroslavski et al. 2020; Wadley and Mohapi 2008; Wurz and Lombard 2007) and comparative analyses (Ambrose 2002; Clarkson et al. 2018; Lewis et al. 2014) highlighted the need to take cautiously any assumption that they were all hafted to serve as projectiles or that they were part of the same "phenomenon" (in opposition to convergence). The results presented here may suggest a greater overall variability of backed pieces in the Late Glacial and Early Holocene, compared to more recent periods. The influence of raw material type and distance is certainly limited as most backed pieces in our sample are in obsidian and the sites are located in very close proximity to obsidian sources – it remains uncertain only in the case of 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 based on a larger sample of sites and in combination with use-wear analyses. If we accept that these artefacts 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).

7.4. The Horn of Africa in an eastern African perspective

The HoA corresponds to a large and diverse geographic unit that can be compared to other ones of similar size such as East Africa (Tryon 2019, p. 271). Here we have actually used data from Ethiopia only; the inclusion of assemblages and backed pieces from Somalia and Somaliland would certainly 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 certainly do not account for all the regional diversity and that we had to limit our study to the few assemblages for which we had a good stratigraphic and chronological control. The result is an incomplete but reliable framework, with the first quantified multi-site comparisons for the backed pieces in the HoA.

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 to a certain extent faces the same lack of consensus regarding the nomenclature as the HoA (e.g., Wilshaw 2016). Comparisons based on data available in the literature would be, to our knowledge, limited to mean metrics for given types of tools. Because of competing definitions for different sub-categories of backed pieces and because of strong intra-assemblage variability and important overlap between variables like length and width, comparisons of such data are likely to produce inconclusive results. We believe that the methods presented here would prove efficient in making comparisons between regions with rich corpuses of backed pieces like East Africa where non-linear patterns of evolution have already been identified (e.g., Ambrose 1984b, 1998; Wilshaw 2012).

8. Conclusion

One important result of this paper is that using attribute and geometric morphometric analyses we were able to identify diverse groups of backed pieces, in a replicable manner and without the use of any subjective typology. For example, our analysis enabled to set 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 an attribute analysis using relevant criteria can be useful to highlight morphometric patterns of variability of backed pieces in a more objective and reproducible way than the use of "classic" typologies. This was a pilot study aiming to apply this approach to backed pieces in the HoA in order to discuss patterns of variability over time and their significance in the LSA. Whereas our study relies on a limited number of assemblages, further analysis including data from other dated contexts, and integrating high-resolution palaeoenvironmental data will help to detect and formulate hypotheses to explain further patterns of variation of backed pieces.

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Online Resources

Supplementary materials for the paper can be downloaded here: https://doi.org/10.6084/m9.figshare.7825607 (doi:10.6084/m9.figshare.7825607)

SM1 List of variables recorded and their definitions (.pdf).
SM2 Database of backed pieces used in the analysis (.csv)
SM3 Photographs of artefacts (.zip)
SM4 R Project (.zip) compiling all R scripts and data sets used in the analysis
SM5 Tables of the results of the Kruskal-Wallis and pair-wise Mann-Whitney test on the quantitative variables used in the analysis (.pdf).
SM6 Tables of the results of PERMANOVAs tests on outlines and open curves (.pdf)

Conflict of Interest

The authors declare that they have no conflict of interest.

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