Blank predetermination in the Iberian Acheulean. Insight from the cleaver on flake assemblage of Casal do Azemel site (Leiria, Portugal) by a Geometric Morphometric approach

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Abstract

Over the last decades, the increase of data available for the study of the archaeological topic in the Iberian Peninsula during the Middle Pleistocene has favoured the understanding of the technological trends of the Iberian Acheulean assemblages. These have features of a Large Flake Acheulean (LFA), displaying, among other traits, a significant presence of cleavers on flake, a specific tool type that is of great cultural and technological value. Particularly, these artefacts are privileged to discuss the importance of blank predetermination in the Acheulean techno-complex. Following this reason, in the present work we aimed to explore this topic through the 2D Geometric Morphometric Analysis of the cleaver on flake assemblage from Casal do Azemel (Leiria, Portugal), an example of a paradigmatic Iberian Acheulean site that has one of the largest collections of this type of tools in Western Europe.

The results obtained revealed that no significant morphological differences were found according to the technological solutions applied to the acquisition of the blank and its secondary transformation. Considering that in most of the cases these tools display a low degree of secondary transformation, these data suggest that underlying the production of Casal do Azemel's cleaver on flake assemblage was not only a technological and cognitive flexibility (given its typological composition), but also a conceptual, structural, and morphological standardisation. These observations allowed us to discuss the significance of blank predetermination in the Acheulean, implying the existence of greatly structured technical and cognitive prerequisites.

Keywords: Large Flake Acheulean; Cleavers on flake; Geometric Morphometric Analysis; Flake Blank; Predetermination; Standardisation.

1. Introduction

Over the last decades, the increase of geoarchaeological data available for the study of the Lower Palaeolithic in the Iberian Peninsula, as well as the expansion of archaeological research

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into different parts of this territory, have favoured a better understanding of the technological and chronological trends of the Iberian Acheulean techno-complex (Méndez-Quintas *et al.* 2020; Santonja *et al.* 2016; Santonja & Pérez-González 2010).

Current data show that the proliferation of Acheulean sites occurs mostly from the Marine Isotopic Stage (MIS) 11 to MIS 6 (Daura *et al.* 2018; Ferreira *et al.* 2021; Méndez-Quintas *et al.* 2020; Rubio-Jara *et al.* 2016; Santonja *et al.* 2016), after emerging during MIS 13, with a later chronology than in other European regions (Antoine *et al.* 2019; Falguères *et al.* 2015; Key *et al.* 2022; Moncel *et al.* 2013; 2015; 2019; 2020; 2022; Moncel & Ashton 2018; Voinchet *et al.* 2015) - although it has been proposed that an Early Acheulean presence in Iberia could be recorded at Barranc de La Boella, dated between 1.0-0.8 Ma (Vallverdú *et al.* 2014), the presence of lithic elements that would allow it to be unequivocally linked to this techno-complex was regarded as problematic by some researchers (*e.g.*, Méndez-Quintas *et al.* 2018: 8; Moncel *et al.* 2015: 303; Santonja *et al.* 2016: 370), with recent data promoting new discussions on this topic (Ollé *et al.* 2023).

Overall, the Iberian Acheulean assemblages are mostly located in fluvial environments related to the main Atlantic regional river basins (Ferreira *et al.* 2021; Méndez-Quintas *et al.* 2020; Santonja & Villa 2006; Santonja & Pérez-González 2002; 2010; Santonja *et al.* 2016). Reference is also made to other open-air sites not directly associated with specific fluvial terrace heights (Santonja & Pérez-González 2010), as well as to assemblages from marine terraces (*e.g.,* Meireles 1992; Monteiro-Rodrigues *et al.* 2016), or from karstic deposits (*e.g.,* Barroso Ruíz *et al.* 2011; Daura *et al.* 2018; García-Medrano *et al.* 2014; García-Vadillo *et al.* 2022; Ollé *et al.* 2016), although some of the latter display technological traits distinct from those recognised in river terraces sites, having their association to the Acheulean been recently discussed (Méndez-Quintas *et al.* 2020: 933; Santonja & Pérez-González 2021; Santonja *et al.* 2016: 372; 2022: 19).

From a technological point of view, most of the sites are characterised by the extensive use of large-sized flakes, detached from large cores, as blanks for the manufacture of Large Cutting Tools (LCTs) (*e.g.,* Arroyo & de la Torre 2013; Baena Preysler *et al.* 2018; Bárez del Cueto *et al.* 2016; Ferreira *et al.* 2021; García-Vadillo *et al.* 2022; Méndez-Quintas *et al.* 2020; 2021; Rubio-Jara *et al.* 2016; Santonja & Pérez-González 2010; Santonja & Villa 2006). These features, which in Europe only have similarities in south-western France (Jaubert & Servelle 1996; Mourre & Colonge 2007; Santonja & Villa 2006; Tavoso 1986; Turq *et al.* 2010), have been highlighted as being representative of the Large Flake Acheulean - LFA *sensu* Sharon (2010) - affinity of the Iberian Acheulean (Méndez-Quintas *et al.* 2020; Santonja & Pérez-González 2010; Santonja *et al.* 2016; Sharon & Barsky 2016), in contrast to the reality identified beyond the Garonne and Tarn rivers, where the concept of large flake management is virtually absent (Santonja & Villa 2006; Sharon & Barsky 2016).

Among the LCTs usually identified in the Iberian Peninsula, the presence of cleavers on flake - expression used to refer to LCTs initially defined as *hachereau* in French (*sensu* Tixier 1956), *i.e*., tools produced on large flakes characterised by the presence of an unretouched distal cutting edge that is predetermined by the intersection of the ventral face with the cortical surface of the blank, with one or more removals previous to the detachment of the blank, or by the intersection of two ventral surfaces (Balout *et al.* 1967; Tixier 1956) - stands out.

Indeed, these artefacts are considered to be the main techno-typological markers of the LFA assemblages (Sharon 2010) and, therefore, have served as catalysts for discussing the variability of the Acheulean techno-complex in Europe, since their geographical distribution in this continent is mainly confined to the Iberian Peninsula and Aquitaine (Jaubert & Servelle 1996; Mourre 2003: 251 (Vol. 3); Mourre & Colonge 2007; Santonja & Pérez-González 2010; Santonja & Villa 2006; Sharon & Barsky 2016; Tavoso 1986; Turq *et al.* 2010), a topic that raises important questions about the process of hominin expansion across the continent and its possible connection to Africa (Méndez-Quintas *et al.* 2018; 2020; Santonja & Pérez-González 2010; Santonja *et al.* 2016; Sharon 2010; 2011; Sharon & Barsky 2016).

Simultaneously, cleavers on flake are an important source of technological information. Their reduction sequence is easier to trace than that of handaxes and they are privileged artefacts to discuss the impact of raw material, blank features and shaping technology on the morphology of the finished product (Sharon 2010: 229), since in most cases these artefacts' blanks were not extensively modified (Roche & Texier 1991; Texier & Roche 1995). Moreover, given the unretouched nature of their main active area, these are the remains that best represent the concept of predetermination (*sensu* Texier & Roche 1995: 404-405) in Acheulean assemblages, which highlights the sophisticated cognitive faculties underlying their production (Herzlinger *et al.* 2017b; Roche & Texier 1991; Sharon 2007; Texier & Roche 1995).

Following this reason, we aimed to discuss to what extent predetermined features can be displayed in these tools and their blanks. For this purpose, we defined as a case study the cleaver on flake assemblage from Casal do Azemel site (Leiria, Portugal) (Cunha-Ribeiro 1999: Chapter 9), as it has one of the largest collection of this type of tools in Western Europe; and resorted to a 2D Geometric Morphometric Analysis (GMA), since we wanted to assess the degree of shape variability according to certain techno-typological attributes and GMA is a highly effective way to quantitatively describe shape variability within and between groups of artefacts (*e.g.*, Falcucci & Peresani 2022; García-Medrano *et al.* 2020b; 2023; Herzlinger & Grosman 2018; Herzlinger *et al.* 2021; Hoggard *et al.* 2019; Iovita & McPherron 2011; Méndez-Quintas 2022; Timbrell *et al.* 2022). Although mainly applied to the study of handaxes in Acheulean research (*e.g.*, Brande & Saragusti 1996; Costa 2010; Courtenay 2023; García-Medrano *et al.* 2020a; 2020b; 2022; Herzlinger *et al.* 2017a; 2021; Hoggard *et al.* 2019; Iovita & McPherron 2011; Iovita *et al.* 2017; Key 2019; Méndez-Quintas 2022), this type of approach can also be an important pathway of data for discussing other LCTs, as highlighted in this work.

2. Casal do Azemel site (Leiria, Portugal)

In the Iberian Atlantic margin, the hydrographic basin of the Lis River, central Portugal, is an area that displays a significant record of geoarchaeological data from the Middle Pleistocene (Cunha-Ribeiro 1999; Ferreira *et al.* 2021; Méndez-Quintas *et al.* 2020). Indeed, the work carried out in the Lis River Valley at the end of the last century has allowed the identification of four main fluvial formations, as well as some colluvium formations interrelated with the river terrace sequence, or that affect the top of other sedimentary formations present in the region (Texier & Cunha-Ribeiro 1992), to which several sites characteristic of a LFA are linked.

Regarding the assemblages from colluvial deposits, the one from Casal do Azemel (Figure 1A) stands out.

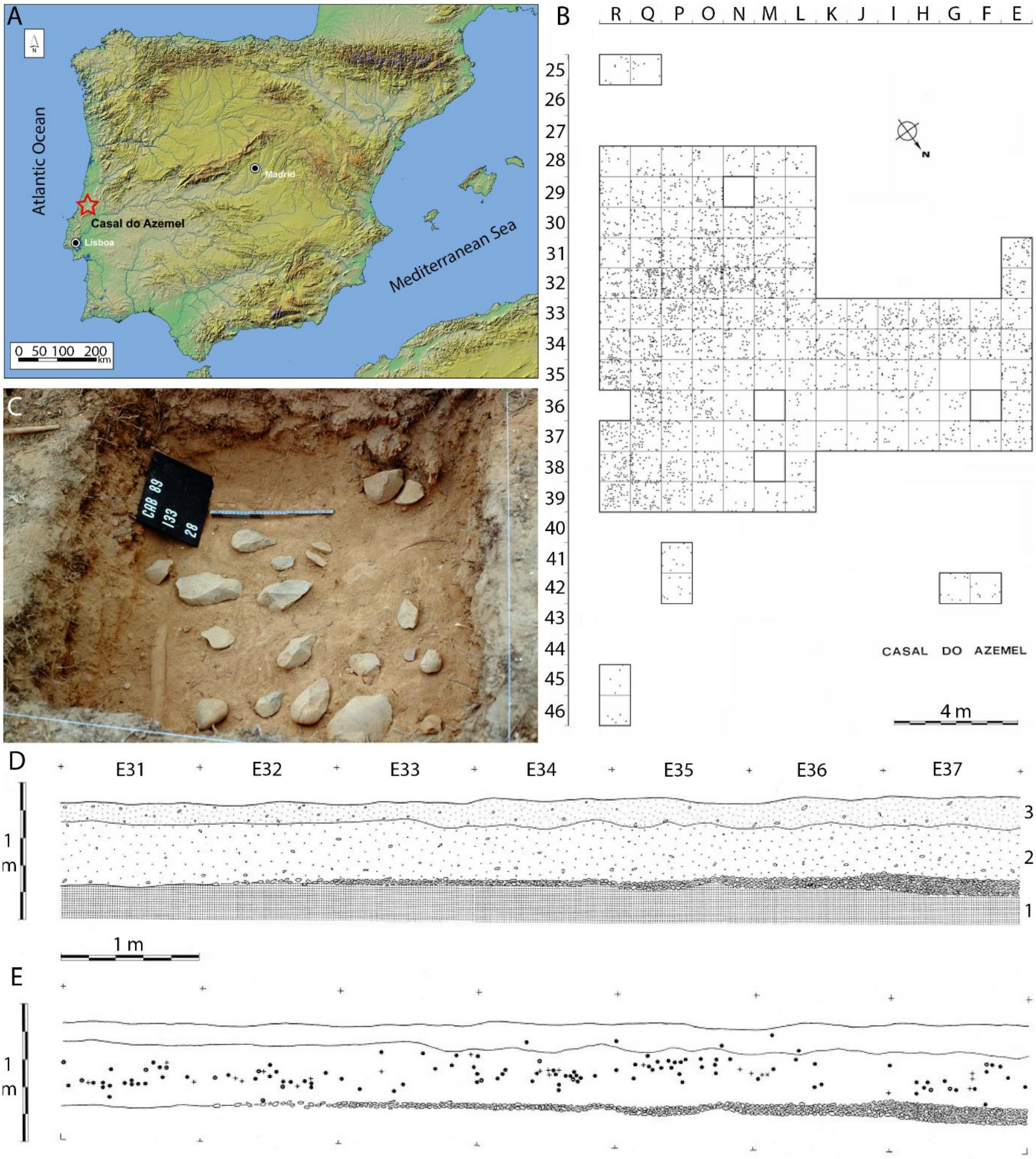

Figure 1. (**A**) Casal do Azemel location. (**B**) Excavation plan with distribution of the lithic materials. (**C**) Example of an accumulation of LCTs. (**D**) Site stratigraphy and (**E**) vertical distribution of the lithic industry (squares E31-E37) (Cunha-Ribeiro 1999: Fig. 43 and 46).

Located near the edge of an extensive sandy plateau (+120 m above the sea level) that develops northwest of the town of Batalha, overlooking the Lis River Valley, the site was discovered in the late 1970s and was excavated between 1988 and 1991 (Cunha-Ribeiro 1995). A total of 135 m^2 were excavated (Figure 1B), 18 of which were spread over peripheral pits, while the rest were concentrated in the central zone of the accumulation. These works resulted in the recovery of 3957 lithic pieces integrated within colluvial deposits that locally affect the top of the sandy-textured Pliocene marine formation represented in the area (layer 1) (Figure 1D). Specifically, two layers associated with two colluviums (layer 2 and layer 3) were identified. Most of the remains come from layer 2 (Figure 1E), which is an older colluvial deposit associated with a phase of biorhexistasy linked to a deflation episode, while a residual number of pieces were recovered in Layer 3, a more recent colluvial deposit (Cunha-Ribeiro 1999: 301-306).

Overall, the archaeological artefacts are gathered in a concentrated patch of remains that do not stand out topographically from the surrounding flat surface. Taking into account the texture of the deposits that comprise them, that the site's location does not allow for extensive mobilisation of materials, nor the movement of the objects of larger dimensions, as well as the fact that only a reduced number of small products were identified in the furthest test pits (materials that might have been dispersed by the low energy associated with the formation of the deposits), it has been proposed that the assemblage, despite its secondary context, resulted from a process of anthropic accumulation in the area where it was found (Cunha-Ribeiro 1999: 452). On the other hand, given its location in the middle of an extensive sandy plateau, it was suggested that the occupation could have occurred during a period of scarce vegetation, which would allow for perception and control over the surrounding area, being the pronounced aeolisation of the overwhelming majority of the remains (95% of the pieces are strongly aeolised) compatible with a significant deflation phase (Cunha-Ribeiro 1999: 462). Although the age of the site could not be established, considering its Acheulean features and the geoarchaeological record of the region, there are suggestive elements to associate it to the second half of the Middle Pleistocene.

Despite the absence of a more precise chronometric framework, the secondary context of the assemblage, the aeolisation of the remains (which made use-wear studies unviable), or the lack of fauna (given the acidic nature of the soil), Casal do Azemel is an important site for the study of the human occupation in the Iberian Atlantic margin during the Middle Pleistocene. Not only due to the concentration of almost 4000 lithic pieces belonging to a homogeneous set, in terms of the pieces' physical state, the raw material used (93% of the material is in quartzite) and its techno-typological and techno-economic features (Cunha-Ribeiro 1999: 461) but also due to the high number of LCTs: 556 handaxes (mostly on flake blanks), 124 cleavers on flake and 63 other large flake tools (*e.g.*, knives, massive scrapers, denticulates, notches…).

Constituting the largest collection of LCTs for an excavated site in the Iberian Peninsula (Méndez-Quintas *et al.* 2020: 931), these artefacts represent ca. 85% of the site's tools (Ferreira 2023: 255) and ca. 19% of the site's industry (Table 1) (Cunha-Ribeiro 1999: Chapter 9). Given the absence of large cores, and the fact that the area where the site is located corresponds to the surface of an extensive Pliocene marine deposit with a predominantly sandy texture, LCTs' blanks were obtained off-site, through the exploitation of appropriately sized pebbles, with two potential source areas identified in Quaternary deposits of the Lena River valley within a distance of 1.5 to 5 km (Cunha-Ribeiro 1999: 455). Although it was previously proposed that the blanks would have been transported to the site, where their subsequent transformation into tools would have taken place (Cunha-Ribeiro 1999: 456), the clear identification of flakes from LCTs' configuration processes is lacking. Consequently, it remains to be properly assessed in future studies if the LCTs from Casal do Azemel were shaped on-site (at least most of them) or if they were knapped elsewhere and brought for usage and subsequent abandonment, taking part in a complex dynamic of exploitation and occupation of the landscape.

Table 1. Distribution of Casal do Azemel assemblage according to the classification categories considered (modified from Cunha-Ribeiro 1999).

Group	*n*	%
Flakes	1620	40.9
Cores	434	11.0
Knapping waste	483	12.2
Detaches, manuports and hammerstones	525	13.3
Handaxes	556	14.1
Cleavers on flake	124	3.1
Other large flake tools	63	1.6
Tools < 10 cm	152	3.8
Total	3957	100

3. Materials and methods

3.1. The cleaver on flake assemblage from Casal do Azemel

The Casal do Azemel's cleaver on flake collection comprises 124 items, exclusively made on quartzite, with an average size of 124.76 x 85.74 x 38.36 mm and 423.63 g of weight (Table 2).

In addition to being an extensive collection, it also stands out for having a balanced distribution between specimens whose blanks proceed from cores in different exploitation phases (and with distinct reduction patterns), given the typological (*sensu* Tixier 1956) composition of the assemblage (Table 3), which highlights the ability of Casal do Azemel's knappers to explore and control different technological solutions to obtain this type of tool. Overall, these artefacts (*e.g.*, Figures 2-4) display a considerable frontal symmetry and, regardless of the type, they tend to display a relatively low degree of secondary transformation (Cunha-Ribeiro 1999: 437; Ferreira 2023: 77-80).

Table 2. Main metric attributes and weight of the cleavers on flake from Casal do Azemel.

Metric attributes	Min.	Max.	Mean	SD
Length (mm)	88	183	124.8	17.7
Width (mm)	57	127	85.7	12.2
Thickness (mm)	25	62	38.9	7.3
Weight (g)	110	1124	423.6	165

Table 3. Typological distribution of the cleavers on flake from Casal do Azemel.

Type	n	%
0	47	37.9
I	16	12.9
II	35	28.23
V	1	0.81
VI	25	20.16
Total	124	100

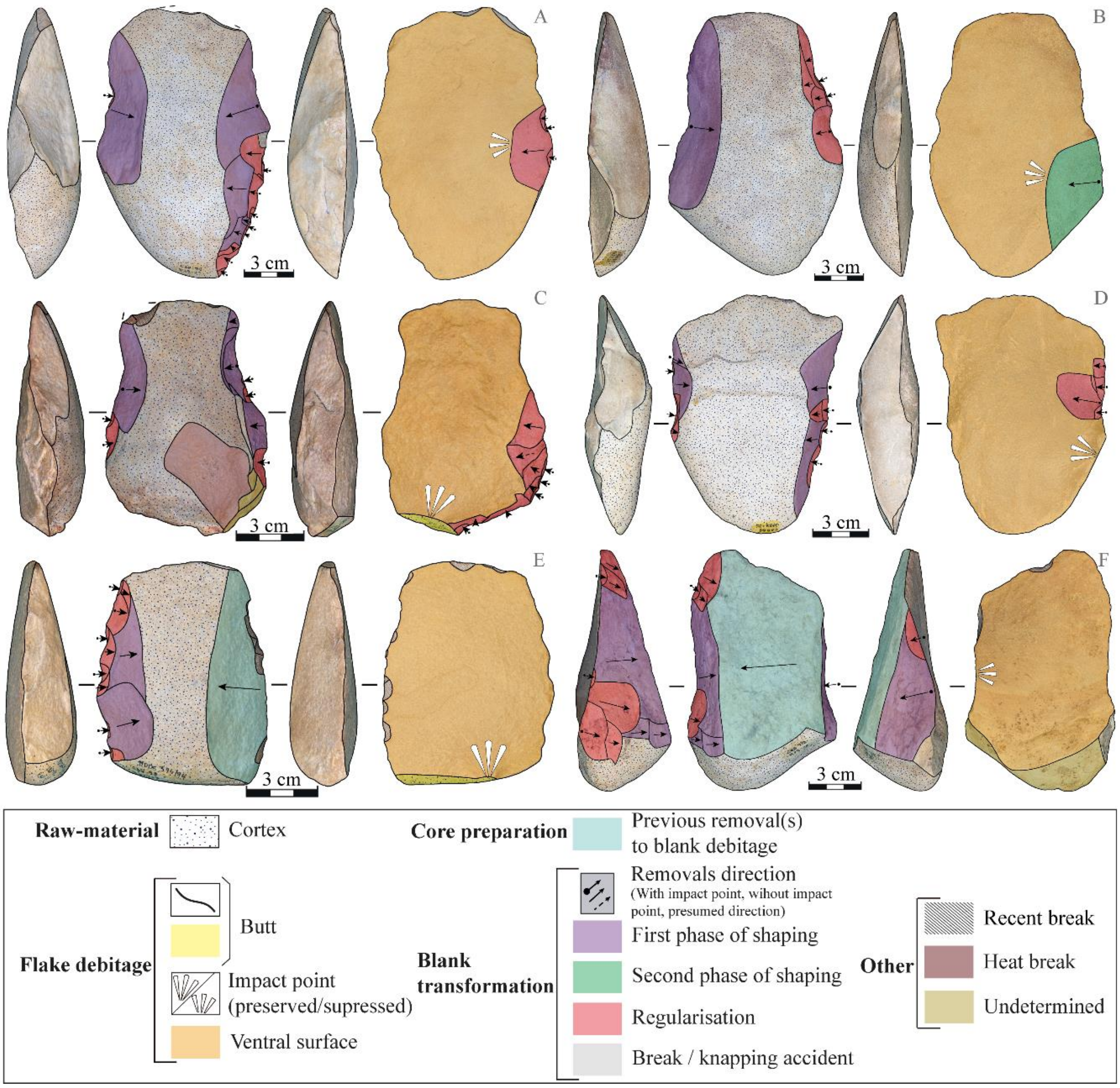

Figure 2. Diacritical drawing of some cleavers on flake from Casal do Azemel: (**A-E**) Type 0 and (**F**) Type I.

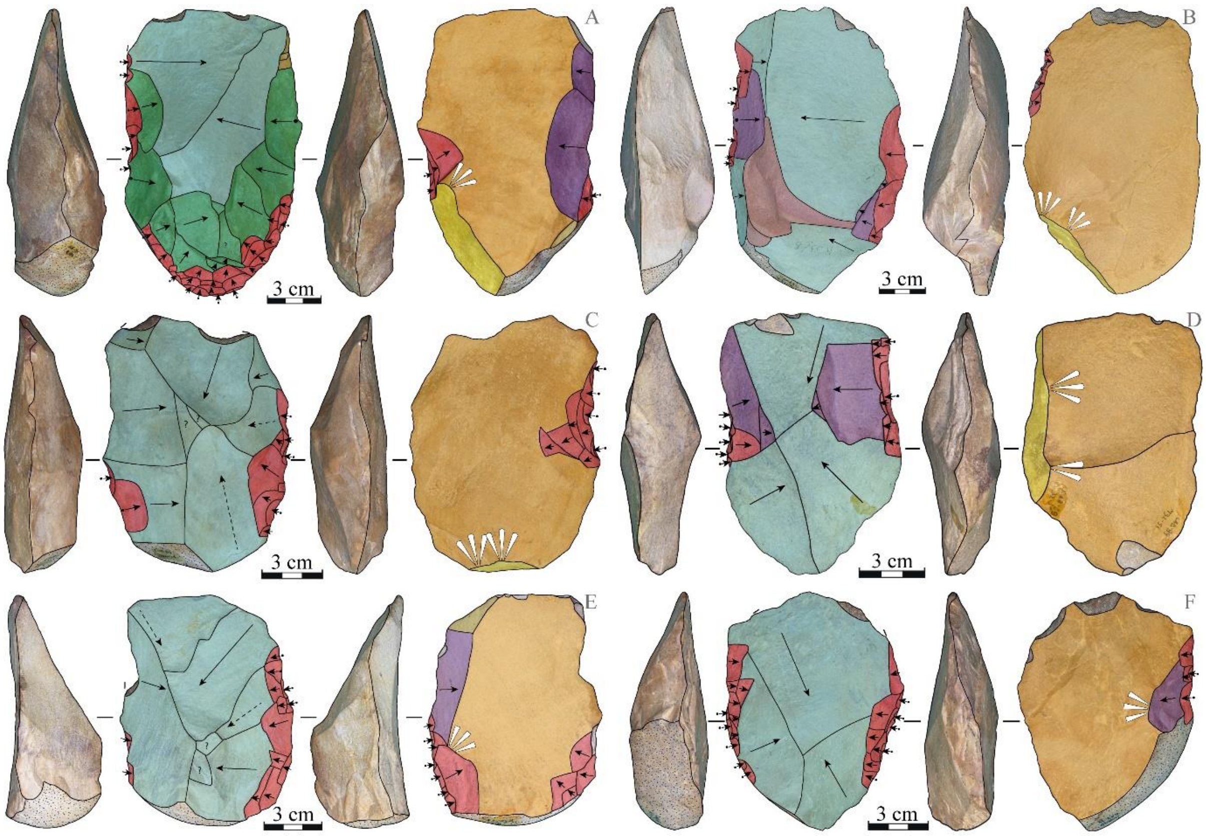

Figure 3. Diacritical drawing of some cleavers on flake from Casal do Azemel: (**A-F**) Type II.

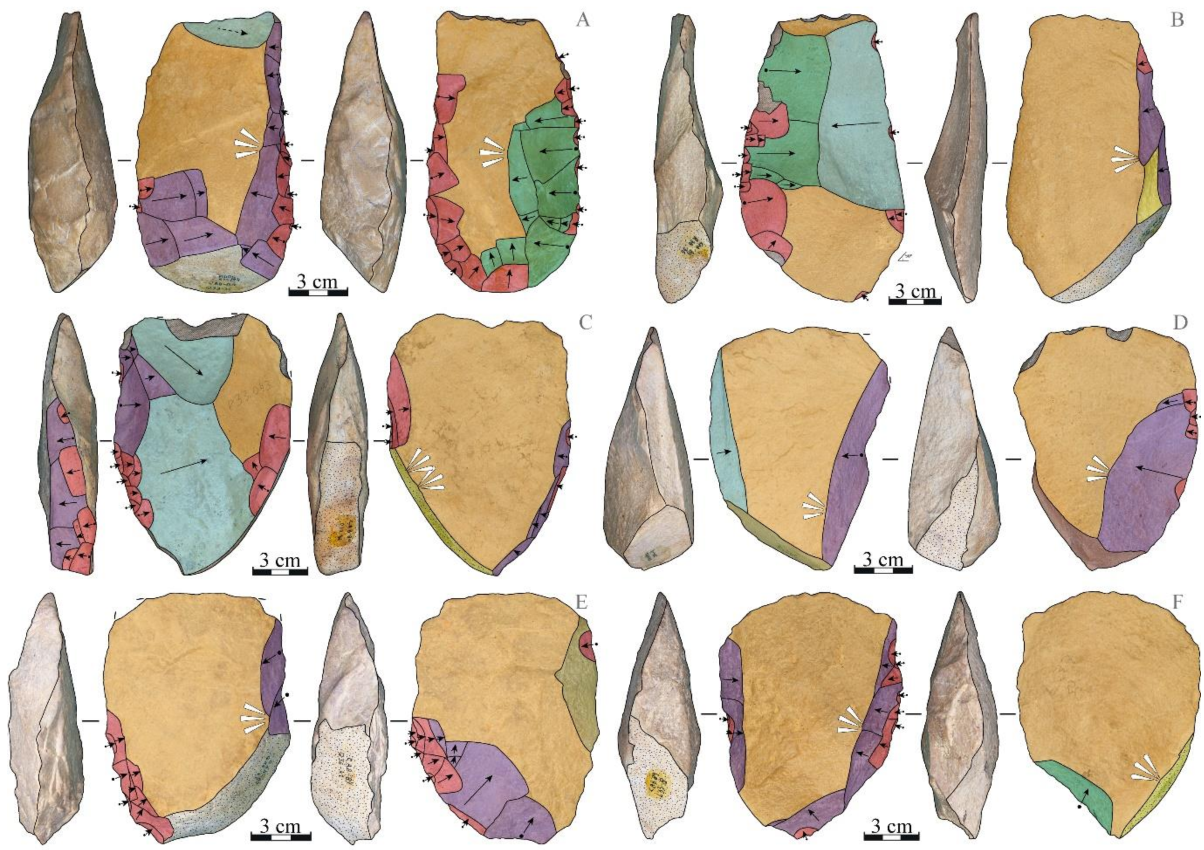

Figure 4. Diacritical drawing of some cleavers on flake from Casal do Azemel: (**A-F**) Type VI.

3.2. Geometric Morphometric Analysis

In the present study we performed 2D GMA on 114 cleavers on flake (10 pieces with considerable fractures were excluded) (SF1 Table 1). We adopted the systematisation developed by Jacques Tixier (1956), which includes six types - 0 to V - to which type VI has been added (Balout *et al.* 1967). This choice was based on the notion that the great advantage of Tixier's typology is the fact that it is based on the strategies employed to obtain the blank (Mourre 2003: 62 (Vol. 1), whose degree of predetermination we wanted to discuss. In addition to analysing the morpho-typological relationship in the sample, we sought to explore the influence of some technological variables on the overall shape of these tools, namely: the direction of the blow, the type of striking platform, the shaping, regularisation and distal cutting edge indexes (perimeter shaped, regularised, or occupied by the distal cutting edge, in relation to the total perimeter of the tool - following Méndez-Quintas 2017: 66; SF1 Figure 1), the dorsal and ventral surface area affected by knapping removals (following Sharon 2007: 211), the surface area affected by removals previous to the detachment of the blank, the number of shaping and regularisation scars, their total combined and the secondary reshaping strategy.

3.2.1. Datasets and recording procedures

The data acquisition procedure consisted of photographing each tool and, for each one, 32 landmarks were measured and distributed proportionally by superimposing a regular distance grid on the photographed image, using Adobe Illustrator software. We closely adopted the template used by García-Medrano *et al.* (2020b) and Méndez-Quintas (2022), adding 4 extra landmarks (2 on the tip and 2 on the base). The landmark measurement was performed using tpsUtil and tpsDig open-source software on jpeg images of each cleaver on flake with the grid. The images were synthesised into one thin-plate spline (tps) file in tpsUtil 1.74 (Rohlf 2017b) and the position of the landmarks was obtained in tpsDig 2.30 (Rohlf 2017a) (Figure 5). Following these procedures, we measured 114 cleavers on flake and recovered a dataset with 7296 Cartesian coordinates. We share the dataset (Ferreira *et al*. 2023) for comparative purposes and validation of the results obtained (SF2).

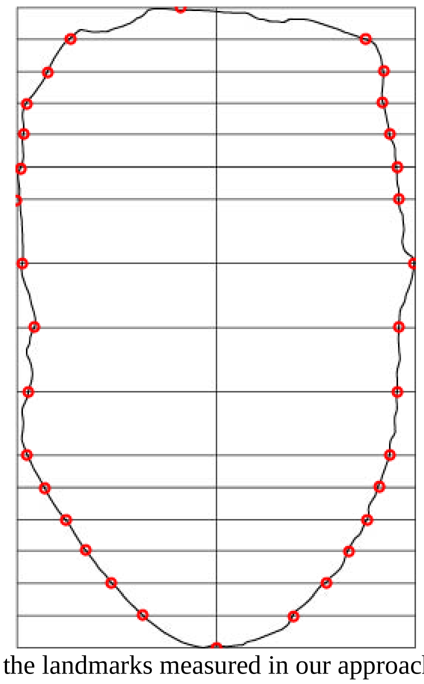

Figure 5. Example of distribution of the landmarks measured in our approach.

3.2.2. Analytical procedure

Regarding the analytical procedure, all statistical tests have been performed with MorphoJ and PAST software (Hammer *et al.* 2001; Klingenberg 2011). The landmark dataset was processed following the Generalised Procrustes Analysis (GPA) (Figure 6), a process that minimises the differences between landmarks' position in the analysed sample, bringing all artefacts' outlines to a standardized size, orientation, and position, before subsequent analysis (García-Medrano *et al.* 2020b: 5).

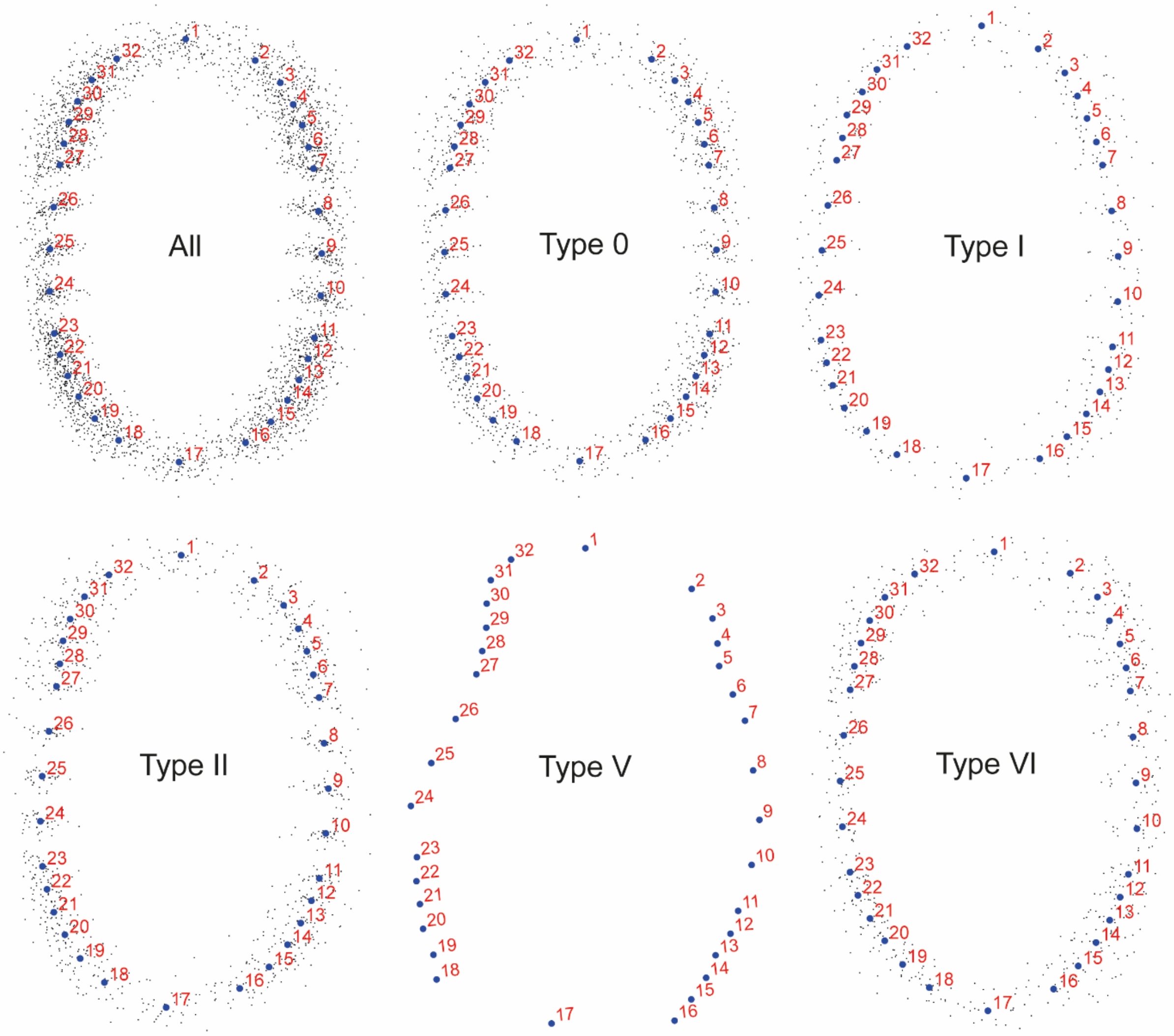

Figure 6. Landmark features after Procrustes alignment.

Additionally, on the GPA dataset, we calculated the coefficients (harmonics) according to Elliptic Fourier Analysis (EFA) (Ferson *et al.* 1985; Kuhl & Giardina 1982) since it has been proposed that EFA is a procedure that can better explain the shape variability in outline specimens such as LCTs (Courtenay 2023; Hoggard *et al.* 2019; Iovita & McPherron 2011; Méndez-Quintas 2022). The test returns 32 harmonics, and we retain in the study the first 16 (*n(landmarks)*/2 = 32/2 =16), according to Ferson *et al.* (1985).

On the EFA dataset, we performed Principal Component Analysis (PCA) to initially describe the diversity of shapes in the studied sample. Taking into account that PCA "only explores the shape variability and the scattering pattern of the data, but does not test hypotheses about differences between groups" (Méndez-Quintas 2022: 12), we also considered the Linear Discriminant Analysis (LDA) scatter plot (all plots have 95% confidence ellipses to better define the area occupied by each sample and to observe the degree of overlap between groups) and then resorted to two statistical tests to evaluate the existence of significant differences between the predefined groups (*i.e.*, the options of the variables under study).

Specifically, we performed pairwise comparisons by a Discriminant Functional Analysis (DFA), a process that tests each pair of groups separately and reports a classification table (*i.e.*, confusion matrix) of numbers of correctly and incorrectly classified specimens. These results are based on a Jackknife cross-validation test (Zelditch *et al.* 2012a: 217-218) and display the degree of statistical "robustness" of the shape difference between the groups - ideally each specimen should be assigned to its respective group if it has a distinctive morphological pattern. Lastly, we performed non-parametric permutational analysis of variance (PerMANOVA) to further assess the statistical significance of differences (Anderson 2001), based on the Euclidean distance and with 9999 replicates. Given previous observations (Falcucci & Peresani 2022; Hoggard *et al.* 2019), we used the sequential Bonferroni adjustment (Zelditch *et al.* 2012b: 456) to identify significant pairwise PerMANOVAs comparisons, which is considered to be less conservative than the Bonferroni adjustment (*Idem*).

4. Results

4.1. Main typological types

Regarding the type of cleaver, the PCA scatter plot shows a large overlap between the groups (Figure 7A). The first five principal components (PC) explain between 97.6% and 98.1% of the whole sample variability, while PCs 1-2 account for 77.2% and 90.1% of the variance (SF1 Table 2).

In relation to the LDA scatter plot (Figure 7B), a significant overlap between the ellipses of the different types of cleavers on flake is also observed (not taking into account the only one of type V, deprived of statistical representation), with the number of cases in a more eccentric position being low. Types 0 and VI have more specimens on the negative side of Axis 2, while type II units are mostly on the positive part, where all the cases of type I are found. In addition, cleavers on flake of types I and VI fall more positively on Axis 1, whereas types 0 and II show a greater spread along that axis. Despite these nuances, the data from the confusion matrix display a low percentage of overall successful classification (23.7%) (Table 4), pointing that there is not a significant association between type and shape, a finding corroborated by the PerMANOVA (SF1 Table 3; Table 5).

Table 4. Confusion matrix results (based on a Jackknife cross-validation test) concerning the type of cleaver on flake - 23.7% of specimens correctly classified.

Type	**0**	**I**	**II**	**V**	**VI**	**Total**
0	8	5	13	2	14	42
I	1	3	7	2	1	14
II	9	7	7	2	10	35
V	1	0	0	0	0	1
VI	5	3	5	0	9	22
Total	24	18	32	6	34	114

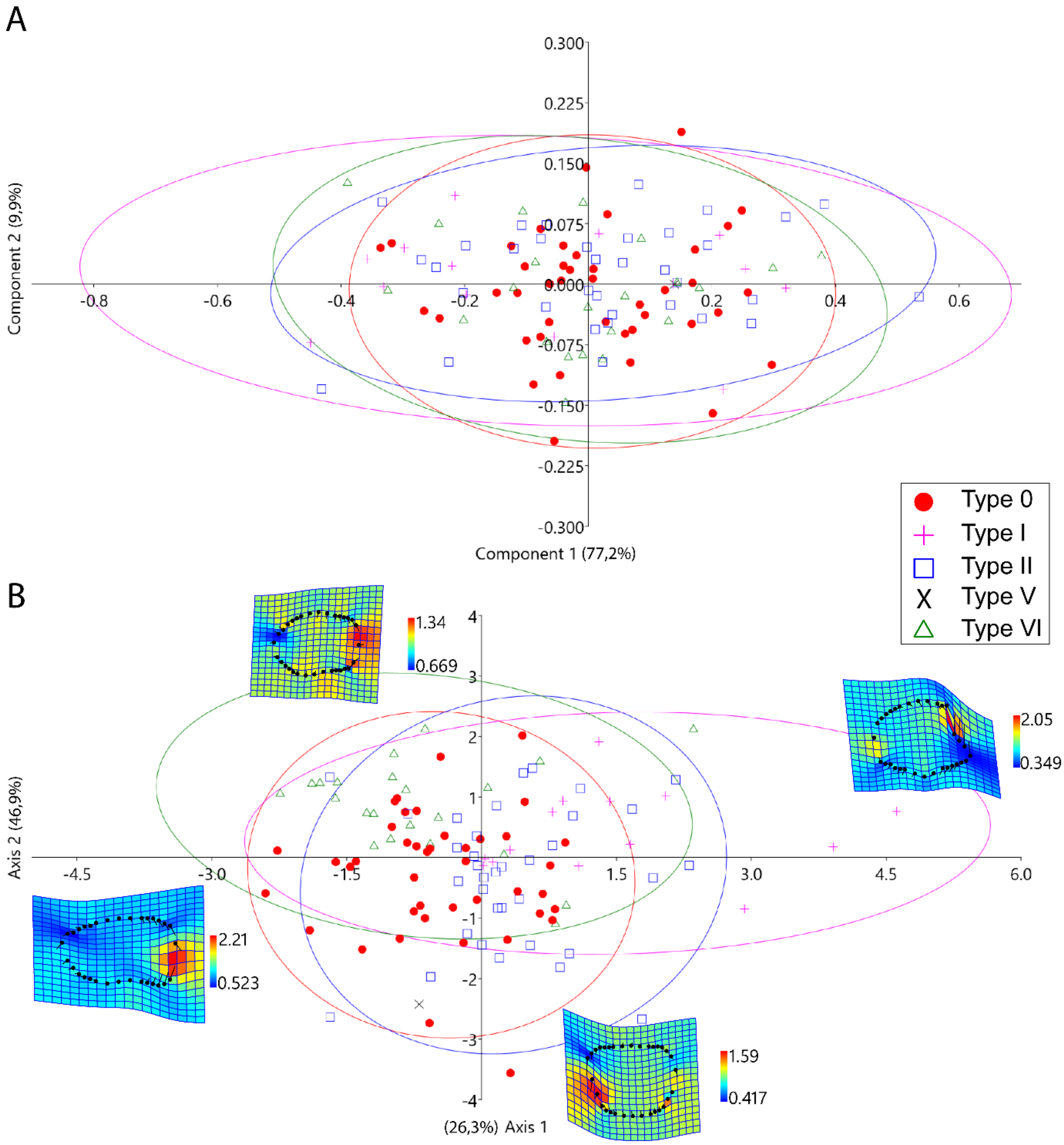

Figure 7. Scatter plot of the (**A**) PCA and (**B**) LDA results of the types of cleavers on flake. The 95% confidence ellipses are plotted.

Table 5. Pairwise PerMANOVAs comparisons concerning the type of cleaver on flake (statistically significant values are in bold; *p-values* < 0.05 not considered statistically significant with the Bonferroni sequential adjustment are underlined).

Type	0	I	II	V	VI
0		0.1515	0.6308	0.5145	0.8331
I	0.1515		0.1867	0.6001	0.3823
II	0.6308	0.1867		0.61	0.4944
V	0.5145	0.6001	0.61		0.4733
VI	0.8331	0.3823	0.4944	0.4733	

4.2. Technological attributes

In addition to analysing the morpho-typological relationship in the sample, we investigated the degree of shape variability according to certain technological variables. In these cases, we opted to report the LDA scatter plots and the data from the confusion matrix and the PerMANOVA, since they provide more robust information than the PCA (Méndez-Quintas 2022 and references therein) and allow to easily understand the degree of variability in the sample.

Regarding the direction of the blow, the LDA scatter plot (SF1 Figure 2A) displays a considerable overlap between the ellipses of the different groups, with a very similar pattern observed between side-struck and special side-struck flakes (though the former fall slightly more negatively along Axis 1). Cleavers in which it was not possible to determine the direction of the blow and those on end-struck flakes (that are rare in the assemblage) tend to have an opposite disposition along Axis 2, with the ellipse of the former being closer to that of the side-struck and special side-struck cases. On the other hand, the data from the confusion matrix (28.1% of specimens correctly classified) (SF1 Table 4) suggest no expressive differentiation in shape according to the direction of the blow. In relation to the PerMANOVA results, at the level of the assemblage no significant differences were found, although the *p*-value is close to 0.05 ($p = 0.056$) (SF1 Table 5). The *p*-values from the pairwise comparisons between end-struck blanks and the remaining options are lower than 0.05, although no significant comparisons were identified between them when the sequential Bonferroni adjustment is applied (SF1 Table 6).

Concerning the type of striking platform, the LDA scatter plot also exhibits a significant overlap between the ellipses (SF1 Figure 2B). Despite some variations in the arrangement between certain units along Axis 1 (*e.g.,* between plain and partially supressed), or Axis 2 (*e.g.,* between cortical and plain), the data from the confusion matrix (SF1 Table 7) (24.6% of specimens correctly classified) and PerMANOVA (SF1 Tables 8-9) do not report significant differences.

Analysing the main indexes assessed, whose values were grouped in ranges, some remarks should be made.

Starting with the shaping index (Figure 8A), there is a predisposition for the ellipses from the different ranges to overlap, with the exception of those with the highest values (> 0.75). The latter tend to fall as a distinct cluster on the positive side of Axis 2, although it is important to note that the number of units is too low (N = 5). On the other hand, some nuances among groups are also identified, such as the fact that most of the specimens with a shaping index < 0.25 and in the 0.50-0.75 range fall more negatively along Axis 1, or that the former and those in the 0.25-0.50 range tend to have more units on the negative side of Axis 2. Nonetheless, the results from the confusion matrix (24.6% of specimens correctly classified) (SF1 Table 10) reveal that the higher or lower value of the shaping index does not lead to tools with significantly distinct silhouettes, an observation supported by the PerMANOVA (SF1 Table 11; Table 6).

Overall, the same reasoning applies to the regularisation index (Figure 8B; SF1 Table 12; SF1 Table 13; Table 7).

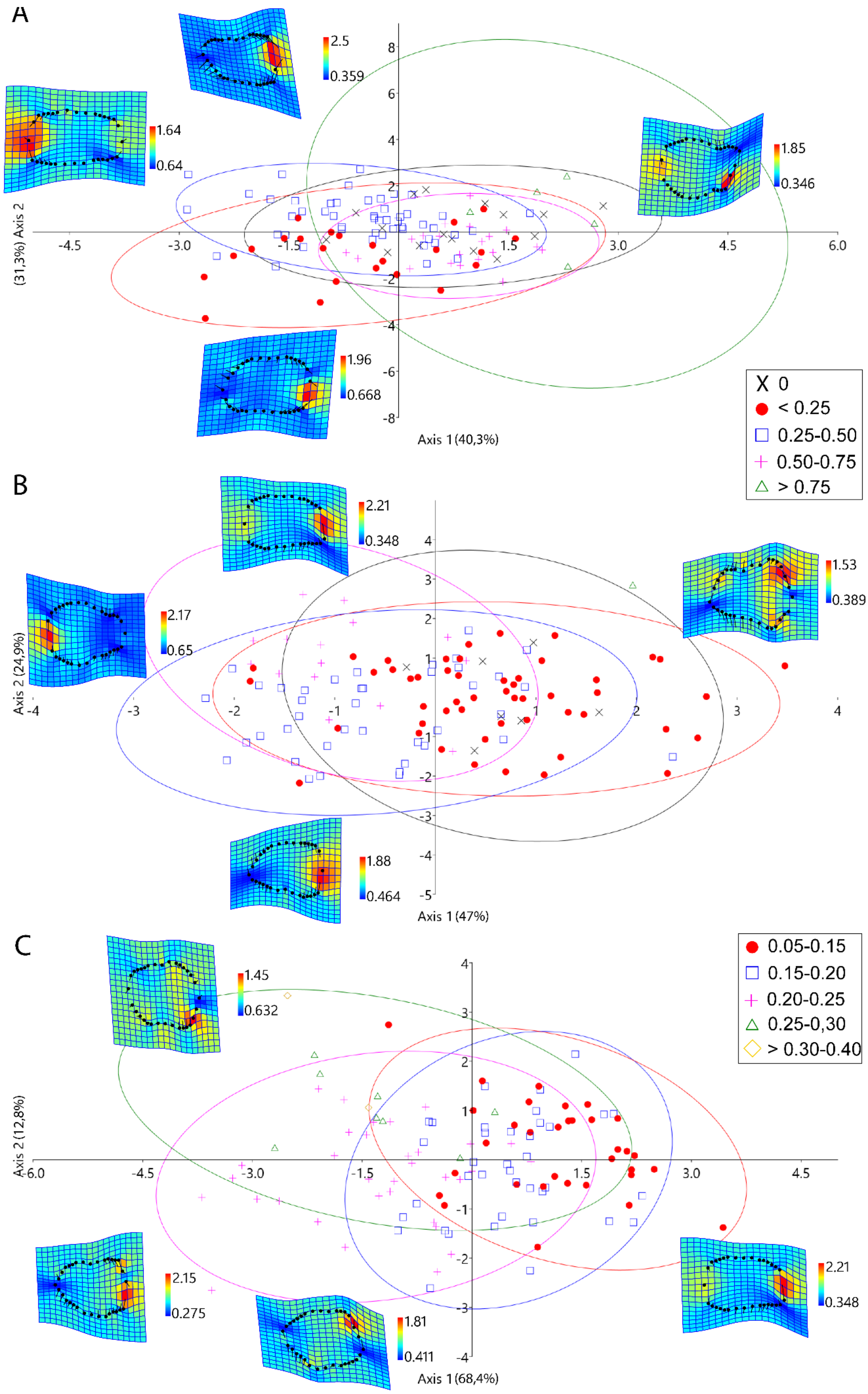

Figure 8. Scatter plot of the LDA results of (**A**) the shaping, (**B**) regularisation and (**C**) distal cutting edge indexes. The 95% confidence ellipses are plotted.

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Table 6. Pairwise PerMANOVAs comparisons concerning the shaping index.

Shaping index	0	< 0.25	0.25-0.50	0.50-0.75	> 0.75
0		0.2149	0.3566	0.7834	0.6036
< 0.25	0.2149		0.1613	0.3026	0.2824
0.25-0.50	0.3566	0.1613		0.8034	0.2851
0.50-0.75	0.7834	0.3026	0.8034		0.4902
> 0.75	0.6036	0.2824	0.2851	0.4902	

Table 7. Pairwise PerMANOVAs comparisons concerning the regularisation index.

Regularisation index	0	< 0.25	0.25-0.50	0.50-0.75	> 0.75
0		0.7063	0.3555	0.4813	0.7496
< 0.25	0.7063		0.4079	0.7848	0.7241
0.25-0.50	0.3555	0.4079		0.434	0.7351
0.50-0.75	0.4813	0.7848	0.434		0.9367
> 0.75	0.7496	0.7241	0.7351	0.9367	

In relation to the distal cutting edge index (Figure 8C), the LDA scatter plot points to a more significant grouping between cleavers with the lowest values on the positive side of Axis 2, and between those with the highest values on the opposite side. Although this seems to be partially endorsed by the pairwise comparisons of the confusion matrix (SF1 Table 14), the overall percentage of successful classification is considerably low (29.8%) and no significant differences were found by the PerMANOVA (the *p*-value of the comparison between 0.05-0.15 and 0.20-0.25 ranges is lower than 0.05, though no significant comparison was identified with the sequential Bonferroni adjustment) (SF1 Table 15; Table 8).

Table 8. Pairwise PerMANOVAs comparisons concerning the distal cutting edge index.

Distal cutting edge index	0.05-0.15	0.15-0.20	0.20-0.25	0.25-0.30	0.30-0.40
0.05-0.15		0.4734	0.0336	0.224	0.3897
0.15-0.20	0.4734		0.1577	0.3717	0.5664
0.20-0.25	0.0336	0.1577		0.479	0.9588
0.25-0.30	0.224	0.3717	0.479		0.5328
0.30-0.40	0.3897	0.5664	0.9588	0.5328	

Regarding the percentage of surface area affected by knapping removals, despite some nuances that can be pointed out in the LDA scatter plots (*e.g.*, in SF1 Figure 3A the pieces whose dorsal face was not affected by knapping and the specimens in the 50-75% range are mostly on the negative side of Axis 1, whereas the units from the remaining options have a greater spread along that axis; *e.g.*, in SF1 Figure 3B the cleavers whose ventral surface was not affected by knapping tend to be on the negative side of Axis 1), for both faces the ellipses of the different options overlap considerably (SF1 Figure 3). In addition, the confusion matrix data pertaining to the ventral face display a relatively low percentage of specimens correctly classified (31.6%) (SF1 Table 19), and, although in the case of the dorsal side the percentage is a bit higher (38.6%) (SF1 Table 16), the PerMANOVA data suggest that for both faces the variation in the extent of the surface affected by knapping removals is not reflected in significantly different silhouettes (SF1 Tables 17-18 and 20-21).

In relation to the percentage of the area of the tool covered by the surface of previous removals (SF1 Figure 3C), there is once again a substantial overlap between the ellipses of the different ranges. Moreover, the confusion matrix displays a relatively low percentage of successful classification (31.6%) (SF1 Table 22), and, although pairwise comparisons seem to suggest a more specific affinity between cleavers without previous removals, no significant differences were found between the ranges by the PerMANOVA (SF1 Tables 23-24).

As for the number of shaping and regularisation scars, in both cases, the LDA scatter plots show a relative proximity between the specimens of the most represented ranges (SF1 Figure 4). The ellipses of the pieces with the highest values display a more distinct pattern, although it is important to note that the respective number of cases is low. On the other hand, the confusion matrix data pertaining to the regularisation removals display a low percentage of specimens correctly classified (21.1%) (SF1 Table 28). Although in the case of the dorsal face the percentage is higher (40.4%) - which may be influenced by the unbalanced distribution between the ranges (*e.g.*, one of the groups comprises more than 50% of the pieces) -, in all cases the number of specimens assigned to the other intervals is substantially higher than the number of cases assigned to its group (SF1 Table 25). The apparently low affinity with the pieces in the 10-16 range can be the result of the reduced number of cases of the latter rather than the existence of a considerable real difference, reasoning also applicable to the comparison with the pieces with a higher number of regularisation scars. Moreover, for both stages, no significant differences were found by the PerMANOVA (SF1 Tables 26-27 and 29-30).

These findings are corroborated by the data on the total number of removals made after the blank was obtained. Indeed, concerning the LDA scatter plot (Figure 9A) a significant overlap between the ellipses of the most represented ranges (that comprise 92% of the specimens) is also observed. The ellipse of cleavers on flake with > 30 removals tend to fall as a more distinct group on the positive side of Axis 2, although it is important to mention that the number of units is too low (N = 9) compared to the remaining groups, and that most of the cases fall within the other ellipses. Furthermore, both the confusion matrix (31.6% of specimens correctly classified) (SF1 Table 31) and PerMANOVA (SF1 Table 32; Table 9) data point to the fact that the lower or higher number of technical gestures subsequent to the detachment of the blank does not lead to the definition of products with significantly distinct shapes.

Table 9. Pairwise PerMANOVAs comparisons concerning the total number of knapping removals.

Total removals	1-10	10-20	20-30	> 30
1-10		0.7206	0.8527	0.4895
10-20	0.7206		0.8208	0.3825
20-30	0.8527	0.8208		0.3172
> 30	0.4895	0.3825	0.3172	

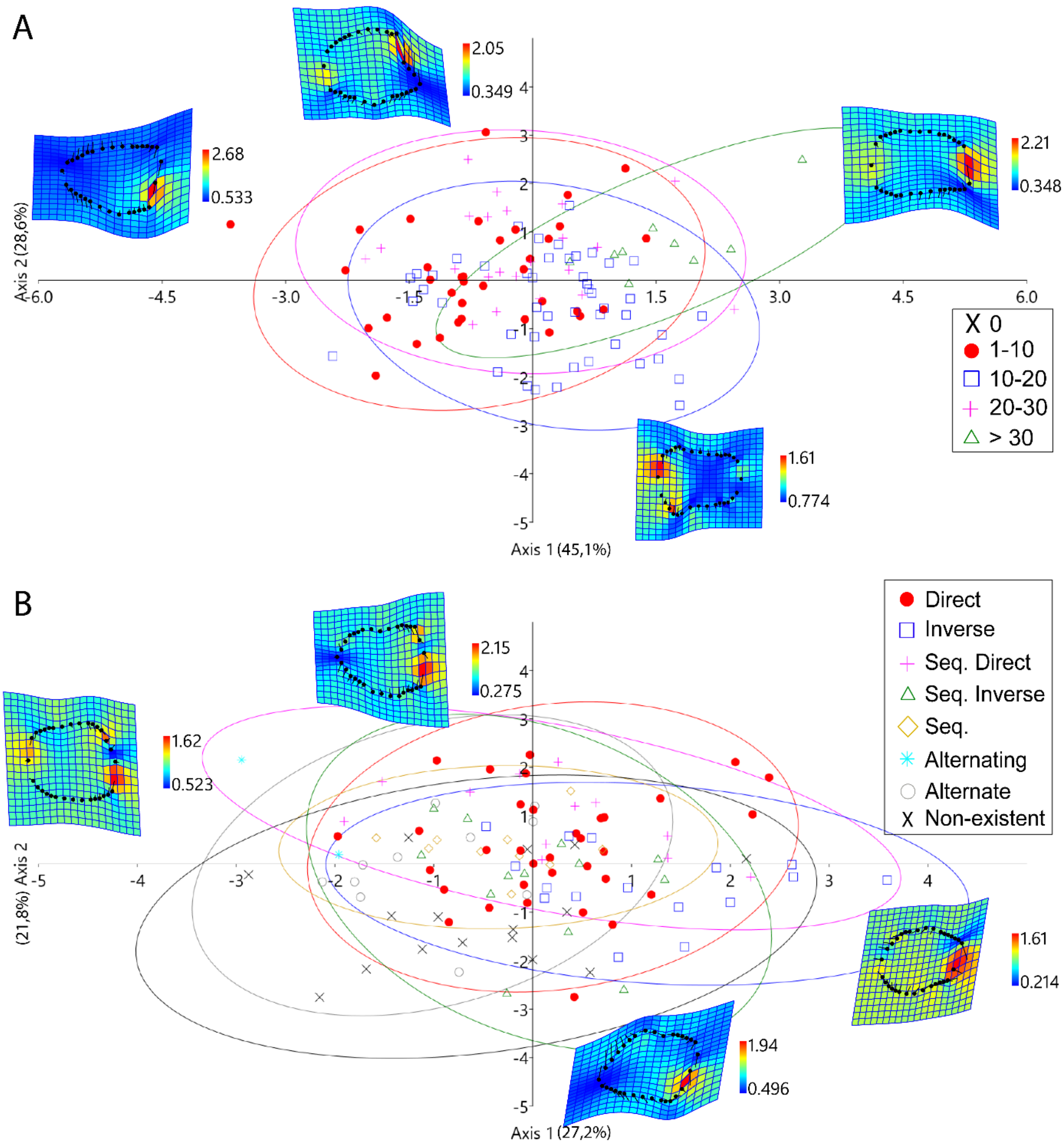

Figure 9. Scatter plot of the LDA results of (**A**) the total number of knapping removals and (**B**) the secondary reshaping strategy. The 95% confidence ellipses are plotted.

Lastly, with regard to the secondary reshaping strategy, despite some patterns that can be pointed out in relation to the LDA scatter plot (*e.g.*, most of the cleavers with alternate or sequential removals are on the negative part of Axis 2, while most of those shaped inversely or in a sequential direct order are on the positive side; the units with direct removals have a greater dispersion on both axis…), there is also significant overlap between the ellipses of the most represented groups (Figure 9B). Moreover, the results of the confusion matrix (13.2% of specimens correctly classified) (SF1 Table 33) and PERMANOVA (SF1 Tables 34-35) reveal that the different shaping strategies do not lead to the definition of significantly different overall shapes.

5. Discussion

Even though the individuality of cleavers on flake is the subject of a long debate (Biberson 1954; Bordes 1961: 77-80; Chavaillon 1965; Guichard & Guichard 1966; Kleindienst 1962; Roe 1969; 2006; Tixier 1956; White 2006), we consider that these tools have been underestimated with respect to handaxes in European Acheulean research.

As previously mentioned, they are relevant items to the study of population and behavioural dynamics in Europe during the Middle Pleistocene and are an important source of technological information. Specifically, these are the artefacts that best testify to the concept of predetermination in the Acheulean techno-complex, which is inherent in the definition of the distal cutting edge, the most important aspect of their manufacturing process (Herzlinger *et al.* 2017b; Texier & Roche 1995; Tixier 1956). Therefore, cleavers on flake, which are characterized by a very elaborate conceptual scheme - that required an early decision in the establishment of their main active area (Herzlinger *et al.* 2017b) - and a short operational one (Roche & Texier 1991), are privileged remains to explore the cognitive complexity of the Acheulean technology (Herzlinger *et al.* 2017b), since their production inevitably derives from a strong interrelationship between cognitive and motor skills.

Taking into account the informative potential of cleavers on flake, we analysed one of the largest collections of these tools in Western Europe through a GMA in order to discuss to what extent the properties of the blank are reflected in the morphometric features of the finished product.

Regarding the morpho-typological relationship in the sample, the data obtained showed that in Casal do Azemel it is not possible to distinguish the different types of cleavers on flake on the basis of morphological criteria. Although this is not exactly innovative, since Tixier classification is based on technological criteria, the data reported are of relevance. Indeed, they suggest that Casal do Azemel's knappers aimed to define a tool with a predetermined distal cutting edge in an implement with a relatively analogous shape and that they were able to achieve this, even though the blanks proceeded from cores in different stages of exploitation and with distinct reduction patterns.

Additionally, shape variation was tested according to some technological attributes related to the blank and its secondary transformation. In almost all cases no significant differences were recognised. Indeed, only in the case of the direction of the blow were significant pairwise PerMANOVA comparisons found, but prior to the sequential Bonferroni adjustment, specifically between end-struck flakes and the remaining options (side-struck, special side-struck, unknown) - this could be linked to the different size features of the flakes according to the direction of the blow, which might have had some effect on the morphology of the tool.

Consequently, the data collected are of great informative value for the topic under discussion in this work. Taking into account that "The shape of most cleavers was dictated by two related factors: a) The core method by which the cleaver's blank was produced. b) The morphology of the blank that was selected prior to any secondary reshaping." (Sharon 2007: 144), and, on the other hand, that the rule is for Casal do Azemel's cleavers to display a secondary transformation that is not very intense, involving short operational schemes (*sensu* Roche & Texier 1991) and non-invasive removals (Cunha-Ribeiro 1999: 437; Ferreira 2023: 77-80), we consider that there is evidence suggesting that the morphology of the finished tool was usually predefined, to a great extent, in the respective blank. In this sense, in most cases the removals identified *only* contribute to better precise it (particularly its bilateral balance by the trimming of the lateral edges, and often the thinning of the bulb of percussion), or to improve the ergonomic design of the tool. Naturally, there are also some specimens with a more significant secondary reshaping (*e.g.*, Figures 3A; 4A) - as a rule, the degree of modification is more extensive only in one of the faces, with the other remaining unaffected or barely modified (*e.g.,* Figure 3A). Overall, they are a minority in the assemblage, and their presence is also relevant, as they attest to a flexible behaviour that allowed the correction of blanks with morphometric features less suitable for the intended implement.

Therefore, "as a rule, the part played by shaping is inversely proportional to the degree of predetermination of the blank." (Inizan *et al.* 1999: 57).

Furthermore, considering that no significant differences were found according to the technological solutions applied to the acquisition of the blank and its secondary transformation, these results also suggest that there was an *ideal shape* underlying the definition of these tools. Although we are aware there is no objective data (*e.g.,* use-wear analyses - unviable given the aeolisation of the materials) to explain the reason behind this trend, given that form and function are usually related (Key & Lycett 2017), it is suggestive to think that this could be the most suitable implement for the task(s) to be performed.

Despite the absence of the large cores, the tendency towards sharing a close formal predisposition would probably be the outcome of the existence of well-structured and standardised core reduction processes that aimed and enabled to obtain large blanks with specific shape features, and a pattern of selection of the most suitable ones -as proposed for other assemblages (*e.g.,* Sharon 2007)-, accompanying a degree of complexity and standardisation that can be seen in the site's remaining debitage schemes and configuration processes (Cunha-Ribeiro 1999: 456-463; Ferreira 2023: 255-258).

Overall, these findings suggest a strong correlation between cognitive and motor skills, significant technical expertise and a considerable degree of complexity underlying the production of artefacts with similar techno-functional and morphometric features, that came largely predefined in the flake blank -which in turn limited the degree of their secondary transformation. This reality seems to be inextricably linked to the existence of a well-defined *imposed form* (Sharon 2010: 229) and to be the outcome of a *cleaver concept* governed by expert cognition, as previously highlighted (Herzlinger *et al.* 2017b).

Lastly, if we think about the typological composition of the cleaver on flake assemblage from Casal do Azemel, we note that even the presence of type 0 specimens (made on *entame flakes* - Sharon 2011), traditionally considered as being "crude", reveals a predetermination pattern linked to the skilful selection and intelligent use of the regular convexity of the cortex of well-calibrated rolled cobbles to ensure the removal of a suitable primary flake (Cunha-Ribeiro 1997; 1999; Sharon 2009), which was reflected in the minimal necessity of further transformation (Sharon 2011). The complexity of the *chaîne opératoire* of Casal do Azemel's cleavers on flake is further reinforced by the high number of type I and II pieces (since they implied a higher degree of technical development linked with the preparation of the core, with type II specimens displaying centripetal patterns), and, on the other hand, by the considerable presence of type VI cleavers. These were made on flakes obtained through the Kombewa method (Balout *et al.* 1967), considered by Texier & Roche (1995: 408) as the method that represents the highest level of predetermination in the Acheulean, along with the Levallois method. Furthermore, the presence of a single type V cleaver on flake, a type characterized by a more intense secondary reshaping, is another piece of evidence that reinforces the suitability of the blanks in which these tools were defined.

6. Conclusions

Cleavers on flake are one of the main techno-typological hallmarks of the Acheulean techno-complex. Although they usually receive less attention than handaxes, their analysis can be of great importance in discussing human behaviour during the Lower Palaeolithic. Not only because they testify to one of the main innovations of the Acheulean technology - the management of large volumes of raw material aimed at obtaining large-sized flake blanks - but also because their production reveals an important degree of technical and cognitive complexity (Herzlinger *et al.* 2017b; Roche & Texier 1991; Texier & Roche 1995).

Unlike a significant portion of handaxes, cleavers on flake usually retain a minimal degree of transformation of the blank, which makes it “possible to identify the type of blank that was used and examine its original morphology” (Sharon 2006: 144), as we explored with the cleaver on flake assemblage from Casal do Azemel site.

Overall, no significant shape differences were found according to the technological solutions applied to the acquisition of the flake blank and its secondary intervention. Considering that in most of the cases the degree of their secondary transformation is low, these data suggest that the production of the analysed tools resulted not only from a technological and cognitive flexibility but also from a conceptual, structural and morphological standardisation. Therefore, “we can not only speak of predetermination but also of standardization” (Texier & Roche 1995: 405), and, taken together, a considerable degree of behavioural complexity is noted.

In conclusion, these findings imply the existence of significant technical and cognitive prerequisites that may be relevant to understanding behavioural dynamics in Western Europe during the second half of the Middle Pleistocene, highlighting the importance of this specific tool type for the larger discussion regarding the cognitive complexity of our ancestors’ technological skills (Muller & Clarkson 2022; Muller *et al.* 2017; Stout *et al.* 2015), and attesting to the potential of GMA approaches for the study of other Acheulean LCTs besides handaxes.

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Data accessibility statement

The authors confirm that the data supporting the findings of this study are available within the paper and its supplementary files. The dataset can be found in Zenodo in open access (Ferreira 2023; or link in SF2) (see References).

List of supplementary files

Supplementary File 1 (SF1). Supplementary information of the GMA study presented in the results section.

Supplementary file 2 (SF2). Link with access to the raw data and datasets of the GMA performed.

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Predeterminação no Acheulense Ibérico. Uma abordagem baseada no estudo de Morfometria Geométrica dos machados de mão do sítio do Casal do Azemel (Leiria, Portugal)

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Resumo

Ao longo das últimas décadas, o aumento do número de dados disponíveis para o estudo da ocupação humana na Península Ibérica durante o Plistocénico Médio tem potenciado a discussão em torno das características cronológicas e tecnológicas do tecno-complexo Acheulense neste território. Globalmente, as informações provêm maioritariamente de jazidas de ar livre associadas a ambientes fluviais das principais bacias hidrográficas atlânticas, assistindo-se à proliferação deste tipo de indústrias durante a segunda metade do Plistocénico Médio.

De um ponto de vista tecnológico, os conjuntos acheulenses peninsulares caracterizam-se, entre outros aspetos, pelo uso recorrente de grandes lascas enquanto suportes para a elaboração de *Large Cutting Tools* (LCTs), tendência que tem sido destacada enquanto representativa do carácter de um *Large Flake Acheulean* (LFA) do Acheulense Ibérico. Entre os tipos de LCTs usualmente identificados nesta área, destaca-se a presença significativa de machados de mão, um tipo específico de utensílio com um elevado potencial informativo de um ponto de vista cultural e tecnológico.

Por um lado, têm servido como catalisadores para discutir a variabilidade das indústrias acheulenses europeias, uma vez que, para além de identificações esporádicas noutras regiões, a sua presença está maioritariamente confinada à Península Ibérica e Aquitânia. Por outro, são os vestígios materiais que melhor testemunham a introdução do conceito de predeterminação nas cadeias operatórias do tecno-complexo Acheulense, caracterizando-se por terem um esquema conceptual bastante elaborado, que implicava uma decisão antecipada no estabelecimento da sua principal área ativa (o gume distal), e um esquema operativo curto. Regra geral, por oposição aos bifaces, a transformação secundária do suporte é pouca intensa e marginal, o que torna os machados de mão em artefactos privilegiados para discutir o impacto do suporte nas características do implemento final.

Neste sentido, no presente trabalho procurámos discutir o grau de predeterminação deste tipo de utensílios com base no caso de estudo da extensa coleção de machados de mão da jazida do Casal do Azemel (Leiria, Portugal), através de uma análise de Morfometria Geométrica (2D), uma vez que pretendíamos avaliar a existência de potenciais variações nas respetivas silhuetas consoante um conjunto de variáveis tecno-tipológicas.

Globalmente, os dados da análise realizada revelaram a inexistência de diferenças morfológicas significativas consoante as soluções tecnológicas aplicadas ao nível da aquisição do suporte e da sua intervenção secundária. Ora, tendo em conta que a tendência é para este tipo de artefactos exibirem uma transformação secundária pouco intensa e relativamente marginal, consideramos que existem evidências

que revelam que as características morfométricas do implemento final vinham usualmente, em grande medida, predefinidas no respetivo suporte.

Neste sentido, os resultados obtidos sugerem que subjacente à produção dos machados de mão da estação paleolítica do Casal do Azemel se encontra não apenas uma interessante *flexibilidade* tecnológica e cognitiva (dada a distribuição tipológica do conjunto), mas também uma estandardização conceptual, estrutural e morfológica. Em conjunto, estas observações indiciam a existência de pré-requisitos tecnológicos e cognitivos bem estruturados relevantes para o conhecimento das dinâmicas comportamentais no ocidente europeu durante a segunda metade do Plistocénico Médio, e para a discussão mais alargada em torno da complexidade cognitiva do comportamento tecnológico dos nossos antepassados, reforçando a importância do papel dos machados de mão nesse debate.

Palavras-chave: Acheulense de grandes lascas; Machados de mão; *Geometric Morphometric Analysis*; Lasca suporte; Predeterminação; Estandardização.