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Approaching raw material functionality in the Upper Magdalenian of Coímbre cave (Asturias, Spain) through geometric morphometrics

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ABSTRACT

Coímbre cave (Peñamellera Alta, Asturias) is an Upper Palaeolithic site in Northern Spain, spanning an occupation sequence from the Gravettian to the Magdalenian periods. The upper layers -layer I and II-, corresponding to the Upper Magdalenian, register the highest intensity of human activity. In this paper, we analyse raw material functionality at the site through the study of cut-marks found on bone remains. At Coímbre, we have documented mainly quartzite, followed by flint; other raw materials are found in very low frequencies. There are several types of local quartzite that appear mainly as flaking debitage and stone tools such as burins and scrappers. On the other hand, flint is mainly knapped to elaborate blades and bladelets, as well as specialised implements, such as different types of side scrappers. Retouched flakes on flint are relatively more abundant than those made on quartzite. In this paper we employ the use of photogrammetry, geometric morphometrics and statistics to analyse the cut-marks from the Upper Magdalenian assemblage of Coímbre cave. Our aim is to determine the lithic raw material preferentially used for carcass processing at the site.

1. Introduction

Raw material analysis is one of the main methodological approaches for understanding the subsistence strategies of Pleistocene hunter-gatherers. Studies of this type consider several variables, such as procurement, mobility, and use; aiding in the determination of raw material management models and the production of lithic implements by Palaeolithic human groups. Similarly, the affordances and limitations of different raw materials condition tool production strategies and the engagement in subsistence activities that require cutting edges.

Traditionally raw material analyses tend to focus primarily on petrological characterisation in order to identify provenance of the raw material and thus propose mobility patterns in the archaeological sites. These are now paramount to assess the degree of immediacy and complexity in resource supplies.

Until very recently, the scope of lithic raw material analysis was exclusively centred around these questions of mobility and procurement, together with use-wear analyses. However, the integration of taphonomy enabled the assessment of raw material use in animal processing activities (Yravedra et al., 2017a, b). This new approach represents a significant methodological contribution to our understanding of lithic resources at archaeological sites. The relationship between raw materials, the tools manufactured and the activities undertaken is crucial for understanding the use and management of these resources. These also rely on human choices that involve raw material hardness, quality and/or edge durability.

The detailed analysis of butchery practices based on the traces left on exploited carcasses is therefore becoming an invaluable source of information for the study of raw material use in a site (Maté-González et al., 2015, 2016; Yravedra et al., 2017a, 2017b; Courtenay et al.,

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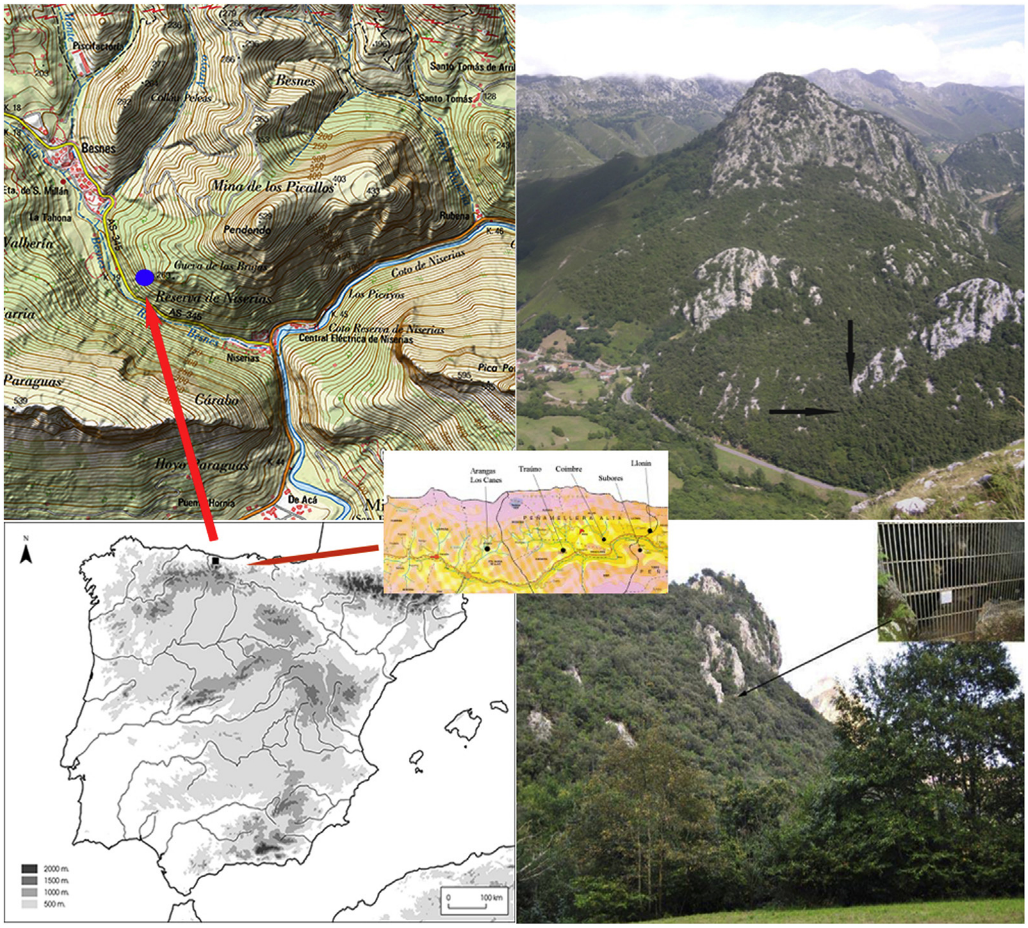

Fig. 1. Coímbre cave: geographical location (Asturias, Spain), regional context, and other Upper Palaeolithic sites nearby.

2018).

Since the 1980s, the analysis of cut-marks has been developed to, among others; identify raw materials, integrating experimental insights to the practical assessment of carcass butchery practices at several sites (Walker, 1978; Shipman and Rose, 1983; Olsen, 1988; Spennerman, 1990; Greenfield, 1999, 2004, 2006a, b; Bello et al., 2009). Greenfield (1999), for example, identified the use of metal tools for carcass-processing during the Copper and Bronze Age in Europe through cut-mark characterisation. Bello et al. (2009) and Yravedra et al. (2010) observed the use of handaxes in animal exploitation in the Lower Palaeolithic sites of Boxgrove and Aridos.

Through the application of new technologies in morphometric and photogrammetric analyses, Yravedra et al. (2017a, b) identified that the cut-marks found at sites such as BK or FLKW (Olduvai Gorge, Tanzania) were produced primarily with simple quartzite flakes, discriminating from a whole set of different tool types and raw materials. These new technologies can be applied to taphonomic analyses in different ways, employing the use of different techniques and equipment.

Some of the main approaches make use of Scanning Electron Microscopes (SEM) (Shipman, 1981; Olsen, 1988; Greenfield, 1999, 2004, 2006a,b; Smith and Brickley, 2004; Lewis, 2008), binocular microscopes for high resolution pictures (Domínguez-Rodrigo et al., 2009; De Juana et al., 2010; Marín-Monfort et al., 2013), digital imaging techniques (Gilbert and Richards, 2000), 3D reconstructions (Bartelink et al., 2001; During and Nilsson, 1991; Kaiser and Katterwe, 2001), 3D digital microscopes (Boschin and Crezzini, 2012; Crezzini et al., 2014), the Alicona 3D Infinite Focus Imaging microscope (Bello and Soligo, 2008; Bello et al., 2009; Bello, 2011; Bonney, 2014), Micro-Photogrammetry with the use of reflex cameras (Maté-González et al., 2015, 2016, 2017a, b), and the use of the DAVID structured-light scanner SLS-2s in both 2D (Maté-González et al., 2017c) and 3D analysis (Courtenay et al., 2017). We could also add the use of white-light non-contact confocal profilometers using Digital Surf's Mountains R software (Pante et al., 2017) as well as full 3D morphometrics aided by Bayesian analysis (Otárola-Castillo et al., 2018). However, these two last applications have only been applied to taphonomic alterations, namely cut and tooth marks that can be recognized macroscopically without the requirement of sophisticated techniques. On the other hand, the new morphometric techniques using Micro-photogrammetry and the DAVID structured-light scanner SLS-2s, in both 2D and 3D, offer similar results in cut-mark analysis than those use a 3D digital microscope or a laser scanning confocal (Maté-González et al., 2017b, c). Cut-marks produced with tools of different raw materials have also successfully been identified through these techniques (Courtenay et al., 2017; Maté-González et al., 2017c).

Using these methodological approaches, we attempt to study and characterise the cut-marks found at the Upper Magdalenian bone assemblage from Coímbre cave. Our aim is to determine which raw materials were predominantly used for carcass processing during the late Upper Palaeolithic. We have identified a series of raw materials, such as quartzite, quartz, and several flint varieties at level Co.B.1 (Upper Magdalenian) of Coimbre cave (Álvarez-Alonso et al., 2017). Nonetheless, the functionality of all the tools and unmodified lithic implements, is yet unknown. We will consider this aspect of the lithic assemblage through this study, to determine which raw materials were preferentially used in the exploitation of animal carcasses during the Upper Magdalenian of Coímbre Cave.

2. Coímbre cave

Coímbre cave is in Peñamellera Alta (Asturias, España), on the Southern face of the Cuera range, near the Picos de Europa mountain range, located in the central-western part of the Cantabrian region. This site is located on the Western slope of monte Pendendo, on a rocky outcrop known as Pica de Coímbre, from which the cave takes its name (Álvarez-Alonso et al., 2013a, 2013b; Álvarez-Alonso, 2017a). The cave is on the middle Cares River valley, drained by the Besnes River. The cave is at 145 m above sea level. Its UTM coordinates are: HUSO 30 (Datum ETRS 89), X.363.165, Y.4.798.482 (Álvarez-Alonso, 2017a). Coímbre cave is located within one of the areas in Northern Spain with the largest density of late Upper Palaeolithic sites, including rock-art cave sites such as Llonín, Covaciella, El Bosque, Arangas, Los Canes, La Loja and Traúno (Álvarez-Alonso, 2017b) (Fig. 1).

The site was discovered in 1971, after the identification of Magdalenian engravings on the cave walls (Moure y Gil, 1972, 1974). The first archaeological excavations took place between 2008 and 2012 (Álvarez-Alonso et al., 2009, 2011, 2013a; 2013b, 2016).

Due to the size, volume and complexity of the site, it has been divided into several areas, with zone B being the focus of archaeological research to date. This area encompasses around 100 m^2 of the site, although only 4 m^2 have been excavated (Álvarez-Alonso and Yravedra, 2017b). Several occupation levels have been identified belonging to the Upper Magdalenian (level Co.B.1), Middle Magdalenian (level Co.B.2), Lower Magdalenian (level Co.B.4), Archaic Magdalenian (level Co.B.5.1) and Gravettian (level Co.B.6) technocomplexes. Levels Co.B.3, Co.B.5 and Co.B.7 are archaeologically sterile (Álvarez-Alonso et al., 2013b, 2016) (Fig. 2). The chronological framework of this site encompasses from the end of OIS3 to OIS 2, i.e. from the latest phases of the Last Glacial Maximum until the end of the Late Upper Pleistocene (Álvarez-Alonso and Jordá Pardo, 2017).

Palaeoenvironmental evidence suggests colder climates, particularly during the Gravettian phase, with several short warmer intervals towards the end of the sequence (Álvarez-Alonso and Jordá Pardo, 2017; Álvarez-Alonso and Yravedra, 2017c; Iriarte et al., 2017).

2.1. The Upper Magdalenian at Coímbre cave. A case of study

Coímbre is one of the Magdalenian sites of the Iberian Peninsula that has provided the greatest amount of information pertaining the later phases of this period. It has become a fundamental site for the study of the Upper Magdalenian in the north of the Iberian Peninsula, due to the abundance and significance of its archaeological remains. The Upper Magdalenian level at Coímbre cave has yielded the richest assemblage within the sequence, evidencing a high-density occupation of the cave during this phase (Alvarez and Yravedra, 2017a).

The Upper Magdalenian lithic industry of Coímbre cave is very characteristic, mainly composed of backed elements, such as backed points, backed bladelets and backed denticulated bladelets, together with burins and implements with simple retouch. A series of bone tools, such as spear-throwers, harpoons, together with a series of decorative elements and personal ornaments (needles, pendants, etc.) made on bone, deer teeth, and shell have been identified at the site (Álvarez-Alonso et al., 2016; Álvarez-Alonso, 2017c; Álvarez-Fernández, 2017).

This level is characterised by a predominance of quartzite (56.63%) over flint, followed by other raw materials such as rock crystal, far less represented (Álvarez-Alonso et al., 2017; Andrés-Herrero et al., 2017). The lithic assemblage of this level is comprised by 47.352 remains (including debris of less than 1 cm). Excluding the debris, the lithic assemblage (n = 615) is still predominantly composed by quartzite elements (67.47%), even though most lithic tools were made on different types of flint (75.8%), most of them come from distant exogenous sources. This indicates a selective strategy in terms of raw material choice for the elaboration of retouched pieces (backed elements, burins or end-scrapers). On the other hand, flake-producing *chaînes opératoires* were conducted mainly on quartzite. Quartzite flakes are mostly unmodified and unretouched. With regards to flint, this raw material has experienced a series of blade and bladelet-oriented *chaînes opératoires* for the production of blanks, intended for further knapping into different implements. Quartzite is abundant within the immediate local surroundings of the site, however, even though high-quality sharp cutting edges can be obtained from quartzite, this raw material is not optimal for preparing suitable blanks for the predominant type of implements found at the site, including backed elements (Álvarez-Alonso et al., 2017).

It is therefore necessary to reflect upon the aim of producing such a high number of unmodified quartzite flakes, with the exception of some side-scrapers and denticulates.

The faunal assemblage is diverse and abundant, including Iberian ibex (*Capra pyrenaica*), roe deer (*Capreolus capreolus*), deer (*Cervus elaphus*), chamois (*Rupicapra pyrenaica*), and auroch (*Bos primigenius*),

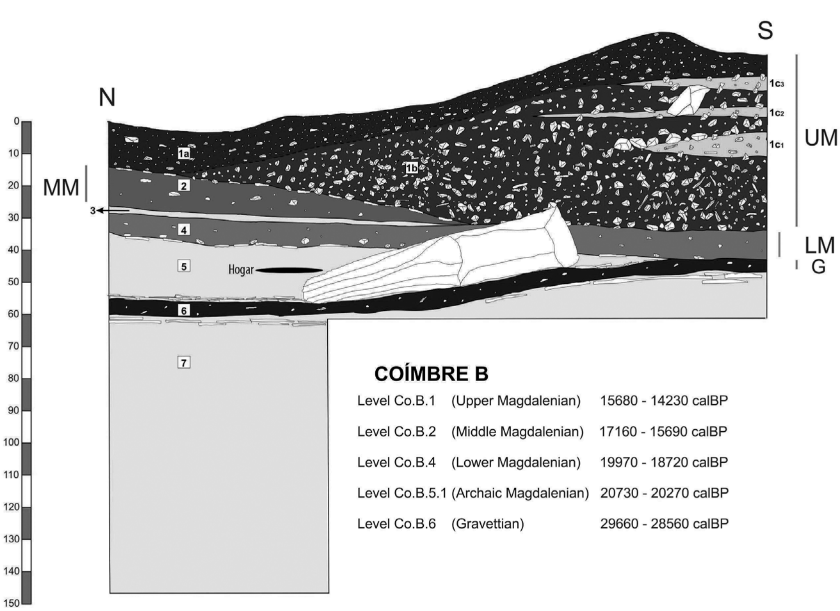

Fig. 2. Chronostratigraphic sequence at Coímbre cave.

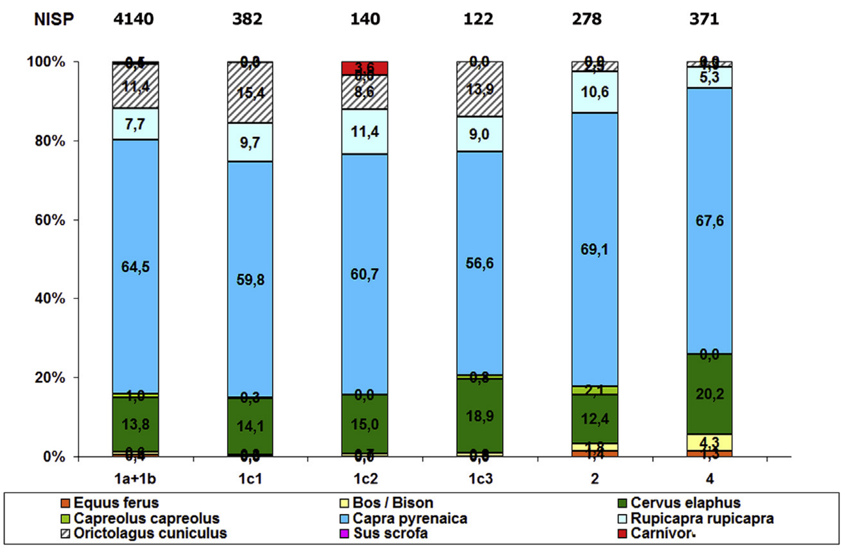

Fig. 3. Animal frequencies in %NISP (Number of Identified Specimens) for the Magdalenian levels of Coímbre cave (Yravedra et al., 2017b).

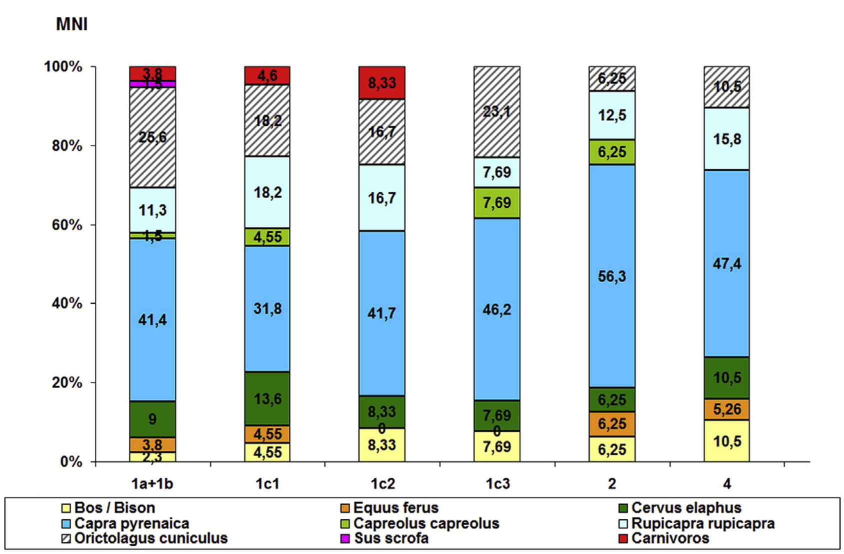

Fig. 4. Animal frequencies in %MNI (Minimum Number of Individuals) for the Magdalenian levels of Coímbre cave (Yravedra et al., 2017b).

together with some bear and fox remains. Evidence of carcass-processing has been identified across all macromammal species, other than on the carnivore remains. Some of the lagomorph, bird, and fish remains also show evidence of anthropogenic alterations. According to Yravedra et al. (2017a, b), the faunal record of Coímbre cave is dominated by Iberian ibex followed by red deer, both in terms of the NISP (Fig. 3) and the MNI (Fig. 4).

Taphonomic analyses have revealed that most faunal remains might have been brought to the site and consumed by humans (Yravedra et al., 2017c, d). Additionally, the Gravettian level of Coímbre contains evidence of the use of bones as fuel (Yravedra et al., 2016). Other agents might have scarcely altered the osteological assemblage including, for example, carnivore scavenging (Yravedra et al., 2017c, d). On the contrary, human activity at the site was intensive, reflected in a large quantity of cut-marks associated with different activities, including defleshing, skinning and disarticulation.

The Coímbre assemblage is especially relevant for the application of morphometric techniques because of its abundant and diverse set of cut-marks. Additionally, the presence of two well-defined *chaînes opératoires*, each implemented on different raw materials (flint and quartzite) and oriented towards the acquisition of different tools and implements, provide further interest in order to understand the use of these tools.

3. Materials and methods

3.1. Coimbre sample – quartzites and Coimbre cut marks

A total number of 214 cut marks were analysed for this study, including 24 cut marks from area A and of the Coímbre cave and 38 cut marks from area B. These were compared with 3 samples named Q4, Q5 and S2 (Fig. 5). Sample Q4 consists of 41 cut marks produced by local quartzite, easily accessible to the immediate surroundings of the site. Q5 and S2, on the other hand, are non-local materials consisting in flint (S2, cut marks = 50) found in the Pedroso region of Cuenca (Spain) and quartzite (Q5, cut marks = 45) found in the nearby River Cares (Cantabria, Spain). Samples Q4 and Q5 have similar grain size and morphology to the flints found at Coimbre, while observations made by Maté-González et al. (2017a) identified important similarities between different types of flint from different geographical regions.

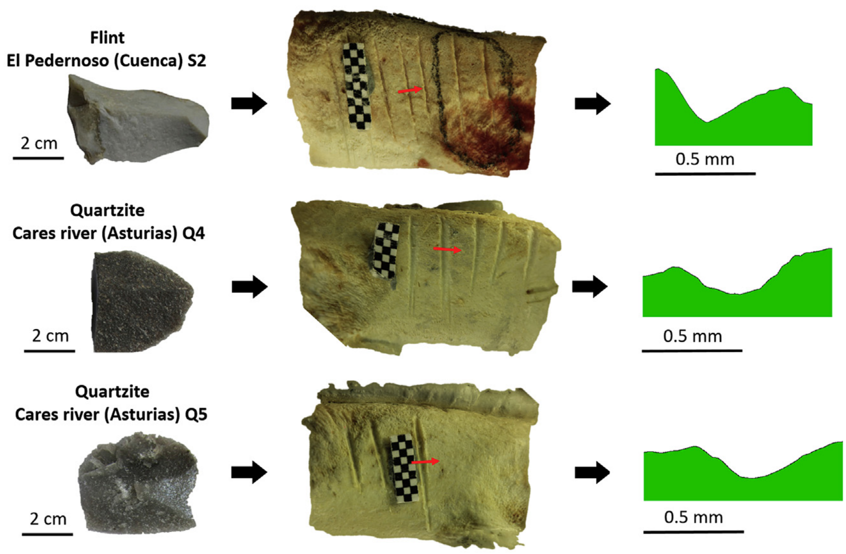

Fig. 5. Cut marks generated with a flint (S2) and with two quartzite (Q4 and Q5) flake. Detail of the V sections in the three types of marks.

3.2. Digitization of cut marks

All cut marks were digitalized using the methodology employed and described by Maté-González et al. (2015). Micro-Photogrammetry was used to generate precise metrical models of cut marks when using images taken with oblique photography (Fig. 6). As in previous work, a Canon EOS 700D reflex camera was used, with a 60 mm macro lens, which yielded high-resolution and high-quality images (Maté-González et al., 2016, 2017a, b, c; Aramendi et al., 2017; Arriaza et al., 2017; Palomeque-González et al., 2017; Yravedra et al., 2017a, b, e).

Once the photographs had been taken, they were processed to generate a 3D model for each mark. Consequently, the photographs were treated using the photogrammetric reconstruction software GRAPHOS (inteGRAted PHOtogrammetric Suite, Fig. 6) generating high-quality 3D models of cut marks on bone (average GSD (mm) = ± 0.0078; average scaling error (mm) = ± 0.0157; average photogrammetric error (mm) = ± 0.0058; average precision (mm) = ± 0.0168). Final 3D models correspond to meshes coming

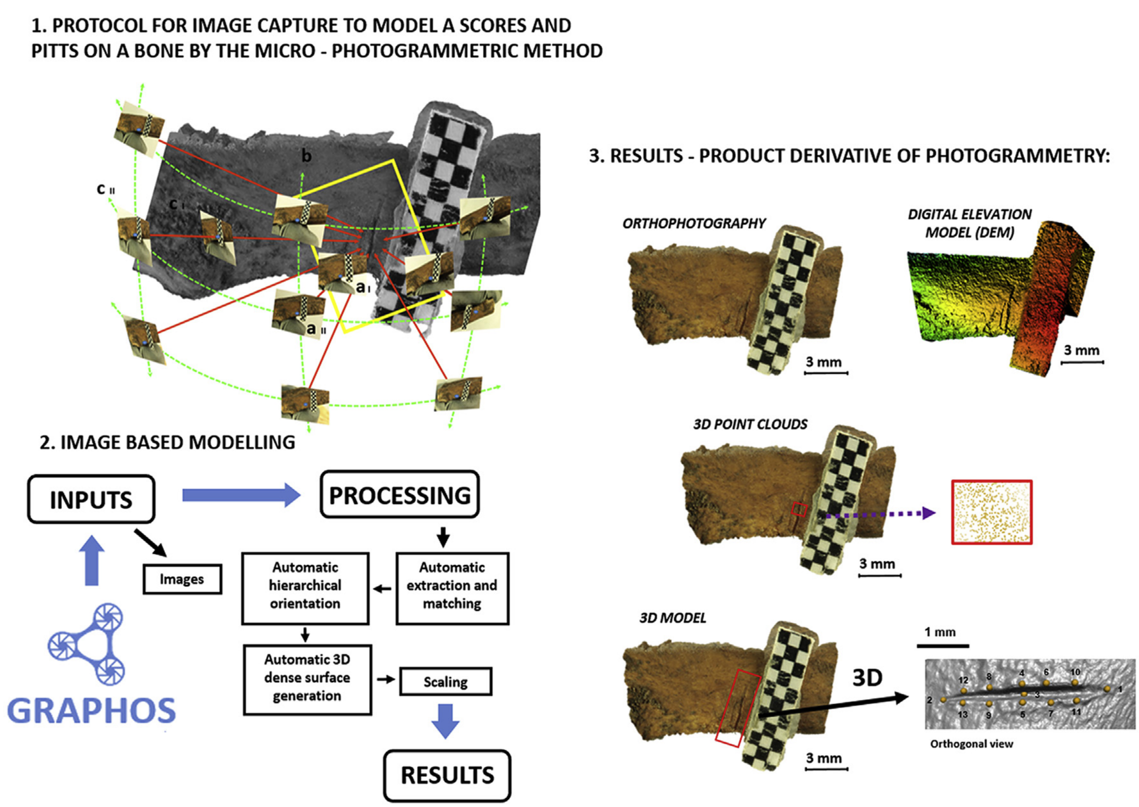

Fig. 6. (1) Protocol for image capture to model a cut mark on a bone by the micro-photogrammetry method, with convergent photographic shots. CP, Master and dependent images in central position. V, Vertical slave images. H, Horizontal slave images. (2) Workflowof the image-basedmodelling technique. (3) Results obtained from data collection and extraction of the cross-section profiles of the cut marks and location of the 7 landmarks used in the 2-dimensional morphometric analysis and measurements taken at each cut mark profile.

from a triangulation algorithm based on Delaunay strategy.

The data produced through the scans are directly imported into Avizo software (Visualisation Sciences Group, USA) where the allocation of the 13 landmark model is performed for each cut mark following Courtenay et al. (2017).

3.3. Statistical analysis

Geometric morphometric analyses were performed in the free software R (www.rproject.org, Core-Team, 2014) to compare the morphology of each archaeological cut mark with our experimental samples. The sets of 3D landmark coordinates were edited and imported into R using the package 'geomorph' (Adams et al., 2017) where a full Procrustes fit and orthogonal tangent projection were carried out (Dryden and Mardia, 1998), preparing each sample for multivariate statistical analysis. This method, commonly referred to as generalised Procrustes analysis (GPA), standardises the information presented through our digital model through a series of superimposition procedures, including translation, rotation and scaling. Any remaining differences are exposed through patterns in variation that can be assessed statistically (Rohlf, 1999; Slice, 2001).

A principle components analysis (PCA) was performed to assess shape variance patterns. The advantages of such analysis allows each individual to be converted and plotted as a single point on a 2D or 3D graph. 95% confidence ellipses were then generated to create a more visual representation of variance distribution. PC scores obtained from PCA were exported to carry out several tests, including the jackknifed cross-validation linear discriminant analysis (LDA) in R's 'e1071' package (Meyer et al., 2016) and the multiple variance analysis (MANOVA) in the 'RVAideMemoire' package (Hervé, 2018). Finally, canoncial variate analyses (CVA) were carried out to determine and better understand trends of variation and covariation amongst groups.

LDA was conducted to determine differences between groups through calculating confusion matrices (Efron and Stein, 1981). The generation of LDA confusion matrix is based on the collection of random data samples from the population and systematically leaving one individual out at a time in each comparison. MANOVA tests were used to statistically assess differences between groups through their mean distribution. The magnitude of differences presented in these results, in the case of structurally similar samples, however, were then tested using an estimation of the effect size using Cohen's D (Cohen, 1988; Lakens, 2017). Through this test group means and standard deviations were first calculated from the PC scores and then used to assess the differences between groups.

Changes in shape were finally visualised by means of transformation grids and warpings computed through thin-plate splines (Bookstein, 1989).

4. Results

Samples found in Zone B of the Coímbre cave are considered identical; therefore the cut marks found at the site was grouped in all statistical comparisons. PCA analysis (Fig. 5) presents a similar morphological trend between the cut marks found in Coímbre cave and those produced by the experimental quartzite sample Q4. A great deal of overlapping, however, can be observed through the first two PC scores, representing a total cumulative variance of 57.45% of the sample over a total of 32 PC scores. The overlapping of samples is fairly typical in a study of this particular nature and can be expected when samples are structurally similar. The CVA graph (Fig. 6) shows a much clearer separation of samples with a complete overlap of Q4 and Coímbre cut marks in a 2D space where 91.65% of the total morphological variance is expressed. Mahalanobis and Procrustes distances calculated through CVA (Table 1) indicate a highly significant similarity between Q4 and the Coímbre sample ($p = 0.96$ and 0.97, respectively). Cut marks belonging to the Q5 sample are not significantly different from Coímbre cut marks though close, according to the p value calculated for the Procrustes distance between these two groups ($p = 0.097$).

Numerical data produced through jack-knifed LDA confusion matrices indicate a higher percentage of association of Coímbre with the Q4 sample (Tables 2 and 3), than any other raw material. These results indicate that at least 63% of the Coimbre sample is produced by Q4 flakes. MANOVA results match with the CVA results, since there is a significant association of the Coímbre cut mark sample with the Q4 sample ($p = 0.98$) and with the Q5 sample (Table 4). The results obtained here may reflect on the structural similarities of the cut marks based on the similar nature of the raw materials, two different types of quartzite. Further testing of these results indicates a small effect size using Cohen's d (Table 5), confirming that the two quartzite samples are practically identical. Nevertheless, considering the higher level of significance and larger LDA percentile reflected with the Q4 sample, Q4 quartzite seems to be more strongly associated with the Coímbre archaeological sample, suggesting its use at the site.(see Figs. 7 and 8)

5. Discussion and conclusion

In this paper, we present the first systematic study of cut-marks from a faunal assemblage of the European Palaeolithic to identify the raw materials involved in carcass exploitation. Usually, the study of tool use is based on use-wear analysis, which can provide information on the employment of lithic tools for processing meat, vegetal fibres, hideworking, etc. (Hayden, 1979; Semenov, 1981). Nevertheless, in this study we aim at understanding the nature of the lithic tools that were used in carcass consumption in Upper Magdalenian populations occupying Coímbre Cave. In order to achieve this, we applied an innovative methodological approach based on 3D virtual reconstruction and the subsequent analysis of cut-marks through photogrammetry and geometric morphometrics. According to our results we can conclude that most of the cut-marks at the Upper Magdalenian level of Coímbre were made with quartzite tools. This is in line with the observations made in the more general raw material analysis: quartzite is the most abundant raw material, and the lithic assemblage includes a large number of unmodified quartzite flakes (Álvarez Alonso et al., 2017).

On the basis of these results, we can confirm that quartzite tools were employed for the processing of carcasses brought to the site, with flint implements reserved for other uses, to be elucidated through use-wear analysis. This pattern would explain the existence of an extensive *chaîne opératoire* of quartzite flakes, when most of the lithic implements were made of flint. Furthermore, we were able to identify the preferential use of local quartzite in the process of carcass processing. Among these results, the integration of taphonomic studies and use-wear analyses could be highly interesting in confidently assessing the range and nature of activities carried out in Palaeolithic sites.

The results from this paper are relevant for a number of reasons: first, it offers a functional perspective into raw material use at Coímbre cave on the basis of cut-mark analysis; secondly, this paper embodies significant developments in the field of taphonomy, applying to the archaeological record a new research avenue mostly developed experimentally (Maté-González et al., 2015, 2016, 2017a, b, c) and only exceptionally applied to archaeological sites (Yravedra et al., 2017a, 2017b; Courtenay et al., 2019); thirdly, the results that we present here were previously only obtainable through use-wear analysis, which can be an issue under certain preservation conditions.

Even though the results obtained using these new methodologies have proved to be consistent, some authors have raised some critical concerns (Pante et al., 2017; Sahle et al., 2017; Otárola-Castillo et al., 2018), offering different methods based on alternative techniques to those shown in the present paper. However, these studies have also been highly criticized. Domínguez-Rodrigo and Baquedano (2018) have demonstrated that the analysis carried out by Sahle et al. (2017), and their critique to taphonomic analyses of the last 30 years is just an

Table 1
Mahalanobis and Procrustes Distance numerical results as obtained through the CVA analysis of the different cut mark samples compared with Coímbre.

		Coimbre	P-Value	Q4	P-Value	Q5	P-Value
		Distance		Distance		Distance	
Q4	Mahalanobis	0.8668	0.9606				
	Procrustes	0.0112	0.9761				
Q5	Mahalanobis	1.9953	< 0.0001	2.0131	< 0.0001		
	Procrustes	0.0302	0.0973	0.031	0.1348		
S2	Mahalanobis	1.748	< 0.0001	1.7262	< 0.0001	2.0148	< 0.0001
	Procrustes	0.0438	0.0031	0.0461	0.003	0.0403	0.0278

Table 2
Jack-knifed Linear Discriminant Analysis results presenting the percentage and number of marks from coimbre classed as each sample.

	Coimbre Class	Percentage
S2	18	23%
Q4	49	63%
Q5	11	14%

Table 3
Jack-knifed Linear Discriminant Analysis results classifying each individual with percentage of classification.

Class	Q4	Q5	S2	Class	Q4	Q5	S2
S2	10%	19%	71%	Q4	66%	2%	32%
Q4	92%	5%	3%	Q4	94%	1%	4%
Q4	73%	24%	4%	S2	5%	5%	89%
Q4	97%	3%	0%	S2	8%	34%	57%
Q4	61%	24%	15%	Q4	49%	6%	45%
S2	45%	8%	47%	Q4	75%	6%	19%
S2	24%	5%	71%	S2	18%	24%	58%
Q5	0%	99%	0%	Q4	47%	42%	11%
Q4	61%	16%	22%	Q4	38%	25%	37%
Q5	30%	40%	30%	Q5	46%	51%	4%
Q4	61%	12%	27%	Q4	42%	29%	29%
Q4	98%	0%	1%	Q5	35%	62%	4%
Q4	87%	3%	10%	Q4	65%	24%	11%
Q4	51%	29%	20%	S2	21%	32%	47%
Q4	79%	10%	11%	Q4	35%	30%	35%
Q5	3%	54%	43%	Q4	80%	13%	8%
S2	3%	28%	69%	Q4	60%	13%	27%
S2	31%	14%	55%	Q4	98%	1%	0%
S2	17%	10%	72%	Q4	96%	2%	3%
Q4	83%	6%	12%	Q4	59%	6%	35%
Q4	90%	7%	3%	Q4	98%	2%	0%
Q4	57%	2%	42%	Q4	67%	29%	4%
Q4	66%	7%	27%	S2	46%	5%	49%
Q4	85%	6%	10%	Q4	73%	19%	9%
Q4	63%	9%	28%	Q4	99%	1%	0%
Q4	63%	15%	22%	Q4	100%	0%	0%
Q5	13%	45%	41%	Q4	61%	10%	30%
Q5	34%	44%	22%	Q4	66%	9%	26%
S2	6%	34%	60%	Q4	41%	32%	27%
Q5	14%	51%	35%	S2	1%	15%	84%
Q4	57%	24%	19%	Q5	16%	48%	36%
Q4	38%	34%	28%	Q5	3%	65%	32%
Q4	67%	24%	9%	S2	3%	8%	89%
S2	22%	27%	51%	Q4	51%	15%	33%
S2	30%	3%	67%	Q5	25%	69%	6%
Q4	98%	1%	1%	Q4	60%	22%	18%
Q4	89%	2%	10%	Q4	93%	4%	2%
S2	15%	16%	69%	Q4	76%	2%	22%
S2	27%	32%	41%	Q4	81%	12%	7%

unfounded, subjective opinion, without any relevant empirical data to support those claims. Studies using white-light non-contact confocal profilometers and Digital Surf's MountainsR software (Pante et al., 2017) as well as full 3D morphometrics aided by Bayesian analysis (Otárola-Castillo et al., 2018) have been recently published, not

Table 4
Pairwise MANOVA p-values comparing the morphological differences of cut marks from each sample.

	Coimbre	Q4	Q5	S2
Coimbre		0.9772	0.218	0.000111
Q4	0.9772		0.3302	0.000173
Q5	0.218	0.3302		0.00024
S2	0.000111	0.000173	0.00024	

Table 5
Effect-Size comparisons of the different quartzite samples and the cut marks from Coimbre.

	Raw Bounds		CI		p – value	
	Low	High	Low	High	Low	High
Coimbre – Q4	−0.0211	0.0211	−0.0103	0.0101	0.0005	0.0004
Coimbre – Q5	−0.0214	0.0214	−0.0084	0.0132	0.0002	0.0022
Q4 – Q5	−0.0210	0.0210	−0.0146	0.0086	0.0059	0.0005

without some criticism (Courtenay et al., 2018). On one hand, they analysed small samples, which are not statistically representative; on the other hand, they compare taphonomic alterations which are easily distinguished macroscopically, e.g. cut-marks versus tooth-marks (Pante et al., 2017), and that have already been defined and differentiated in several classic taphonomic works (Binford, 1981; Shipman, 1981). Therefore, we argue that there is absolutely no need for virtual reconstructions and statistical analyses for telling apart these two types of bone surface modifications.

Otárola-Castillo et al. (2018) propose a novel attempt, trying to distinguish cut-marks made at different types of angles (45° and 90°). However, there are two associated issues: the first one is that the two sets of experimental cut-marks could be distinguished macroscopically without the need for 3D morphometrics aided by Bayesian analysis or any other type of sophisticated approach, because the results were predictable. The second issue is that, despite this circumstance, Courtenay et al. (2018) replicated the same experiment, and obtained a higher degree of resolution, using a 2D and a 3D approach that required less number of landmarks and much less computational effort. On top of that, the equipment used for this study as well as in Courtenay et al. (2018) is much more affordable (Maté-González et al., 2017c), than the microscopes presented by Pante et al. (2017) and Otárola-Castillo et al. (2018).

In contrast to this, studies that present no significant results in archaeological terms, there are a series of more relevant attempts to distinguish traces prone to equifinality, such as cut-marks produced by tools of different raw materials, both experimentally (Maté-González et al., 2015, 2016, 2017a, b, c; Palomeque-González et al., 2017; Courtenay et al., 2017) and archaeologically (Yravedra et al., 2017a, 2017b; Courtenay et al., 2019); percussion marks without internal microstriation and carnivore pit tooth marks (Yravedra et al., 2018); tooth marks made by different carnivores (Aramendi et al., 2017;

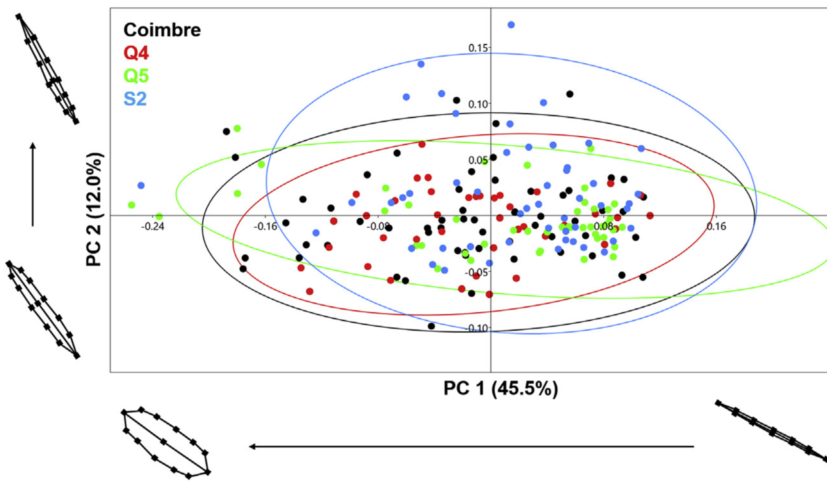

Fig. 7. Scatter plot presenting the PCA results comparing the cut marks from Coímbre with the three raw material samples in shape space. Extreme shape changes can be observed across the axis of each PC score.

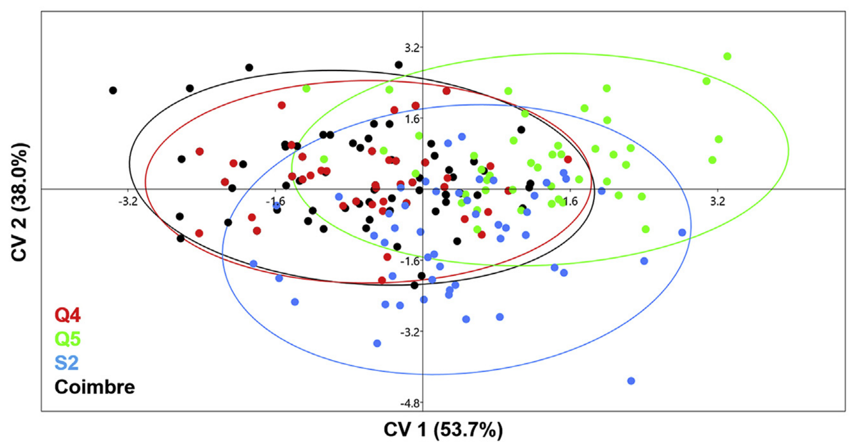

Fig 8. Scatter plot presenting CVA results comparing Coímbre with the three raw material samples.

Arriaza et al., 2017; Yravedra et al., 2017e).

To sum up, the 3D virtual reconstruction of bone surface modifications by means of micro-photogrammetry for the geometric morphometric study of 3D features has proved to achieve enough resolution, to determine the use of quartzite flakes for carcass processing at the Upper Magdalenian levels of Coímbre cave.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quaint.2019.01.008.

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