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Cut marks and raw material exploitation in the lower pleistocene site of Bell's Korongo (BK, Olduvai Gorge, Tanzania): A geometric morphometric analysis

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ABSTRACT

The Lower Pleistocene site of Bell's Korongo (BK) in Olduvai Gorge (Tanzania) has been a key site for the study of the origin of human behaviour. The lower archaeological levels of BK are characterized by anthropogenic activity related to the exploitation of megafauna (elephant, hippopotamus, Sivatherium) and smaller game (zebra, wildebeest and antelopes). These remains display a high frequency of cut marks. The exceptional state of preservation of the BK fossil assemblage has allowed a wide range of different analyses that, among other things, detected the use of quartzite in butchering activities through the study of cut marks. Following up previous analyses, this paper presents the study of a series of cut marks from the BK faunal assemblage using a 3D geometric morphometric methodological approach in order to determine the mineralogical properties of the quartzite used at the site. BK cut marks are compared with experimentally produced cut marks using 9 mineralogically different quartzite types from Olduvai Gorge. This comparative analysis provides valuable hints about the exact nature of the raw materials used in butchering activities. The results presented here identify a preferential use of quartzite with a finer granular composition, suggesting that hominin populations were already selecting the best raw materials for their use in specific activities 1.3 Mya.

1. Introduction

Olduvai Gorge (Tanzania) contains one of the richest and best-preserved Pleistocene fossil records on Earth. To date, more than 120 archaeological sites have been discovered, where over 90 hominin remains representing four different species have been recovered. The great abundance of lithic tools and faunal assemblages associated with these hominin populations has inspired abundant research in the area (L. Leakey, 1959; M. Leakey, 1971; Domínguez-Rodrigo et al., 2009a, 2013a, 2015). In this regard, taphonomy has played a key role in enhancing our understanding of early hominin diets and their associated behavioural patterns. For example, one of the main discussions fuelled by taphonomy is the hunter-scavenger debate (Binford, 1981; Blumenschine, 1986, 1995; Domínguez-Rodrigo, 1997; Domínguez-Rodrigo and Barba, 2006; Domínguez-Rodrigo et al., 2007, 2015) that according to recent investigations stresses a recurrent primary access to animal carcasses by early hominin populations at least 1.8 Mya (Domínguez-Rodrigo and Barba, 2006; Domínguez-Rodrigo et al., 2007, 2014a, b). Taphonomic analyses of archaeological sites such as Bell's Korongo (BK) and Sam Howard Korongo (SHK) have also proved the intensive exploitation of large animal carcasses by *Homo erectus* populations at least 1.3 and 1.5 Mya respectively (Egeland and Domínguez-

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Rodrigo, 2008; Domínguez-Rodrigo et al., 2009a, 2013a,b, 2014c; Pickering et al., 2013; Organista, 2017; Organista et al., 2016, 2017). Amongst these sites, the large quantity of elephant, hippopotamus, *Sivatherium*, wildebeest, zebra and other large mammal remains show clear evidence of butchering activities (Domínguez-Rodrigo et al., 2009a, 2013a,b; Organista, 2017; Organista et al., 2016, 2017).

Nevertheless, a great number of other agents usually intervene in the formation of a site creating problems of equifinality (Binford, 1981; Behrensmeyer, 1984; Fiorillo, 1984; Behrensmeyer et al., 1986; Olsen and Shipman, 1988; Blasco et al., 2008; Domínguez-Rodrigo et al., 2009b; De Juana et al., 2010; Bello, 2011; Pineda et al., 2014; Domínguez-Rodrigo et al., 2017; Egeland et al., 2018). This can only be assessed through archaeological experimentation based on actualistic analogous observations (Bunge, 1981; Gifford-Gonzalez, 1989, 1991). Recent advances in this field have made technological developments applied to the digital reconstruction of taphonomic traces. These studies have provided new tools to overcome certain limits imposed by equifinality (Maté-González et al., 2015, 2016, 2017a, b, c; Aramendi et al., 2017; Arriaza et al., 2017; Courtenay et al., 2017; Yravedra et al., 2017a, b, c). First, the use of microscopy in the analysis of bone cortical modifications (Potts and Shipman, 1981; Shipman and Rose, 1983; Bromage and Boyde, 1984; Olsen, 1988; Greenfield, 1999, 2006; Lozano-Ruiz et al., 2004; Smith and Brickley, 2004; Lewis, 2008; Blasco and Rosell, 2009) provided high resolution images of the traces, which can be used to generate virtual models (Bello and Soligo, 2008; Bello et al., 2009, 2013; Bello, 2011; Boschin and Crezzini, 2011; Archer and Braun, 2013; Crezzini et al., 2014; Bonney, 2014). Later, the development of micro-photogrammetry in combination with geometric morphometrics to analyse cut mark cross-section morphology in experimental (Maté-González et al., 2015, 2016, 2017a, b) and archaeological samples (Yravedra et al., 2017a, c) achieved more conclusive results. Subsequent taphonomic studies based on virtual reconstructions included 3D landmark models capturing morphological features of the traces in their entirety (Aramendi et al., 2017; Courtenay et al., 2017; Yravedra et al., 2018).

Recent studies based on 2D geometric morphometrics and multivariate statistics have been able to identify the important presence of quartzite flakes in sites such as BK and FLK-West (Yravedra et al., 2017a, c). Here we present a new study of the BK cut marks based on a 3D geometric morphometric approach to assess the effects on mark morphology that are conditioned by the crystal or grain size of the raw materials present at Olduvai Gorge. Our analysis confronts the possibility of deciphering the exact nature of the cut marks observed at BK, and subsequently the inference of the mineralogical properties of quartzite that could have been preferentially used by *Homo erectus* populations.

1.1. The BK site

In 1935, L. Leakey discovered the site of BK in the uppermost part of Bed II, approximately 3 km away from the junction with the main gorge (Fig. 1). The original excavations carried out by the Leakey family unearthed a large faunal and lithic assemblage (Leakey, 1971). Since 2006 the expansion of Leakey's original trenches by The Olduvai Palaeoanthropology and Paleoecology Project (TOPPP) adopted a more systematic approach (Domínguez-Rodrigo et al., 2009a), recovering more than 6000 faunal remains, 1575 lithic artefacts as well as the only *Paranthropus boisei* partial skeleton (Domínguez-Rodrigo et al., 2013a,b).

Chronostratigraphically, BK is situated above Tuff IID (Fig. 2) and has most recently been dated at 1.338 ± 0.024 Ma using $^{40}\mathrm{Ar}/^{39}\mathrm{Ar}$ isotopic ratios (Domínguez-Rodrigo et al., 2013a,b). Geological as well as spatial analyses tend to agree on the interpretation of this site as product of a large meandering river, where most of the archaeological levels are found in the point-bar (Domínguez-Rodrigo et al., 2009b; 2014d; Uribelarrea and Domínguez-Rodrigo et al., 2017), though with low impact on the osteological material distribution (Organista, 2017). A total of four sedimentary units with the two lowermost units preserving 6 different archaeological levels have been identified at the site (Uribelarrea and Domínguez-Rodrigo et al., 2017). Of the two archaeologically rich units, Unit 1 is found to contain levels BK3, BK3b, BK4, BK5, while Unit 2 contains BK1 and BK2.

The archaeological remains recovered at BK present an abundant lithic assemblage consisting mostly of quartzite simple flakes associated to the Developed Oldowan B technocomplex (Leakey, 1971; Díez Martín et al., 2009; Sánchez-Yustos et al., 2016, 2017). Alongside the simple lithic artefacts the site contains retouched tools including a limited number of bifacial handaxes (Sánchez-Yustos et al., 2017). The analysis of knapping strategies as well as the physical properties of these tools in accordance with the technological requirements associated with megafaunal exploitation (Diez-Martín et al., 2009; Sánchez-Yustos et al., 2016, 2017) have allowed the identification of a preferential selection of quartzite simple flakes.

The faunal assemblage of BK consists of a wide range of taxa, including Bovidae, Equidae and Suidae. The taxa present at BK are representative of an open landscape accompanied by areas of abundant sources of water (Domínguez-Rodrigo et al., 2014a, d; Yravedra et al., 2017a). Slight differences, however, can be seen in the upper layers through a predominant representation of medium and small sized fauna, whereas inferior levels contain a high number of megafaunal remains including, hippopotami, elephants, *Sivatherium* and more than a couple dozen *Pelorovis oldowayensis* (Organista et al., 2016). The BK megafaunal assemblage shows traces of anthropogenic exploitation, which imply that hominins were the primary accumulating agents at the site.

2. Methods and sample

2.1. Geological sample

All quartzite samples used for this study (Q1-Q6, N1, N2 and O) were collected at the Naibor Soit Precambrian inselberg (Kisele Formation, Hay, 1976), on the northern side of the Olduvai Gorge (Tanzania). Quartzite is the most abundant raw material in this area of the Serengeti, appearing frequently throughout all Beds of the Olduvai Gorge. The predominance of Olduvai Gorge Quartzite in BK is especially relevant considering over 90% of this lithic materials across all levels are knapped in this material (Diez-Martín et al., 2009; Sánchez-Yustos et al., 2017).

Samples range in colour from milky white to blue grey, with large enough crystals and mechanical properties to be confused with quartz (Santonja et al., 2014). The study of thin sections in cross-polarized light reveals a tight interlocking network of large quartz crystals, commonly accompanied with oriented prismatic muscovite crystals (Fig. 3).

Along with the standard mineralogical characterization, major crystal axes (D1) and perpendicular axes (D2) were measured and averaged for 100 crystals using point-counting methods as explained in Fesharaki et al. (2015) for each geological thin section and recorded in Table 1.

2.2. Taphonomic sample

For the purpose of this study a total of 314 cut marks were analysed. The total BK sample consists of 109 cut marked specimens across levels BK1 through to BK5. Nevertheless, not all cortical surfaces presented sufficient cortical preservation for geometric morphometric analysis, reducing the sample size within this study to 44 cut marks (See Supplementary File 1). BK cut marks were previously identified following the criteria established by Domínguez-Rodrigo et al. (2009b) and De Juana et al. (2010).

To tie in the geological results with the study of these cut marks, 9

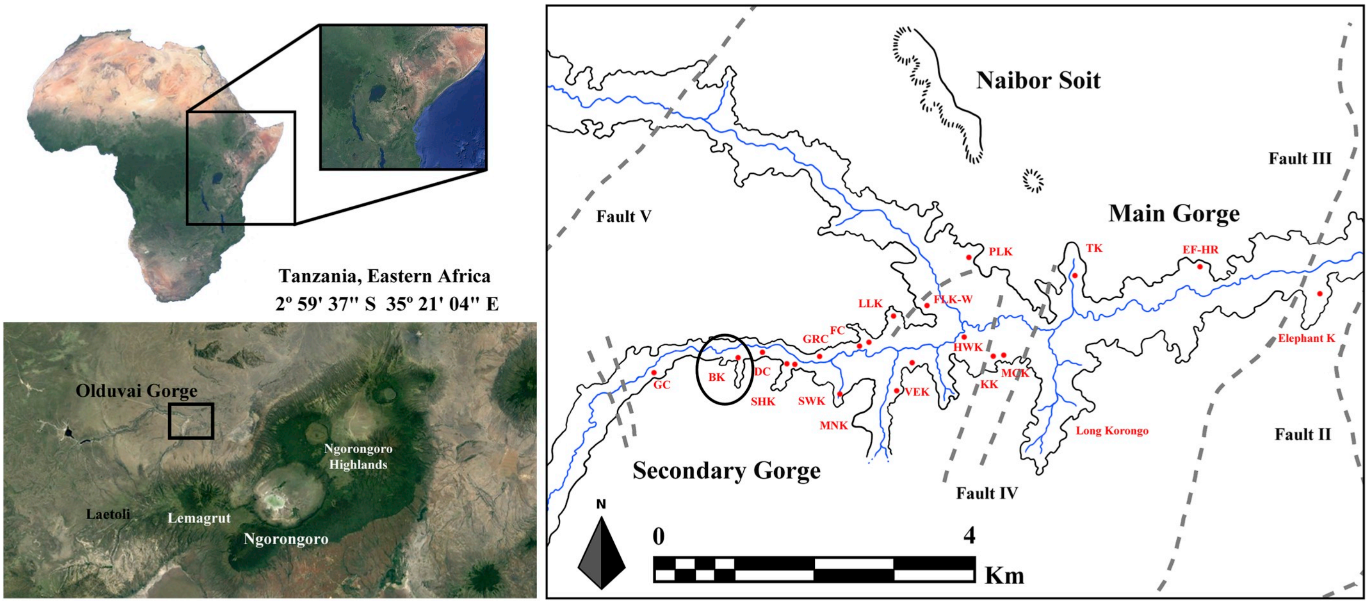

Fig. 1. Geographic location of the Olduvai Gorge (Left) and the site of BK in relation to other key sites of Bed II (Right).

Olduvai quartzite raw material types were knapped by an experienced individual to produce a series of simple flakes. These flakes were then used to produce cut marks on the fresh radii (n = 9) and tibiae (n = 9) of an adult suid with meat still on the bone. All cut marks were produced by a single right handed individual homogeneously across the diaphysis of each bone. In order to maintain analogy with the marks observed in the archaeological sample, all incisions tried to maintain cutting angle perpendicular to the bone, without producing scrape or slice marks. Considering observations made by Maté-González et al. (2019), neither the anatomical element nor size of the animal was considered a conditioning factor for morphological studies. The experiment was solely focused on cut marks produced by simple flakes due to the predominance of these tools at BK and the insignificant number of retouched flakes and handaxes. A total of 270 cut marks were generated using the different quartzite types from Olduvai Gorge: 30 cut marks produced by simple flakes of each quartzite were selected to perform the comparison with the BK archaeological sample.

Firstly, the entire selection of marks produced by the different raw material types were compared with BK, however, considering the very small difference between the granular composition and texture of the quartzite samples, cut marks were grouped according to the crystal surface size of the quartzite; quartzite of small (Q4, Q6 and N1), medium (Q1, Q3 and N2) and large (Q2, Q5 and O) granular composition. The grouping of these samples was based on the average overall area of the crystals calculated using D1 and D2 axes measurements.

A visual example of some of the archaeological as well as the experimental cut marks has been provided in Fig. 4.

2.3. Virtual reconstruction and morphometric analysis

The morphological analysis of cut marks was carried out following the methodology described in Courtenay et al. (2017). This analytical technique is based on the allocation of 13 landmarks (Table 2) on a 3D digitally reconstructed model of each cut mark. The cut marks were processed using a DAVID structured-light scanner SLS-2 that belongs to the TIDOP research group, located at the University of Salamanca (Spain). Reconstruction protocols are specified in Maté-González et al. (2017b) and Courtenay et al. (2017). The DAVID structured-light scanner SLS-2 generates high-resolution 3D models that can be directly imported as PLY files into Avizo software (Visualization Sciences Group, USA) where landmarks were collected.

The use of landmarks in modern morphometrics has enhanced the analysis of structures that can be described through homologous means (O'Higgins and Johnson, 1998; Bookstein, 1991; Hall, 2003; Klingenberg, 2008). Landmark configurations contain shape and size information in the form of Cartesian coordinates that after standardization (orientation, translation and scaling) can be analysed using multivariate statistics (Rohlf, 1999; Slice, 2001). The distances between structures can expose patterns of variation that can be studied using several tests.

Principal component analyses (PCA) were used to assess patterns of variation among the data in shape space, where each cut mark is plotted according to principal components (PCs) that successively account for decreasing proportions of the total sample variance (Bookstein, 1991). Plots with 90% confidence ellipses were created to better define the area occupied by each sample in shape space and to observe the degree of overlap between groups. Changes in shape were visualized with the aid of transformation grids and warpings (Bookstein, 1989) computed using thin-plate splines in Morphologika 2.5 (O'Higgins and Johnson, 1998).

Firstly, individual groups for each quartzite type were established and compared to our archaeological sample. Secondly, BK cut marks were compared with larger sets grouped based on the granular composition of the raw materials used to generate the experimental marks.

Multiple variance analyses (MANOVA) were performed on the PC scores to assess shape differences and similarities among the cut mark sample. The Pairwise MANOVA tests the null hypothesis that the mean of all groups is equal, providing significance values in pair comparisons. MANOVAs were performed in the R environment (www.rproject.org, Core-Team, 2015).

Canonical variate analyses (CVA) and jackknife cross-validated linear discriminant analyses (LDA) were performed to determine the morphometric features that best differentiate between groups and to examine the assignation of BK cut marks. A priori defined groups of the three quartzite grained sizes and BK were tested in MorphoJ (Klingenberg, 2011). Permutation tests (N = 10,000) were computed to assess the significance of the differences between groups. Jack knife cross-validated LDA were performed on the shape PC scores using the MASS package in R. Association probabilities were observed to evaluate the classification of BK cut marks.

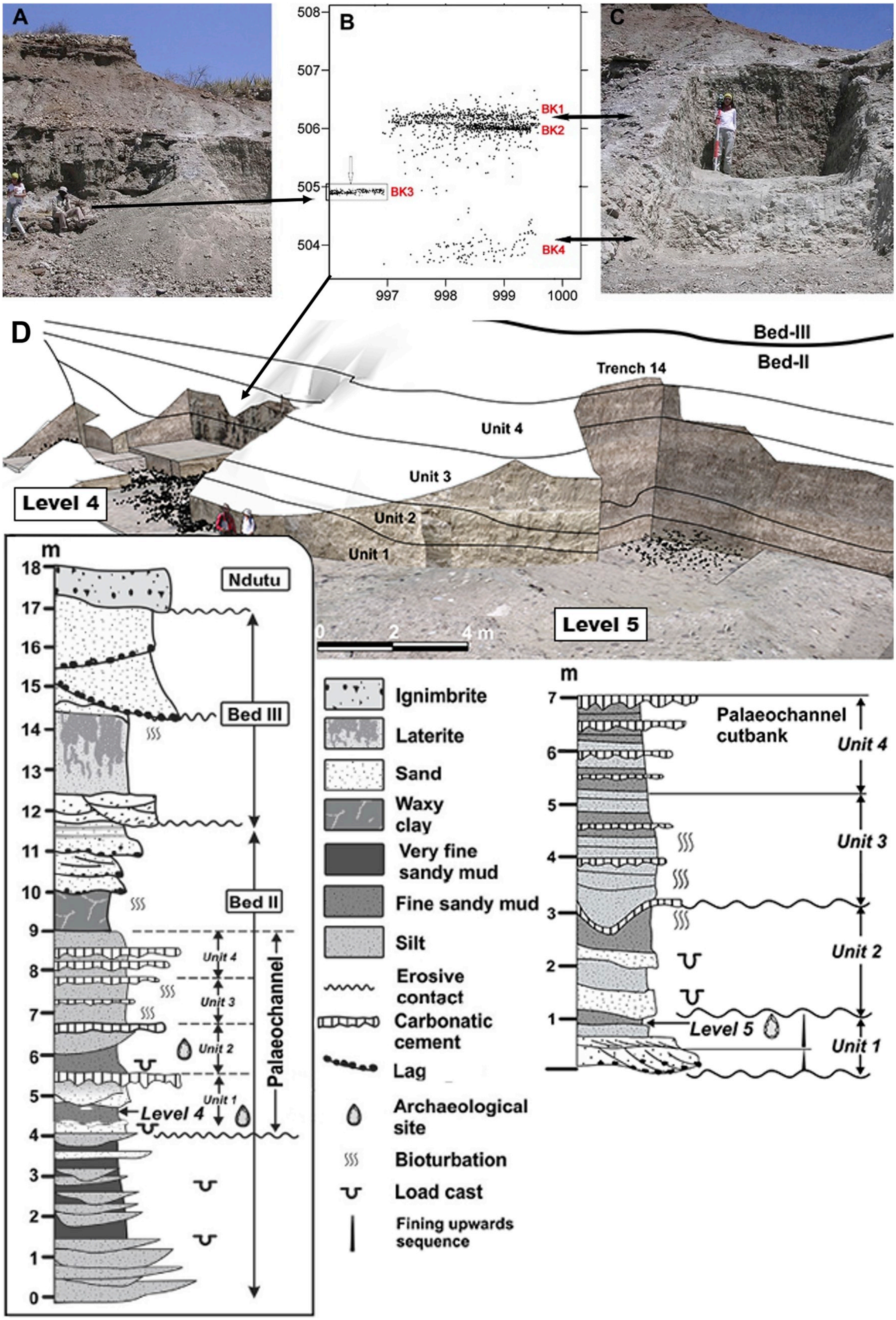

Fig. 2. (A–C) Figures from Domínguez-Rodrigo et al. (2009a) indicating the distribution of materials from BK, including levels BK1 through to BK4. Here Leakeys's original trench (A) can be seen (A) and their spatial distribution in relation with the materials recovered from the TOPPP trench (C). (D) Location of both Levels 4 and 5 at BK. Below each of the corresponding levels detailed stratigraphic sections have been included describing the location of levels in their stratigraphic context. This figure has been adapted from Domínguez-Rodrigo et al. (2014a,b,c) and Organista et al. (2016) where further stratigraphic detail can be consulted.

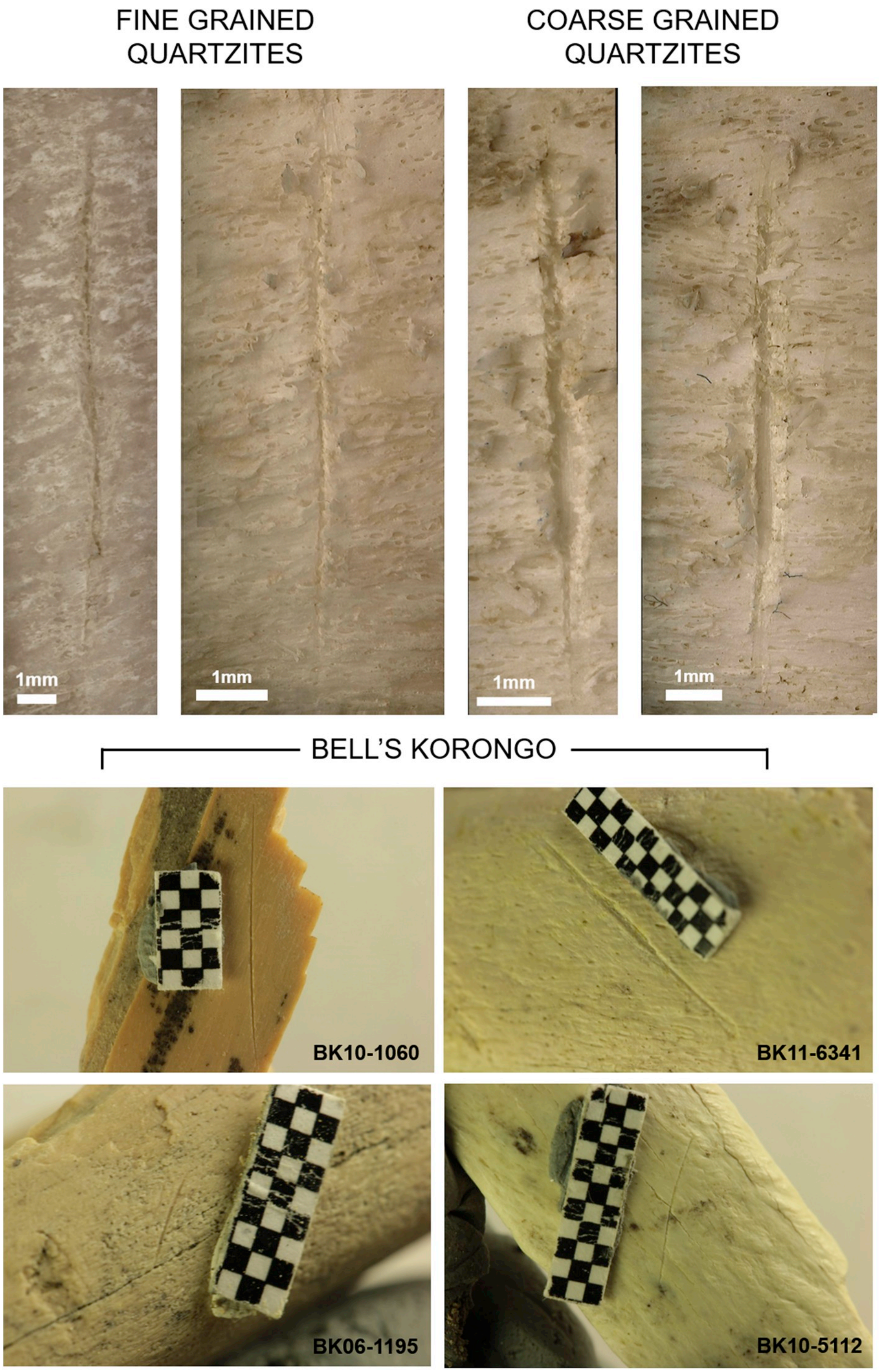

Fig. 3. Examples of both experimental and archaeological cut marks. Experimental cut marks were photographed using the HIROX KH-8700 3D Digital Microscope located at the *Institut Català de Paleoecologia Humana I Evolució Social* laboratory (Tarragona) at 100× magnification. Archaeological cut marks were photographed using a Canon EOS 700D reflex camera. More examples of archaeological traces can be found in Supplementary File 1.

Table 1
Average measured length of major crystal axis (D1) and perpendicular axis (D2). Length of major crystal axis (D1) of sample "O" taken from Maté-González et al. (2017a,b,c).

	Q1	Q2	Q3	Q4	Q5	Q6	N1	N2	O
D1(mm)	4.11	3.98	3.84	2.87	4.35	3.14	3.95	3.95	5.00
D2(mm)	2.95	3.21	3.11	2.64	3.02	2.79	2.72	3.17	–

3. Results

The original PCA and CVA graphs (Fig. 5) comparing all samples individually are highly overlapping while the numerical results obtained by means of multivariate statistics provide conflicting results (Table 3). Only one quartzite sample (Q6) appears to be associated with BK cut marks in both the MANOVA and CVA results. According to the Pairwise MANOVA, the sample mean Q4 is not significantly different from that of BK, while CVA results based on Mahalanobis distances stress greater similarities between BK and Q5 and N2 samples (Table 3).

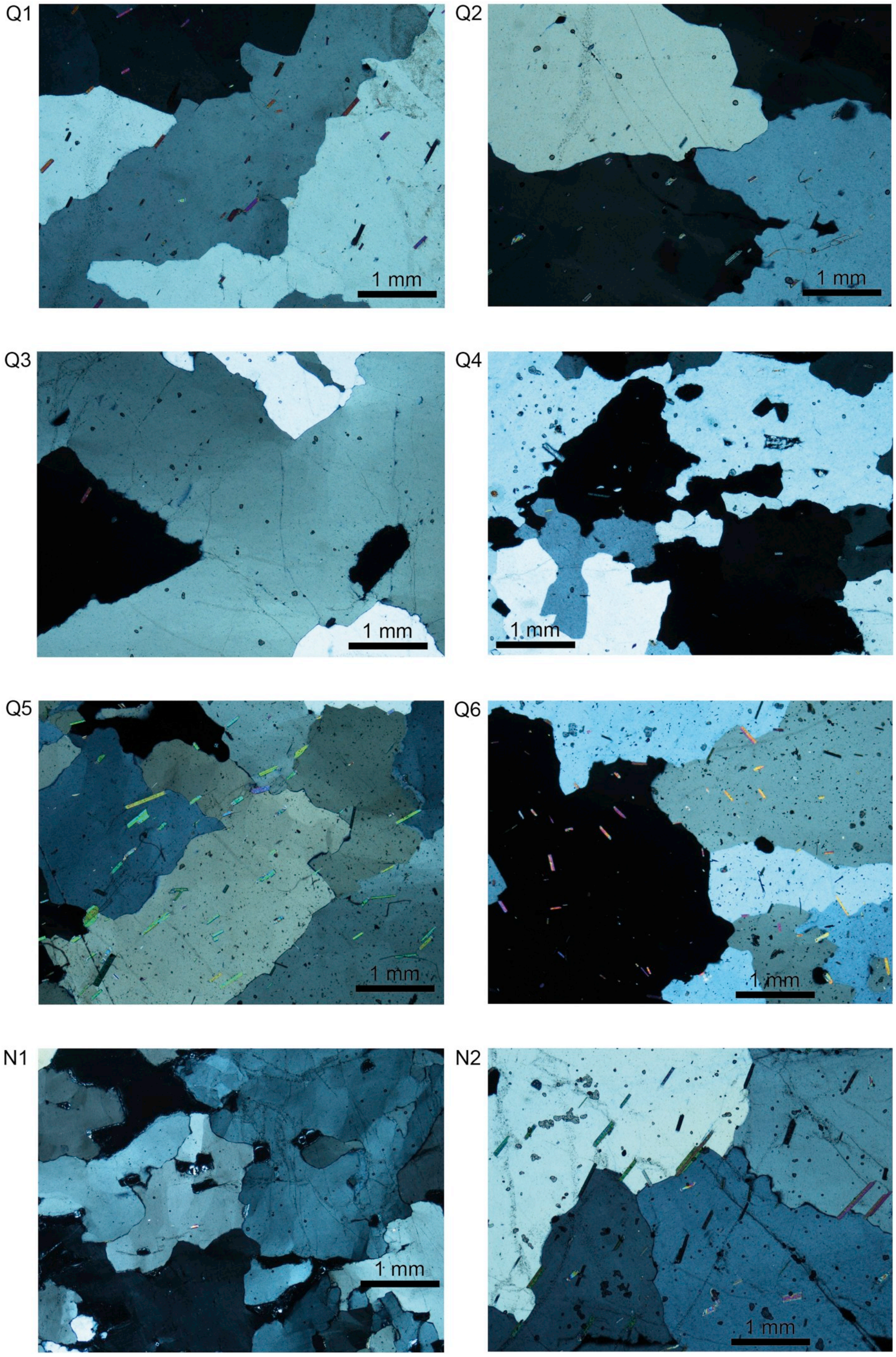

Fig. 4. Thin sections of the geological samples as seen with cross-polarized light. Thin section for sample O can be consulted in Maté-González et al. (2017c:4). Of the quartzite samples presented here, these were later grouped into quartzites of small (Q4, Q6 and N1), medium (Q1, Q3 and N2) and large (Q2 and Q5) granular composition.

Regarding these results, the quantity of individuals being compared must be re-organized to reduce statistical noise.

The PCA comparing all the quartzite samples organized into their respected size groups with BK cut marks is explained by a total of 32 PC scores, with the first two PCs accounting for 58% of the sample variance. All groups overlap in shape space scatter-plot (Fig. 6), though slight differences are noticeable. The "Large" group shows a wider dispersion across PC1, indicating larger changes in the overall width of the mark. The "Large" sample is represented by cut marks with the broadest and slimmest cross-sections at both PC1 ends. The rest of the samples are less scattered along PC1. While the "Medium" sample also tends to be a little more dispersed along PC2, the "Small" group and BK show very similar scattering patterns occupying a relatively reduced portion of the graph. These graphical differences were assessed using Pairwise MANOVA tests on the PC scores (Table 4) the results indicate that only the "Small" quartzites cannot be distinguished from BK sample.

CVA analysis (Fig. 7a) of these 4 samples does not provide clear graphical results either. No clear pattern linking BK to any of the quartzite groups can be detected, though the "Small" group shows a slightly larger degree of overlap with the BK sample. The Mahalanobis and Procrustes distances calculated between the groups show

Table 2
Table presenting the number, location and type of landmarks used in the geometric morphometric analysis. These landmarks are presented following the 2nd landmark model presented by Courtenay et al. (2017).

Landmarks		Landmark Type
Nº	Location	
1	Beginning of the Cut Mark	II
2	End of the Cut Mark	II
3	Deepest point in the middle of the Cut Mark	II
4	Left hand shoulder of the middle of the Cut Mark	II
5	Right hand shoulder of the middle of the Cut Mark	II
6	Left hand shoulder, halfway between the beginning and the middle of the Cut Mark	III
7	Right hand shoulder, halfway between the beginning and the middle of the Cut Mark	III
8	Left hand shoulder, halfway between the middle and the end of the Cut Mark	III
9	Right hand shoulder, halfway between the middle and the end of the Cut Mark	III
10	Left hand shoulder, at the opening angle of the Cut Mark	II
11	Right hand shoulder, at the opening angle of the Cut Mark	II
12	Left hand shoulder, at the closing angle of the Cut Mark	II
13	Right hand shoulder, at the closing angle of the Cut Mark	II

significant ($p < 0.0001$) distances between all samples, except for the pair comparison BK-“Small” Procrustes distance (Table 5).

According to the LDA results the “Medium” sample is the least likely match for BK, while 38.6% of BK marks are classified as “Small” and 29.5% are mistaken for cut marks produced with coarse-grained quartzite types (Table 6). These results are not as conclusive as the previous ones, where only the “Small” values clearly approximate the BK sample. Nevertheless, it seems clear that the “Medium” group can be removed in order to delimit the scope of the analyses and facilitate their interpretation.

Cut marks samples excluding the “Medium” group overlap in the PCA scatter plot (Fig. 8). However, here we can observe emerging variation patterns with the larger grained quartzites generating a more scattered distribution in the Euclidean space (especially along PC1) while both BK and small grained quartzite present a similarly tight trend occupying the same area. Distribution of the three sample groups is similar along PC2, including all of them specimens within the morphological features expressed by the warped shapes (Fig. 7). Differences in shape are expressed through thin-plate splines; the “Small” group as well as BK present much thinner and homogenous cut marks whereas the “Large” group shows a much greater variation in cut mark morphology (Figs. 6 and 8). The main differences presented by PC1 display a variance in shape depending greatly on the width of the cut mark,

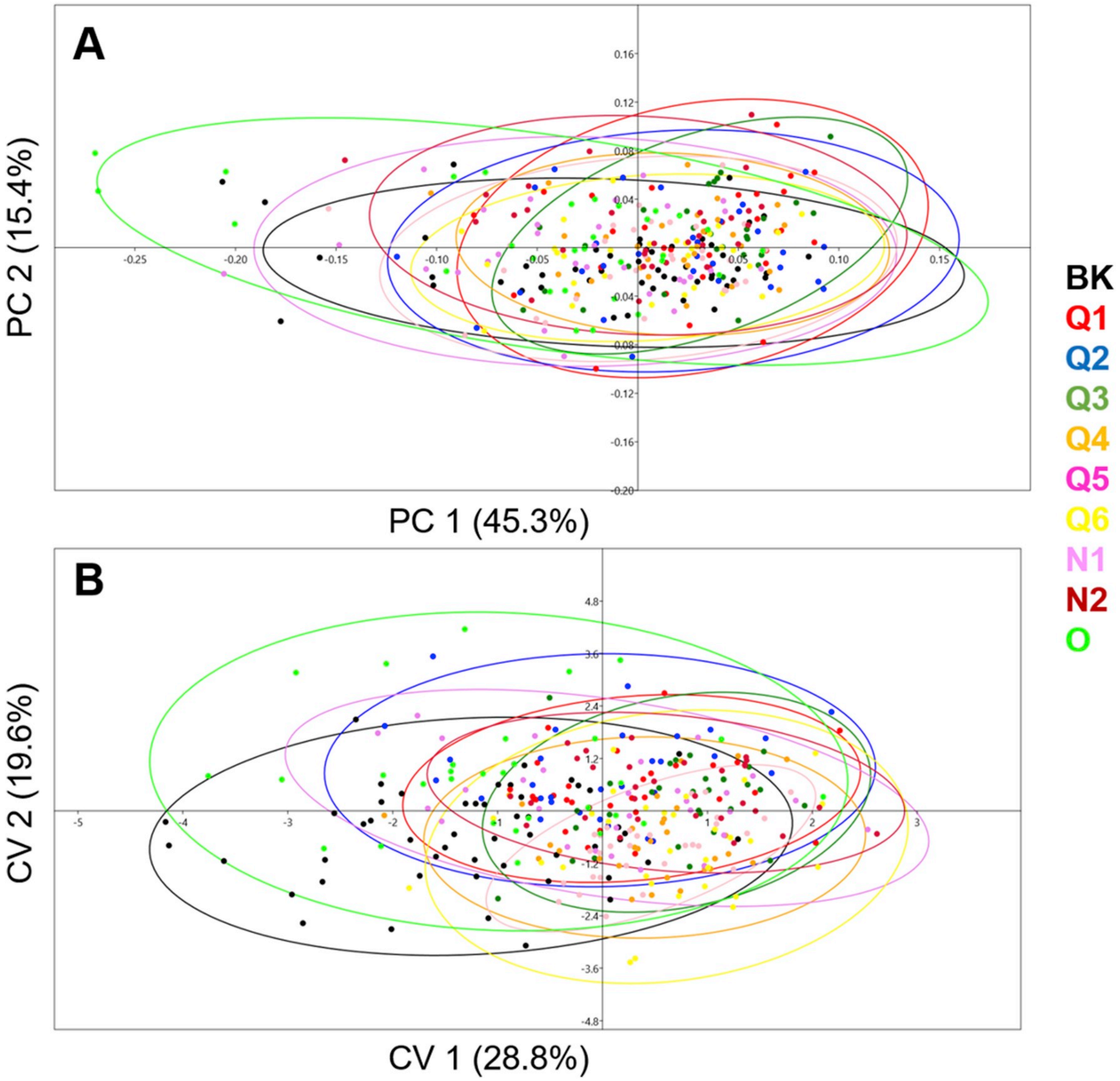

Fig. 5. Two scatter plots presenting (A) PCA and (B) CVA graphs comparing all 9 quartzite samples (ungrouped) with the cut marks from BK.

Table 3
P-Values from MANOVA tests as well as the Mahalanobis and Procrustes distances comparing BK to each of the Quarztie Samples.

	Q1	Q2	Q3	Q4	Q5	Q6	N1	N2	O
MANOVA	0.000511	0.000304	0.000241	**0.066373**	0.001245	**0.064839**	0.043967	6.05E-10	0.006525
Mahalanobis	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Procrustes	0.0007	0.0045	< 0.0001	0.0177	**0.0556**	**0.1098**	0.0196	**0.1256**	< 0.0001

with larger grained quartzites producing much wider cut marks than the smaller grained materials. PC2 on the other hand mainly represents the depth of the mark, and to a much lesser degree, a minute variation in the positioning of landmark 3 possibly indicating the cutting angle (PC2: Figs. 5 and 7). Variations in depth, however, appear much more evident and significant than the angle of the incision, as can be seen if compared to results produced from other experimental studies into cutting and slicing butchery marks (Courtenay et al., 2018a). Width and depth, therefore, represent the largest percentage of the variation in cut marks according to granular composition.

MANOVA results clearly stress these trends observed in the PCA plot, with no significant differences between BK and "Small" group means and a p-value < 0.05 for the pair comparison BK – "Large" (Table 4). CVA results on the "Small", "Large" and BK sample are more conclusive. The CVA graph explaining 100% of the variance is mostly occupied by a widespread "Large" sample, whereas BK and small-grained quartzites are confined within a reduced area where they overlap (Fig. 7b). While the Mahalanobis numerical values (Table 7) still present significant distances between all groups, the significance values obtained via permutation for the Procrustes distances indicate that BK resembles the smaller grained quartzite group. The classification/misclassification matrix produced through the LDA tests display a slightly higher classification percentage of the BK sample as product of "Small" grained samples (Table 6). However, 45.5% of the BK sample is also assigned to the coarse-grained quartzite group. Thus, this implies a preferential use of small grained quartzites in butchery activities with a more marginal use of larger grained raw materials.

Table 4
P-Values from MANOVA tests comparing BK with each of the quartzite size groups as well as comparisons excluding the "Medium" group.

	Small	Medium	Large
BK	**0.084081** **0.071168**	3.86E-07 –	0.000464 0.000342

4. Discussion

The results presented in this paper suggest that the BK cut marks were preferentially produced using quartzite tools of a small granular texture. The relevance of these results is multiple; firstly this study proves the value and reliability of our methodological approach with regards to its application to archaeological assemblages. Secondly, the results obtained highlight the high resolution reached with this methodology, which allows not only the differentiation between cut marks made with different raw materials (Courtenay et al., 2017; Maté-González et al., 2017a,b,c), but also between cut marks generated with the same raw material but with different grain or crystal size. Finally,

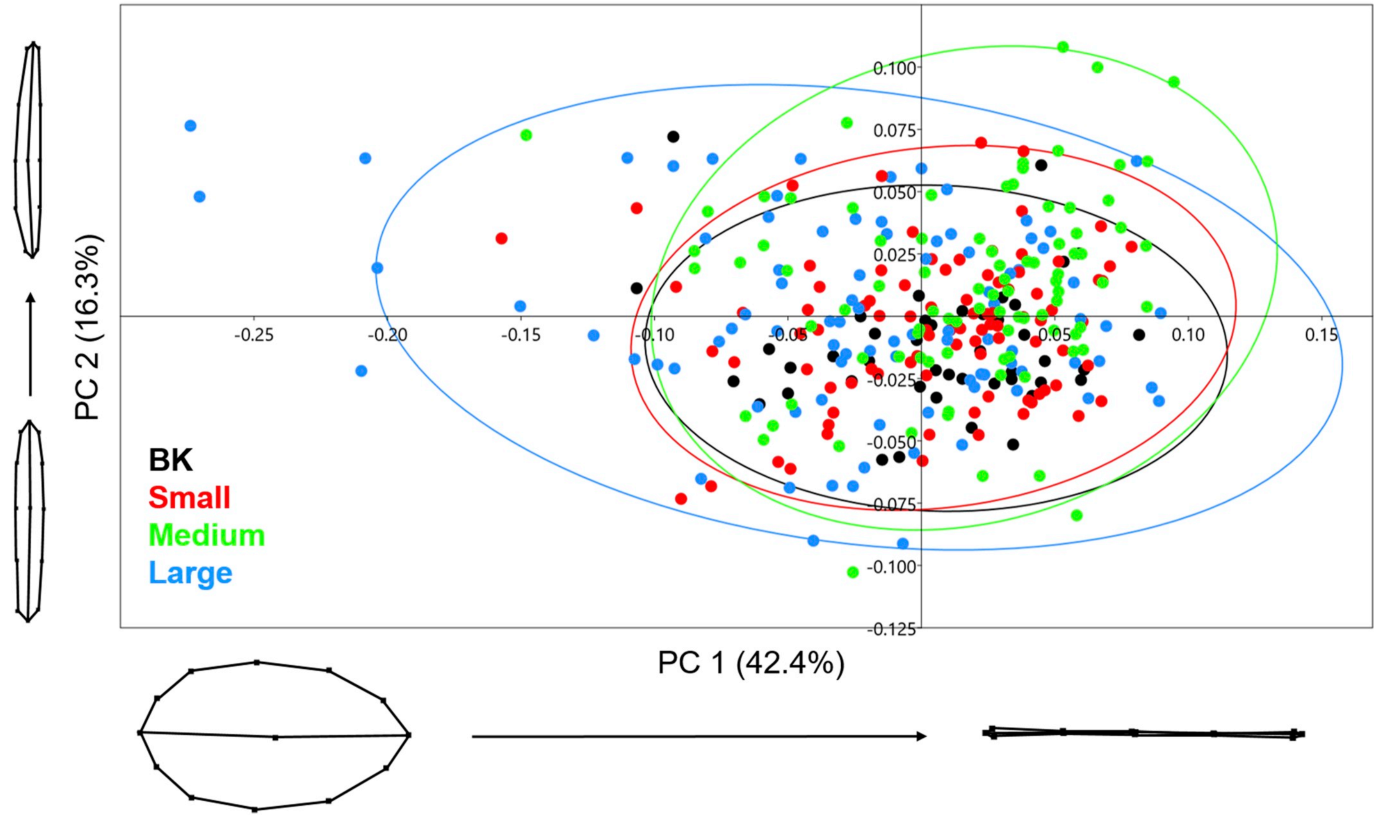

Fig. 6. Scatter plot of the PCA results comparing the morphological shapes of BK cut marks with the three main quartzite size groups (small, medium and large) in shape space. Extreme shape changes can be observed across the axis of each PC score.

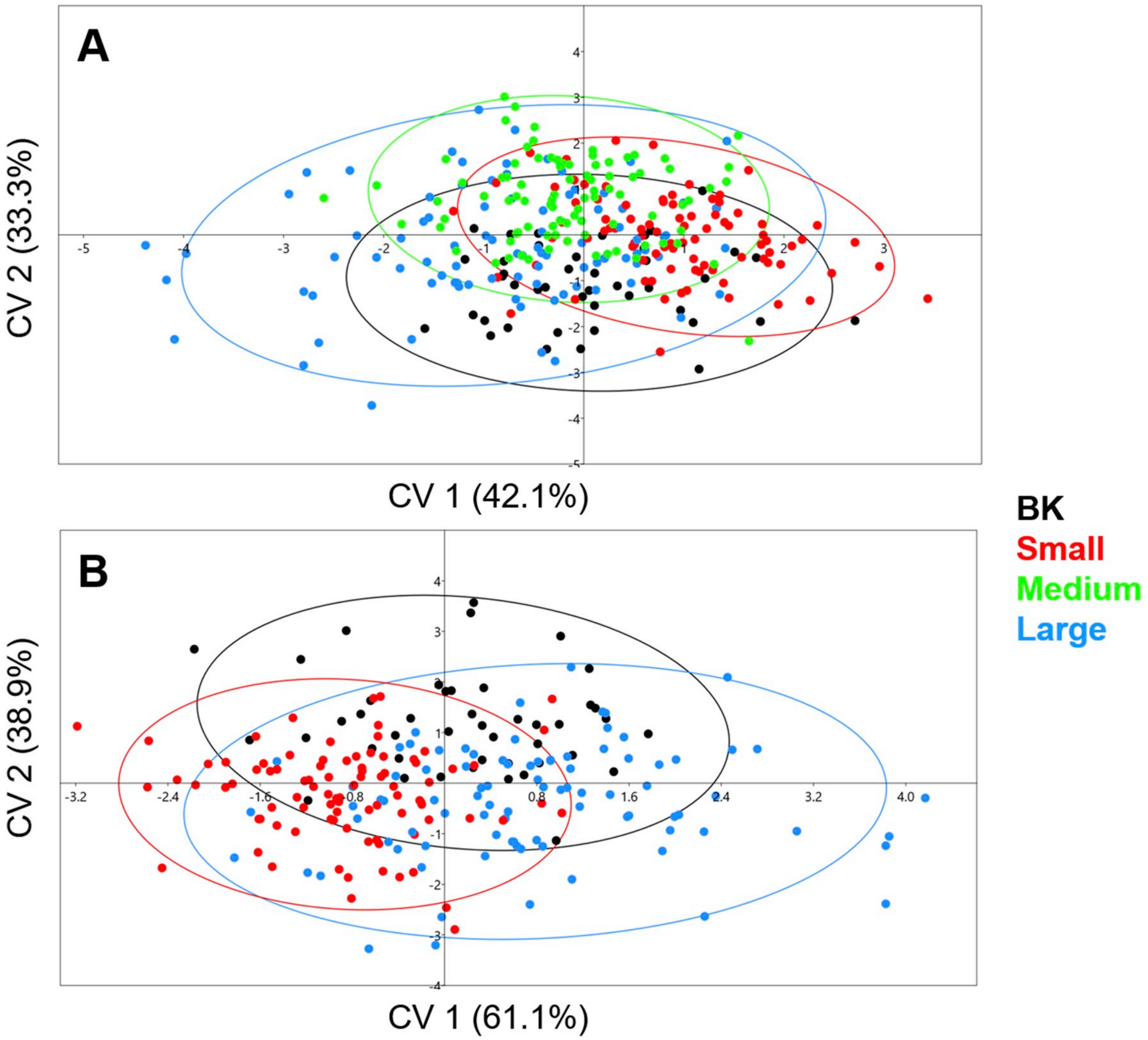

Fig. 7. Two scatter plots presenting the CVA graphs comparing BK with the grouped quartzite samples (A) including and (B) excluding the medium size group.

Table 5
Mahalanobis and Procrustes distance numerical results as obtained through the CVA analysis of Quartzite groups.

		BK		Small		Medium	P-Value
		Distance	P-Value	Distance	P-Value	Distance	
Small	Mahalanobis	1.8101	< 0.0001				
	Procrustes	0.0186	**0.0852**				
Medium	Mahalanobis	1.8938	< 0.0001	1.5583	< 0.0001		
	Procrustes	0.039	< 0.0001	0.0291	0.0003		
Large	Mahalanobis	1.7835	< 0.0001	1.7358	< 0.0001	1.4891	< 0.0001
	Procrustes	0.0367	0.003	0.0314	0.0005	0.0433	< 0.0001

reflections can be made based on these results regarding how *Homo ergaster/erectus* populations were selectively choosing ideal raw materials 1.3 Mya.

The significance of these results are relatively important because so far most morphological studies have tried to confront differences between raw materials, such as flint, quartzite (Olsen, 1988; Dewbury and Russell, 2007; Bello and Soligo, 2008; Maté-González et al., 2017c) and metal (Greenfield, 1999; 2006; Maté-González et al., 2016) but are yet to explore the differences between granular composition. Several works have focused on testing the differences between different tool types (Bello et al., 2009; De Juana et al., 2010; Courtenay et al., 2017; Yravedra et al., 2017c), with the occasional relatively obvious and less informative comparison between taphonomic traces that can be differentiated with the naked eye e.g. cut and tooth marks (Pante et al., 2017; Sahle et al., 2017).

One of the main objectives of this study was to isolate each quartzite type based on the cut marks produced with them. However, the minute differences between each sample, forced us to group them according to their relative size. Considering the minute variability on a geological scale, one would assume that differences between groups would be practically inexistent. Our results show that when gathered into size groups, quartzites with different grain size can be statistically and graphically distinguished. Our findings strongly suggest that mark morphology is conditioned by grain or crystal size of this particular raw material. In case further tests endorse our preliminary results, it could be argued that BK hominins show a preferential use of fine-grained

Table 6
Linear Discriminant Analysis jack-knifed confusion matrix presenting the percentage of likelihood that each cut mark from the BK sample be associated to each group.

	Probability of Association				Probability of Association			
	Including Medium sample				Excluding Medium Sample			
CV	Bk	Large	Medium	Small	CV	Bk	Large	Small
Large	5.3%	74.5%	11.0%	9.2%	Large	8.1%	83.1%	8.8%
Small	16.8%	24.6%	28.3%	30.2%	Large	24.6%	39.0%	36.4%
Small	29.9%	16.5%	13.5%	40.2%	Small	34.3%	23.3%	42.4%
Small	10.5%	8.9%	11.6%	69.1%	Small	10.9%	14.6%	74.5%
Small	14.4%	16.8%	16.3%	52.5%	Small	16.9%	22.1%	61.0%
Large	18.9%	47.5%	13.9%	19.7%	Large	22.3%	59.3%	18.5%
Medium	25.4%	25.1%	31.6%	18.0%	Large	34.2%	39.2%	26.6%
Large	26.2%	32.6%	19.1%	22.2%	Large	28.6%	39.6%	31.8%
BK	41.9%	24.9%	12.4%	20.8%	Small	39.4%	21.0%	39.6%
Large	27.5%	40.1%	9.0%	23.4%	Large	29.6%	42.0%	28.4%
Large	32.1%	34.8%	18.0%	15.1%	Large	35.4%	43.7%	20.9%
Small	24.7%	14.6%	12.7%	48.0%	Small	28.4%	19.1%	52.5%
Large	9.1%	40.2%	24.9%	25.8%	Large	13.2%	50.5%	36.3%
Medium	6.9%	17.7%	41.1%	34.3%	Small	13.5%	34.8%	51.7%
Large	5.5%	51.8%	6.4%	36.3%	Small	8.1%	41.3%	50.7%
Small	10.5%	11.6%	19.7%	58.1%	Small	12.9%	19.8%	67.3%
Small	17.2%	17.9%	27.7%	37.2%	Small	27.1%	30.0%	42.9%
BK	41.0%	24.4%	16.3%	18.3%	BK	47.1%	30.5%	22.4%
Medium	14.7%	30.6%	34.8%	19.9%	Large	22.2%	43.7%	34.1%
Medium	9.4%	35.0%	36.7%	19.0%	Large	15.3%	50.0%	34.7%
Medium	21.8%	20.4%	33.6%	24.2%	Small	31.0%	33.2%	35.8%
Medium	15.2%	24.4%	39.6%	20.8%	Large	28.8%	38.5%	32.7%
Large	12.6%	61.9%	17.6%	7.9%	Large	18.0%	72.4%	9.7%
Large	16.6%	29.8%	28.9%	24.7%	Large	26.1%	40.7%	33.3%
Small	17.1%	35.7%	4.3%	42.9%	Large	20.4%	46.1%	33.5%
BK	32.1%	18.4%	18.1%	31.4%	Small	37.0%	23.6%	39.4%
Small	7.7%	16.4%	22.6%	53.3%	Small	10.2%	26.8%	63.1%
Large	27.1%	29.2%	14.9%	28.9%	Large	31.2%	35.7%	33.1%
Small	35.9%	19.8%	7.6%	36.7%	BK	37.8%	29.7%	32.5%
Small	16.6%	12.5%	26.5%	44.5%	Small	27.9%	20.9%	51.2%
Small	6.5%	8.2%	2.8%	82.5%	Small	7.2%	10.9%	81.9%
Large	35.7%	42.4%	3.1%	18.7%	Large	30.3%	41.8%	27.8%
Medium	4.1%	24.8%	68.0%	3.1%	Large	11.5%	77.9%	10.6%
Small	11.6%	20.4%	7.9%	60.0%	Small	10.8%	19.2%	70.0%
Small	16.5%	21.8%	10.7%	51.0%	Small	19.3%	28.7%	52.0%
Small	22.9%	18.7%	25.5%	32.9%	Small	30.1%	29.4%	40.5%
Large	38.0%	41.5%	11.3%	9.2%	BK	46.1%	38.8%	15.0%
Small	29.7%	19.3%	15.1%	35.9%	Small	29.4%	22.7%	47.9%
Medium	16.6%	18.2%	47.5%	17.7%	Large	29.4%	37.0%	33.6%
Small	8.2%	21.4%	21.2%	49.2%	Small	7.9%	24.7%	67.4%
Medium	13.0%	34.0%	34.6%	18.4%	Large	21.3%	46.0%	32.7%
Large	21.0%	37.6%	5.3%	36.1%	Small	23.4%	37.2%	39.4%
Medium	10.2%	20.0%	57.2%	12.6%	Large	23.9%	46.7%	29.3%
Medium	4.2%	13.4%	55.9%	26.4%	Small	10.9%	34.4%	54.7%

quartzite. This would imply the call for further discussion on the raw material knowledge these populations might have had as early as 1.3 Mya.

Some properties of the quartzite sample also affected the experimental phase of this study. For example, Q5 was hard to knap and produced relatively unclear cut marks with a very rugged form. The physical knapping properties of the different quartzite types provide a possible explanation for the selection of raw materials among ancient populations. Diez-Martín et al. (2009) and Sánchez-Yustos et al. (2016, 2017) have already argued the precise qualities of the cutting edges these types of flakes present. Paired with our results we can confirm that a preferential management of raw materials towards a specific type of quartzite and its use in butchering activities is present in the archaeological record at BK. For a long time Oldowan knappers and butchers were considered to be relatively simple from a cognitive perspective, making the most of local raw materials (Schick and Toth, 2006). Nevertheless, we have now multiple pieces of evidence that suggest that the exploitation of raw materials was not as simple as picking up the first stone they came across. Preferential representation of quartzite in a site is enough to argue a selective nature behind the behaviour of these hominin populations (Diez-Martín et al., 2009; Sánchez-Yustos et al., 2016; 2017). Through recent advances, paired with our results, we might even be able to decipher the selection of a specific quartzite in relation to a particular activity, indicating that knapping activities and raw material exploitation could be more complex than previously thought.

From a different perspective, the implications that this has regarding the cognitive evolution of *Homo erectus/ergaster* populations are multiple. In recent years, studies applied to lithic and cognitive analysis have discussed a series of technical gestures that novice knappers have to learn in order to reach certain technical capabilities (Geribàs et al., 2010). Paired with recent studies into the advantages of social learning (Lombao et al., 2017), the cognitive capabilities of the first species of knapping hominins appears to be much more elevated than previously conceived (Lepre et al., 2011; Lewis and Hamand, 2016; Toth and Schick, 2018). As currently understood, the development of Broca's area is strongly correlated to knapping capabilities as well as the development of communication and language (Stout et al., 2000, 2008; Stout and Chaminade, 2007; Higuchi et al., 2009; Putt et al., 2017). The linking of this concept to the selection of raw materials is also a great possibility, especially when considering the simplicity of communicating complex messages through mostly monosyllabic sounds simply through association of the sound to an object/concept (Seyfarth et al., 1980; Adelman et al., 2018). In fields related to teaching as well as children's education, common practice encourages sound-object association when teaching how to read, write and talk (Underhill, 1994; Armbuster et al., 2000; Geyser, 2006). Recent studies in tool use (Petö et al., 2018), as well as the previously cited experiments regarding social learning, indicate a need to consider how early hominin populations were much more cognitively advanced as we are currently aware. Paired with the implications of our results, this notion is definitely worth further investigation.

Additionally, the results presented in this paper highlight the value of the methods published by Courtenay et al. (2017) when applied to the archaeological register. The inclusion of micro-photogrammetry and the DAVID Structured-Light SLS-2 scanner in recent taphonomic analyses (Maté-González et al., 2016, 2017a,b,c; Aramendi et al., 2017; Courtenay et al., 2017, 2018a; Yravedra et al., 2017b, c; Maté-González et al., 2019) have achieved similar resolution degrees to those provided by other microscopes such as the Hirox KH-8700 Digital Microscope and Confocal microscopes (Maté-González et al., 2017b; Courtenay et al., 2018b). Certain critical responses (Otárolla-Castillo et al., 2017) have tried to discredit these studies, making remarks that Bayesian analysis and the use of sliding semi-landmarks provide better results. However, the taphonomic and archaeological questions proposed by these authors assess traces of little equifinality alongside a statistically insignificant sample size (see discussion in Courtenay et al., 2018a). On countless occasions experimental conditions (Blumenschine et al., 2007; McPherron et al., 2010; Harmand et al., 2015; Sahle et al., 2017) have been discredited through their lack of reliability from a scientific point of view (Domínguez-Rodrigo et al., 2007, 2011; Domínguez-Rodrigo and Alcalá, 2016; Egeland et al., 2018; Domínguez-Rodrigo, 2018; Domínguez and Baquedano, 2018). This, unfortunately, is a frequent case of malpractice, especially seen among extraordinary claims of rather suspicious taphonomic traces (Malassé et al., 2016a, b) that might require a closer look at other possible variables that could be conditioning the results (Fernández-Jalvo and Andrews, 2003; Blasco et al., 2008; Domínguez-Solera and Domínguez-Rodrigo, 2011; Pineda et al., 2014, 2017).

5. Conclusion

The current paper presents the application of a new methodology to the study of cut mark morphology, combining geological and taphonomic features with virtual reconstruction and geometric

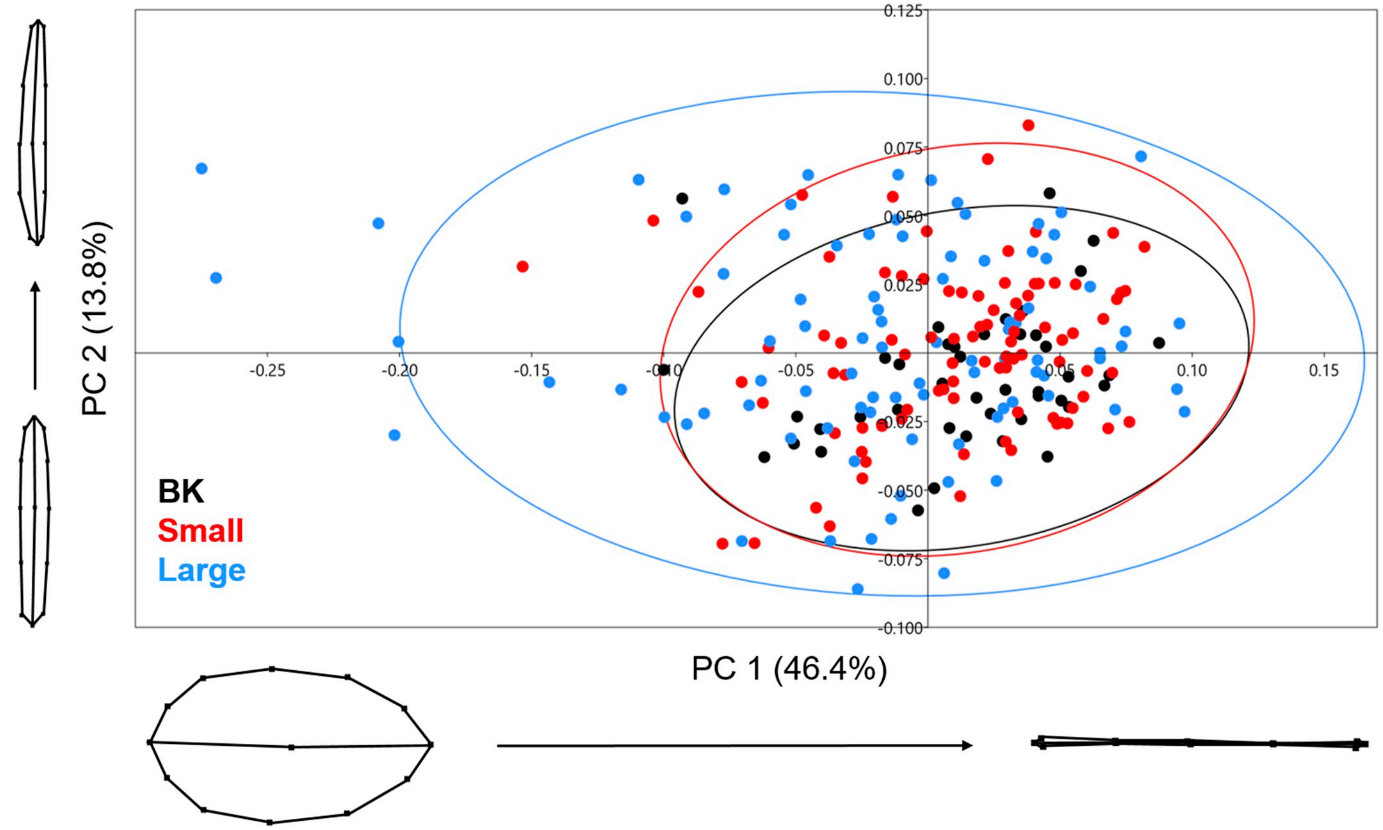

Fig. 8. Scatter plot of the PCA results comparing the morphological shapes of BK cut marks with the "Small" and "Large" quartzite groups in shape space. Extreme shape changes can be observed across the axis of each PC score.

Table 7
Mahalanobis and Procrustes distance numerical results as obtained through the CVA analysis of Quartzite groups.

		BK	
		Distance	P-Value
Small	Mahalanobis	1.7458	< 0.0001
	Procrustes	0.0186	**0.0865**
Large	Mahalanobis	1.6754	< 0.0001
	Procrustes	0.0368	0.0025

morphometrics. This interdisciplinary analysis has opened up a number of different possibilities, highlighting that cut mark morphology can be strongly conditioned by minute variables such as the granular texture of a simple flake.

So far investigation within this field has focused mainly on providing a clear methodological framework that can be applied to archaeological sites. Thus, currently more studies directly working with the taphonomic and fossil register are necessary. The specific selection of raw materials detected at BK at least 1.3 Mya could set up a new line of investigation in other contexts associated with ancient hominin populations.

The number of possible questions that can be addressed using the technique presented here remains infinite. Caution is needed, however, regarding all possible variables that condition experimental works. The difficulty of analysing an archaeological site is immense due to an enormous number of factors that can cause equifinality. Nevertheless, as demonstrated with this paper, an interdisciplinary approach can contribute to more reliable results when confronting interpretive issues in the archaeological register. Thus, future studies in this line should assess the extent taphonomic variables affect cut mark morphology, e.g. the presence of fluvial abrasion and rounding, weathering etc. We are confident that this paper could be the starting point for future 3D cut mark analyses applied to the archaeological record.

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Appendix A. Supplementary data

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