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TITLE :

# The application of geometric-morphometric shape analysis to Middle Paleolithic bone retouchers from the Altai Mountains, Russia

Ksenia Kolobova <sup>a,\*</sup>, William Rendu <sup>b,c</sup>, Alena Shalagina <sup>a</sup>, Pavel Chistyakov <sup>a</sup>, Vasilii Kovalev <sup>a</sup>, Malvina Baumann <sup>b</sup>, Anastasia Koliashnikova <sup>a</sup>, Andrei Krivoshapkin <sup>a</sup>

<sup>a</sup> Institute of Archaeology and Ethnography, Russian Academy of Sciences, Siberian Branch, Ak. Lavrentieva 17, Novosibirsk, 630090, Russia

<sup>b</sup> PACEA, UMR 5199, CNRS, Université de Bordeaux, Ministère de La Culture et de La Communication (MCC), F-33400, Pessac, France <sup>c</sup> New York University, Department of Anthropology, CSHO, New York, NY, 10003, USA

**Abstract ::**

Here, we apply geometric-morphometric shape analysis to Middle Paleolithic bone retouchers from Chagyrskaya Cave in the Altai Mountains of southern Siberia. The cave contains evidence of the easternmost manifestation of the Micoquian industry, associated with Neanderthals at end of MIS4 and the beginning of MIS3. Taphonomic and scar pattern analyses were performed first on random samples exhibiting appropriate characteristics. Several retouchers produced on intentionally modified blanks were identified in our sample, suggesting that some of the Chagyrskaya Cave bone retouchers can be described as formal tools. All retouchers from Chagyrskaya Cave exhibit a similar general morphology. The most variable group is comprised of complete retouchers without blank modifications. Retouchers exhibiting minor damage affect the general pattern of variability and it is not possible to identify them only by means of geometric-morphometric shape analysis. Complete retouchers *with* blank modifications fall within the range of variability of complete retouchers *without* blank modification, suggesting intentional shaping of blanks to conform to a standard template. The range of variability of the bone retouchers does not differ significantly from that of the most highly modified lithic artifacts at Chagyrskaya – plano-convex bifaces – which may indicate intentional shape control for such artifacts. Geometric-morphometric analysis indicates that the anatomical origin of bone blanks does not significantly influence the retouchers' shape, which may point to strict blank selection and, at the same time, intentional modification. Our results raise questions regarding the integration of retouchers into a complex, multidimensional "chaîne-opératoire" as well as the nature of Neanderthal cognitive abilities. Geometric-morphometric shape analysis represents a major step forward in the study of prehistoric retouchers.

**Key words:** Geometric-morphometric shape analysis Bone retouchers 3D modeling Altai mountains Siberia Russia Middle paleolithic Taphonomy Scar pattern analysis

## 1 Introduction

The Paleolithic of the Altai Mountains in southern Siberia is now widely known, not only because of the recent paleogenetic studies (Slon et al., 2018), but also due to the discovery of the earliest known ornamental and bone tool complex in Eurasia, dating to the transition from the terminal Middle to Initial Upper Paleolithic (Krivoshapkin et al., 2018; Douka et al., 2019). Middle Paleolithic bone tools, on the other hand, have not been documented until recently (Kolobova et al., 2016; Baumann et al., 2018; Kozlikin et al., 2019). Two waves of Neanderthal in-migration to the Altai region have been recently defined on the basis of genetic and archaeological evidence. The origin of the Chagyrskaya Cave Neanderthals has been traced back to Central-Eastern Europe and the Caucasus region. A second Neanderthal migration took place around 70-60 kyr. B.P., bringing to the Altai a specific lithic assemblage similar to the European Micoquian/*Keilmessergruppen* characterized by the presence of radial cores and bifacial reduction sequences. This assemblage is predominated by simple and convergent side-scrapers and retouched points (Kolobova et al., 2020a, b). Bifacial plano-convex scrapers and points including Keilmesser type are numerous (144 items). These lithic artifacts occur in association with numerous bone tools (780 items), most of which are classified as retouchers (680 items, 87,2%) (Baumann et al., 2020). The identification of these bone tool complexes raises numerous questions related to the cognitive abilities of Central Asian Neanderthals and Denisovans as well as their subsistence strategies, which have not yet been investigated. In this study, we focus on bone artifact assemblage from Chagyrskaya Cave, which has yielded the largest known osseous complex in the region (Kozlikin et al., 2019). Recent advances in archaeological, paleoanthropological and paleontological researches have demonstrated the great scientific value and efficiency of geometric-morphometric analyses based on high-quality 3D models (Otarola-Castillo et al., 2017; Chen et al., 2019; Herzlinger et al., 2017; Herzlinger and Grosman, 2018; Shalagina et al., 2020). Because bone retouchers are at the interface of two crucial activities for the subsistence of the groups: the butchery and the lithic tool production, the application of this analytical approach should provide new insights for our understanding of past human behaviors. However, due to the high degree of morphological variability among bone retouchers resulting from a combination of factors (bone anatomy, breakage patterns, taphonomy, etc.), geometric-morphometric approaches were not applied to these specific components of the material culture. In addition, sample size constraints (a minimum of 30 specimens, according

to limitation of PCA) have strictly limited the technique's effective application. Here, we test the efficacy of geometric-morphometric analyses for quantitatively characterizing the retoucher shape. This study is a first step in the application of this method to the entire Altai Middle Paleolithic record.

## 2 Chagyrskaya Cave

Chagyrskaya Cave (51°26'34.6" N; 83°09'18.0" E) is situated on the left bank of the Charysh River in the Tigirek Range of the Altai Mountains of southern Russia. The 2007–2019 excavation campaign yielded significant lithic (117,421 specimens) and bone tool (780 items) assemblages as well as faunal and Neanderthal remains. The stratigraphy is composed of several archaeological layers (Layers 5–7) attributed to the final Middle Paleolithic. Layer 6 yielded the material used for this specific retoucher analysis. A series of absolute dates attribute the Neanderthal occupation of the cave to a relatively short period during final MIS4 and the beginning of MIS3. Paleoenvironmental data suggest that a steppe or semi-desert steppe environment prevailed under dry continental climatic conditions in the Charysh Valley at this time (Derevianko et al., 2018; Kolobova et al., 2020a,b). Abundant evidence of Neanderthal activities was uncovered in Layers 5–6c2. Layer 6c2, the lowermost in the Upper Pleistocene sequence, is preserved essentially *in situ*. The faunal assemblages from Layers 6a–6c2 include numerous bison remains (up to 47.2%) resulting from Neanderthal hunting activities that focused mainly on young individuals and females. The human impact on the Layer 6c2 assemblage is very high (31% of bones bear cut-marks, traces of scraping, and notches), while carnivore impact on the material is limited (8%) (for a synthesis of the paleontological and zooarchaeological data, see Derevianko et al., 2018 and Kolobova et al., 2020b). The systematic search for anthropogenic modification of faunal remains from Chagyrskaya Cave led to the identification of a new Middle Paleolithic bone tool assemblage composed of 680 retouchers. These artifacts are associated with diverse intermediate tools, retouched tools and implements with rounded tips, the functions of which remain to be determined (Kolobova et al., 2017; Kolobova et al., 2018; Baumann et al., 2020, this volume). Chagyrskaya lithic assemblages have been associated with the Sibiryachikha Altai Middle Paleolithic variant, the easternmost manifestation of the Micoquian techno-complex (Kolobova et al., 2020a,b). Assemblages from Chagyrskaya Cave (layers 6a–6c2, 2008 excavation campaign) are characterized by flake production from radial and orthogonal cores; most flakes have trapezoidal or triangular shapes with relatively large flat or partly faceted striking platforms. The numerous toolkits (up to 30% of the assemblage, not including chips and debris) are dominated by simple and convergent scrapers of various shapes (70% of toolkits) and retouched points (15%). Bifacial flakes comprise up to 7% of the Chagyrskaya Cave lithic assemblage; a small component, but culturally significant in the Altai region. Here, Neanderthals undertook the selection of high-quality raw material to produce highly modified tools including convergent scrapers and bifacial implements (Derevianko et al., 2015; Kolobova et al., 2019a). Retouchers define the interface of two technical systems; those directed toward animal exploitation and lithic production (Costamagno et al., 2018); that comprise a formidable proxy for tackling the question of past hominin cognitive capacities through the analysis of a complex, multi-dimensional “*chaîne-opératoire*.” Layer 6c2 lithic assemblage demonstrate the frequent use of soft hammers by Neanderthals to produce unifacial and bifacial tools. The morphological characteristics of the proximal parts of flakes and core preparation spalls include numerous pronounced lips combined with diffused or absent bulbs in approximately 30% of the specimens examined. The pronounced bulbs and absent lips observed on the remaining flakes attest of the use of hard hammer percussion. Within the flake assemblage, only bifacial thinning flakes exhibit 100% of soft hammer reduction characteristics (Kolobova et al., 2019a). All these facts support a direct correlation between the numerous bone retouchers and the bifacial tools in Chagyrskaya Cave lithic assemblages. Prior to conduct our analysis, we have tested the efficiency of bone retouchers for the specific production of Chagyrskaya bifacial tools. According to our experimental model, the following technological sequences is observed: shaping of the flat surface, shaping of the convex surface and edge shaping. Our experiments attest of the greater efficiency of bone retouchers in comparison with hard and soft hammers for the final stages of the biface production. Moreover it demonstrates the advantages of bone retouchers in lithic tool retouching (Shalagina et al., 2020; for similar results see: Kolfshoten et al., 2015). The significant number of bone retouchers in the assemblage of Chagyrskaya Cave associated with the large number of unifacial tools strongly suggests that the first were also used for retouching the second.

## 3 Materials and methods of analysis

Bone retouchers were sampled from a large assemblage ( $n = 680$ ) derived from Chagyrskaya Cave cultural sub-layers 6a, 6b, 6c1 and 6c2. First of all, we excluded from the analysis specimens with major breakage in their functional areas (489 specimens, 72%) leaving 191 complete or almost complete retouchers, from which 40 specimens were randomly sampled from each layer for geometric-morphometric analyses. The entire sample was submitted to a thorough taphonomic analysis. Specimens were identified to the most precise taxonomic level possible and, when it was not possible to assign a specific attribution, ungulate size classes were used (Brain, 1981). Anatomical identification followed the “element, portion, segment” system of Gifford and Crader (1977). Bone surfaces of all specimens were first observed under low-oblique lighting using a 40X loupe for basic taphonomic and zooarchaeological observations. Evidence of weathering, root etching, anthropogenic and carnivore modification was systematically sought (Olsen and Shipman, 1988; Blumenschine et al., 1996; Behrensmeier, 1978; D'Errico and Villa, 1997; Pickering and Egeland, 2006). Oxide coloration of bone cortical surfaces was also recorded and the proportion of preserved cortical surface was estimated per quartile (Rendu, 2010; Rendu et al., 2019). When uncertain modification was detected, specimens were more thoroughly examined with a 20–80X light microscope. Overall, alteration was very rare; 90% of the bones exhibit complete or nearly complete preservation of their cortical surfaces. The principal taphonomic modifications result from light weathering or root etching. The assemblage of retouchers includes the following:

1. Complete retouchers without blank modifications (Figs. 1 and 14 specimens);
2. Complete retouchers with intentional blank modifications (Figs. 2 and 10 specimens);

### 3. Retouchers with minor damage (Figs. 3 and 16 specimens).

The Chagyrskaya Cave bone tool assemblage includes a large number of complete or nearly complete retouchers (28%), 30% of the tools have post-depositional damages and 41% of the retouchers exhibiting marginal damages with dry fractures. The average length of complete retouchers – 92.9 mm, width – 37.2 mm, thickness – 7.6 mm, weight – 39.5 g. Our analysis focused on evaluating how this minor damages influenced retoucher shape and geometric-morphometric results. Complete retouchers without any intentional blank modifications reflect the variability of blanks and selection criteria. Complete retouchers exhibiting intentional edge modifications marked by spall negatives were analyzed to evaluate the selection of specific blank shapes by Paleolithic artisans. Our landmark-based geometric-morphometric shape analysis generated a quantitative description of variability within and between groups of specimens. This approach is based on the calculation of shape by measurement of the distances among landmarks and semi-landmarks located on the artifact, which were later processed in Cartesian space (Herzlinger et al., 2017). We have employed Artifact GeoMorph Toolbox 3-D (AGMT3-D) to analyze retoucher shapes and followed the classical methodological approach of Herzlinger and Grosman (2018). This analytical method has become widespread among archaeologists as an effective tool for evaluating the shape of Paleolithic artifacts (Iovita, 2010; Iovita, 2011; Iovita and McPherron, 2011; Archer et al., 2015; Morales et al., 2015; Herzlinger et al., 2017 etc.; Iovita et al., 2017). Generalized Procrustes Analysis (GPA) was used as a superimposition procedure, removing non-shape related variability, thus differences in landmark coordinates can be explained only by shape differences among retouchers. Thus, artifact size was not taken into account. The AGMT3-D package allows minimization of scaling by GPA, including minimizing the data dimension at each point by Least Squares criteria. Principal component analysis was employed for data dimensionality reduction and to provide a number of new axes (components) (Lycett et al., 2006; Dryden and Mardia, 2016). The analysis has included three steps: 3D scanning and modelling, positioning and measuring of landmarks and statistical processing of data. Digital 3-D models of retouchers were created using a RangeVision PRO 5M structured-light scanner. After scanning, models were processed using RangeVisionScanCenter and RangeVisionScanMerge software (Kolobova et al., 2019b). All models were then oriented in one perspective with the active retouching area in the northern or uppermost position. Positioning and measurement of landmarks were processed with AGMT3-D software. The landmarks were established within a dense grid of 30 × 30, resulting in 1800 landmarks recorded per artifact. According to our sample composition, we have defined three attributes corresponding to complete retouchers without blank modifications, complete retouchers with spall negatives and retouchers exhibiting only minor damage. In order to estimate the influence of the anatomical origin of bone blanks, we have defined six additional attributes according to the anatomical composition of the sample: femur, tibia, humerus, radius, vertebra and indeterminate long bone. We have performed statistical investigations with the relevant module in AGMT3-D and PAST-3 software. The PAST program was used for one-way parametric Multivariate Analysis of variance test (MANOVA) and a non-parametric PERMANOVA test was applied to the PCA scores analyses. The univariate non-parametric Wilcoxon Rank Sum Test was used to evaluate differences between samples (Hammer et al., 2001; Herzlinger and Grosman, 2018). In order to describe retouchers exhibiting intentional spall negatives, we have performed a scar pattern/working steps analysis used to reconstruct tool-manufacturing sequences. Scar pattern analysis was based on the reconstruction of manufacturing and rejuvenation stages of lithic artifacts as well as on the chronological order of each stage in the manufacturing process (Pastoors, 2000; Kot, 2014; Shalagina et al., 2015; Shalagina et al., 2019a,b).

## 4. Analytical results

### 4.1. Zooarchaeological characterization of the retoucher

Our sample is constituted of remains attributed to bison (NISP = 12), horse (NISP = 5) and non-identified large ungulates (NISP = 23) reflecting the other proportion already identified in the faunal spectrum. At the exception of one fragment of a transversal process of a bison vertebrae, all the blanks are made from long bones elements (Humerus: 5; Radius: 1; Femur = 3; Tibia = 15; unidentified long bone = 15). The preservation of the cortical surface is good (4 pieces have more than 50% of their cortical surface altered) and only the first stages of weathering are recorded on the retoucher sample. The only potential carnivore marks are pits on the bison vertebrae and a fragment of a humerus shaft, but because of some local exfoliation on their surface, it is not possible to exclude other possibilities. Fifty percent of the blanks exhibit evidence of scraping prior to their use as retouchers and 30% display notches linked to breakage of the bone for extracting marrow and grease.

### 4.2. Scar pattern analysis results

We have analyzed retouchers with negative scars mostly on cortical bone surfaces that could not have resulted from butchery or marrow consumption processes (Grunwald, 2016; Morin and Soulier, 2017). Recent experimental studies of marrow consumption at Chagyrskaya Cave reveal that during the flaking process it is virtually impossible to generate cortical negatives, in contrast with scars on the inner, medullary surfaces of bones (Seletsky et al., 2019). The scar pattern analysis defines several types of spall negatives on bone surfaces, including those related to intentional blank modifications (Figs. 2, 1–4). The first cluster of negatives modified the initial bone shape (Figs. 2, 1, 2; negatives A). Some small negatives probably resulted from tool utilization (Figs. 2, 1, negatives B, D). Several negatives used to sharpen retoucher edges are also observed (Figs. 2, 1, negatives E; Fig. 2 and 2, negatives C, Figs. 2, 3, negatives B; Figs. 2, 4, negatives A, B). Since negative scars are located on various parts of bone blanks in a less regular way than in the case of stone artifacts, the complete reduction sequence is impossible to reconstruct, except when utilization traces overlap the main modification negatives (Figs. 2, 1).

### 4.3. Geometric-morphometric analysis results

The PCA plot obtained with our geometric-morphometric approach present the variability of the retoucher shape (Fig. 4). The two first principal components account for 40.32% of the variability, which is a satisfactory outcome for geometric-morphometric approaches applied to paleoenvironmental reconstructions (Kocovsky et al., 2009; Shaukat et al., 2016). The first three principal components account for more than 49.9% of the variability. These results demonstrate that all the retouchers analyzed have a relatively similar morphology. The

variability of complete retouchers without blank modifications (193.27) is similar to the variability of retouchers bearing minor damage (193.2). To the contrary, retouchers bearing intentional spall negatives form a less variable group (166.15). All complete retouchers exhibiting intentional spall negatives are triangular in shape. The PERMANOVA multivariable test based on all PCA scores demonstrates no significant differences among the three retoucher groups ( $F: 0.6971; p: 0.8131$ ). When all groups include several specimens, the sample composition allows us to use a parametric multivariable test. MANOVA, based on the three first PCA scores ( $F: 0.7477; p: 0.6133$ ), confirmed the PERMANOVA results. We have performed paired tests to estimate the variability of the retoucher groups (Wilcoxon Rank Sum Test on within-group interpoint distances, on interpoint distances between-group means and on group centroid sizes). All the tests indicate an absence of difference between modified and unmodified retouchers on the one hand, and between unmodified retouchers and those with minor damages on the other. In order to understand the impact of initial shape of bone fragment on retoucher morphology, we have carried out a second geometric-morphometric analysis on the same sample. Among the 40 retoucher blanks analyzed, belonging to bisons and horses, 3 femora, 15 tibiae, 5 humeri, 1 radius, and 1 vertebra were identified, while 15 were assigned to the indeterminate long bone category. PCA plots generated from the geometric-morphometric analysis demonstrate the relative distribution of retouchers depending upon skeletal element attribution (Fig. 5). Because we analyzed the same sample, we observed the same variability coverage, thus we conclude that the nature of the blanks does not significantly influence the general variability of retouchers. At the same time, retouchers made from the same long bones demonstrate significant morphological differences (e. g., tibia or femur, Fig. 5). In the case of the small sample size groups (some groups are composed by only one specimen, such as a vertebra or radius), we were not able to use a parametric multivariable test. The PERMANOVA multivariable test based on all PCA scores demonstrates the similarity of all retouchers made on different blanks ( $F: 0.7782; p: 0.8732$ ). If we exclude the two groups containing only one element (vertebra and radius), the MANOVA test based on the three first PCA scores ( $F: 0.5851; p: 0.8055$ ) supports these results. Pair tests for estimating the variability of the retoucher groups (Wilcoxon Rank Sum Test on within-group interpoint distances, on interpoint distances between-group means and on group centroid sizes) also did not reveal any significant differences.

## Discussion and conclusions

Appearing during the Lower Paleolithic, bone retouchers were frequently used during the Middle and Upper Paleolithic throughout the human-inhabited world. Eurasia has yielded the earliest evidence of bone blanks used as retouchers to fabricate lithic tools in Lower and Early Middle Paleolithic contexts: i.e., Caune de l'Arago (Moigne, 1996), La Micoque (Langlois, 2004), Quesem Cave (Blasco et al., 2013b); Boxgrove (Roberts and Parfitt, 1999), Terra Amata (Moigne et al., 2016), and the Gran Dolina (Rosell et al., 2011). In East Asia, the earliest bone retouchers are found at the Chinese Middle Paleolithic Lingjing site in Xuchang, Henan dated to 105–125 kyr BP (Doyon, Li, Hao, d'Errico, 2018). Numerous anatomical elements (e.g., upper limb bones, metapodials, skulls, mandibles, ribs) of large vertebrate taxa, mostly subjected to the butchery process, were used to produce various blanks. During the Upper Pleistocene, human societies may have assigned specific symbolic implications to the acquisition and use of unusual osseous tool blanks such as the Neanderthal skulls at La Quina, France (Verna and d'Errico, 2011), *Ursus spelaeus* long bones at Scladina, Belgium (Abrams et al., 2014) or, as in the case of some Aurignacian sites in southwestern France, large carnivore (*Panthera spelaea*) canines (Castel et al., 2003). Retouchers have generally been of interest to archaeologists only in the context as functional implements and are described as being produced on bone blanks, sometimes without evidence of carcass part selection (Armand and Delagnes, 1998). They have often been considered informal, opportunistic tools made on blanks randomly obtained during the process of marrow extraction (Chase, 1990; Vincent, 1993; Armand and Delagnes, 1998; Patou-Mathis and Schwab, 2002; Karavanić and Šokec, 2003). According to such hypotheses, there should be no morphological similarity with the exception of function-based size: weight ratios. Consequently, geometric-morphometric analyses have many advantages such as facilitating morphological classification without reference to the size. Our application of geometric-morphometric analyses to retouchers was successful. The most variable groups are composed of unmodified retouchers and retouchers exhibiting only minor damages. Some damaged retouchers fall outside the 95% ellipse of the complete retoucher variability, indicating that taphonomy can have a major impact by occluding artifact original forms (Fig. 4). Thus, in order to reduce general variability, it is necessary to exclude damaged retouchers from the analytical sample. Based on geometric-morphometric data, it is nearly impossible to separate complete retouchers from those exhibiting minor damages, hence taphonomic studies should always be conducted prior any further investigation on bone retouchers. Complete retouchers bearing intentional spall negatives (Fig. 3) constituted the least variable group. All of the modified retouchers are triangular or sub-triangular in plan form, which underscores the necessity of conducting research on specific shapes obtained due to human modification. The scar pattern analysis reveals that the modified portions of retouchers (Figs. 2, 1, 2) could significantly influence the geometric-morphometric results. The complete retouchers without blank modification constitute the most variable group. It is important to note that complete retouchers exhibiting intentional spall negatives fall within the middle range of retouchers without blank modifications 95% ellipse (Fig. 3). We assume that the blank modification was a significant technological stage in the retoucher shaping and the application of the approaches outlined in this study on a larger sample should confirm this hypothesis. Additionally, we have analyzed the influence of the anatomical origin of bone blanks. Our results (Fig. 5) do not demonstrate any significant effect of the anatomical origin of the bone retoucher blanks on their relative ordinal positions. Retouchers made from the same carcass elements often exhibit significantly variable shapes, suggesting that original bone morphology did not influence the morphological variability of the retouchers in our sample. This may indicate that while Neanderthals applied strict criteria to the selection of the retoucher blanks based on their physical properties (shape, weight, curvature, etc.), their specific anatomical origin was not taken into account. This may indicate the significant influence of intentional modification of blanks, whereby blanks of various shapes derived from different bones were intentionally modified to fall within certain parameters. In addition to define selectivity criteria of Middle Paleolithic retouchers (Mallye et al., 2012; Auguste, 2002; Costamagno et al., 2018), this could imply the existence of defined morphological patterns for retoucher blanks resulting from intentional selection and modification, which could change our understanding of Neanderthal subsistence strategies and

cognitive abilities. There is a parallel between the predetermination of standardized shapes of lithic bifacial tools from Chagyrskaya Cave and the production of bone retouchers of a specific shape, accompanied by the absence of constraint on bone morphology. This implies that the selection and production of bone retouchers may have occurred very early in the butchery process, as Costamagno et al. (2018) proposed and, consequently, would constitute evidence of the very strong imbrication of carcass processing and the selection of bone tools for the production of lithic artifacts. This is additional evidence of the role of bone retouchers as an interface between lithic production and hunting activities, and highlights their great potential for addressing the question of predetermination in complex, multidimensional “*chaîne-opératoire*” and, ultimately, discussions of the cognitive capacities of our hominin ancestors.

**Declaration of competing interest** None.

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