

Using bone retouchers in the early Middle Palaeolithic. First application of a multi-proxy approach to Biache-Saint-Vaast (MIS 7)

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Abstract (150-200 words)

In recent years, the number of studies on bone tools from Middle Palaeolithic contexts has increased considerably. Mainly identified as retouchers and predominantly documented during the transition from the Middle to the Upper Palaeolithic, around 50 to 40 ka BP, these bone tools provide key insights into *Homo neanderthalensis* behaviour. The bone tool assemblage from Biache-Saint-Vaast (Pas-de-Calais, northern France, MIS 7), although never studied in detail, is one of the largest known for early Neanderthal occupations in northern France. Several approaches can be applied to the study of bone artefacts, particularly those focusing on raw material management and techno-functional aspects. Owing to the exceptional preservation of its surfaces, the Biache-Saint-Vaast material is especially well-suited for testing different analytical techniques. Here, we present the results of a multi-scalar approach combining anatomical studies, palaeoproteomics (ZooMS and LC-MS/MS), taphonomy, traceology, and experimentation. Applied to 10 archaeological artefacts, this study represents the first successful application of such an approach to ancient bone tools. Our results highlight the potential and importance of conducting similarly comprehensive studies on larger assemblages of bone artefacts, including those recovered from ancient open-air contexts, as well as the need to develop additional comparative datasets.

Keywords: Neanderthal, Middle Palaeolithic, bone tools, proteomics, use-wear, experimentation

Introduction

The use of animals as nutritional and non-nutritional resources in a variety of daily activities is well documented in Upper Palaeolithic contexts (i.e., *Homo sapiens*) in Europe (e.g., Patou-Mathis (ed.) 2002; Schwab 2005; Tartar 2009; Arrighi et al. 2020; Hutson (ed.) et al. 2018; etc.). The recognition of bone tools in assemblages attributed to ancient hominins, including *Homo neanderthalensis*, has been widely accepted from the Lower Palaeolithic onwards (e.g., Villa and d’Errico 2001; d’Errico and Backwell 2009; Gaudzinski-Windheuser and Kindler 2012; Daujeard et al. 2014; Julien et al. 2015; Averbouh et al. 2017; Baumann et al. 2023; d’Errico et al. 2022; Parfitt et al. 2022 and references therein). During the Middle Palaeolithic (hereafter MP), bone tools are often considered “expedient tools” because they were generally unshaped, and used to fulfil a specific short-term need (Johnson 1985; Lyman 1994; Klein 2009). Bones showing areas with ‘impressions’ that appear to result from percussion on lithic edges were first mentioned by L. Henri-Martin (1906) for the Mousterian level of La Quina (Charente), and were called “*retouchoirs*”. To date, so-called retouchers remain the most common type of bone tool identified in Neanderthal contexts in Europe, particularly during MIS 5 (Southeastern France, Daujeard et al. 2018; South Western France, Vincent 1993, Armand and Delagnes 1998, Tartar et al. 2022, Baumann et al. 2023; Czech Republic, Auguste 2002; Belgium, Abrams 2018) and MIS 3, during the transition from Middle to Upper Palaeolithic (South Eastern France, Daujeard et al. 2018; Southwestern France, Vincent 1993, Mallye et al. 2012, Costamagno et al. 2018, Martisius et al. 2020, Tartar et al. 2022; Germany, Tonatio et al. 2018; Italy, Jéquier et al. 2018, Thun Hohenstein et al. 2018, Arrighi et al. 2020; Spain, Mozota Holgueras 2012, Mateo-Lomba et al. 2019, Pérez et al. 2019, Romero et al. 2023; Belgium, Abrams 2018; Central Asia, Baumann et al. 2025). Some earlier occurrences have also been documented (Southeastern France, Daujeard et al. 2014, Dumont 2023; Southwestern France, Vincent 1993; UK, Parfitt and Bello 2022; Germany, Julien et al. 2015, van Kolfschoten et al. 2015; Spain, Rosell et al. 2015, Moigne et al. 2016; Portugal, Sanz et al. 2024). However, bone tools remain relatively scarce throughout the entire period in northern France (Moigne et al. 2016; Sévêque and Auguste 2018).

Like faunal remains resulting from butchery activities, bone tools - even expedient ones – are highly informative for documenting interactions between human populations and their environment, particularly regarding large terrestrial mammals, which constitute the most common raw material used for bone tools (e.g., Mozota Holgueras 2012; Hutson (ed.) et al. 2018 and references therein). The study of socio-economical contexts and, more broadly, subsistence behaviours can be enhanced through the analysis of raw material management. Indeed, several studies have demonstrated the targeted selection of raw materials according to species (Abrams 2018; Desmond et al. 2018; Romandini et al. 2018; Abrams et al. 2025). However, because of the fragmented state of the bones, resulting either from anthropogenic activities or post-depositional processes, taxonomic identification based solely on morphological comparison can be limited for bone tools. Developments in the biomolecular field of palaeoproteomics (Tokarski et al. 2006; Buckley et al. 2009), combined with the advances in minimally invasive sampling techniques (Evans et al. 2023; Hansen et al. 2024), have yielded promising results for late MP sites (Brown et al. 2015; Sinet-Mathiot et al. 2019, 2023; Welker 2019; Bray et al. 2020, 2022; Martisius et al. 2020). The decision to implement palaeoproteomics rather than palaeogenetic analyses is based both on the lower cost of proteomic analyses and on the assumption that DNA degrades significantly over time (Buckley et al. 2009). Nevertheless, the application of this approach on bone tools remains underdeveloped, particularly in the context of early MP (von Holstein et al. 2014; Desmond et al. 2018; Tomasso et al. 2018; McGrath et al. 2019; Pétillon et al. 2019; Martisius et al. 2020; Bradfield et al. 2021; Dekker et al. 2021; Bray et al. 2022; Hansen et al. 2024).

Another important aspect of the study of bone tools concerns the techno-functional components associated with MP expedient tools. The use-wear approach, following the methodology

implemented by Semenov (1964), considers traces related to the possible manufacture and use of these bone tools. To ensure reliable interpretations, a detailed taphonomic analysis of the bone is also necessary. Previous studies have demonstrated the potential confusion between percussion marks and traces produced by other post-depositional processes (Binford 1981; David 2024; Parfitt and Bello 2024; Speth 2024). Furthermore, the variability of anthropogenic marks (shape, intensity, position on the artefact, etc.) has been widely discussed, and their origin (accidental, shaping, use) sometimes remains debatable (Domínguez-Rodrigo et al. 2009; Julien et al. 2015; David 2024; Parfitt and Bello 2024). Consequently, experimental work is essential for understanding and characterising the gestures underlying the observed marks through comparisons between experimental and archaeological use-wear traces.

In an attempt to maximise the informative potential of bone artefacts, we present here a multiproxy approach applied to selected samples of bone tools from the Biache-Saint-Vaast collection, combining morphological comparison, palaeoproteomics, taphonomy, use-wear analyses and experimentation. Although identified for some time, this material has yet not been subjected to a comprehensive investigation (Auguste 2002; Sévêque and Auguste 2018). The objectives of this study are twofold: first, to provide further insight into the implementation of the first palaeoproteomics study of early MP bone tools in a northern France context, and second, to develop a multidisciplinary framework by testing its potential on a small sample of the assemblage. To our knowledge, such a multiproxy approach has so far only been applied to a much more recent (Holocene) material (Hansen et al. 2024); consequently, applying it to a Middle Pleistocene collection from an open-air context represents a particularly challenging endeavour.

Context of the study

Biache-Saint-Vaast (BSV, Pas-de-Calais, northern France) is an open-air site excavated in the 1970s and the 1980s that revealed several human occupations dating from MIS 7 to MIS 6 (Figure 1). The main archaeological layer, IIa, has been dated to approximately 230ka BP (Bahain 2007). Level IIa, associated with level IIb (MIS 7), are well preserved and have yielded the highest concentrations of artefacts, including more than 190,000 faunal remains, of which around 20,000 have been anatomically and taxonomically identified (Auguste 1995a). In addition, two Neanderthal skulls were discovered in level IIa (Rougier 2003; Guipert et al. 2011). Levels IIa and IIb display a high degree of homogeneity in lithic production, which mainly consists of Levallois flakes. Raw materials were procured locally, and all stages of the *chaîne opératoire* have been identified in the assemblage (Hérisson 2012). Use-wear studies have enabled the identification of a variety of activities, including hunting (projectiles), butchery, and woodworking, while also confirming the hafting of some artefacts (Beyries 1988; Rots 2013). Among more than 50,000 lithic remains, less than 1% (Number of remains, N IIa = 423; N IIb = 112) are retouched (Hérisson 2012).

The faunal assemblage comprises 18 species of large and medium-sized mammals, three of which dominate: the aurochs (*Bos primigenus*), the brown bear (*Ursus arctos*) and the narrow-nosed rhinoceros (*Stephanorhinus hemitoechus*; Auguste 1995a). The environment of BSV, largely composed of swampy areas, appears to have functioned as a natural trap, potentially influencing hunting strategies towards large fauna, particularly aurochs. In the case of aurochs (level IIa and IIb, Number of Identified Specimens, NISP = 9,456), evidence of defleshing and marrow extraction have been identified (Auguste 1995b, 2009). The continental climate favoured the presence of bears (level IIa and IIb, NISP = 6,912), which, weakened after hibernation, may have been hunted and butchered in spring, providing meat, marrow and fur (Auguste 1995b, 2003). Hunting of the narrow-nosed rhinoceros (level IIa and IIb, NISP = 1,040) is considered to have been opportunistic. Present mainly during autumn and winter, its availability led to an *in-situ* slaughtering in the swampy areas (Auguste et al. 1998).

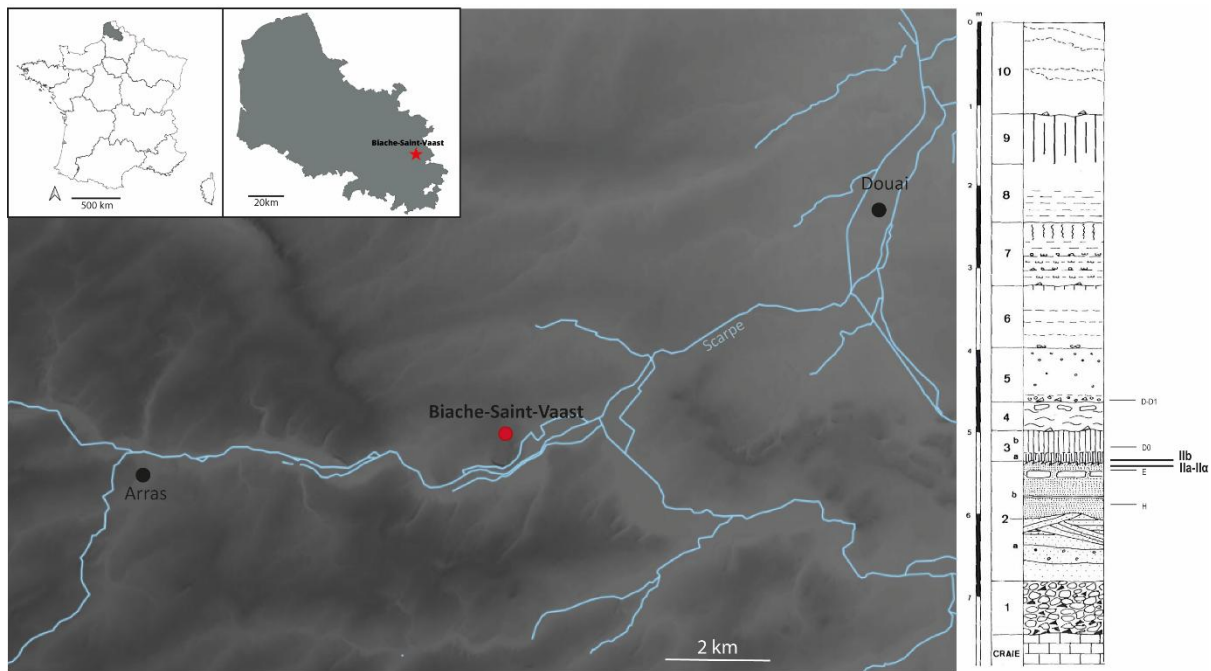


Figure 1: Left: location of Biache-Saint-Vaast; right: stratigraphy of human occupations (after Tuffreau and Sommé, 1988).

Material and methods

So far, 333 bone retouchers have been identified in levels IIa and IIb of BSV, corresponding to one of the largest assemblages known for the MP (see e.g., [Auguste 2002](#); [Hutson \(ed.\) et al. 2018](#)). We randomly selected 10 tools from level IIa (Figure 2; Table 1). The random selection and limited number of bones studied was determined by the costs associated with proteomics analyses, and by the exploratory objective of the study, which aimed to assess the feasibility and informative potential of this approach on early MP osseous artefacts, and the tight timing involved with this specific research project.

Morphological and molecular identification

The morphological comparison of the artefacts studied here was carried out by P. Auguste ([1995a](#)) and re-examined for the present study. When it was not possible to determine the family rank, the bones were classified into three size classes based on cortical thickness ([Saladié et al. 2011](#)): small mammals (SMAM from 10 to 100 kg), medium mammals (MMAM from 100 to 200/300 kg) and large mammals (LMAM over 300 kg).

The 10 selected bones were sampled and analysed using the palaeoproteomics ZooMS and LC-MS/MS techniques, according to previously published methodologies ([Bray et al. 2022, 2023](#)). Considering the age of the bones, we decided to manually sample 10 mg of bone powder in order to maximise collagen recovery. Detailed methodologies are described in Supplementary data 1.

Taphonomy and use-wear analyses

The study of surface alterations was performed using a low-power approach, including naked eye observation and the use of a binocular microscope (Olympus SZX12, x7 to 90) to evaluate the preservation state of the surfaces, identify weathering and biological non-anthropogenic impacts, and assess the anthropogenic origin of the studied marks ([Behrensmeyer 1978](#); [Binford 1981](#); [Shipman 1981](#); [Villa and Mahieu 1991](#); [Lyman L. R. 1994](#); [Auguste 2002](#); [Domínguez-Rodrigo and Piqueras 2003](#); [Guadelli 2008](#); [Domínguez-Rodrigo et al. 2009](#); [Denys and Patou-Mathis \(ed.\) 2014](#); [Fernández-Jalvo and Andrews 2016](#); Table 2). Anthropogenic marks of carcass processing, such as cut marks, bone breakage, and possible burning damage, were recorded according to published studies and personal

experimental data (Binford 1981; Valensi 1991; Villa and Mahieu 1991; Stiner et al. 1995; Soulier and Costamagno 2017; Vettese et al. 2020).

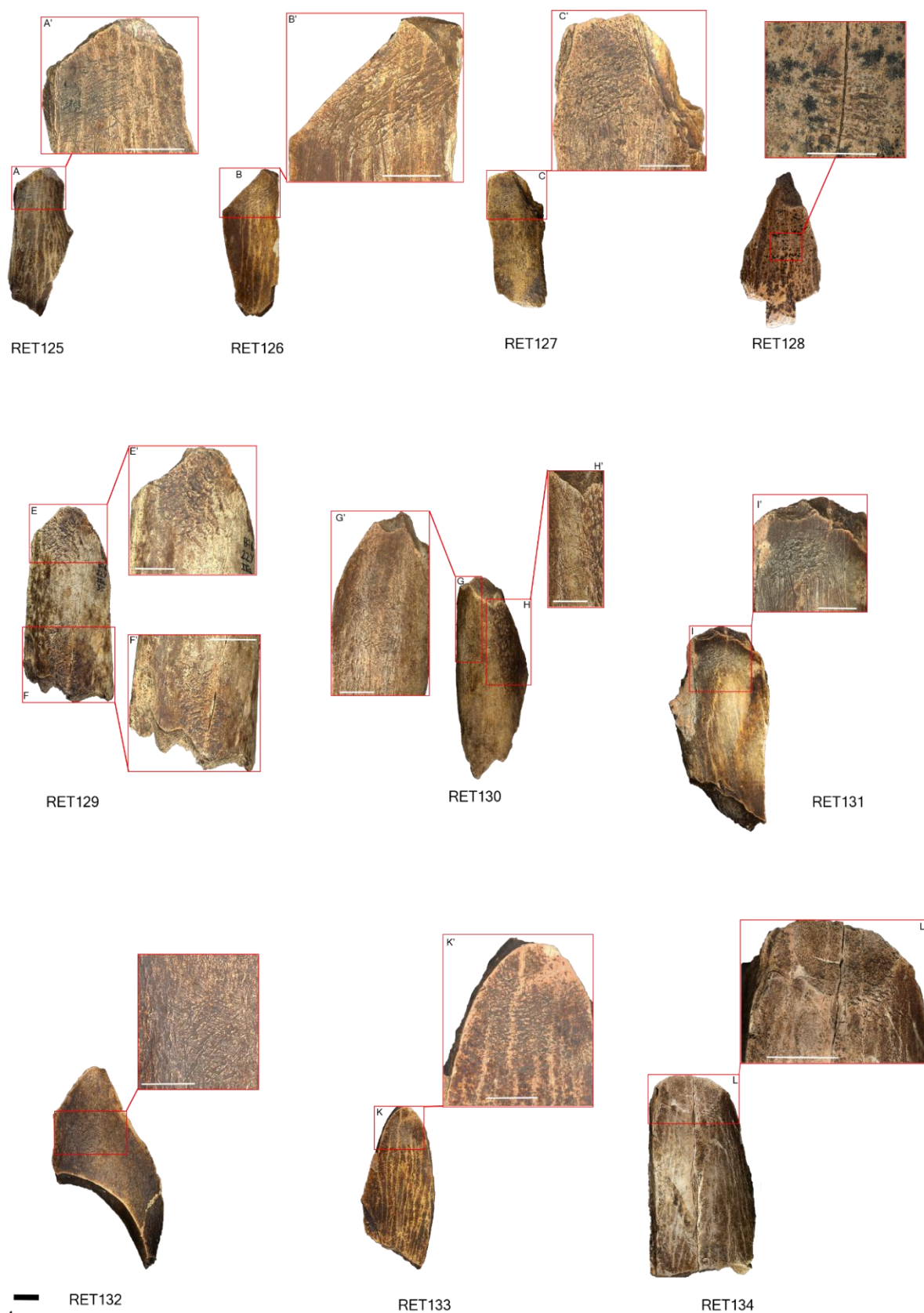


Figure 2: Biache-Saint-Vaast retouchers selected for this study; cortical and close-up views of the UAs; scale bar = 1cm (©R. Habert & M.-P. Vignes).

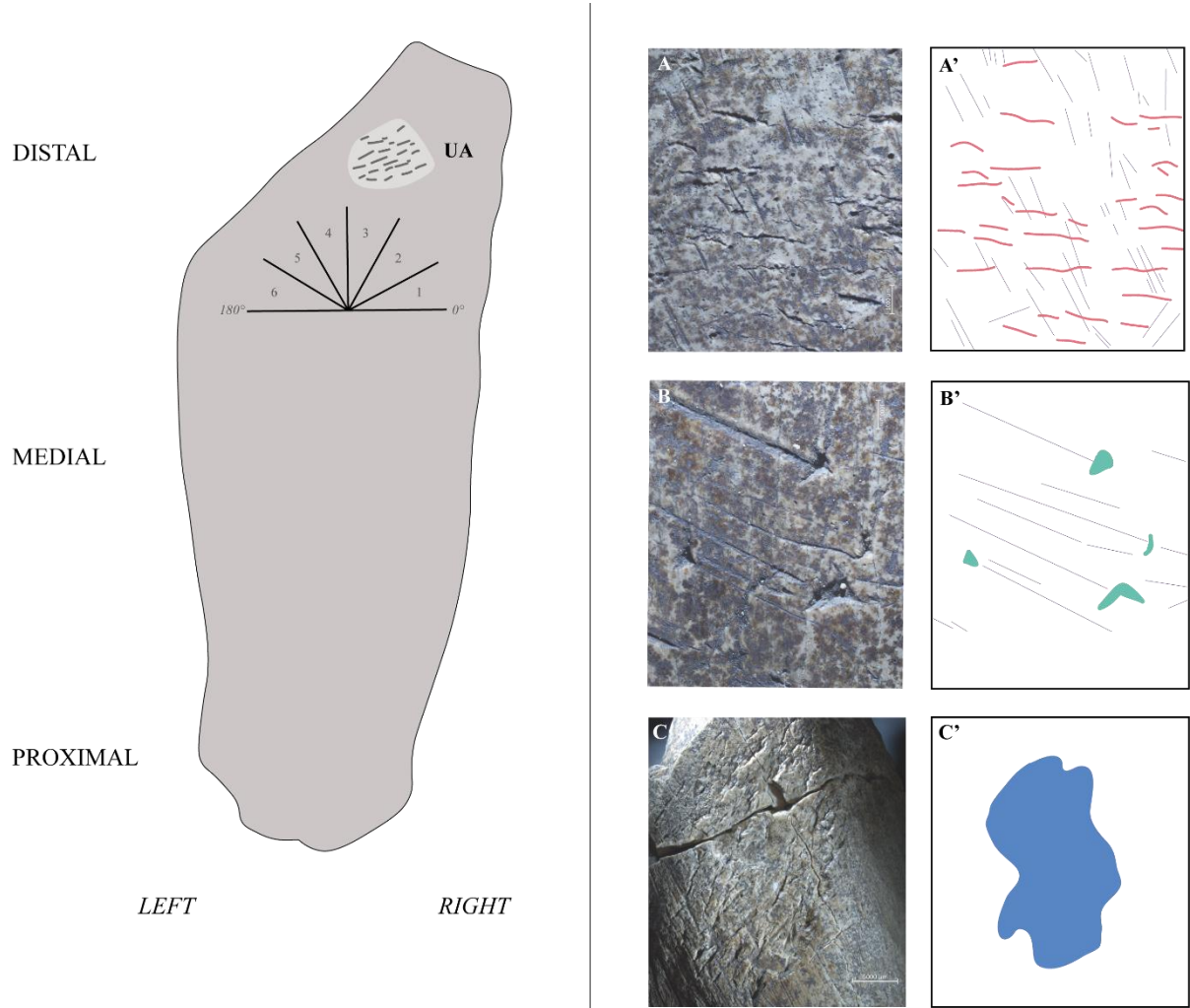


Figure 3: use-wear analytical criteria used in this study compiled from Mallye et al. 2012 and Mateo-Lomba et al. 2019; on the left, orientation of the support with use area (UA) delimitation in a distal position; on the right, close-up views of marks observed on UAs of Biache-Saint-Vaast bone tools; A-A' striations in purple and linear impressions in red (RET31); B-B' striations in purple and trihedral impressions in green (RET2); C-C' massive scaling in blue (RET76) (©M.-P. Vignes).

Use-wear analyses had already been initiated on the BSV bone tool assemblage, and here we propose a more systematic study using both macroscopic and microscopic analyses with different microscopes (Sévêque and Auguste 2018). Pictures of the use areas (thereafter UAs) were taken with a Keyence VHX-X1 (Figure 4; Supplementary 4, Figures 1 to 6). Pictures of each UA from the experimental artefacts were taken using a Zeiss Axio Zoom.V16 microscope equipped with a dedicated camera (Figures 2). The artefacts were oriented with the UA in a distal position (Figure 3). In cases where several UAs were present on each extremity, the artefact was oriented according to the area under study. The UAs were identified and described according to previous studies (Chase 1990; Armand and Delagnes 1998; Patou-Mathis (ed.) 2002; Tartar 2009; Mallye et al. 2012; Daujeard et al. 2014; Mozota Holgueras 2012; Mozota 2018; Martellotta et al. 2021). Different measurements were taken, including the length, width, and cortical thickness of each bone, as well as measurements of each UA (maximum length, width, and dispersion in cm²). The position of each UA on the diaphysis was recorded according to its location across the shaft (lateral or centred), and along its length (distal or medial). The terminology used to describe the marks followed that proposed by Mozota (2018), differentiating linear impressions, trihedral impressions, striations, and massive scaling, which were counted for each UA in ranges of 10 (Figure 3; Table 3). The classification of the general aspect of the UA was based on the predominant mark observed. Their concentration was recorded according to

Mallye et al. (2012): isolated, scattered, concentrated, or concentrated and superposed. The orientation of the marks, according to their main axis, as well as their dispersion, was also recorded (Mallye et al. 2012; Mateo-Lomba et al. 2019). An intensity of use, ranging from marginal to invasive, was attributed to each UA according to the number and extent of the marks.

Experiments

Experiments were performed at TraceoLab by C. Lepers, a trained flintknapper, using *Bos taurus* long bones (two humerus, three radio-ulna, two femur, and two tibias) to knap flint according to Levallois methods and to retouch flint flakes, following what has been documented at BSV (Hérisson 2012). This experimental session was carried out on two semi-fresh radio-ulna, which have been left to dry for several months (one of which has also been boiled prior to the experiment; Supplementary 5), and the remaining seven were on a fresh state (Table 4). The experiment involved breaking the long bones, in order to produce fragments, as observed and described for many MP sites, including BSV (e.g., Villa and Mahieu 1991; Auguste 1995b; Vettese et al. 2017, 2020; Moclán and Domínguez-Rodrigo 2018), and then using the resulting bone fragments for retouching and knapping activities. Every shaft fragment larger than five centimetres was selected (N = 39) without any supplementary criteria. In total, 34 blanks were used in tangential retouching of Levallois flint flakes to produce scrapers, and five were used in knapping activities to produce Levallois flint flakes, resulting in a total of 39 UAs (Figure 5; Table 3). The time range of each activity varies between two and 10 minutes.

The same use-wear analyses protocol was applied for the study of marks on the experimental artefacts. The results were then compared with those from the archaeological assemblage (Figure 5; Tables 3 and 4).

Results

Morphological and molecular identification

The 10 tools selected from the BSV level IIa assemblage are fragments of long bone shafts (Figure 2; Table 1). Three were identified both anatomically and taxonomically, while three others were identified only taxonomically based on morphological comparison. Three artefacts were attributed to *Bos primigenius*: one tibia and two indeterminate long bone shafts (RET131, RET132 and RET133). Fragments of a tibia and a humerus were attributed to *Ursus* sp. (RET129 and RET130). A radius fragment was attributed to the Rhinocerotidae family (RET134). Among these 10 artefacts, four long bone diaphyses could not be identified either anatomically nor taxonomically but were assigned to the LMAM category (RET125, RET126, RET127 and RET128; Table 1).

Few marker peptides were identified using ZooMS, suggesting poor collagen preservation in the BSV faunal material (Supplementary 2, Table 1). Despite the degradation of the remaining peptides caused by a high mineralisation of the bones, deamidation percentages indicate the presence of ancient collagen. Several peptides were identified, indicating the presence of mammalian collagen (COL1A1T47 and COL1A2T43; Supplementary 2). For samples RET126, RET127, RET129, RET130, RET132, RET133, and RET134, peptides were detected but did not allow taxonomic identification because of the omnipresence of contaminant peaks, mainly corresponding to trypsin. Sample identification for RET128 was restricted to the Equidae-Rhinocerotidae families, and to the Bovidae-Cervidae families for RET 125 and RET131 (Table 1; Supplementary 2, Table 1).

LC-MS/MS analyses allowed the identification of six samples (Table 1). However, data queried in the UniprotKB database showed a strong presence of contaminants. Proteins such as keratin type I, type II, desmoplakin, and hornerin were identified in all samples. In addition to these contaminants, COL1A1, COL1A2, COL2A1, and COL3A1 were identified, COL1A1 and COL1A2 being the collagens with the highest number of identified peptides (Shoulders and Raines 2009; Warinner et al. 2022). Specific

peptides were identified and validated by BlastP analyses (Supplementary 2, Table 2; Supplementary 3, Figures 1 and 4). LC-MS/MS analyses identified RET128 as belonging to the Rhinocerotidae family, RET131 to the Bovidae-Cervidae families, and RET125, RET126, RET132, and RET133 to *Bos* sp. (Table 1). RET127, RET129, RET130 and RET134 could not be identified using either biomolecular techniques employed.

Taphonomy

The bone tools from BSV generally exhibit an exceptional state of surface preservation, except for browning and the presence of stains (Figure 2; Table 2). Edge alteration was observed on nine artefacts and is characterised by a decolourisation and slight abrasion extending a few millimetres around the edges (Figure 2). Weathering, root traces, and trampling damage were identified on eight, five and one artefacts, respectively, but their impact on the surfaces remained minimal (Table 2). No carnivore impact was observed on any of the 10 tools.

Dry bone fractures and recent breakage (tool impacts and breakage that can be refitted) were identified on all the artefacts presented in this study (Table 2). Green bone breakage was recognised through the presence of fresh bone fractures associated with cortical removals on nine fragments (Tables 2 and 3). Cut marks and scraping marks were each present on nine artefacts (Table 3). Deep scraping marks covering the surfaces of six artefacts were observed (Figure 4, A-C-D; Supplementary 4, Figures 1, 2 and 4). No burning damage was observed.

Morphology and use-wear: archaeological material

The artefacts range from 80 mm to 99 mm in length, with a mean of 90.5 mm (standard deviation, SD = 6.38); from 34 mm to 56 mm in width, with a mean of 41.3 mm (SD = 7.35); and from 8 to 17 mm in cortical thickness, with a mean of 12.6 mm (SD = 2.67; Table 3). Thanks to the refitting of some recent fractures, complete dimensions were obtained for one artefact (RET130). Two artefacts are almost complete, with a mean length of 97.5 mm (SD = 2.12), a mean width of 51 mm (SD = 7.07), and a mean cortical thickness of 14.5 mm (SD = 2.12). Seven artefacts are incomplete and bear dry and/or recent fractures that could not be refitted, with a mean length of 87.6 mm (SD = 5.19), a mean width of 39.1 mm (SD = 5.73), and a mean cortical thickness of 12.4 mm (SD = 2.76; Table 3).

Among these 10 tools, eight bear a single UA, whereas two display two UAs, resulting in a total of 12 UAs (Figure 2; Table 3). All the UAs are located on the cortical part of the bones: eight positioned distally, two medially, and two in a medial-to-distal position (Table 3). Among the 12 UAs, five are located laterally relative to the diaphysis axis (four left, one right), five are centred, and two are covering (Table 3). The cortical surfaces are flat (N = 2), flat-to-convex (N = 5), or convex (N = 5). Most analysed bones display concentrated impression areas (Table 3). Among them, 10 show predominantly linear impressions, including six displaying intense use (RET125, RET127, RET129, RET131, RET132, and RET133), while four exhibit more moderate use intensity. Finally, three artefacts display massive scaling. Six UAs are complete (RET126, RET128, RET130, RET132, and RET134), with a mean of 3.2 cm² (SD = 0.87), whereas six are incomplete, with a mean of 6.4 cm² (SD = 2.80). Except for RET129 and RET130, which display crossed marks, all marks are obliquely oriented in the same direction within a UA; seven of them are oriented from right to left and two from left to right (Table 3). On the two tools bearing two UAs, one presents opposite UAs with similar marks (RET129) whereas the other exhibits consecutive UAs differing in concentration and orientation of the marks (RET130). In RET130, the surfaces of the two UAs also differ in convexity.

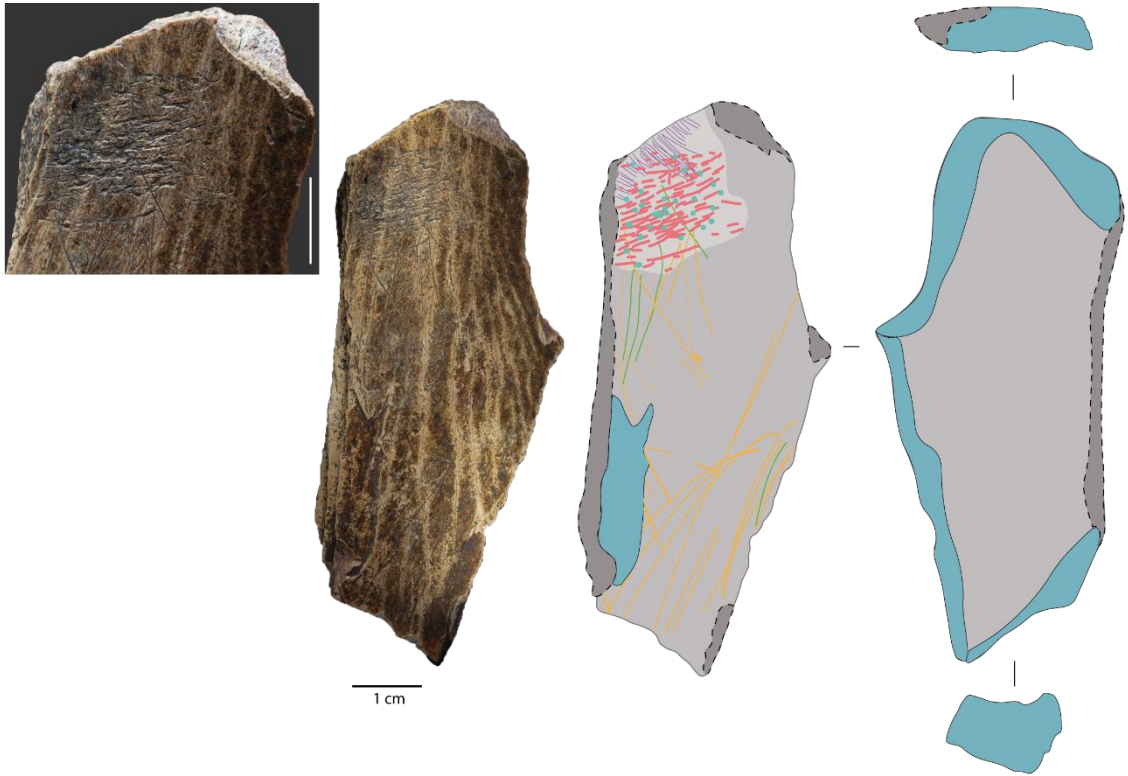
Artefacts ID			Identifications				
Artefact	Square	Sub-square	Anatomical	Morphological	MALDI FT-ICR	LC-MS/MS	Final ID
RET125	4A	-	LONG BONE UN.	LMAM	<i>Bovidae; Cervidae</i>	<i>Bos sp.</i>	<i>Bos sp.</i>
RET126	-	-	LONG BONE UN.	LMAM	?	<i>Bos sp.</i>	<i>Bos sp.</i>
RET127	15F	SE	LONG BONE UN.	LMAM	?	?	LMAM
RET128	8E	-	LONG BONE UN.	LMAM	<i>Equidae; Rhinocerotidae</i>	<i>Rhinocerotidae</i>	<i>Rhinocerotidae</i>
RET129	22Y	-	TIBIA	<i>Ursus sp.</i>	?	?	<i>Ursus sp.</i>
RET130	27N	SW	HUMERUS	<i>Ursus sp.</i>	?	?	<i>Ursus sp.</i>
RET131	4H	-	TIBIA	<i>Bos primigenius</i>	<i>Bovidae; Cervidae</i>	<i>Bovidae; Cervidae</i>	<i>Bos primigenius</i>
RET132	27I	-	LONG BONE UN.	<i>Bos primigenius</i>	?	<i>Bos sp.</i>	<i>Bos primigenius</i>
RET133	10D	SW	LONG BONE UN.	<i>Bos primigenius</i>	?	<i>Bos sp.</i>	<i>Bos primigenius</i>
RET134	22	SW	LONG BONE UN.	<i>Stephanorhinus sp.</i>	?	?	<i>Stephanorhinus sp.</i>

Table 1: artefacts from level IIa of Biache-Saint-Vaast; - = no data; anatomic and taxonomic identifications; UN. = Undetermined; LMAM = large mammal; ? = no molecular results ; darker colours = identification to the rank of the Specie-Family; lighter colours indicate a less precise identification.

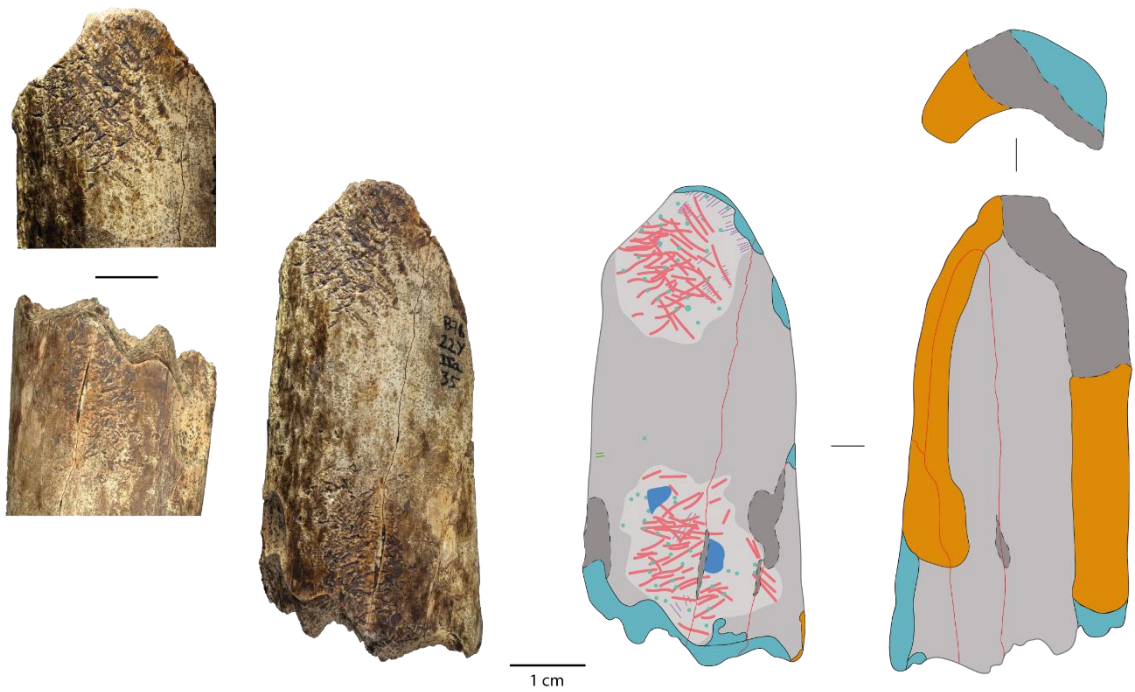
Artefact	Non anthropogenic marks				Breakage		
	Water damage	Roots	Weathering	Trampling	Fresh bone	Dry bone	Recent
RET125	x		x			x	B/T
RET126	x		x		x	x	T
RET127	x	x	x		x	x	T
RET128	x	x	x	x	x	x	T
RET129	x	x			x	x	B
RET130	x		x		x	x	T
RET131	x		x		x	x	B/T
RET132	x	x			x	x	B
RET133	x		x		x	x	B
RET134	x	x	x		x	x	B/T

Table 2: taphonomical marks, except anthropogenic modifications, Biache-Saint-Vaast bone tools ; water = dissolution and/or concretions and/or staining and/or blunt; weathering = cracking and/or desquamation; B = breakage; T = tools; x = presence of the mark ; empty field = absence.

A)



B)



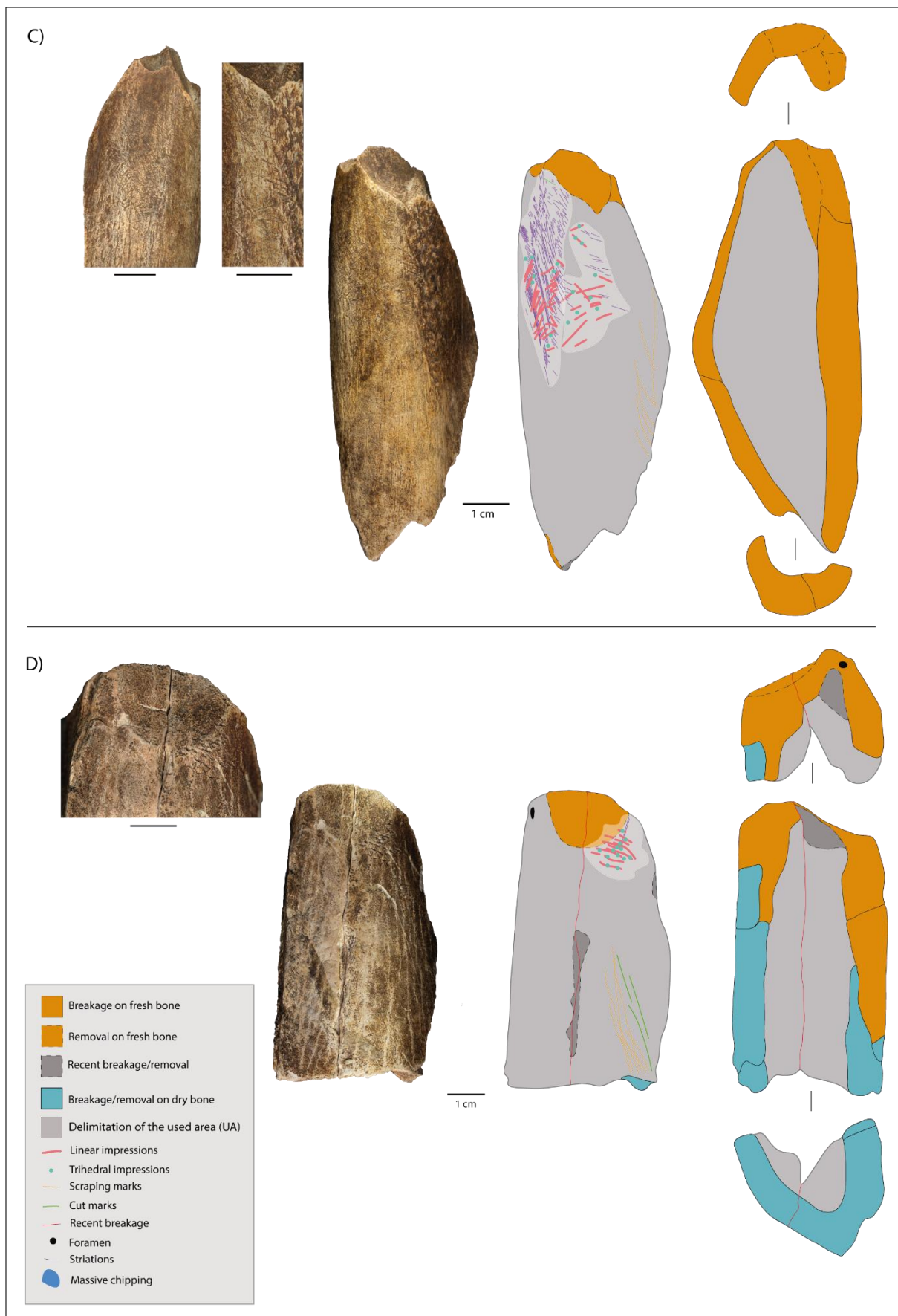


Figure 4: Bone tools from Biache-Saint-Vaast ; A) RET125; B) RET129; C) RET130; D) RET134 ©R. Habert & M.-P. Vignes.

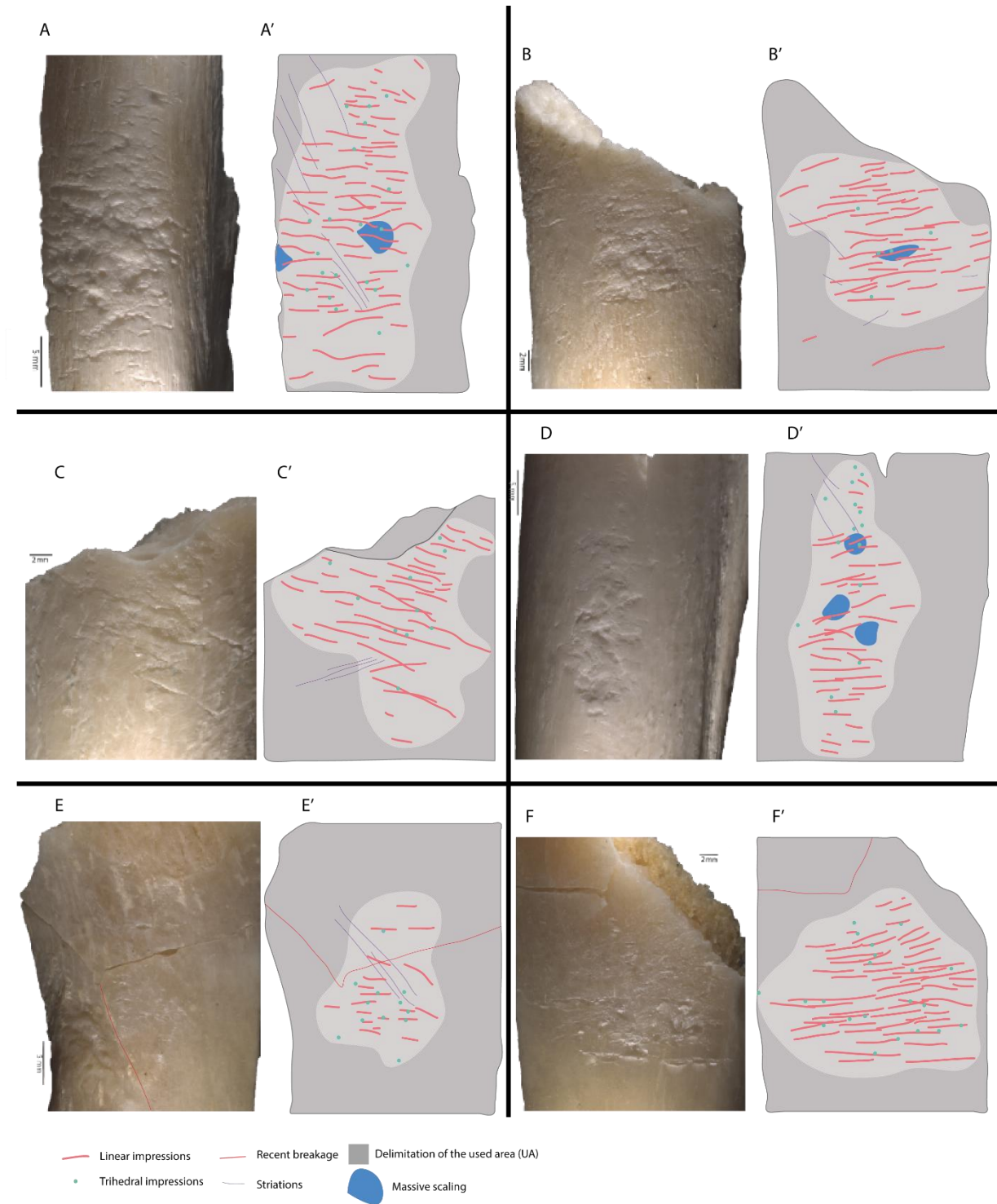


Figure 5: UAs from the experimental session, semi-fresh radio-ulna from *Bos taurus*. A-A' = EXP98/1; B-B' = EXP98/2; C-C' = EXP98/3; D-D' = EXP98/4; E-E' = EXP98/5; F-F' = EXP98/6 (© M.-P. Vignes).

Artefact	Total dimensions	Length	Width	Cort. Th.	UA nb	UA (cm ²)	Scraping	Cut marks	Notches/ cort. rem.	Loc. on the length axis	Loc. on the width axis	Nb LI	LI (or.)	Nb TI	St (or.)	MS	Conce.	Conve.
RET125	Incomplete	91	37	14	1	>3,4	x	x		dist	left	50-60	2	20-30	5		consup	f-conv
RET126	Incomplete	89	34	17	1	7,5	x	x	x	dist	cov	50-60	2	20-30	5	x	consup	f-conv
RET127	Incomplete	81	34	12	1	>6,3	x	x	x	dist	cent	40-50	1-2	20-30	4		consup	f-conv
RET128	Incomplete	94	50	13	1	3,5	x		x	med	cent	20-30	6	10-20			con	f-conv
RET129	Incomplete	90	41	11	2	>11,2		x		dist	cent	40-50	4-2	20-30	4-2	x	consup	conv
						>7,6				dist	cent	50-60	5-2	20-30	3-4	x	consup	conv
RET130	Complete	97	37	10	2	2,6	x	x	x	med-dist	cent-left	20-30	3	<10	4		con	conv
						2,8				med-dist	cent	10-20	2-5	<10	5		sca	f-conv
RET131	Almost complete	96	46	16	1	>4,3	x	x	x	dist	cent-left	50-60	2	10-20	2		consup	f
RET132	Almost complete	99	56	13	1	4,2	x	x		med	cent-left	30-40	3	10-20	5		consup	f-conv
RET133	Incomplete	80	36	8	1	>5,3	x	x		dist	cov	50-60	2	20-30	4		consup	f
RET134	Incomplete	88	42	12	1	2,9	x	x	x	dist	right	10-20	6	10-20	3		con	conv

Table 3: Biache-Saint-Vaast bone tools morphology and use-wear data; x = presence of the mark (scraping, cut marks, and notches); empty field = absence of the mark; dimensions in millimetres; nb = number; Cort. Th. = cortical thickness; cort. rem. = cortical removal; loc. = location; dist = distal; med = medial; med-dist = medial-to-distal; cov = covering; cent = centred; LI = linear impressions; TI = trihedral impressions; or. = orientation; St = striations; MS = massive scaling; Conce. = concentration; con = concentrated; sca = scattered; consup = concentrated and superposed; sca = scaled; Conve. = convexity of the surface; conv = convex; f = flat; f-conv = flat-to-convex.

		P (N = 5)	R (N = 34)
Length	Mean	117,6	160,0
	SD	39,8	46,5
Width	Mean	39,4	42,4
	SD	14,3	16,0
Cortical thickness	Mean	10,1	12,0
	SD	3,3	1,1
UA cm ²	Mean	4,7	13,3
	SD	1,9	9,7
Loc. on the length axis	Med	4	1
	Med-dist		1
	Dist	28	3
	Cov	2	
Loc. on the width axis	Lat	14	4
	Cent-lat	1	
	Cent	15	1
	Cov	4	
Nb LI	0-10	1	
	10-20	9	2
	20-30	10	2
	30-40	4	
	40-50	3	1
	50-60	4	
LI (or.)	6	12	4
	6-5		1
	6-2	2	
	5	3	
	2	3	
	1	11	
Nb TI	0-10	6	1
	10-20	14	1
	20-30	10	3
	30-40	3	
	40-50	1	
St. (or.)	2	1	
	3	5	
	4	6	1
	5	1	
	5-3	1	
MS		9	3
Concentration	Con	7	
	Con-sca	1	4
	Sca	8	
	Consup	18	1
Convexity of the surface	Conv	12	3
	F	7	
	F-conv	9	1
	F-conc	6	1
Broken during use		3	4

Table 4: Experimental data – morphology and use-wear of Retouchers (R) and Percussors (P) from *Bos taurus* long bones diaphysis; Number of Remains (N) per category; empty field = absence of the mark; mean dimensions in millimetres; SD = standard deviation; Nb = number; Loc. = location; med = medial; dist = distal; cent = centred; cov = covering; LI = linear impressions; TI = trihedral impressions; St. = striations; MS = massive scaling ; con = concentrated; sca = scattered; consup = concentrated and superposed; con-sca = concentrated and scattered; or. = orientation; conve. = convexity of the surface; conv = convex; f = flat; f-conv = flat-to-convex; f-conc = flat-to-concave.

Striations are present on all the UAs except on RET128 and are perpendicular to the linear impressions, except on RET132 (Figure 4; Table 3; Supplementary 4). These marks were observed on nine artefacts and predate the linear and trihedral impressions, and are oriented in the opposite direction (Figure 4, Table 3; Supplementary 4, Figures 1, 2 and 4 to 6). In addition, scraping marks (N = 9) appear to be concentrated beneath some UAs (Supplementary 4, Figures 3 and 6).

On RET126 and RET134, cortical removals located at the extremities predate the UAs (Figure 4, D; Supplementary 4, Figure 1). Similar removals were observed on RET127, RET128, RET130, and RET131, although no chronological relationship with the UAs could be established (Figure 4, C; Supplementary 4, Figures 2 to 4).

Morphology and use-wear: experimental material

The experimental bone tools used for tangential retouching have mean dimensions of 117.6 mm in length, 39.4 mm in width, and 10.1 mm in cortical thickness (Table 4). The ones used for knapping have mean dimensions of 160 mm in length, 42.4 mm in width, and 12 mm in cortical thickness. Even in the case of semi-fresh bones, the fragments display smooth edges and oblique fracture angles characteristic of fresh bone breakage.

For the fragments used for knapping, the activity was not considered effective by the experimenter as three out of five broke during use. UAs are located in a distal position on three fragments and in a medial or medial-to-distal position for the remaining two specimen (Figure 5; Table 4). Across the width of the fragments, the UAs are located in a central position on one of them and in a lateral position on four. Massive scaling was observed on three fragments, and the marks are concentrated (including some dispersed marks) to centred and superposed, with a mean UA area of 13.3 cm². Linear and trihedral impressions were recorded on all fragments. They tend to be oriented perpendicular to the longitudinal axis. Three UAs are located on a convex surface, one on a flat-to-convex surface, and one on a flat-to-concave surface.

For the 34 shaft fragments used for retouching, three broke during use. 27 UAs are located in a distal position, four in a medial position, and two cover the length (Figure 5; Table 4). 15 UAs are centred across the width, 13 are laterally located, one occupies a centred-to-lateral position, and four cover the width. Linear impressions predominate in all UAs except three, which correspond to supports that broke early in the activity. Trihedral impressions were observed on all supports. Six UAs exhibit massive scaling, and 14 exhibit striations mainly oriented obliquely to the longitudinal axis and in the same direction within each UA. The mean area of the UAs on supports used for tangential retouching is 4.7 cm². Most marks are concentrated, to concentrated and superposed, except for eight UAs corresponding to the bones that broke during use for three of them. A majority of UAs are located on a convex or flat-to-convex surface (N = 21), while seven are located on a flat surface and six on a flat-to-concave surface.

Discussion

Taxonomic identification and enhancement from palaeoproteomics

Morphological comparison yielded a moderate rate of identification, with six out of the 10 artefacts from level IIa of the BSV assemblage being identified taxonomically.

LC-MS/MS helped to narrow down the identification for specimens RET125 and RET128, which have remained undetermined based on morphological comparison, and to specify ZooMS identification. In addition, LC-MS/MS enabled the identification of three artefacts that did not provided results with ZooMS (RET126, RET132, and RET133), one of which was also not identified using morphological comparison (RET126; Table 1). Three samples were identified only through morphological comparison (RET129, RET130 and RET134). Only morphological comparison has enabled a precise identification of the RET131. Neither approach enabled a precise taxonomical

identification for RET127. The combination of morphological comparison and palaeoproteomics enabled the taxonomic identification of a total of nine artefacts (see Table 1, 'Final ID' column).

Therefore, the biomolecular techniques helped to fill the gaps left by morphological comparison. However, we identified limitations regarding the application of these methods to such ancient samples, despite successful results obtained from more recent contexts, even for poorly preserved material (Desmond et al. 2018; Tomasso et al. 2018; Pétilion et al. 2019; Sinet-Mathiot et al. 2019, 2023; Martisius et al. 2020; Korzow Richter et al. 2022; Bray et al. 2023; Morin et al. 2023). Despite the good preservation of the artefacts surfaces, we observed significant mineralisation resulting from post-depositional processes and the age of the artefacts, which led to a low rate of taxonomic identification using ZooMS. Studies have shown that collagen protein degradation can be influenced by the chemical composition and diagenetic conditions of the soil, including soil pH and hydrology, although this information was not recorded at BSV at the time of excavation (Collins et al. 2002; Kendall et al. 2018; Procopio et al. 2021). Furthermore, LC-MS/MS analyses highlighted a high level of contaminants, likely resulting from excavation and handling.

Nevertheless, the application of ZooMS proved useful for providing indications of collagen preservation in very old or mineralised material (Welker et al. 2016; Bradfield et al. 2021; Hansen et al. 2024), while attribution to the species level remain complex, mainly because sequenced data for Pleistocene species are still lacking (Bray et al. 2022; Abrams et al. 2025). This is why a morphological approach remains fundamental. Recent studies have already demonstrated the necessity of combining ZooMS with other techniques when studying earlier assemblages in order to improve taxonomic identification (Cappellini et al. 2012, 2019; Sinet-Mathiot et al. 2019; Bray et al. 2020, 2022). ZooMS remains less expensive and easier compared to other methods.

The combination of different palaeoproteomics methods is crucial for the study of ancient faunal material, particularly bone tools, as the number of available samples remains limited. Reducing the volume of osseous tissue sampled is essential from a curatorial perspective and helps preserve future traceological and other biomolecular analyses, as well as the long-term integrity of the artefacts themselves (McGrath et al. 2019; Pétilion et al. 2019; Bray et al. 2020; Martisius et al. 2020; Morin et al. 2023). Here, we demonstrated, on a small number of specimens, the contribution of palaeoproteomics to the study of an early MP bone tool assemblage.

Taphonomy and use-wear of the bone tools

Aside from stains and slight abrasion, likely induced by post-depositional water-related alterations, and the presence of recent fractures related to excavation and storage, our taphonomic analysis shows a predominance of anthropogenic modifications on the bones. The UAs observed on the BSV tools analysed here, as well as those produced experimentally, display the main characteristics of MP retouchers described in previous studies: long linear impressions, numerous punctuations, relatively moderate flaking, and perpendicular to oblique impressions (e.g., Vincent 1993; Tartar 2009; Mallye et al. 2012; Mozota Holgueras 2012; Hutson (ed.) et al. 2018). On the archaeological artefacts, UAs tend to cover a wider area of the blank when located on flat or flat-to-convex surfaces. Our experiments showed that, after only up to two minutes of use, linear and trihedral impressions were already well developed and concentrated. This observation, together with the predominance of a single UA on the archaeological material, supports the expedient use of these artefacts. No diagnostic marks were identified that would allow an unambiguous distinction between the use of bone tools for knapping or tangential retouching, as all types of marks – linear impressions, trihedral impressions, and massive scaling – were observed in both activities (Figure 5; Table 4). In addition, the bone fragments appeared poorly suited for percussion as they lacked sufficient mechanical resistance and broke easily. The condition of the experimental blanks may differ from that of the fresh bones potentially used by Neanderthals at BSV, resulting in differences in marks concentration (i.e., smaller

UAs on the experimental tools), greater control of gestures, and/or variations in surface modification (i.e., overall fewer linear impressions on the experimental tools).

Moreover, the presence of intense scraping on some of the studied archaeological artefacts raises questions regarding its relation with carcass processing or other activities (cf. [Auguste 2002](#)), as these marks could be linked to the removal of the periosteum prior to bone breakage (see e.g., [Armand and Delagnes, 1998](#); [Daujeard et al. 2014](#); [Julien et al. 2015](#); [Mozota 2018](#); [Rosell et al. 2018](#); [Sanz et al. 2024](#)). The depth of these marks and their concentration beneath some UAs call into question the actual benefit of such a process. It has been suggested that these traces may indicate the freshness of the bones at the time of use ([Mallye et al. 2012](#)).

Perspectives

The promising results obtained through this initial study highlight the potential of extending proteomic analyses to a larger number of bone tools from the BSV assemblage. Such an approach would provide a more comprehensive understanding of raw material procurement and selection strategies, a key issue in the study of MP bone technologies and Neanderthal behaviour. Several studies have already demonstrated that bone tool manufacture could involve targeted taxa selection ([Mallye et al. 2012](#); [Daujeard et al. 2014, 2018](#); [Thun Hohenstein et al. 2018](#); [Martisius et al. 2020](#); [Bray et al. 2022](#)), making the BSV assemblage particularly relevant for investigating these questions.

Our analysis also revealed significant variability in the arrangement, number, and orientation of use-related marks, both between artefacts and, in one case, within a single tool. Such variability likely reflects differences in gestures, activities, or use histories. In particular, the relationship between striations and trihedral or linear impressions deserves further investigation. These traces were observed on both archaeological and experimental specimens, although they appear more developed on the archaeological material. One possible explanation is their association with *égrésage*, a technique involving the abrasion of lithic edges with a retoucher prior to retouching in order to strengthen the edge ([Jéquier et al. 2018](#)). The current experimental reference framework remains too limited to establish robust diagnostic criteria distinguishing retouching, knapping, and other technical activities. Expanding and refining the experimental reference collection therefore represents a major research priority.

More broadly, the study contributes to ongoing methodological discussions regarding the functional analysis of bone tools. While qualitative macroscopic descriptions have sometimes been criticised as insufficient for interpreting bone-tool use ([Martellotta 2023](#)), microscopic approaches remain time-consuming and are still constrained by the limited availability of comparative datasets. The development of extensive experimental reference collections is therefore essential for improving the reliability of functional interpretations.

The multidisciplinary framework developed here offers a promising avenue for addressing these challenges. Its application to the entire BSV assemblage represents a logical next step as it provides a particularly favourable context for such research because it contains an unusually large number of bone tools recovered from a single archaeological deposit. Furthermore, the exceptional preservation of bone surfaces in this MIS 7 assemblage makes it a unique case study for investigating early Neanderthal bone technologies. Extending this approach to the full collection has the potential not only to refine our understanding of raw material management and tool use, but also to provide important new insights into Neanderthal technological behaviour in north-western Europe, where comparable bone tool assemblages remain exceptionally rare for the early MP.

Conclusion

We implemented a multidisciplinary approach to an early MP bone tool assemblage to a randomly selected set of 10 tools from the BSV assemblage (MIS 7), in order to assess the feasibility and informative potential of this approach for the investigation of early MP osseous artefacts .

Proteomics applied in archaeological and paleontological contexts can yield results from samples smaller than 10 mg, but it was particularly challenging here due to the age (Middle Pleistocene) and sedimentary context (open-air) of the samples, and ZooMS was insufficient. Proteomic analyses helped overcome some of the limitations of anatomical identification, although the high degree of bone mineralization still prevented confident taxonomic attribution for a subset of the artefacts. Through LC-MS/MS, five artefacts were assigned taxonomically, including two that could not be attributed by morphological comparison and confirming morphological comparison identifications for the three others, corresponding to the first successful proteomic analyses performed on such ancient bone tools. The combination of morphological and biomolecular approaches allowed and confirmed the identification of a total of nine specimens corresponding to the three main taxa in the faunal assemblage (aurochs, brown bear and narrow-nosed rhinoceros).

The taphonomic study confirmed the excellent preservation of the bone surfaces, making them ideal for identifying anthropogenic modifications. The analysis of use-wear traces was further supported by an explorative experimental programme. The latter highlighted a variability of the marks, and allowed us to confirm that some of the BSV bone tools had been used for knapping or lateral retouching. Some traces, such as scraping marks identified on archaeological specimens raised questions regarding their relationship either to carcass processing or to the use of the blanks themselves. Our results underline the need to expand comparative datasets through experimental studies and systematic use-wear analyses of bone tools.

The results presented here demonstrate the value of a multidisciplinary approach for integrating information preserved within ancient and/or highly mineralised bone artefacts with evidence recorded on their surfaces. More broadly, the study of expedient bone tools, particularly with regard to raw material procurement and techno-functional aspects, remains insufficiently explored for the early MP in northern France and elsewhere, despite its considerable potential to enhance our understanding of early Neanderthal behaviour.

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Declaration of AI use

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Data availability

The mass spectrometry proteomics data have been deposited to the Proteomics Identification Database (PRIDE) with the dataset identifier PXD059787 (Username: reviewer_pxd059787@ebi.ac.uk, Password: ZX1BrwBq44WH; <https://www.ebi.ac.uk/pride/login>).

Competing interests

The authors declare that one of the co-authors is a member of the journal's editorial board.

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