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RESEARCH

Antler working by the last European Pleistocene hunter-gatherers of Santimamiñe cave (Northern Iberian Peninsula): technological implications of osseous equipment during the Magdalenian

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Abstract
This paper assesses the exploitation of osseous raw materials, namely antler, used by hunter-gatherer populations in the Late Upper Palaeolithic of Santimamiñe cave. The different categories of products (waste products, blanks, and finished objects) are analysed from a technological perspective to identify the fabrication methods employed by Magdalenian groups. A predominant operational scheme is identified, extraction by the double grooving procedure, related to the production of highly standardised rods. This study will allow us to explore possible cultural variations in the application of this procedure. It also addresses other aspects in relation to the circulation of osseous implements, the mobility of hunter-gatherer groups, and the useful life of the weapons, as regard maintenance and discard behaviour.

Keywords Cantabrian region · Santimamiñe · Upper Palaeolithic · Debitage by extraction · Magdalenian · Antler-working

Introduction

The study of tools made from hard animal material can provide valuable information about the technical and conceptual behaviour of hunter-gatherer societies (Tejero et al. 2012; Averbouh et al. 2016; Goutas and Tejero 2016; Baumann et al. 2023; Lefebvre et al. 2023). These types of studies have become essential to comprehend the different sub-systems that made up the cultural sphere of the groups and to propose the organisation of the different procedures and techniques that were applied in the operational chains of transformation.

Technological studies are a quite recent approach in the Iberian Peninsula (Tejero 2004, 2009, 2013; Tejero and Fullola 2008; Borao 2012, 2022; Borao et al. 2016; Erostarbe-Tome et al. 2022; Tejero et al. in press) but have contributed notably to an understanding of the management of osseous raw materials and the manufacturing techniques for different kinds of tools. These studies follow some of the contributions of the various scholars who in some way explored this topic (Mujika 1983, 1990, 2007–2008; Adán 1993, 1997; Álvarez-Fernández 2006; Garrido 2015).

The present study focuses on antler-working by the human groups who occupied Santimamiñe cave in the Magdalenian. This site contains one of the richest Magdalenian levels in the Basque Country (Aranzadi et al. 1925; Aranzadi and Barandiarán 1935; Barandiarán 1976; López Quintana 2011), which enables the present study to characterise the production of antler equipment from the acquisition of the raw material and its transformation into tools to their maintenance or repair. The results will be useful to analyse dense Magdalenian occupations where different material transformation schemes are identified as information on the inter-connection patterns between northern Spain and the Pyrenees. This study also reinforces the hypothesis that both the manufacture and circulation of reindeer antler in the Iberian Peninsula might have been more important than previously thought.

Santimamiñe cave

Santimamiñe cave is located in the eastern side of the Urdaibai valley, on the southern slopes of Ereñozar mountain, in the municipality of Kortezubi (Biscay, Spain) (Fig. 1). It is at 150 m above sea level and about 6 km from the modern

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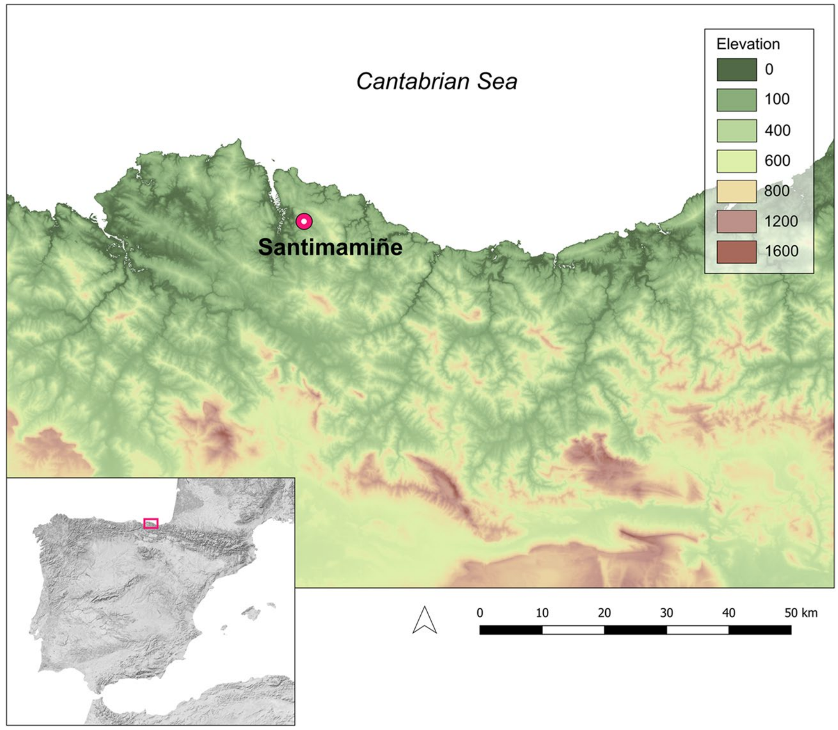

Fig. 1 Location of Santimamiñe cave (made with QGIS Development Team, 2023. QGIS Geographic Information System. Open Source Geospatial Foundation. http://qgis.org)

coastline. In 2008, due to its outstanding Palaeolithic rock art, it was added to UNESCO's list of World Heritage Sites.

The cave formed in Albian-Aptian reef limestone, in the Urgonian facies, with rudists and corals that create a massive appearance of the rock. It is located in a strategic position overlooking the Mundaka estuary and its saltmarsh (Maeztu and Aranzabal 2011).

The cave entrance faces south-southeast and is 5.5 m high and 3 m wide. It consists of a single passage 365 m long with alternating chambers and narrower corridors (Fig. 2). The archaeological deposit is located in the cave entrance hall (Aranzadi and Barandiarán 1935; Maeztu and Aranzabal 2011).

Santimamiñe cave was discovered in 1916 by a group of young people and became the first Magdalenian cave art ensemble found in the Basque Country and one of the first in northern Spain. The deposit has been excavated in three main stages. The first excavations in the cave were carried out by T. Aranzadi, J. M. Barandiarán, and E. Eguren between 1918 and 1926 (Aranzadi et al. 1925; Aranzadi

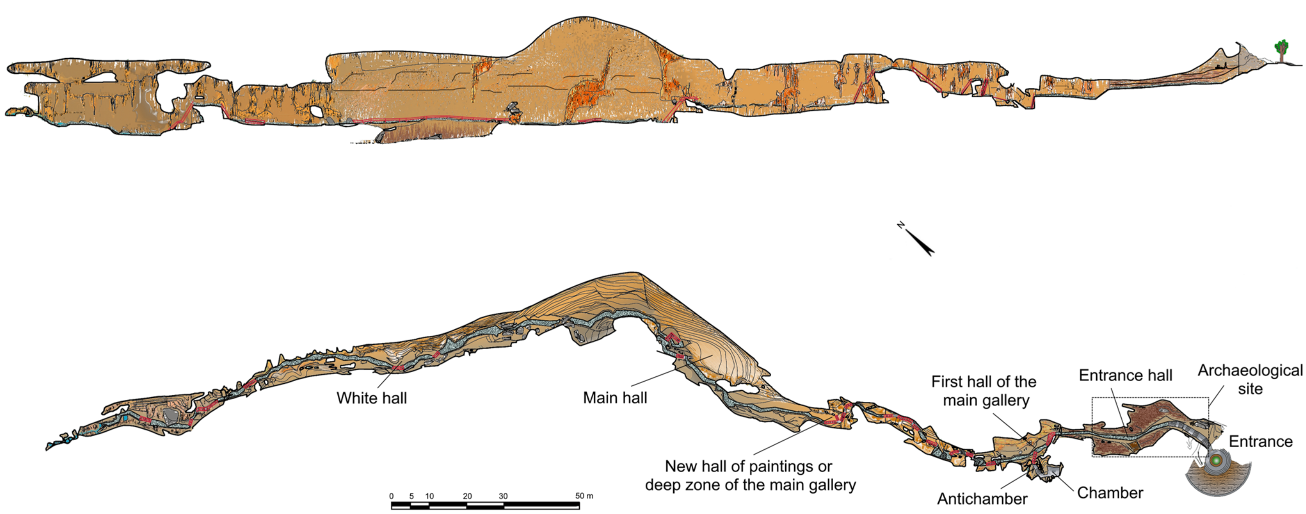

Fig. 2 Plan of Santimamiñe. The main halls and archeological site are indicated. Figure ADES Espeleologia Elkartea

and Barandiarán 1935). When J. M. Barandiarán returned from exile, he undertook a second phase of excavations at Santimamiñe between 1960 and 1962 (Barandiarán 1976). The third and most recent series of excavations were performed by J. C. López Quintana from 2004 to 2006 (López Quintana 2011). The stratigraphic sequence is 8 m thick and covers the period from the Aurignacian, in the Early Upper Palaeolithic, to the Roman Age, including dense Solutrean and Magdalenian occupations (Table 1). The osseous industry studied here came from the Magdalenian levels: level VI (Late-Upper Magdalenian) in the two old excavations (Aranzadi and Barandiarán 1935; Barandiarán 1976); and Csn-Camr (Lower Magdalenian), Almp (Late-Upper Magdalenian, with stratigraphic instability), and Slnc (Late-Upper Magdalenian) in the last archaeological fieldwork (López Quintana 2011).

The dates corresponding to the Magdalenian levels in Santimamiñe cave, obtained in the last study, confirm an occupation in about 14,650 ± 80 cal. BP and 14,670 ± 80 cal. BP for the Csn-Camr stratigraphic structure. The Slnc level, in contrast, was dated to 12,790 ± 70 cal. BP. Finally, the level with stratigraphic instability, which contains materials from the underlying Slnc level, was dated to 12,250 ± 70 cal. BP (López Quintana 2011).

Materials and methods

Technological analysis of osseous industries

The methodology followed in the present study is based on the analytical protocol established by Averbouh and Provenzano (Averbouh and Provenzano 1998–1999; Averbouh 2000; Provenzano 2004). This methodology has been largely followed by other researchers (e.g., Christensen 1999, 2016; Goutas 2004; Pétillon 2006; Tartar 2009; Tejero 2010).

In this technological analysis of the Magdalenian material, the main objective is to characterise the operational schemes that were involved in the manufacture of an object. The identification of the theoretical schemes of antler transformation allows us to understand the succession of gestures undertaken by hunter-gatherers in the exploitation of this raw material. The study incorporates different categories of objects (waste products, blanks, and finished objects) which provide a mental order of the detachment of a fragment of matter from the block ("refitting by default"; Averbouh 2000). Waste products are elements resulting from a specific action that may result from any of the transformation operations. The blanks are defined as elements without manipulation or transformation, obtained from primary or secondary blocks of matter, destined to be transformed into objects. Finished objects are the final objective of the operational chain, the result of the transformation of bone material (Averbouh 2000).

The materials studied are deposited in the Arkeologi Museoa (Bilbao, Biscay). An optical microscope was used for their analysis (a stereo-microscope at magnification up to × 70). The thickness of the cortical tissue is an indicator of the possible origin (hunting or collecting) of the antler. We have followed the convention of classifying the cortical thickness of the antler into three raw material sizes: small (2–4 mm), medium (4–6 mm), and large (7–10 mm). N. Goutas (2004) established these categories based on measurements of the reference collections in the *Muséum national d'Histoire naturelle* in Paris. The archaeozoological study of the levels VI, Csn-Camr, Almp, and Slnc

Table 1 Stratigraphy of Santimamiñe and the chronological attribution of the assemblage. All dates are AMS (López Quintana 2011)

Barandiarán (1976)	Culture	López Quintana and Guenaga (2011)	Culture	Lab number	Date BP	Standard error
Ia	Roman Age					
Ib	Iron Age					
IIa	Bronze Age	Lsm	Bronze Age–Chalcolithic	Beta-240896	3710	40
IIb	Chalcolithic					
III	Neolithic	Slm	Neolithic	Beta-240897 Beta-240898	5010 5450	40 50
IV	Mesolithic	H-Sln	Mesolithic	Beta-240899	7580	50
V	Azilian	Arcp	Azilian	Beta-240900 Beta-240901	10100 10060	60 60
VI	Magdalenian	Slnc	Late Upper Magdalenian	Beta-240902	12790	70
VII	Solutrean	Almp	¿Middle–Upper Magdalenian?	Beta-240903	12250	70
VIII	¿Gravettian?	Csn-Camr	Lower-Middle Magdalenian	Beta-240904 Beta-240905	14670 14650	80 80
IX	Aurignacian					
X	Undetermined	Lsr-Ap Arp-Sa	Flooded complex (sterile)			

(Castaños 1984; Castaños and Castaños 2011) has been taken into account to improve the comprehension of the acquisition patterns of the raw material. Our technological study concentrates on the Magdalenian evidence of antler found during the three stages of excavations in Santimamiñe cave. It will use technological data published on antler-working at Magdalenian sites (e.g., Averbouh 2000, 2014; Pétillon 2006, 2016; Langley 2014, 2015; Langley et al. 2016; Lefebvre 2016; Villaverde et al. 2016; Borao 2022). Equally, for each morphotype of finished object we have followed the categories established by several authors: projectile points (Tyzzer 1936; Hahn 1988), barbed points (Julien 1982; Weniger 1992, 2000), and spear throwers (Cattelain 1988, 2005), among others.

Selected study sample

The study is composed of a sample of 75 antler objects, including both finished artefacts and technical pieces (blanks and waste products) (Table 2). Of the finished objects, hunting and fishing weapons (projectile points and barbed points) are the most common morphotypes ($n = 50$). A spear thrower and perforated batons ($n = 2$) have also been documented. The technical pieces are represented by blanks ($n = 7$) and waste products ($n = 15$). It was not possible to determine the technical status of 12 items. The bone tools consist of awls ($n = 16$), *lissoirs* ($n = 6$), a needle ($n = 1$), bevelled piece ($n = 1$), decorated bones ($n = 3$), and tubes ($n = 1$).

The antler collection is well preserved in general. Some of the objects display alterations to their surfaces (thermal alterations, concretion, and erosion) generally owing to various post-depositional factors, but always in low proportions (d'Errico and Villa 1997).

Table 2 Typo-technical distribution of antler items from Santimamiñe

Morpho-technical categories	Items number
Objects	
Projectile points	38
Barbed points	12
Spear-thrower	1
Perforated batons	2
"Technical pieces"	
Blanks	7
Debitage wastes	15
"Other" items	
Indet. elements	12[a]
Total	**75**

[a]Antler distribution of indeterminate elements is not taken into accout

Results

Raw material acquisition

The faunal assemblage in the Magdalenian levels in Santimamiñe cave is dominated by red deer (*Cervus elaphus*), which in all cases was the main prey to be targeted (Fig. 3, Table 3). In level VI, for example, red deer makes up 65% of the total number of ungulates remains identified (Castaños 1984), while in the Csn-Camr level, the percentage reaches 91% (Castaños and Castaños 2011). Remains of reindeer (*Rangifer tarandus*), in contrast, are completely testimonial (< 1%) although their antlers were used to make tools, as explained below. In the Magdalenian, a clear hunting specialisation in red deer (sites located in the valley) or in ibex and chamois, preferably in rocky mountain habitats, is observed in numerous sites (Altuna 1972, 1990; Yravedra 2002a, b). The age at death of the prey in the levels at Santimamiñe shows that hunting was not limited to any particular season. Thus, two neonate individuals, five juveniles, and eight adults were hunted throughout the levels attributed to the Magdalenian (Castaños and Castaños 2011).

In Santimamiñe cave, five bases of shed antlers have been identified. These must be related to how the antlers were collected, as those shed antlers would be perfectly formed with a maximum cortical thickness. In addition, a sixth antler base has been identified; this is an "arched base" from a reindeer that was undoubtedly obtained by hunting.

Not all antlers possess the necessary properties to be used technically. Antler is an osseous formation characterised by annual cycles of loss and regrowth (Goss 1983; Crigel et al. 2001) and its mineralisation is not completed until the end of the cycle (or 1 or 2 months before), after which the stags shed them (Averbouh 2000). The antlers worked at Santimamiñe possess a thickness of compact osseous tissue that is balanced between the medium (4–6 mm: 44%) and large categories (7–10 mm: 40%). The thickness of compact tissue is a parameter to take into account in the calculation of the original size of the worked antlers. It should be noted that during artefact manufacture, the thickness of the compact bone tissue is reduced, so some of the objects with compact bone tissue between 4 and 6 mm may also have originally come from large modules. This means that the antlers may have come from 2- to 3-year-old stags or from individuals over 4 years of age (Goutas 2004) and/or from adult female reindeer (Averbouh 2000).

Consequently, the faunal information for the site, the presence of antler bases, and the significant working of large modules are evidence supporting the acquisition of

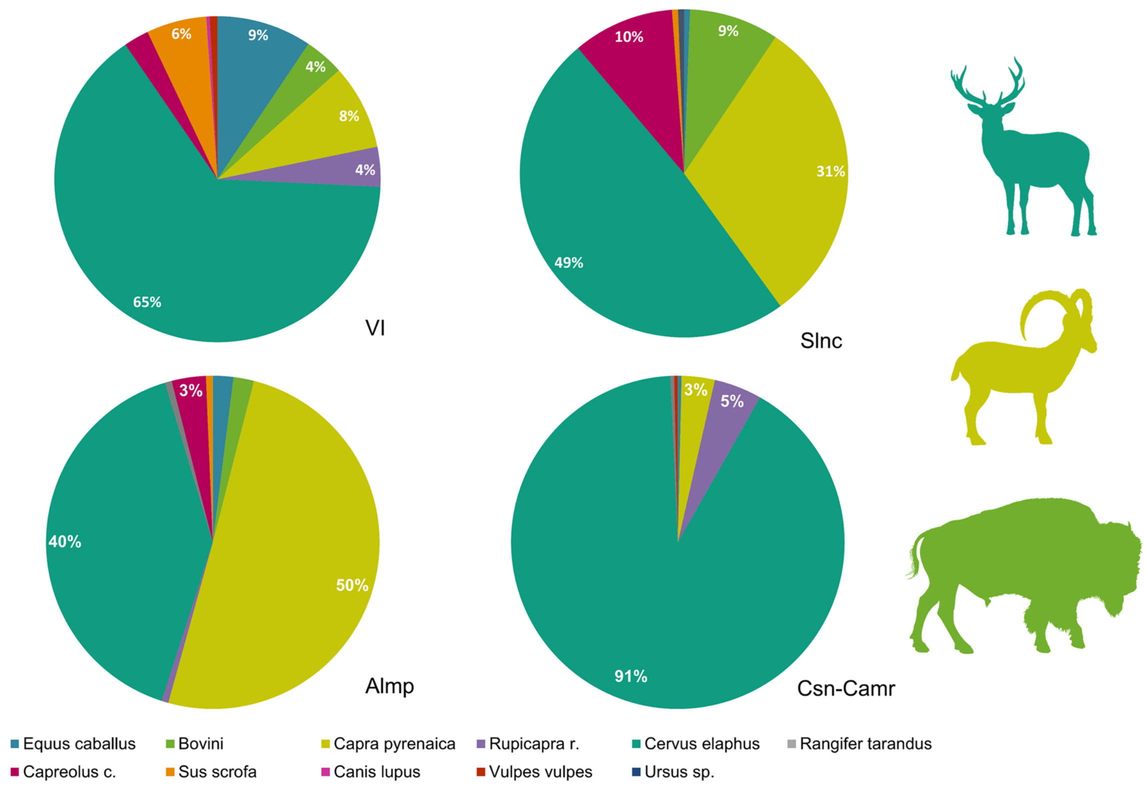

Fig. 3 Percentage of species identified in the zooarchaeological record (Castaños 1984; Castaños and Castaños 2011). Species with less than 5 remains of birds and small carnivores are excluded

Table 3 Distribution of number of identified specimens (NISP) at each level

	VI (1918–1926)	Slnc (2004–2006)	Almp (2004–2006)	Csn-Camr (2004–2006)
Equus caballus	136	1	3	1
Bovini	57	15	3	
Capra pyrenaica	122	52	76	9
Rupicapra r.	57		1	13
Cervus elaphus	935	83	61	255
Rangifer tarandus			1	1
Capreolus c.	36	17	5	
Sus scrofa	86	1	1	
Canis lupus	5			
Vulpes vulpes	11			1
Ursus sp.		1		
Total	1445	170	151	280

antlers by collecting them during the Magdalenian at Santimamiñe cave. However, this anthropic procurement of the antlers does not rule out other forms of acquisition, as this might have been complementary to the supply of food (consumption of the prey). The first way, antler collection, denotes an exclusively technical behaviour as antler lacks any nutritional value, whereas the second, hunting activities, corresponds to the food-acquisition strategies of the hunter-gatherers. These modes of procurement require previous planning of the tasks to ensure both requirements are met efficiently.

Reindeer antler exploitation: a more frequent raw material than expected?

Remains of reindeer have been identified at numerous sites in the north of the Iberian Peninsula (Castaños 1984, 1986; Altuna 1971; Altuna and Mariezkurrena 1984; Yravedra et al. 2010; Castaños and Castaños 2011; Lefebvre 2016). Several authors, such as Costamagno and Mateos Cachorro (2007), have traditionally advocated for reindeer, among other species, the existence of an ecological barrier between the Cantabrian region and the Pyrenees. However, recent studies seem to question that hypothesis with data for the spread of reindeer from the Western Pyrenees to the northern Cantabrian region and north-east Catalonia (Gómez-Olivencia et al. 2013; Castaños et al. 2014; Lefebvre et al. 2023). In fact, archaeological and geological studies indicate that at least in the last glacial period, part of the Aquitaine basin (south-west France) was a peri-glacial desert covered by sands and dune fields of low relief, surrounded by accumulations of loess (Bertran et al. 2013). Therefore, the valley of the River Adour would have formed the main part of the corridor for the movement of human and animal groups between the two geographic regions. This is currently supported by studies of different kinds of archaeological materials, like flint, bone, antler, and shells (Tarriño et al. 2016; Álvarez-Fernández 2006; Lefebvre et al. 2023), and rock art and portable art (Sauvet and Wlodarczyk 2008; Rivero and Sauvet 2014; Sauvet 2019; Erostarbe-Tome et al. 2023), which have enriched our understanding of the inter-connections between the regions.

Red deer (*Cervus elaphus*) and reindeer (*Rangifer tarandus*) are the two main species whose antlers are exploited for the manufacture of bone equipment at Santimamiñe. The differences between the two kinds of antler are well known (e.g., the relationship between the thicknesses of the compact and spongy tissue, the structure of the outer surface, and the natural curve of the beams) (Penniman 1952; Averbouh 2000). However, in most cases, the antlers found in archaeological deposits are highly fragmented, altered, or affected by post-depositional agents, which hinders taxonomical identification notoriously. At Santimamine, reindeer antler remains make up 2.66% of the total osseous assemblage. Among the pieces classified as waste products, the proportion of reindeer antler increases to 13.33%. Owing to the transformation of the pieces, the use of reindeer antler could not be identified among the finished artefacts, which produces a bias to be taken into account regarding the use of this material. Among the waste, an arched base (*base arceau*) displays an oblique extraction by the double longitudinal grooving procedure (Goutas 2004, 2009) or the groove and splinter technique (Clark and Thompson 1953) (Fig. 4). To avoid confusion with other extraction methods, we prefer the term "double grooving procedure." This procedure is applied by making deep longitudinal grooves through a repeated unidirectional movement, which allows precise control of the size and shape of the blank. Its use associated with waste products in reindeer antler has been observed at sites in the north of the Iberian Peninsula (Lumentxa), and on the northern side of the east-central Pyrenees (Isturitz, Gourdan, Mas d'Azil, Saint-Michel: Pétillon 2006) in the transition from the Middle to Upper Magdalenian. Beam A2 was separated from the rest of the block with two convergent oblique grooves. The blank thus extracted would be about 92 mm long and 9–10 mm in its maximum width (calculated from the negative of the extraction). The evidence of this procedure is the grooves, which can be seen in both the beam and the bez tine. This extraction method has been linked to the production of portions of the beam to be transported as a reserve or stock (Pétillon 2006, 2016; Lefebvre et al. 2023). On the other hand, we identified a distal fragment of

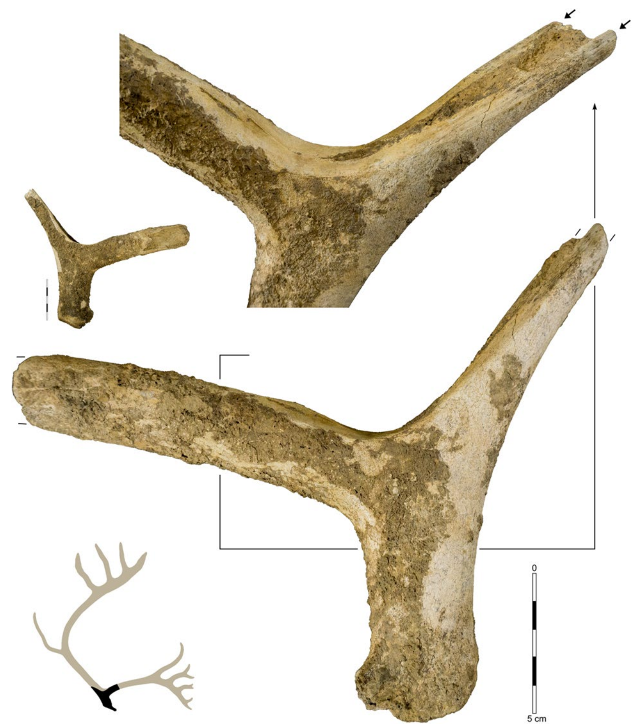

Fig. 4 Arched base of level VI, with evidence for the oblique extraction showing traces of double groove technique

bez tine that has the suppression of the points. This piece was separated from the block by oblique sawing, probably to remove the disturbing anatomical parts of the antler prior to obtaining supports.

These waste products demonstrate that reindeer antler was used to obtain blanks for osseous equipment and provide significant information about the application of the different schemes of transformation. First, they show that it was worked in a similar way to the red deer antler (Tejero et al. 2012; Erostarbe-Tome et al. 2022) as the tines and points were removed by indirect percussion, bending, and sawing. These procedures are usually employed in the first stage of the block exploitation before the debitage phase. Second, the double longitudinal grooving procedure has been documented, which has been attested since the Gravettian (Goutas 2004, 2009). This debitage by extraction is aimed at obtaining rods that can be turned into tools.

Antler debitage

The study of the finished objects and technical pieces from Santimamiñe cave has revealed information enabling the operational schemes for antler-working to be identified.

The first stage in the transformation of the antler is characterised by the preparation of the initial block by removing the tines and points. These ends were separated by direct percussion and sawing. The aim of this procedure is double:

1. to prepare the initial block for the debitage phase and 2. to remove annoying anatomical elements. In some cases, these wastes can become intermediate pieces (Tejero et al. 2012; Tejero 2013, 2014) and even be decorated (Barandiarán 1978; De Blas Cortina and Briansó 2017) although that has not been seen at Santimamiñe.

The secondary block was worked mainly to obtain blanks. In the remains from Santimamiñe, we have identified one of the best-documented procedures used with osseous materials in the Upper Palaeolithic: extraction by double longitudinal grooving (Goutas 2004, 2009). This transformation scheme is applied to the secondary blocks by making deep longitudinal grooves through a repeated unidirectional movement. Once the morphology of the desired blank has been defined, it is extracted by means of a lever movement. The objective of this procedure is to obtain rods for the manufacture of hunting equipment/domestic tools.

At Santimamiñe we documented six waste products and five blanks related to the double longitudinal grooving. In the case of waste products, they refer to the extraction matrices (Fig. 5). One of these is the central part of a red deer antler (union of the A2 and B beams), with two extractions. This piece stands out for preserving part of the rod to be extracted in both extractions. The first is located in the central shaft of the antler, the part most often used by hunter-gatherers. The grooves are parallel and show a bidirectional application. The possible length of the extracted blank was about 210 mm and the maximum width would reach 32 mm. The matrix preserves part of the blank to be extracted (max. length 40 mm, max. width 9 mm), which was fractured in

Fig. 5 Evidence of deer antler procurement. 1, 2, 4, 5: Shed antler bases. 2, 5: Shed antler bases with detachment surface showing traces of double grooving procedure. 3: Beam of deer showing negative extraction by the double grooving procedure with part of the extracted blank preserved

the extraction process (Fig. 5.3). The second extraction is located in the lower face of the central tine and, like the first, was made by parallel, bidirectional grooving. Judging by the negative of the extraction, the blank would have been about 175 mm long and 14 mm wide. In addition, it also has a part of the blank that has not been extracted (max. length 60 mm, max. width 12 mm).

The second matrix from Santimamiñe is a base of a shed antler. It displays an extraction that goes from the burr to the A2 beam. Owing to the presence of concretion and the state of the antler surface, the directions of the double longitudinal grooving cannot be determined (Fig. 5.5). However, we can see that the orientation of the extraction was from the end of the A2 beam to the burr, as shown by the material detached at the end of the burr due to the lever movement. The extracted blank reached at least 170 mm long, with a maximum width of 33 mm.

Another base of a shed antler was used as the matrix for an extraction. Like the previous one, the extraction was located between the burr and the A2 beam. This waste product is eroded, which has led to the almost complete loss of the trace of double longitudinal grooving (Fig. 5.2). The possible length of the blank obtained was about 131 mm, while the maximum width would reach 34 mm.

A further two waste products can be related to the double longitudinal grooving procedure. In both cases, they are small fragments of antler that preserve part of the unextracted blank, and which were discarded. As seen in previous cases, the blanks sometimes break when they are being levered out. One of these waste products displays the traces of convergent double longitudinal grooving with part of the blank (max. length 74 mm, max. width 23 mm). In the second fragment, equally with traces of double longitudinal grooving, the grooves are parallel (max. length 70 mm, max. width 12 mm).

The last waste product is the reindeer antler which was described in the previous section. It is an "arched base", with an oblique extraction made with the double longitudinal grooving procedure. The blank would have been about 92 mm long with a maximum width of 9 or 10 mm.

The extraction matrices are fundamental elements to understanding aspects related to the production of blanks. Unlike lithic reduction, the way in which osseous material is worked does not lead to the formation of identical positive and negative surfaces (Averbouh 2000). Therefore, the study of the matrixes provides data about the technical operational chain. They are also a direct source for approximate estimates about the size of the blanks and thus to determine the parameters that governed the morphological needs of the hunter-gatherers. At Santimamiñe, the negatives of extractions in antler indicate a production oriented to long blanks, as 60% are over 170 mm in length. One of them may have reached a length of 210 mm. The longest finished artefact in the assemblage is 161 mm in length. In some of them, the maximum width would be 30 or 33 mm; these make up 60% of the sample. In contrast, other blanks would be 9 to 14 mm in width. The widest finished object is 19 mm wide. In this way, we can deduce that production was aimed at obtaining long blanks in two different widths: a larger one (> 30 mm) and one close to the predominant width of the finished object (9–14 mm). It should be taken into account that these values can be considerably reduced during the manufacturing process or in the repair operation.

The assemblage contains five blanks obtained by the double longitudinal grooving procedure (Fig. 6a). Practically all of them are fractured at one or both ends, possibly as a consequence of the extraction process. These rods are from 60 to 100 mm long. The width is variable, between 11 and 20 mm. In contrast, the thickness of the blanks is more regular, since 90% of the sample is 9 or 10 mm thick. This could be related to the standardised depth of the grooves in the antler. Moreover, the cross-section of all the blanks is quadrangular, as that is the usual cross-section resulting from the double grooving procedure. Apart from one blank with convergent grooves, all the blanks display parallel grooves on their sides. As noted above, since these blanks are fractured, their original lengths must have been greater (> 100 mm), which would match the lengths generally observed in the antler matrixes. Although we must be cautious in this sense, since they may also be productions of different blanks; nevertheless, the small sample size does not allow analysis in greater depth.

A second method to obtain blanks has also been identified at Santimamiñe cave: the splitting procedure (Knecht 1997; Liolios 1999; Tejero 2010, 2014; Tejero et al. 2012). Like the double longitudinal grooving procedure described above, the splitting procedure is integrated into the extraction transformation scheme (Goutas 2004; Tejero 2010, 2014). Splitting consists of dividing the block of antler into two or more fragments by means of percussion with an intermediate tool in the direction of its longitudinal axis. It is used to obtain blanks, especially in the Aurignacian technocomplex (Tartar 2009; Tejero 2010, 2014).

Two blanks can be linked to the longitudinal splitting procedure (Fig. 6b). They are similar in size: one of them is 122 mm long, 22 mm wide, and 10 mm thick, while the other blank is 112 mm long, 34 mm wide, and 10 mm thick. The cross-section of both blanks is plano-convex. In general, the morphology of blanks extracted with this procedure is partially predetermined and they are usually quite wide to avoid the blank breaking during the splitting process (Liolios 1999). As observed at Santimamiñe, the blanks made by longitudinal splitting do not differ in the size from those extracted by double longitudinal grooving. However, this is based on a small assemblage of technical objects. These blanks could have been used to manufacture

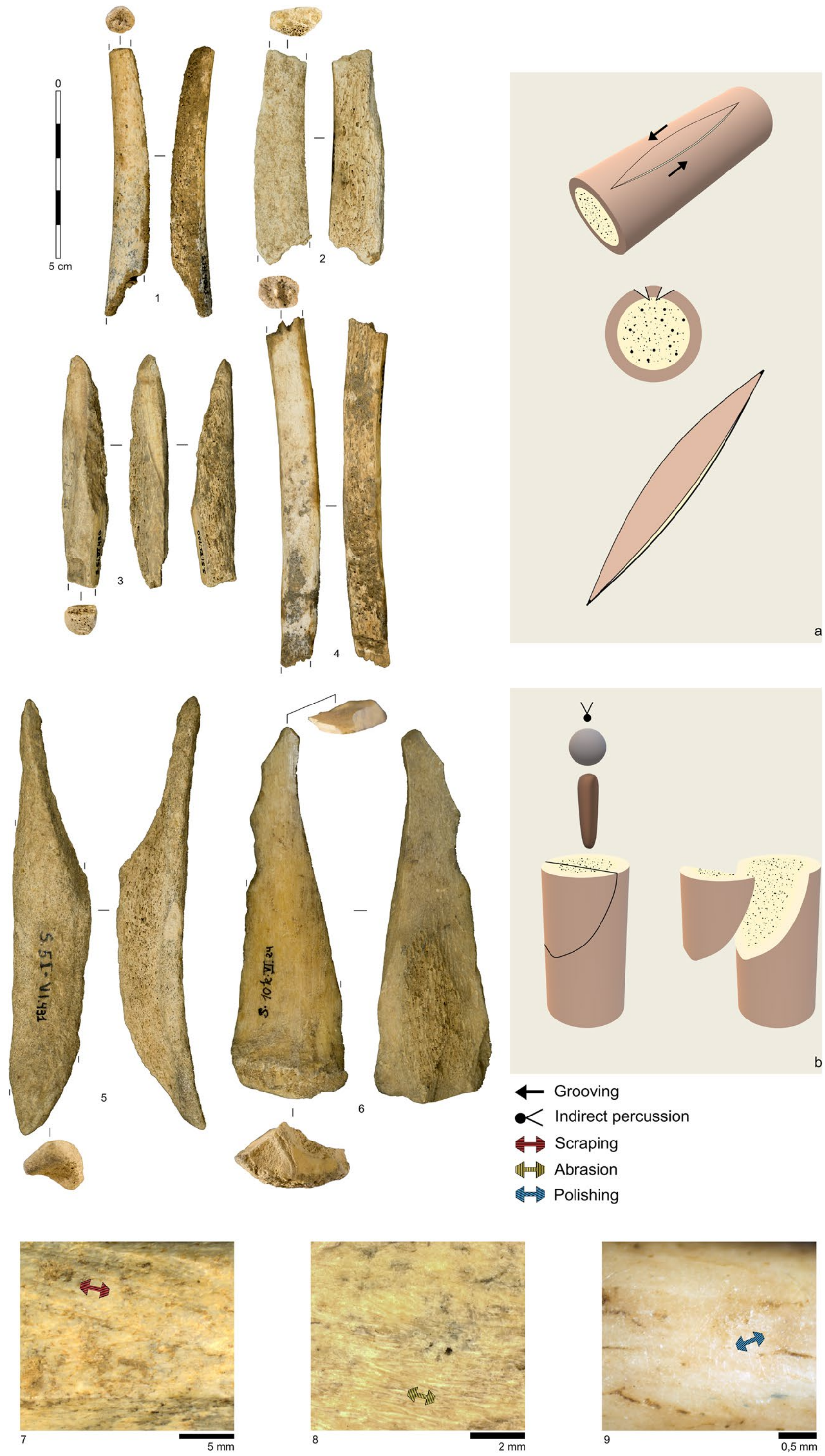

Fig. 6 Blanks obtained by different debitage procedures. 1–4: Double grooving procedure (**a**). 5, 6: Longitudinal splitting (**b**). Traces of the manufacturing phase. 7: Scraping. 8: Abrasion. 9: Polishing

bevelled tools or hunting weapons, although in the latter case, the investment in labour would have been greater than with blanks obtain by the double grooving procedure because their shape is quite different from that of the final artefact.

Manufacturing stage

After the blanks were extracted by either of the two procedures, they were subjected to a manufacturing stage in order to create the shape or final morphological characteristics of an effective finished object. The blanks were worked mainly by scraping, combined with abrasion and polishing. Scraping eliminated fine particles to smooth the surface of the object and reduce its thickness, by using a unidirectional movement in the direction of the osseous fibres (Averbouh 2000). This technique was applied to the edges of the object to obtain solid and symmetrical tools. Scraping would therefore be intense in the distal part of the blanks because, as seen in the negatives in the matrixes, they were mostly extracted by parallel grooving, while the artefacts needed a pointed active part. The characteristic traces left by this technique are striations, which are visible in most of the assemblage studied here. The blanks also had to be worked to create the attributes of the different artefacts (shaft, barbs, holes, etc.). Bevelled hafts were made by abrasion, in which the thickness was reduced by rubbing the blank on an abrasive agent. It also shows the technique of cutting with a razor that attacks the surface by means of dynamic pressure to make shapes such as the barbs on some points (Christensen 2016).

Antler equipment

The antler equipment at Santimamiñe cave is completely dominated by hunting and/or fishing weapons (projectile points, barbed points, and spear-thrower). Fishing should be mentioned because it cannot be ruled out that some of the weapons, especially some barbed points, were used for that purpose. The appearance of that morphotype coincided with an increase in the capture of small prey (fish, birds, lagomorphs) (Pokines 1998; Laroulandie 2005; Rufà et al. 2022) which has led some researchers to defend its use in an aquatic environment (Julien 1982; Weniger 1995). However, both ethnographic and traceological studies carried out so far have not provided conclusive results on this subject (Pétillon 2008). Consequently, we follow the analytical proposal of using the term "barbed point" rather than the traditional name of "harpoon" owing to the uncertainty about the true function(s) of those implements (Weniger 1995; Pétillon 2008; Langlais et al. 2012). In this way, the present study will use the typological classification of barbed points developed by Weniger (1992, 2000).

Ten of the projectile points from Santimamiñe are complete (Fig. 7). The fragmented points are divided into distal parts ($n = 10$), meso-distal ($n = 4$), mesial ($n = 9$), meso-proximal ($n = 2$), and proximal fragments ($n = 5$). They can be classified morpho-typologically based on their hafting system into projectile points with a simple or massive base ($n = 4$), single bevelled points ($n = 7$), and double bevelled points ($n = 6$).

Projectile points are defined as elongated objects with a pointed distal end, a variable cross-section, and a simple hafting system (Camps Fabrer 1988). This type of projectile point is known by various names, such as pointed base points, biconical points, points with a massive base, or

Fig. 7 Projectile points. 1, 4: Points with a massive base. 2, 6: Double-beveled points. 3: Single-beveled point. 5: Mesial fragment of point

simply "points with a non-split base" to differentiate them from earlier European points (Hahn 1988). We prefer the term "point with a massive base" or "simple base" since it is adjusted to the reality and variability of the general morphology of these artefacts (Tyzzer 1936).

These points display mostly two cross-sections: sub-circular (28%) and plano-convex (38%). Sub-triangular (19%) and sub-rectangular (14%) cross-sections are less common. The longest projectile point in the assemblage from Santimamiñe cave is 140 mm in length. The other meso-distal fragments, which have usually lost a small proportion of their original length, measure 70 to 155 mm, whereas the meso-proximal fragments are 80 to 120 mm long. The width and thickness measurements are quite constant as the widths vary between 7 and 14 mm and the thicknesses between 6 and 9 mm. The bases are from 12 to 38 mm long and between 5 and 8 mm wide, where the double-bevelled bases are somewhat shorter than those with a single bevel.

Of the 38 points, nine display either some form of decoration ($n = 6$) or technical striations ($n = 3$) (Allain and Rigaud 1986). The most repeated form of decoration is a series of short oblique parallel lines at regular spaces along the shaft, usually on one of the two sides of the points. These short lines are sometimes accompanied by longitudinal lines along the axis of the point. These lines were engraved with a single deep groove, normally with a single pass. This type of decoration is very common on projectile points in the Iberian Peninsula in the Upper Palaeolithic (Corchón 1986, 2004; Barandiarán 1972; González Sainz 1989). Striations, which are interpreted as a technical aid for better hafting, are always on the bevels of the projectile points and are found on points during practically the whole of the Magdalenian period (Allain and Rigaud 1986).

Projectile points were some of the most usual hunting weapons of European hunter-gatherers in the Palaeolithic (Knecht 1997; Averbouh 2000; Goutas 2004; Pétillon 2006; Tejero 2014; Langley et al. 2016). They were hafted to a spear shaft that penetrated the prey. These points were therefore subjected to the force of impacts and often ended up breaking (Tyzzer 1936; Rozoy 1992; Pokines 1998; Pétillon 2006, Doyon and Knecht 2014). At Santimamiñe, 73% of the sample is fragmented, and consequently, it is possible to identify typical breakage patterns related to their use (Pétillon et al. 2016). Four categories can be discriminated: bevelled breakages with oblique fracture planes ($n = 15$), flattening of the tip of the point ($n = 2$), longitudinal breaks ($n = 1$), and breaks at the base ($n = 6$). The mesial part is the region most often affected by use breakages, followed by the distal end. Most of these breaks are probably the result of impacts against bones or failed throws that hit hard obstacles (Pétillon et al. 2016).

Barbed points are other characteristic Magdalenian hunting weapons identified at Santimamiñe. These are elongated artefacts with barbs on one or both sides of the shaft, with a pointed distal end and a proximal region that varies depending on the hafting system (Julien 1982).

Twelve barbed points have been documented (Fig. 8), of which four are complete. The fragmented barbed points are distal ($n = 4$), meso-distal ($n = 1$), and mesial parts ($n = 2$), and one barb fragment. Following Weniger (1992, 2000), the assemblage can be attributed typologically to R1 points ($n = 5$) and R2 points ($n = 2$). The unilaterally barbed points (R1) can be ascribed to the categories of harpoon/spear ($n = 2$) and multipronged arrow/spear ($n = 3$). The bilaterally barbed points (R2) are divided into a spear or harpoon head ($n = 1$) and arrow ($n = 1$) (Weniger 1992, 2000). The specimens

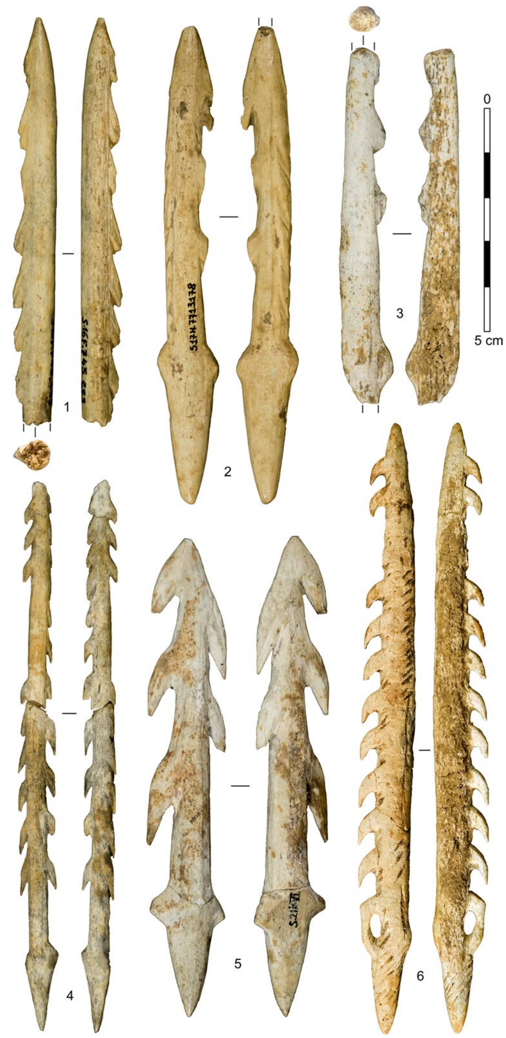

Fig. 8 Barbed points. 1–3, 6: Points with one row of barbs. 4, 5: Points with two row of barbs. Figure 6 Arkeologi Museoa

that preserve the proximal end possess either bilateral bulbs ($n = 3$) or a basal perforation ($n = 1$).

The general morphology of these points is quite standardised as regard their cross-section, which is either circular (57%) or sub-circular (42%). The longest barbed point is 161 mm in length. The complete specimens are 102 to 121 mm long, while the mesial fragments measure 78 to 93 mm. Most of these barbed points possess a mesial width of 7–9 mm and a thickness of 6–9 mm. The exception is a bilateral arrow which is only 4 mm thick. The bases are from 28 to 46 mm long. The points with a single row of barbs are longer than those with two rows.

Three of the twelve barbed points from Santimamiñe cave display some type of decoration and one has functional striations at its proximal end. Two forms of decoration are observed on these artefacts; oblique lines on the upper face of the barbs and composite non-figurative decoration. On its side opposite the barbs, one point has a longitudinal series of lines forming angles framed by two longitudinal lines along the shaft of the weapon. The other barbed point with composite non-figurative decoration displays a series of short oblique parallel lines in the space between the barbs on the upper face and the perforation; in the mesial region of the upper face of the shaft, a series of short oblique traces are combined with several longitudinal lines. In addition, at the base of the implement, on both of the main faces, short oblique striations in the form of a spiral may have helped to secure the point into the shaft of a spear (Allain and Rigaud 1986). The main techniques are engraving, with a variable depth of both single and multiple passes, and low relief made by profile incisions at right angles.

The use of this type of weapon is still a matter for debate about whether they were used against land or water animals or if they were mobile projectiles attached to a spear or other object (e.g., Julien 1982; Weniger 1992, 2000; Julien 1999; Pokines and Krupa 1997; Pétillon 2008). According to Weniger (1992, 2000), most R1 barbed points, except the "Cantabrian type", were fixed, whereas the R2 barbed points were mobile, tied, and interpreted as harpoon heads. Therefore, at least the longest of these points at Santimamiñe may have functioned as mobile harpoon heads. Similarly, the only "Cantabrian type" identified in the assemblage, with a hole at its basal end, can be interpreted as mobile (Weniger 1992, 2000). In contrast, barbed points with thinner shapes with a high number of small barbs have been interpreted as arrows. Different breakage patterns have been identified, of which bevelled fractures ($n = 2$) are the most common, followed by flattening of the tip of the point ($n = 1$) and a longitudinal break ($n = 1$).

The ichthyofaunal study carried out at Santimamiñe cave (Roselló-Izquierdo and Morales-Muñiz 2011) found clear evidence of fishing in the Magdalenian levels, with an almost exclusive identification of salmonid remains. Most of them corresponded to the species *Salmo trutta* (brown trout). Anecdotal evidence of eels (*Anguilla anguilla*) is also noted. These remains, therefore, ratified the practice of fishing by the Magdalenian groups that occupied the cave, and thus some of the weapons would have been used for that purpose.

A spear thrower has also been identified in the antler equipment from Santimamiñe (Fig. 9.1). Those tools are defined as elongated artefacts whose distal end is usually

Fig. 9 Antler equipment. 1, 2: Perforated batons. 3: Spear thrower

designed to hold the end of a projectile while the opposite end sometimes has an element to fix or haft it. The spear thrower acts like a lever to increase the initial velocity of the projectile and theoretically improve its efficacy (Cattelain 1988, 2005, 2017; Rozoy 1992; Stodiek 1992; Cattelain and Pétillon 2015; Whittaker 2016). In the categories proposed by Cattelain (1988: 20), the spear thrower at Santimamiñe is classified as type 2 (male spear thrower with engraved ornamentation that does not modify the shape of the object).

It is the distal fragment of a spear thrower 83 mm long, 10 mm wide, and 13 mm thick, with a circular cross-section. It has a hook with a triangular cross-section on its upper face, shaped by scraping. At its most proximal end, the spear thrower is affected by a bevelled fracture with a detachment of material (Pétillon et al. 2016). It is decorated on both sides. On the right presents the schematised head of an animal, probably a horse (*Equus* sp.), where the head is depicted through a curved frontal line. The muzzle is filled with short horizontal lines. A perfectly round eye is also represented and the ears or mane are projected backwards with short oblique lines. On the opposite side, three figures of stars were engraved by the superimposition of longitudinal and oblique traces. A second possible horse's head can also be appreciated (very schematic outline without details). The decoration was executed by an engraving by numerous passes of the lithic tool. The horse's head was produced in low-relief by scraping the antler to create surfaces that add a third dimension to the figure. Decorated spear throwers have been found in Magdalenian levels at several sites in south-west France and northern Iberia: for example, El Castillo (Cabrera 1984), El Mirón (González Morales and Straus 2009), Isturitz (Cattelain 2017), Placard (Cattelain 2018), and Combe-Saunière I (Geneste and Plisson 1990).

The equipment in antler from Santimamiñe also includes two fragments of a perforated baton (Fig. 9.2 and 3). Perforated batons, usually made from antler, are elongated subcylindrical artefacts with at least one circular or oval hole (Peltier 1992). Although they are relatively common at many sites, their function is still a subject of discussion and debate (e.g., Glory 1965; Bahn 1976; Manos and Boutié 1996; Rigaud 2001, 2004; Lompre 2003; Kilgore and Gonthier 2014; Lucas et al. 2019). The two pieces from Santimamiñe seem to belong to the same antler beam, although they cannot be refitted owing to a longitudinal fracture. The baton was made from the central part of a 7-mm-long rod of compact tissue. It can therefore be classified as corresponding to a large antler (7–10 mm) (Goutas 2004). Unlike other perforated batons, where the shape of the antler was not altered (Nougier and Robert 1975; Mons 1976; Lucas et al. 2019), in this case, it was manufactured from a rod extracted by double longitudinal grooving. The two pieces are identical in their size: 98 mm long, 19 mm wide, and 16 mm thick. The baton was perforated in the central part of the antler beam (probably the B beam judging by its straight shape). However, the specific perforation action could not be identified, such as the technique or the direction of the perforation, because that part is polished. The reconstruction of the two parts shows that the original hole in the baton was large, at least 18 mm in diameter. The longitudinal fracture, parallel to the axis of the shaft, seems to have been caused by lateral traction that split and separated the two pieces. In fact, as experimentation carried out by Rigaud (2001, 2004) has shown, breakages occur with a force equivalent to a 10 kg weight falling a height of 2 m, which undoubtedly rules out some of the functionality hypotheses that have been proposed (Rigaud 2001, 2004). Perforated batons have been documented in all Upper Palaeolithic technocomplexes, at such sites as Gołębiewo 47 site (Osipowicz et al. 2017), Gough's Cave (Lucas et al. 2019), La Vache (Nougier and Robert 1975), Placard (Mons 1976), and Loubressac (Leclerc and Pradel 1948).

Object maintenance

As explained above, antler equipment generally requires a considerable technical investment, a series of actions and manufacture stages, from the procurement of the raw material to the discard of the artefacts (Fig. 10). Moreover, the availability of antler (subjected to an annual physiological growth cycle) is more limited than other types of raw material. This meant that the hunter-gatherers would try to prolong the useful life of the tools when they broke. The repair and recycling of hunting weapons broken during their use have been observed from the Early Upper Palaeolithic onwards (Tejero 2014) and it persisted in later technocomplexes, such as the Magdalenian (Pétillon 2006; Langley 2015; Langley et al. 2016).

Studies of the breakages in hunting weapons show that in most cases, owing to the types of hafting and the direct impact against prey or a missed throw striking a hard object, the fracture patterns are similar (Bergman 1987; Knecht 1997; Pokines 1998; Liolios 1999; Pétillon 2006; Pétillon et al. 2016; Langley 2015). The most common fractures are the bevelled type in the meso-distal region and at the base which, in many cases, were transported back to the site for repair (Langley 2014). This behaviour is reflected in the antler assemblage from Santimamiñe cave. However, these data should be taken with caution due to the size of the available sample. Thus, 38% of the sample studied here consists of meso-distal fragments and 12% are proximal parts (bases of the weapons). In this way, 40% of the fractures were caused by impact. It is worth noting that among the barbed points, impact fractures in the meso-distal region are seen in 41.6% of the sample, whereas no use-fractures have been identified at the proximal end of those points.

Several maintenance methods of hunting weapons were identified in the assemblage from Santimamiñe (Pokines

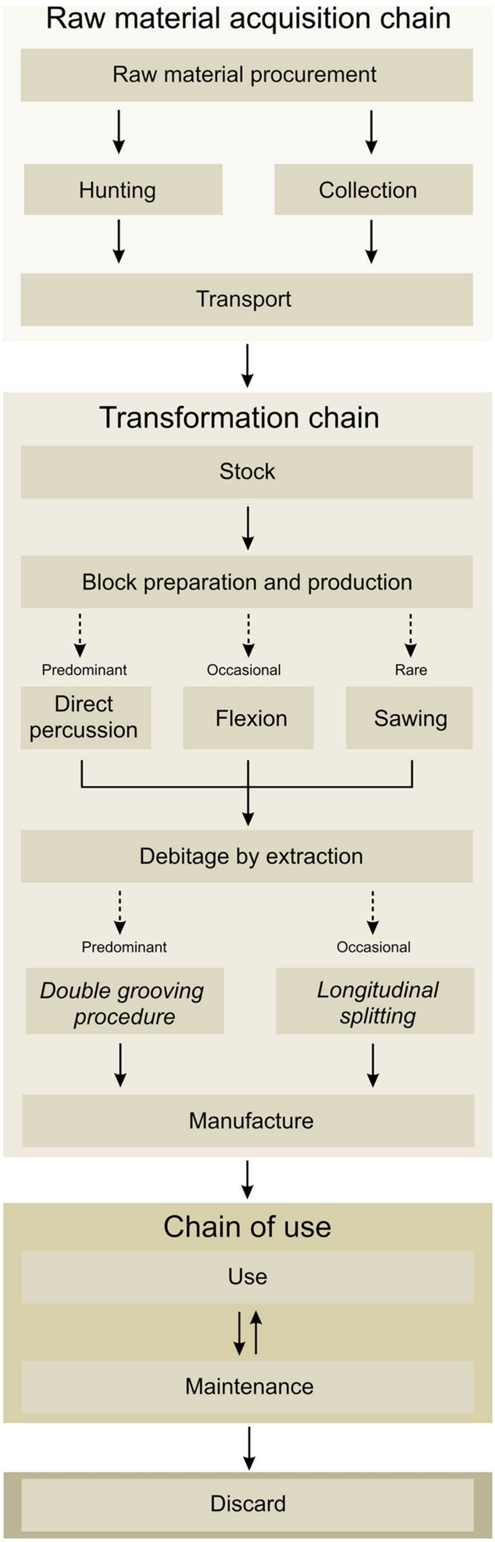

Fig. 10. General *chaîne opératoire* from raw material procurement to discard of hunting weapons evidenced at Santimamiñe

1998; Pétillon 2006; Langley 2015) (Fig. 11). The main signs are striations and faceting, and occasionally changes of axis. As noted, most of the use-fractures occur in the distal part of the points, and therefore they clearly required more attention in their maintenance. On projectile points, the signs of maintenance tasks that have been observed are striations (15.78%), followed by re-worked bases (5.26%). The striations appear mostly at the distal end and are related to the resharpening and rejuvenation of points with impact damage. Two bases were repaired following use-fractures to the bevel. The fracture on the bevel was adjusted by abrading the antler to create a smooth new surface that made use of part of the original bevel. On the barbed points, maintenance tasks are seen in striations (25%), changes of the axis (25%), and spatulate form points (8.3%). The change of axis is attested by a resharpened distal end of the point and is usually associated with a poorly done repair (Langley 2015: 350), as the weapon usually acquires an inefficient asymmetrical form.

The repair of these points inevitably leads to a reduction in their original size (Fig. 11). Studies by authors like Pétillon (2006) corroborate that projectile points shorter than 50 mm lose their utility and efficacy. The longest projectile point studied here is 140 mm long and the most complete barbed point reached 161 mm in length. From the negatives of the extraction in the antlers and the finished objects themselves, we can estimate the original sizes of the weapons and the amount of their reduction. In the northern Iberian Peninsula, projectile points may be up to 200 or 230 mm in length although most of them are between 150 and 200 mm long (Barandiarán 1980; Mujika 1983; González Sainz 1989; Erostarbe-Tome et al. 2022). Some may be longer, bearing in mind the evidence on the northern side of the Pyrenees, where points have been documented between 230 and 450 mm in length (Pétillon et al. 2011). Therefore, we shall follow the proposal of Langley (2015) to estimate the hypothetical material broken or removed by use and maintenance. If 230 mm is taken as the original length of the projectile point, the specimens from Santimamiñe lost between 74 and 158 mm; on average 128.18 mm (55.73%). The material lost from barbed points varies between 69 and 128 mm, on 108 mm (46.95%) on average. Owing to the small sample of barbed points, no differentiation can be made between those with one or two rows of barbs. In contrast, the width and thickness of both projectile and barbed points remain constant in the whole assemblage; between 7 and 14 mm in width and 6 and 9 mm in thickness.

Discussion

Santimamiñe cave is a major Magdalenian site that has been excavated during a period of over 80 years (Aranzadi et al. 1925; Aranzadi and Barandiarán 1935; González Sainz

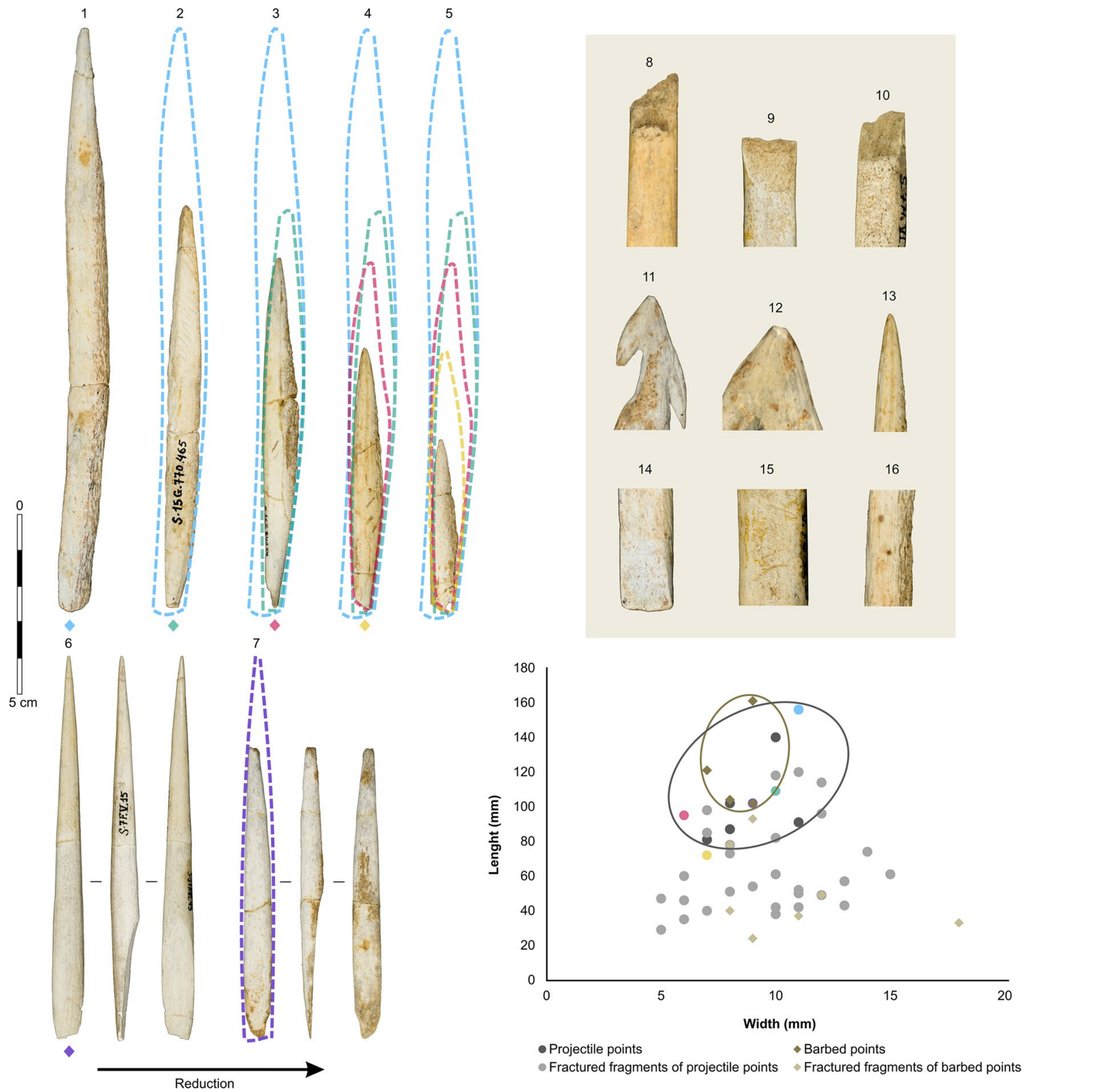

Fig. 11 Maintenance data for antler weapons. (Left) 1–7: Changes in projectile points form throught reduction. (Top-right) 8–10: Beveled breaks. 11: Axis change. 12, 13: Striations as a result of reshapening of the distal part. 14: Remade base. 15, 16: Maintenance traces. (Bottom right) Lenght/width ratio of "intact" and impact fractured mesial-proximal fragments for studied projectile points and barbed points

2011). The study of its rich archaeological assemblage helps us to understand the internal dynamics of hunter-gatherers in southern Europe immediately after the Last Glacial Maximum (LGM) (*c*. 27,000–19,000 years BP). The LGM is usually defined as the time when the global volume of ice last reached its maximum extent and the sea level was at its lowest (Maier et al. 2021). In this way, technological studies based on the detailed examination of industries and faunal remains are able to corroborate especially interesting aspects of the management of raw materials and the operational chains of transformation. It also confirms the important role of re-examining previously excavated site materials with a new approach.

The antler assemblage from Santimamiñe displays similarities with other Magdalenian sites that should be considered. The identification of waste products in reindeer antler shows that this raw material was used to manufacture equipment in northern Iberia in the Upper Palaeolithic. This means that the Pyrenees should be considered an enclave of high permeability for Magdalenian populations (Arrizabalaga et al. 2007; Martínez-Moreno et al. 2007; Álvarez-Alonso et al. 2016) and not an ecological barrier as traditionally has been thought (Costamagno and Mateos Cachorro 2007). Recent studies on evidence of reindeer in the north of the Iberian Peninsula (Gómez-Olivencia et al. 2013; Castaños et al. 2014; Lefebvre et al. 2023) suggest that an ecological niche for that species existed in the region, at least during the period studied here.

An "arched base" has been identified among the reindeer antler remains from Santimamiñe and this provides valuable information about the circulation of osseous equipment and the materials used to manufacture them, as well as about the mobility of hunter-gatherer groups. For instance, this category of waste is the result of a specific technique, with which the antler base was separated from the beam by double longitudinal grooving that left a concave extraction surface at the height of the second basal tine (or bez tine). In northern Iberia, evidence of this procedure has been documented in the final stages of the Magdalenian (e.g., Lumentxa, Lefebvre et al. 2023) whereas, to the north of the eastern central Pyrenees, evidence has been found in the Late Middle Magdalenian (LMM) but also at sites where the Early Upper Magdalenian (EUM) and LMM cannot be clearly differentiated (Pétillon 2006, 2016).

Consequently, the hypothesis can be proposed that this debitage procedure in reindeer antler developed in southwest France during the LMM, the time when socio-cultural exchange networks probably reached their maximum extension and expanded towards northern Iberia at the end of that period. Exchanges are seen not only in antler-working *lato sensu* but also in other forms of evidence, like flint and marine resources (Álvarez-Fernández 2002; Tarriño et al. 2016). Moreover, the waste products resulting from this procedure, a secondary block formed only by the part of the beam used to manufacture equipment, seem to have been transported as a reserve or stock to subsequently obtain various blanks (Pétillon 2006, 2016). This appears to be the case because, in the level that the arched base came from (level VI), no other reindeer remains have been identified (Castaños 1984), which shows that it may have been imported.

At Santimamiñe, debitage by extraction was the main operational scheme for the manufacture of antler equipment in the Magdalenian. This operational scheme is linked to the stage in which blanks are obtained and is one of the best documented methods of debitage in osseous materials. Evidence of double longitudinal grooving appears from the Gravettian onwards, although its emergence and diffusion are still unclear (Goutas 2004, 2009). In northern Iberian, this debitage method has been identified since the early Gravettian (30,000–34,000 cal. BP) at the site of Aitzbitarte III (Altuna et al. 2013). Several studies advocate unanimously for the dominance of this procedure in the Magdalenian (Goutas 2004, 2009; Langlais et al. 2010; Borao 2012; Averbouh 2014; Averbouh et al. 2016; Erostarbe-Tome et al. 2022). The systematic use of double longitudinal grooving increased the maximum productivity of a block of antler, so that between three and six blanks could be obtained per beam (Averbouh 2000). It also allowed the artisan better control over the morphometry of the blanks, compared with previous procedures, such as longitudinal splitting (Tejero et al. 2012; Tejero 2013) or contemporary methods, like debitage by fracturation (Averbouh and Pétillon 2011; Pétillon and Averbouh 2012; Borao et al. 2016). The extraction negatives at Santimamiñe cave indicate a recurrent pattern of long blanks, normally more than 150 mm, with a width of approximately 30 mm. In these extractions, the dominant execution of the grooves was the parallel by a bidirectional application. Extractions from the A beam extend as far as the burr of the antler ($n = 2$), thus maximising the productivity of the block of raw material (Averbouh 2000). Unlike other parallel extractions, at Santimamiñe it occupied the whole upper surface of the beam and did not leave space for another one. This may be because the extracted rod was going to be divided into more slender pieces. Normally the beam is divided into several parallel extractions 10 to 20 mm wide and potentially 200 to 300 mm long, depending on the size and shape of the antler (Averbouh 2000). The reason for this mode of extraction might be connected to the greater ease of dividing a wide blank into narrower rods in the blank itself than in the beam, especially in the case of multiple extractions. However, no evidence of this has been observed in the assemblage. The exhaustive description of this type of procedure (application of the grooves, the position of the extraction, morphometry of the negatives, etc.) is valuable since it allows us to identify possible variations in existing cultural traditions. Grooving used to obtain blanks has been documented at numerous sites, in the north of the Iberian Peninsula (Ermittia, Urtiaga: Mujika 1983; Ekain: Erostarbe-Tome et al. 2022; El Mirón: Straus et al. 2018; Las Caldas: Corchón and Garrido 2007; La Paloma: Hoyos-Gómez et al. 1980), in Mediterranean (Cendres: Borao 2012; Nerja: Aura et al. in press) and in France, e.g. Pincevent (Averbouh 2014, 2017), La Grotte des Scilles (Langlais et al. 2010) and La Gravette (Averbouh et al. 2016).

The second transformation scheme applied to the antler industry is the extraction using indirect percussion (splitting). Before the introduction of double longitudinal grooving in the Gravettian, other techniques were used to produce osseous artefacts in the Aurignacian (Knecht 1991; Liolios 1999; Tejero 2010, 2014; Tejero et al. 2012, Tartar 2009). Known as longitudinal splitting, it consists of breaking the antler into secondary blocks with a determined size and shape and then obtaining the blanks by splitting them longitudinally by indirect percussion. This debitage seems to have been, at least in Santimamiñe, less frequent than the first operational scheme described. Several factors may have influenced this difference. First, in general, the blanks obtained by longitudinal splitting are harder to identify than the negatives or blanks resulting from double longitudinal grooving. In fact, in finished objects, the traces left by the latter procedure are more often visible than in the case of the former. Second, experimental studies (Tejero et al. 2012) have ratified the more expeditious nature of longitudinal splitting, whereas double longitudinal grooving allows a closer approach to the final artefact with greater technical investment. Therefore, the morphological requirements of antler equipment may have been another factor in the choice of double grooving procedure. Nonetheless, the identification of these two extraction procedures demonstrates that the procedures and techniques introduced in previous periods co-existed and remained in use until the end of the Upper Palaeolithic.

The study of antler-working at Santimamiñe reveals the significant dichotomy between the use of antler and other hard animal materials. As we have seen, in that cave, antler was used to manufacture hunting weapons (projectile points, barbed points, and a spear thrower) for the hunter-gatherers. Other hard animal materials occupied a completely secondary position. Bone was used to manufacture all the domestic tools (awls, *lissoirs*, needles, etc.), for which faunal wastes were employed. Therefore, while the exploitation of the antler had a technical purpose (to exploit a raw material to obtain weapons), in the case of the bone it refers strictly to the food sphere and consumption patterns, with an exclusively alimentary purpose. The artefacts in bone, unlike those in antler, were generally fabricated with small modifications to their surfaces, by scraping and polishing.

The osseous industry has traditionally been used as an efficient way to determine the chronology of a level. Thus, the presence of some particular morphotypes, like barbed points or *navettes*, the main types of decoration, or the management of the raw materials, is a factor taken into account to determine whether they belong to one technocomplex or another. Santimamiñe cave suffers from serious issues in the interpretation of its stratigraphy (large depth of the original levels, incorrect labelling, mixtures during storage, the diversity of the dip of the levels, etc.) and these are hard to solve at present. In this way, several researchers have utilised typological and stylistic arguments to advocate the existence of different phases of Magdalenian occupations, which would extend to levels VII, VIII, and IX (Barandiarán 1967; Utrilla 1981; González Sainz 1989; Mujika 1992; Peñalver and Mujika 2005), traditionally attributed to the Solutrean, Gravettian, and Aurignacian, respectively, and which we completely agree with. The recent excavations (2004–2006) support this theory simply because they reached a greater depth than the first excavations without finding occupation floors any older than the Lower Magdalenian (Csn-Camr) (López Quintana and Guenaga 2011). Therefore, future multi-disciplinary research is required to study the alteration of those levels and cast light on this issue.

The identification of the traces of repairs provides new important information about the useful life of the hunting and fishing weapons of Magdalenian populations. In particular, the sample from Santimamiñe was reduced in size by 46 to 55% depending on the kind of weapon (projectile point or barbed point). These reductions must be related to the fractures occurring in the use of the equipment, which were returned to the cave after breaking. If the data obtained here are compared with the results from other sites where these patterns have been studied (Pétillon 2006; Tejero 2013 2014; Langley 2015), this seems to be common behaviour in Europe during the technocomplexes forming the Upper Palaeolithic. Therefore, the identification and description of the repair and maintenance traces are another element to understanding the prehistoric cultural trends that might have existed in different geographic areas.

Conclusion

The complexity of antler-working, documented from the Early Upper Palaeolithic onwards in Eurasia, culminated at the end of the Magdalenian period (19–14 ka cal. BP). As one of the technocomplexes with the highest representation of this raw material, it is an important source of information to understand the operational chains of transformation and technological implications. At Santimamiñe cave antler was used exclusively for the production of artefacts associated with the hunting/fishing activities of the humans who occupied the cave. These weapons, and also the waste products, are chronologically representative objects and display clear similarities with artefacts at other sites across Western Europe, especially in south-west France. This is undoubtedly due to the possibility of communications along the corridor from one side of the Pyrenees to the other. In addition, maintenance and discard patterns add further information about the useful life of the artefacts.

Santimamiñe cave contains remains from long Magdalenian occupations, allowing the characterisation of the antler-working patterns. The data presented here confirm that reindeer antler was employed as a raw material for the manufacture of tools. The waste products identified provide valuable information about the circulation of osseous artefacts and the mobility of hunter-gatherer groups. We also suggest that the exploitation of reindeer in the northern Iberian Peninsula during the Late Upper Palaeolithic may have been more important than previously thought, even if red deer remained the dominant taxon.

The extraction was the main operational scheme of Santimamiñe, based, mainly, on the double grooving procedure. This was a common technological procedure in the whole Magdalenian period; it became the preferred method to obtain blanks as it maximised the productivity of the blocks of raw material. Some possible cultural variations in the application of the double grooving procedure have been noted in the present study and these differences between sites and regions in the way of obtaining blanks should be studied in future research, supported by experimental data.

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Declarations

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