# Informal But Specialized: Mousterian Bone Hideworking Tools From Combe-Grenal (Dordogne, France)

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*submitted: 14 September 2021; revised: 5 March 2022; accepted: 6 March 2022*

**ABSTRACT**

The emergence and subsequent development of bone tool technologies represent important steps in the evolution of human behavior. Here we present a technological, morphometric, and functional analysis of 10 bone tools with smoothed ends from the Quina and Levallois levels of the Mousterian site of Combe-Grenal (Dordogne, France). The ends of these shaft fragments were first abraded and then used to work dry, defleshed hides in order to render them softer and more flexible. We identified three morpho-functional tool types that were probably used in different hide softening stages. Several examples of each tool type were also used as retouchers to shape and/or resharpen stone tools that were likely used during the same hide processing stages. These informal, expedient but specialized bone tools therefore potentially represent a complete toolkit for softening hides. While use-wear analysis of stone tools most often provides information concerning the initial stages of hide processing, the Combe-Grenal bone tools show this process was at times both complex and sophisticated, allowing for the creation of a wide range of items, particularly clothing to guard against the cold and inclement weather. Until now, this level of technical sophistication was considered unique to anatomically modern humans. In addition, our study demonstrates the significant informative potential of informal bone tools for better understanding the complexity and diversity of Neanderthal behavior. By shedding light on activities with typically weak archeological signatures, these informal tools provide new insights concerning the technical responses of Neanderthal groups to fulfill specific needs. Finally, our results highlight the need to better document the role of bone as a raw material for Neanderthal groups in order to explore the socio-economic mechanisms that gave rise to complex bone and antler-based technologies during the Middle-to-Upper Paleolithic transition.

*PaleoAnthropology* 2022:2: 211–236. https://doi.org/10.48738/2022.iss2.112 ISSN 1545-0031

## INTRODUCTION

Tracing the emergence and development of bone technologies continues to play an important role in our understanding of the evolution of human behavior. Traditionally associated with the advent of anatomically modern humans, initially in Africa and later in Eurasia, they figure prominently in debates concerning the emergence of behavioral modernity (Bouzouggar et al. 2018; d'Errico et al. 2003a; Hallet et al. 2021; Henshilwood et al. 2001; McBrearty and Brooks 2000; Mellars 1989). However, the adoption of bone as a raw material was a gradual accumulative process. Although anatomically modern humans played an essential role in this process, the use of bone largely predates their appearance and can be divided into two main phases.

In the first phase, bone ceased to be a simple food waste and was incorporated into the range of raw materials, used either unmodified or with only cursory shaping, mainly using retouch techniques similar to those applied to stone tools. These tools have been described as informal given that their general characteristics and morphology remain more or less those of the original blanks (Klein 1989). The earliest evidence of bone tools predates the emergence of the genus *Homo* and is associated with very early hominins. In Africa, such tools are associated with the Oldowan, dated to around 2 million years ago, and mainly consist of retouched tools and unmodified fragments, including examples used to fish termites out of mounds (Backwell and d'Errico 2001, 2004; Sano et al. 2020; Stammers et al. 2018). In Europe and the Levant, the first evidence of bone tools is more recent, associated with late Lower Paleolithic contexts, dated to between 500–250 kya. Multiple sites from these two regions have produced retouched bone tools, including bifacial examples (Blasco et al. 2013; Dobosi 2001; Mania and Mania 2005; Rosell et al. 2011; Sacca 2012; Villa et al. 1999; 2021; Zutovski and Barkai 2016) and unmodified bone fragments used as retouchers and hammers (Blasco et al. 2013; Goren-Inbar 2011; Julien et al. 2015; Moigne et al. 2016; Moncel et al. 2012; Roberts and Parfitt 1999; Van Kolfschoten et al. 2015). While bone tools are rare during the Lower Paleolithic, they become more common from the Middle Paleolithic onwards.

In the second phase, bone, as well as antler and ivory, were more substantially modified, using particularly well-adapted techniques, including scraping, abrasion, or sawing. These new techniques are reflected in the emergence of a diverse range of standardized, formal tools (Klein 1989). Traditionally attributed to anatomically modern humans, this phase has drawn the most attention from researchers. In Africa, the first formal tools, primarily cutting and spatulate tools, come from the Aterian industries of the North African Middle Stone Age (MSA), while in southern Africa, the earliest bone tools date to between 60 and 75 ka and primarily consist of awls and possible projectile points (Backwell et al. 2008; d'Errico et al. 2012a; Henshilwood et al. 2001; Yellen et al. 1995). The appearance of formal tools, coincident with the emergence of personal ornaments, engravings, and pigment use, led to the "Out-of-Africa" model and the concept of behavioral modernity (McBrearty and Brooks 2000). Accordingly, these innovations were tied to the gradual evolution of the behavioral and cognitive capacities of anatomically modern humans, facilitating the dispersal of these groups out of Africa, as well as their eventual replacement of autochthonous archaic human populations in Eurasia. Since its initial formulation, this model has been frequently challenged, particularly the presumed single-species origin of behavioral modernity (Henshilwood and Marean 2003; Hoffman et al. 2018; Jaubert et al. 2016; Joordeens et al. 2014; Shea 2011; Zilhao et al. 2010; 2020). Concerning the use of bone as a raw material, the principal criticisms concern the small number of MSA sites that have yielded formal bone tools. Furthermore, the emergence of bone technology does not appear to be a uniform process but rather discontinuous over time and space, with innovations appearing, disappearing, and then reemerging. This discontinuous pattern is likely conditioned by multiple taphonomic factors affecting bone preservation. Despite this likelihood, formal bone tools do not appear to be reliable, unambiguous markers of behavioral modernity (Backwell et al. 2008). In Europe, the working of osseous raw materials and the appearance of formal bone tools have long been considered innovations associated with the arrival of anatomically modern humans, coincident with beginning of the Upper Paleolithic, around 40 kya (Bar-Yosef 1998; Mellars 1989). However, the first genuine formal bone tools appear with the Middle-to-Upper Paleolithic transition, associated with the late Neanderthals (d'Errico et al. 2003b; Julien et al. 2019), as well as anatomically modern humans (Hublin et al. 2020). The independent development of techno-cultural innovations among final Neanderthal populations remains heavily debated, with several researchers casting doubts on the reliability of the Châtelperronian-Neanderthal association (Bar-Yosef and Bordes 2010; Gravina et al. 2018) or supporting the acculturation of Neanderthal groups by arriving modern human groups (e.g., Demars and Hublin 1989; Harrold 1989; Hublin et al. 2020; Mellars 1996). This latter position considers the manufacture of formal tools in osseous raw materials to be linked with behavioral and cognitive capacities specific to anatomically modern humans. In fact, bone, antler, and ivory objects from European contexts, whether in the form of weapon elements, domestic tools, personal ornaments, or mobiliary art, do not become widespread until the Aurignacian. However, the manufacturing techniques associated with these items are equally evident in the working of wood during the Lower and Middle Paleolithic, as evidenced by several exceptional finds of wooden spears (Conard et al. 2020; Gaspari et al. 2011; Movius 1950; Oakley et al. 1977; Thieme 1997) and, to a lesser extent, more indirect evidence from the use-wear analysis of stone tools (Claud et al. 2013). Formal bone tools therefore do not appear to constitute reliable and unambiguous markers of behavioral modernity. Instead, the abrupt shift in the use of osseous materials coincident with the beginning of the Upper Paleolithic would reflect profound changes that were undoubtedly less cognitive than they were socio-economic (Bon 2009).

In both Africa and Europe, the interpretation of formal bone tools as reliable markers of behavioral modernity therefore appears wholly unjustified. Continued focus on these tools while neglecting earlier, often considered simpler technologies, has inevitably complicated the identification of the evolutionary mechanisms underlying their appearance. The development of osseous technologies formed part of a complex evolutionary process, whose accurate reconstruction needs to begin with an examination of its earliest manifestations, when bone was primarily used unmodified. In this regard, interest in bone tools associated with Neanderthals has grown significantly over the past fifteen years. Bone retouchers used to shape and maintain stone tools were identified very early on and are today the best-documented category of bone tools (see Hutson et al. 2018 for a summary). These tools are present, often in large numbers, at numerous sites yielding the majority of Middle Paleolithic techno-complexes. The development of techno-functional studies over the last two decades has identified additional tool types, reflecting the relative diversity of Lower Paleolithic and Mousterian bone tools (Tartar and Costamagno 2016). The same applies to retouched bone tools (Baumann et al. 2020; Mozota Holgueras 2012; Romandini et al. 2014; Rosell et al. 2011), intermediate tools (*pièces esquillées*) involving indirect percussion (Baumann et al. 2020; Burke and d'Errico 2008; Mozota Holgueras 2012) and smooth-ended tools (*lissoirs* in French and hereafter referred to as smoothers) used for processing hides (Baumann et al. 2020; Martisius et al. 2020a, 2020b; Mozota Holgueras 2012; Soressi et al. 2013). However, a majority of publications most often report one or only a handful of tools identified among thousands of faunal remains (but see Baumann et al. 2020). The question remains as to whether these implements should be interpreted as the simple, expedient use of bone or the first genuine bone tools? As a consequence, discerning the precise role of bone in Neanderthal socio-economies remains challenging, especially as relevant evidence is currently limited to a small number of sites. The early and mid-twentieth century excavations at the important Middle Paleolithic site of Combe-Grenal in southwestern France produced several examples of bone fragments reported as exhibiting clear evidence of use. However, these previously published artifacts have never been examined in detail (but see Tartar and Costamagno 2016). Given the mention of these potential bone tools, we re-examined all shaft fragments recovered during previous excavations at Combe-Grenal. This comprehensive review of the site's faunal material produced 92 artifacts with smoothed extremities, of which we selected ten particularly well-preserved examples for a detailed technological, morphometric, and functional analysis.

The aim of this article is fourfold: (1) provide a detailed technological, morphological, and zooarchaeological description of the Combe-Grenal bone tools as well as traces of use on their active parts; 2) explore their relevance for hide processing during the Middle Paleolithic; 3) demonstrate how they provide evidence of activities that are otherwise difficult to detect in the archaeological record; and finally, 4) better document Neanderthal technical skills and know-how in order to discuss how they articulate with broader socio-economic mechanisms underlying the emergence of complex bone technologies during the Middle-to-Upper Paleolithic transition.

## COMBE-GRENAL

The rock shelter of Combe-Grenal is located in a small valley near the Dordogne River and is one of the most important Middle Paleolithic sites currently known in southwestern France. The site has been excavated multiple times since its discovery in 1816 by F. Jouanet, with the most extensive excavations carried out by three eminent figures for the prehistory of south-western France—Denis Peyrony, followed by his son Elie, and then François Bordes. While the excavations of Denis (1929) and Elie (1937) Peyrony were limited in scope, comprising two trenches at the front and within the rock shelter, F. Bordes' excavations between 1953 and 1965 focused on a larger area within the shelter and adjacent terrace. These more extensive excavations revealed a near 13-meter-thick stratigraphy, in which Bordes distinguished 65 archeological levels, on three superimposed limestone terraces. The uppermost terrace yielded a sequence of 37 levels (Table 1) that provide an unequalled record of Late Mousterian industries in the region.

Not surprisingly, the Combe-Grenal sequence played a fundamental role in the definition of Bordes' Mousterian "*facies*" (see Table 1: Bordes 1953, 1971, 1972, 1981) and soon after became the basis for various interpretive models of Mousterian variability in southwestern France (see Faivre et al. 2014 for a review). Subsequent studies of the Combe-Grenal record have addressed, among other aspects, specific features of flake production methods. A recent revision of the site's lithic assemblages has also contributed to the characterization of three major regional Middle Paleolithic lithic techno-complexes (LTC): Levallois, Quina, and Discoid (see Table 1; Faivre et al. 2014; 2017).

As well as yielding rich lithic assemblages, the material recovered from Combe-Grenal by F. Bordes includes 29 Neanderthal skeletal remains, some bearing cut-marks (Garralda et al. 2005; Garralda and Vandermeersch 2000; Genet-Varcin 1982; Gomez-Olivencia et al. 2013; Le Mort 1988; Maureille et al. 2009–2010), numerous pigments (see Dayet et al. 2019 for a recent re-analysis), incised raptor claws potentially used as ornaments (Morin and Laroulandie 2012), and diverse faunal assemblages representing an exceptional record of local Pleistocene faunal communities. Consequently, the Combe-Grenal archeofauna (see Discamps and Faivre 2017 for a review) have played a pivotal role in the study of paleoenvironments and subsistence strategies of Neanderthal groups in southwestern France.

## MATERIALS AND METHODS

All diaphyseal fragments held at the French National Museum of Prehistory (Les Eyzies-de-Tayac Sireuil) from the excavations of F. Bordes and D. and E. Peyrony at Combe Grenal were examined (by SC, ET) with the aim of identifying pieces bearing traces of use. A preliminary database was created for each artifact, which included provenance

TABLE 1. COMBE-GRENAL, UPPER TERRACE. MOUSTERIAN FACIES (after Bordes 1972, 1981) AND ASSOCIATED PRODUCTION SYSTEMS (after Faivre et al. 2014).

| Layer | Mousterian Facies (after Bordes) | Technological System | References |
|---|---|---|---|
| 1–4 | Mousterian of Acheulean Tradition | Discoid<br>Bifacial shaping | Pelegrin 1990; Faivre et al. 2014 |
| 5–6 | Typical | Discoid/Levallois | Faivre 2011; Faivre et al. 2014 |
| 7 | Typical | Levallois | Faivre 2011; Faivre et al. 2014 |
| 8–10 | Typical | Discoid/Levallois | Faivre et al. 2014 |
| 11–12 | Denticulate | Discoid | Faivre 2008; Thiébaut 2005 |
| 13–15 | Denticulate | Discoid | Bourguignon and Turq 2003 |
| 16 | Denticulate | Levallois/Discoid<br>Bladelet technology | Faivre 2011 |
| 17–19 | Evolved Quina | Quina | Faivre 2011 |
| 20 | Denticulate | Quina | Faivre 2009–2010 |
| 21–26 | Classic Quina | Quina | Turq 2000 |
| 27 | Ferrassie | Levallois | Faivre 2008 |
| 28–31 | Typical | Levallois | Faivre 2011 |
| 32–35 | Ferrassie | Levallois | Delagnes 1992; Faivre 2011 |
| 36–37 | Typical | Levallois | Faivre 2011 |

(i.e., layer), anatomical part, taxon, length, and the main categories of traces identified. A total of 257 used pieces were identified among the different collections from Combe-Grenal, including numerous retouchers, a few potentially retouched fragments, and 92 diaphyseal fragments with smoothed ends, all in extremely variable states of preservation (Tartar and Costamagno 2016).

A second study trip focused on the previously reported smooth-ended artifacts. In his brief excavation report, E. Peyrony mentions bone fragments recovered from different levels having "worn and rounded e*nds, as they had been used to rub*" or being "*wide and thick splinters, worn at the end, similar to smoothers*" (Peyrony 1937). Similar artifacts were also reported by F. Bordes who, alongside "*compressors*" and a "*bone retouched into a scraper*", equally noted:

> "*Here we illustrate only a handful of used flakes from Combe-Grenal, but we could have included examples from other sites. Their use is evident in the smoothing and polish on one or both ends of the flake (pl. 108, nº 1, 2, 8, 10). These flakes may have been used to pierce holes in leather, or, more likely, as a lacing aid designed to push a lace through a slit in a hide*" (1961: 98, our translation).

During this new trip, artifacts with smooth ends were sorted according to stricter selection criteria, in order to retain only those with reliable anthropogenic modifications that were sufficiently well preserved for a functional analysis. Surfaces were observed (AL and ET) without magnification and then with a Leica M165C stereomicroscope (magnification up to x120), with the aim of eliminating unmodified artifacts or those with ambiguous surface modifications. Two categories of surface modifications proved particularly problematic—sedimentary abrasion (including trampling) and carnivore modifications (for detailed analyses see Andrews and Cook 1985; Brain 1967; Behrensmeyer 1978; Binford 1981; d'Errico and Giacobini 1988; Esteban-Nadal et al. 2010; Koby 1943; Olsen and Shipman 1988). In the case of sedimentary abrasion, the degree to which raised areas, edges, and extremities of artifacts are

**TABLE 2. ARCHAEOLOGICAL CONTEXT OF THE STUDIED MATERIAL.**

| Artifact No. | Illustration | Excavator | Level | Label | Mousterian Facies (after Bordes) | Technological System |
|---|---|---|---|---|---|---|
| 1 | Fig. 1.1 | F. Bordes | 35 | CG X P9 257 | Ferrassie | Levallois (Delagnes 1992; Faivre 2011) |
| 2 | Fig. 1.2 | F. Bordes | 25–26 | CG N1 013 203 | Quina | Quina (Turq 2000; Faivre 2011) |
| 3 | Fig. 1.3 | F. Bordes | 24 | CG M L7 213 | Quina | Quina (Turq 2000; Faivre 2011) |
| 4 | Fig. 1.4 | F. Bordes | 23 | CG L H5 | Quina | Quina (Turq 2000; Faivre 2011) |
| 5 | Fig. 1.5 | F. Bordes | 24 | CG M L8 109 | Quina | Quina (Turq 2000; Faivre 2011) |
| 6 | Fig. 1.6 | F. Bordes | 25–26 | CG N K5 57 | Quina | Quina (Turq 2000; Faivre 2011) |
| 7 | Fig. 1.7 | D. Peyrony | c | - | - | - |
| 8 | Fig. 1.8 | D. Peyrony | d | - | - | - |
| 9 | Fig. 1.9 | F. Bordes | 35 | CG F4 1065 X | Ferrassie | Levallois (Delagnes 1992; Faivre 2011) |
| 10 | Fig. 1.10 | F. Bordes | 25–26 | CG N M9 26 | Quina | Quina (Turq 2000; Faivre 2011) |

smoothed varies according to the extent to which they were displaced after burial. The mechanical action of sediments can sometimes result in numerous striations that are often variable and irregular in form, due to the diverse nature of the abrasive particles in the surrounding sediment and the random displacement of the bone fragments. Carnivores and burrowing animals can also smooth bone surfaces, in particular their extremities, by the combined actions of gnawing, stomach acids, or repeated displacements. However, these carnivore modifications are frequently associated with tooth marks, scratches, compression marks, or crenulated edges (pseudo-retouch). To avoid any risk of confusion, we excluded (1) any fragment with carnivore modifications (incidentally very few in number) as well as those that were too poorly preserved for potential wear to be analyzed, and, (2) retained only artifacts exhibiting clear traces of smoothing, uniquely at their ends and associated with areas bearing homogenous and organized macro-striations visible to the naked eye. In the end, 10 artifacts were selected for further analysis (Table 2; Figure 1).

Two artifacts come from D. Peyrony's excavations, one from layer C, which yielded a *"classic Mousterian industry,"* and the other from layer D, reported as being sterile (Peyrony 1929: 2; see Figure 1: 7 and 8). According to F. Bordes, Peyrony's excavations explored the middle levels of the archeological sequence on the uppermost terrace (Bordes' levels 15 to 31), as the overlying layers had been destroyed a long time previously. As these levels were attributed to different facies (see Table 2; Bordes 1972, 1981) associated with different flake production systems, it is currently impossible to reliably determine the precise archeological context of these two artifacts. The other 8 artifacts come from F. Bordes' excavations (see Table 2)—6 from the Quina Mousterian levels (23, 24, 25–26) (see Figure 1: 2-6 and 10) and two from level 35 attributed to the Ferrassie Mousterian, characterized by the Levallois method (see Figure 1: 1 and 9). The faunal assemblages from levels 23 to 26 are dominated by reindeer, while red deer is the most abundant taxon in level 35. Regional paleoenvironmental correlations (Discamps and Royer 2017) place the Quina levels to around 60 kya cal. BP (MIS 4) and the underlying Levallois ones to before 70 kya (late MIS 5/early MIS 4). We retained only one of the 4 artifacts identified and illustrated by F. Bordes (artifact nº 4: Bordes 1961, plate 108, nº 8; also illustrated in Bordes 1972, fig. 38 nº 4). Two were excluded due to their poor preservation, and the third was not available at the time of our study (on loan to an exhibition). Three additional artifacts included in our study had previously been identified by F. Bordes and bear an arrow in India ink or pencil indicating the worn end (see Figure 1: 2, 3 and 5).

The use-wear analysis carried out at the Archeoscopie plateform (MSH Mondes, Nanterre), combined macro- and microscopic observations of the volume and surfaces of the tools, in order to more effectively isolate wear attributes indicative of tool movement, position during use, and the nature of the worked material (see Legrand 2007; Legrand and Radi 2008; Legrand and Sidéra 2007; Petrullo 2014; Sidéra 1993). Macroscopic observations of the surface (striations) and volume (smoothing, removal scars, pullout, crushing) of the active parts were carried out with the naked eye and using a stereo-microscope (Nikon SMZ1500) at magnifications ranging from 10x to 80x. This was then supplemented by a more detailed microscopic analysis of surface alterations and microtopography using an optical mi-

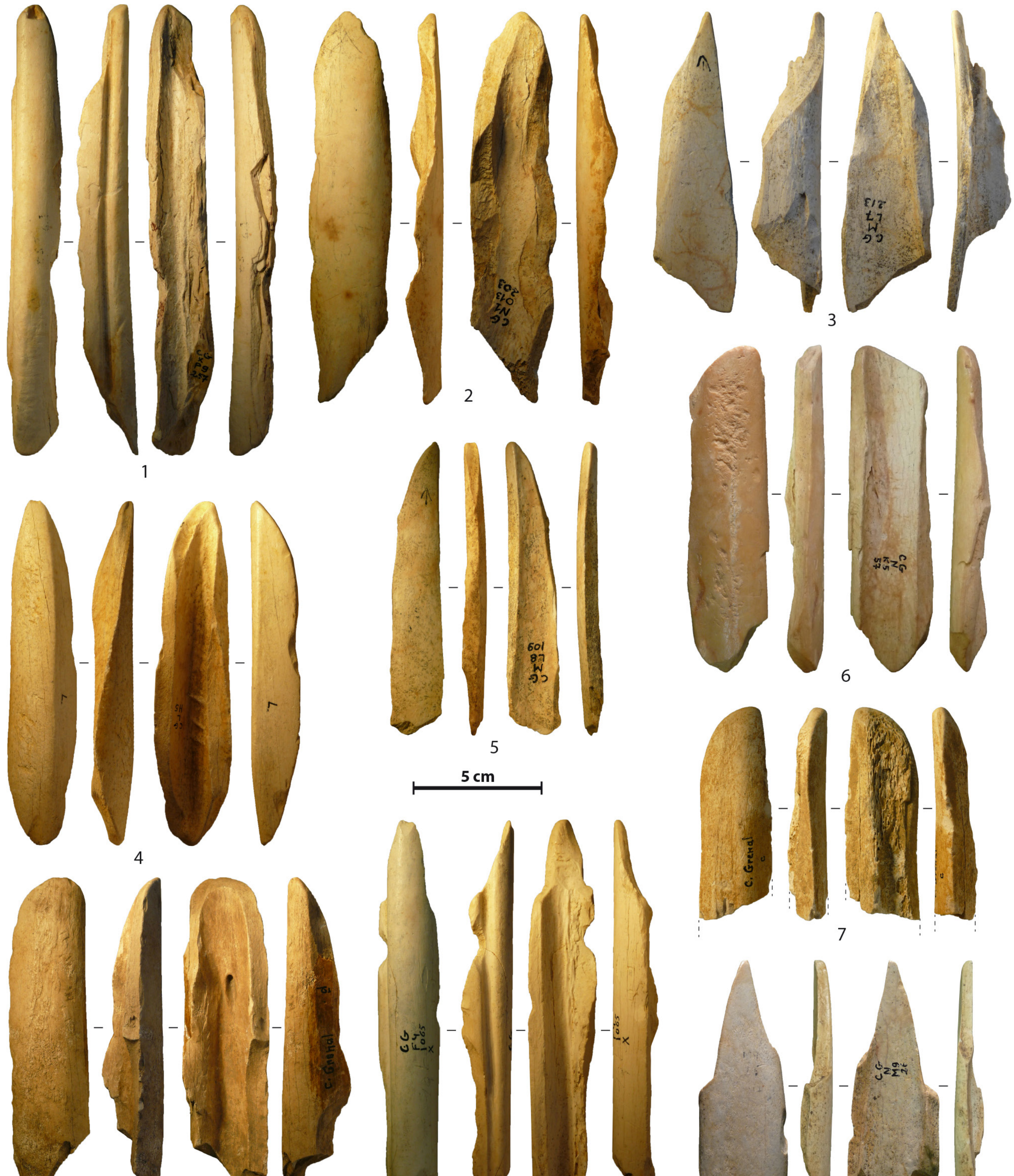


*Figure 1. Studied material. 1-6, 9-10: artifacts from Bordes' excavations; 7-8: artifacts from D. Peyrony's excavations (numbers are the same as those found in the text and the tables).*

**TABLE 3. BONE CHARACTERISTICS: ANATOMICAL PART, SPECIES, AND MORPHO-TYPE (artifact numbers are the same as those in Figure 1)*.**

| Artifact No. | Anatomical Part | Species | L | W | T | Morpho-type | Technological System |
|---|---|---|---|---|---|---|---|
| 1 | metatarsal | *C. elaphus* | 174 | 23 | 15 | broad | Levallois |
| 2 | radius | *C. elaphus* | 151 | 32 | 9 | rounded | Quina |
| 3 | tibia | *C. elaphus* | 115 | 33 | 23 | dihedral | Quina |
| 4 | tibia | *C. elaphus* | 134 | 28 | 16 | rounded | Quina |
| 5 | metapodial | reindeer size | 115 | 18 | 7 | dihedral | Quina |
| 6 | tibia | large bovid | 128 | 32 | 12 | broad | Quina |
| 7 | tibia | large bovid | >81 | 28 | 15 | broad | - |
| 8 | tibia | *C. elaphus* | 122 | 31 | 19 | rounded | - |
| 9 | metatarsal | *C. elaphus* | 146 | 25 | 15 | rounded | Levallois |
| 10 | tibia | *C. elaphus* | 90 | 34 | 9 | dihedral | Quina |

*measurements in mm.

croscope with a reflected light source at magnifications of 100x and 200x (Nikon ME600 Eclipse). During use, the microtopography of the original surface is modified as raised areas are smoothed, altering their appearance and texture. These alterations are accentuated by micro-striations and micro-pits, whose characteristics (frequency, location, dimensions, orientation, arrangement, aspects of the edges and the base, etc.) provide information on the position of the object during use, tool kinematics, and the nature of the material worked (Campana 1989; Christidou 1999; Legrand 2007; Petrullo 2014; Semenov 1964).

The function of the Combe-Grenal bone tools was determined with reference to an experimental bone tool assemblage consisting of more than 100 points, needles, and tools with unmodified edges used to work different materials—fresh hide, dry hide, wood and bark in various conditions, multiple plant fibers (flax, straw, reed, and sedge grass), clay, and bone (Legrand 2007, 2017; Christidou and Legrand 2005). In addition to the material worked, the hardness and the mode of action were also tested to appraise their impact on the formation of use-wear—movement (unidirectional/longitudinal or alternating), working time, working angle (perpendicular or oblique), prehension mode, and how the material was supported (i.e., on the ground or stretched in a frame).

## RESULTS

### BONE CHARACTERISTICS

Apart from a mesio-distal fragment with a typical dry bone fracture (post-depositional break (see Figure 1: 7), all artifacts are complete. One artifact (see Figure 1: 1) displays recent micro-flaking on the lateral fracture planes that only slightly modify the blank's initial volume. Although alterations linked to weathering and edaphic processes are evident, including longitudinal fissures (n=8) and limited manganese staining (n=7), they do not hinder the observation of bone surface modifications. Several artifacts also exhibit limited evidence of erosion (n=4) or root etchings (see Figure 1: 8), although these post-depositional modifications did not affect the active parts of the tools.

In terms of taxa and skeletal part representation, red deer remains are most common (n=7), represented by four diaphyseal tibia fragments, two metatarsal fragments, and a fragment of a radius. These elements are accompanied by two bovid tibia fragments and one metapodial fragment from a reindeer-sized ungulate (Table 3). The predominance of red deer, a species that is most frequent in only one of the layers that produced the bone tools (layer 35, Guadelli 1987), and the high proportion of tibial fragments (n=6) could suggest the preferential selection of this species for tool blanks. With that said, significant biases in the recovery of faunal remains during both Peyrony's and Bordes' excavations considerably impact both the representation of species and anatomical parts (Discamps and Faivre 2017). As such, it is difficult to evaluate blank selection criteria. However, available data demonstrate that reindeer was the dominant prey choice for Quina groups in both the Périgord and Charentes regions, with red deer, horse, and bovids consistently present in much smaller proportions in these assemblages (Beauval in Airvaux 2004; Castel et al. 2017; Costamagno et al. 2006; Delpech 1996; Discamps et al. 2011; Niven et al. 2012; see Discamps and Royer 2017 for a review). The finer compact tissue of reindeer long bones is also less robust compared to other ungulates, including red deer and bovids. Moreover, the choice of anatomical elements for the manufacture of the Combe-Grenal tools does not seem to be random. When fractured, the straight shaft portions of the tibia, radius, and metapodial (especially in red deer) produce long and narrow fragments with thick cross-sections, traits that appear to have been preferred by Mousterian groups for the production of bone tools (see

Martisius et al. 2020b for similar conclusions concerning the Abri Peyrony *lissoirs* made on the ribs of a large bovid).

Bone surface modifications can be connected to different stages of the butchery process (Figure 2). Of the six cut-marked bones, the size, orientation, and location of striations on two red deer tibia fragments, a fragment of a bovid tibia, and a red deer radius (see Figure 2: 2, 4, 6, and 8) are consistent with experimental data for defleshing (Costamagno and Soulier 2019; Soulier and Costamagno 2017). Two red deer metatarsal fragments also display cut-marks referable to skinning (see Figure 2: 1 and 9). Percussion marks are also present on five fragments, in the form of medullar percussion notches and cortical flakes at the percussion point or counterblows typical of percussion on an anvil.

The characteristics of the fragments are sufficiently specific (anatomical part, taxon, morphology of the fragments and their extremities) to suggest that they are not due to chance. The question remains whether the fragments were selected from the range of waste available at the end of the butchery process or reflect long bones fractured using a specific method to produce fragments with predetermined characteristics. These two possibilities are now systematically tested in studies of informal tools, particularly those concerning retouchers. Although the collection of butchery waste is generally accepted as more likely, dedicated bone tool blank productions methods have been suggested for several Middle Paleolithic contexts (Abrams et al. 2014; Mozota-Holgueras 2012). Unfortunately, the extreme bias in the recovery of faunal remains during previous excavations at Combe Grenal (Discamps and Faivre, 2017) makes it impossible to test these two hypotheses.

Three morpho-functional types can be identified based on the characteristics of the fragments and the form of their active ends (see Table 3). The first type (n=3, see Figure 1: 1, 6 and 7), *broad tools*, comprises long diaphyseal fragments (between 128mm and 174mm) of variable width (between 23mm and 32mm) with a thick end bearing somewhat rounded edges. The fracture plane (or planes) between the cortical and medullary surfaces forms a wide angle, approaching 90°. The second type (n=4, artifact nº 2, 4, 8 and 9), *rounded tools*, includes fragments with fairly similar characteristics but with a rounded active end with a narrow profile. The fracture plane connecting the cortical and medullary surfaces is oblique and forms an angle of between 30° and 45° with the cortical surface. The third type of tools (n=3, artifact nº 3, 5 and 10) are smaller, ranging between 90mm and 115mm in length, with widths not exceeding 34mm. Converging lateral fracture planes of the active triangular end resemble a dihedral burin, leading us to refer to these pieces as *dihedral tools*.

## ACTIVE ENDS

The location and extent of use-related wear indicate the active parts of the different tools (both ends of one artifact were used). The active part of the broad tools principally concerns "the end" of the piece, in the area of the terminal fracture plane(s). On rounded tools, the active part extends onto the lower surface of the ridge formed by the intersection of the two surfaces, referred to here as the "cutting edge." Finally, one of the two lateral fracture planes is the primary active part of the dihedral tools.

### General Use-Wear Data and Preservation

All the active parts of the tools exhibit a smoothed aspect resulting from repeated rubbing against a soft, enveloping material, leading to a loss of volume and the alteration of their initial shape (Sidéra 1993). In the majority of cases, this smoothing is fairly extensive. Macroscopic observations of the surfaces demonstrate all working ends to display macro-striations resulting from friction with abrasive particles between the active end and the worked material. Although the artifacts are generally well preserved, their working ends are affected to various degrees by taphonomic alterations, which impact surface analyses at higher magnifications. This is the case for two artifacts (artifact nº 4 and 8) that do not preserve microscopic use-wear traces. On the other hand, the well-preserved working ends of four artifacts (artifact nº 3, 5, 6 and 10) exhibit a clearly interpretable use-related microtopography in the form of micro-striations and micro-pits. The other four artifacts (artifact nº 1, 2, 7 and 9) exhibit discontinuous areas partially preserving use-related micro-traces. Two categories of wear can be identified—macro-striations linked to their manufacture and use-induced wear.

### End Modifications

Macro-striations occur as a series of short, straight, deep, and highly-organized parallel lines. The orientation of these traces varies from one artifact to another and indicates the movement of the tool during use, while their location reflects the position of the tool in relation to the worked material. In addition, the intensity and location of these striations compared to other forms of wear, in particular smoothing, allows a relative chronology for their formation to be determined.

On dihedral tools (Figure 3), macro-striations occur at right angles across the fracture plane that serves as the active part of the tool (left or right) and sometimes extend slightly onto the adjacent surfaces. On artifact 10, the margins of these striations are heavily worn, demonstrating that they formed prior to smoothing (see Figure 3). Macro-traces on broad tools (Figure 4) are oriented either perpendicular to the working end and extend slightly onto the adjacent surfaces (artifact nº 1) or are arranged in a fan shape, centrally along the long axis of the artifact and obliquely on each side (artifact nº 6 and 7). Two artifacts (artifact nº 1 and 6) exhibit relatively fresh use-related wear, which is particularly well preserved in the less-smoothed periphery of the active part. Macro-striations on these artifacts clearly pre-date the smoothing of the surfaces and edges. Finally, macro-striations on rounded tools (Figure 5) occur on the lower surface of the rounded end, extend onto the cutting edge, and are arranged in a fan-shape. However, it was not possible to determine their relative chronology.

Macro-striations result from rubbing against an abrasive surface in a longitudinal to slightly oblique movement

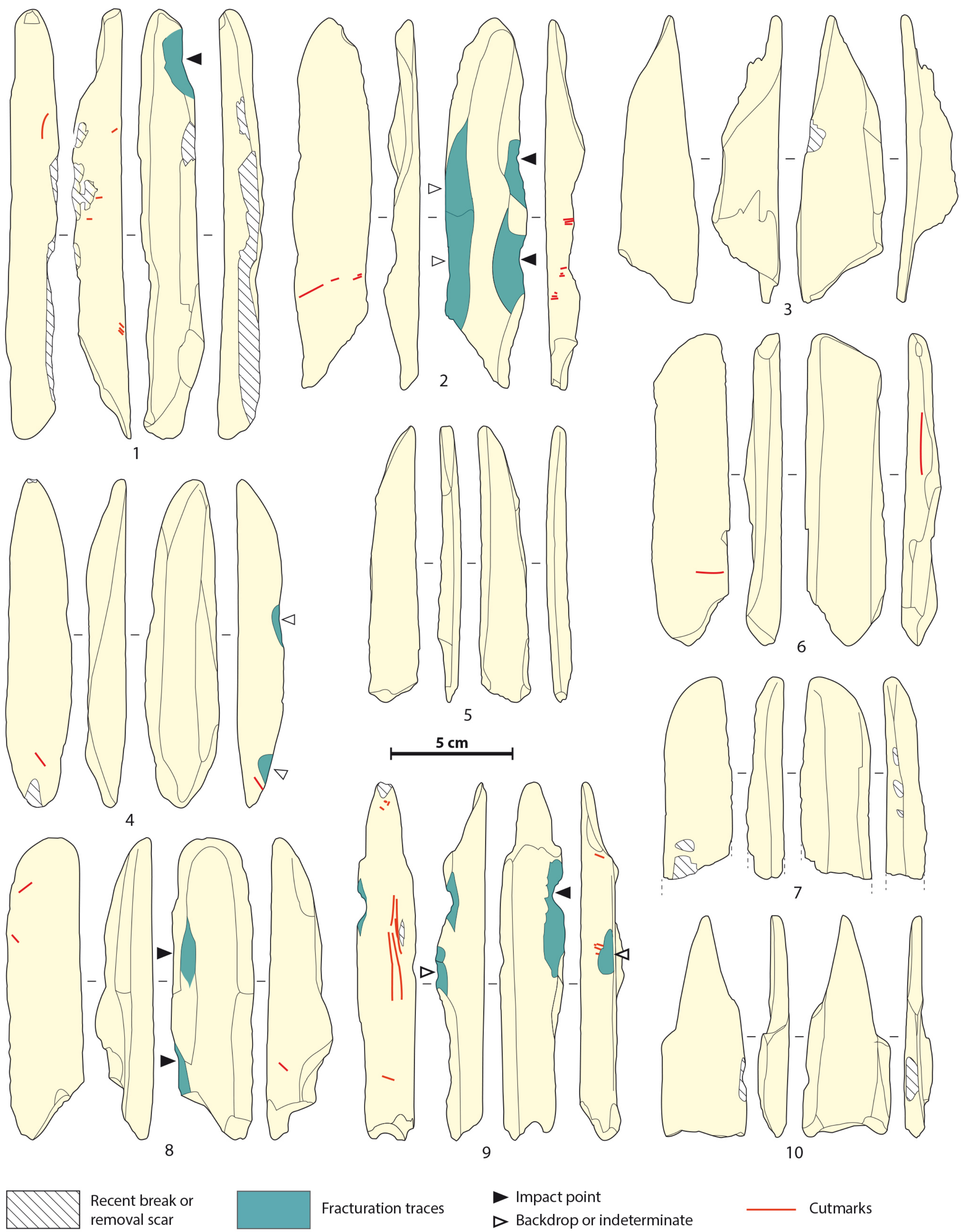


*Figure 2. Summary of butchery marks (percussion marks and cut-marks).*

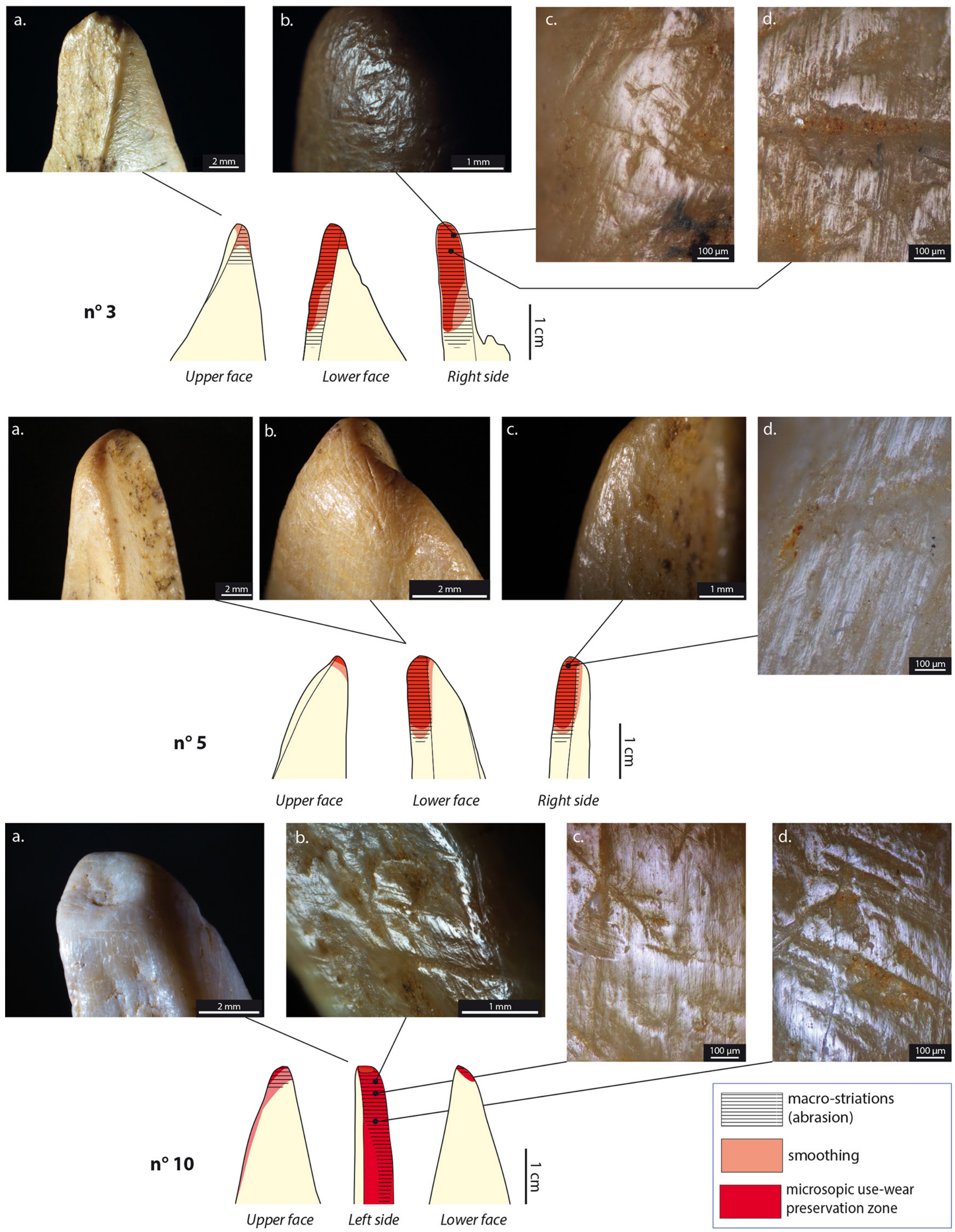


*Figure 3. Traces of macro- and microscopic wear on dihedral tool***s. Artifact nº 3.** *a: macroscopic view of the end (left edge and upper surface). Intersecting, oblique macro-striations (x10 magnification) can be distinguished on the upper surface. b: macroscopic view of wear on the right edge. Longitudinal micro-striations can be distinguished on the shiny worn areas (x30 magnification). c-d: microscopic wear on the right edge of the end. The raised areas have a convex appearance and a smooth texture. Broad and deep transverse macro-striations (d) and longitudinal micro-striations can be distinguished as well as several micro-pits (x100 magnification).* ***Artifact nº 5.*** *a: macroscopic view of the active end (lower surface and left edge). Moderately developed smoothing accompanied by a slight compression of the bone fibers (x10 magnification). b: detail of the end where macro-striations occur at a right angle to the object's long axis (x20 magnification). c: longitudinal micro-striations on the right edge (x30 magnification). d: detail of micro-striations (x100 magnification).* ***Artifact nº 10.*** *a: microscopic view of the active end of the wear facet (x20 magnification). b: detail of microscopic wear with longitudinal micro-striations on the shiny relief (x50 magnification). c: detail of microscopic wear 5mm from the end where the longitudinal micro-striations and the few micro-pits (x100 magnification) can clearly be seen on the domed raised areas. d: detail of microscopic wear 1cm from the end in an area with well-developed macro-striations (x100 magnification).*

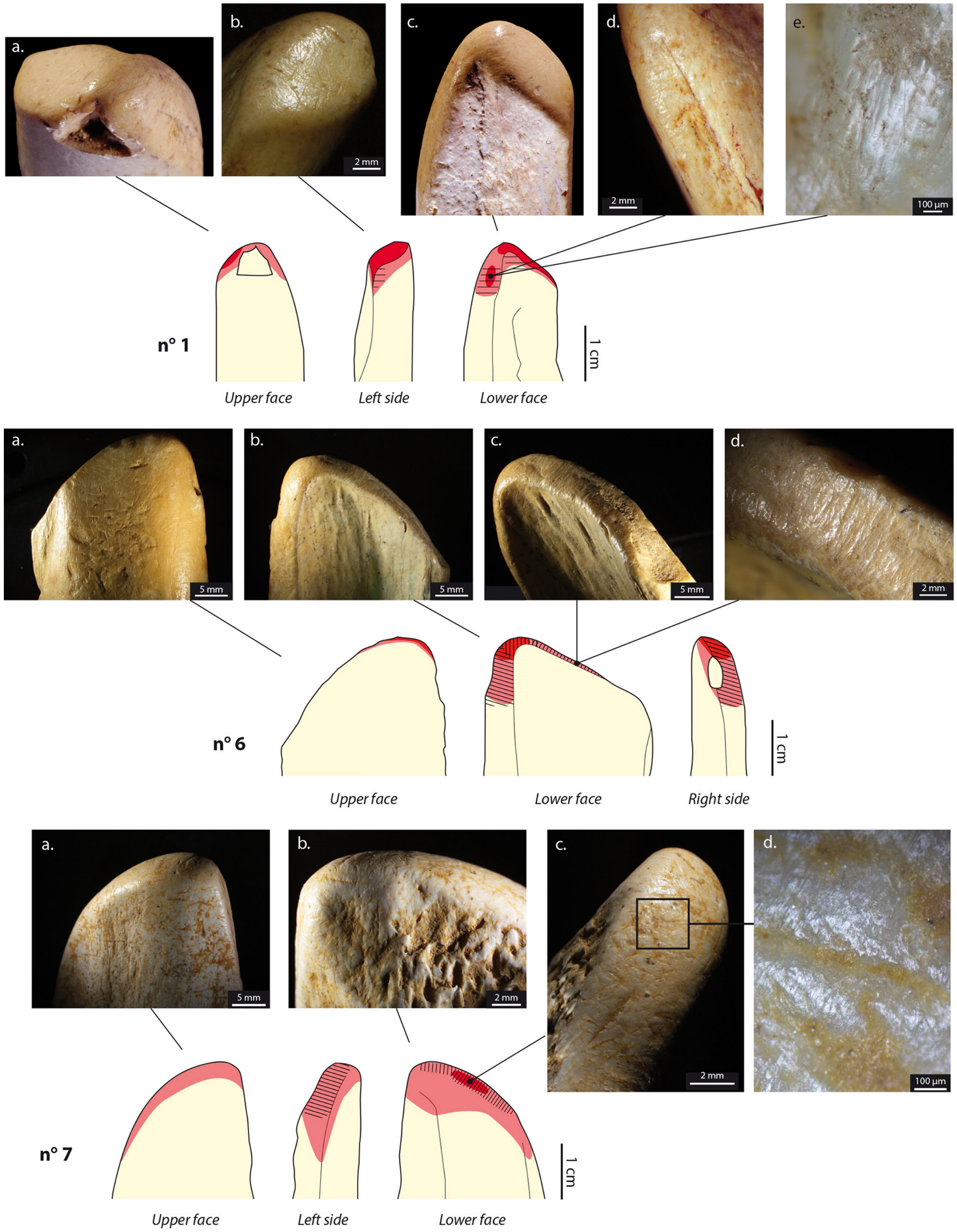


*Figure 4. Traces of macro- and microscopic wear on broad tools (for illustration legends see Figure 3)* ***. Artifact nº 1.*** *a: view of the heavily smoothed end and upper surface with a scar negative. b: macroscopic view of the wear facet with heavily smoothed edges (x10 magnification). c: macroscopic view of lower surface. d: macroscopic view of transverse macro-striations on the right edge (x10 magnification). e: microscopic wear on the left edge exhibiting intersecting, short and fine micro-striations (x100 magnification).* ***Artifact nº 6.*** *a: macroscopic view of the upper surface of the working end. Note the occurrence of chipping slightly above the area used as a retoucher (x3.75 magnification). b: macroscopic view of the lower surface of the end. The smoothing of the volume mainly affects the most convex area of the terminal fracture plane, where the macro-striations are most smoothed (x3.75 magnification). c. view of longitudinal macro-striations on the end (x5 magnification). d: detail of macro-striations (x15 magnification).* ***Artifact nº 7.*** *a: view of the upper surface of the working end with clearly identifiable smoothing (x5 magnification). b: view of the lower surface of the end with smoothing exposing spongy tissue (x10 magnification). c-d: view of the left edge exhibiting transverse macro-striations (x100 magnification).*

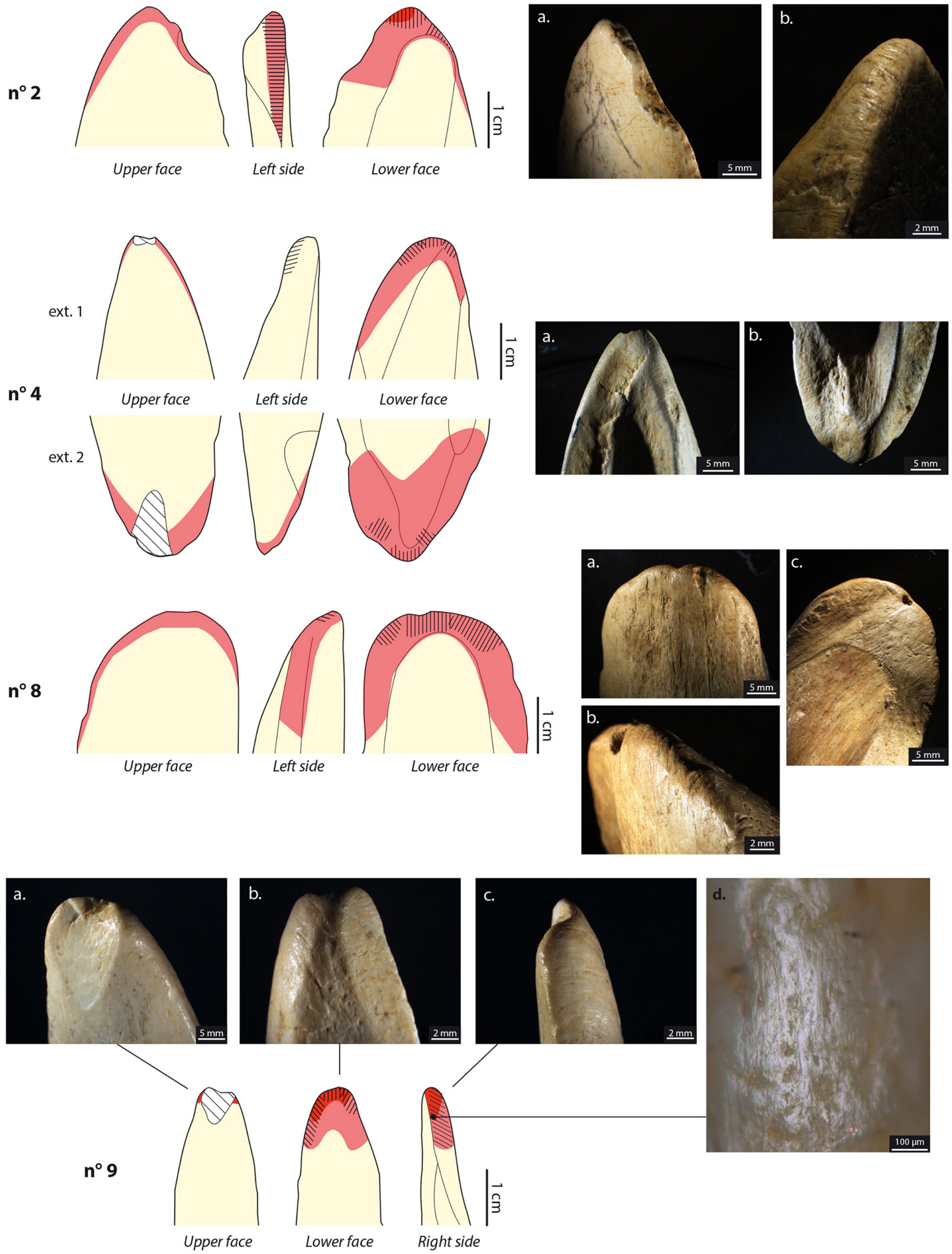


*Figure 5. Traces of macro- and microscopic wear on rounded tools (for illustration legends, see Figure 3).* ***Artifact nº 2.*** *a: view of the working end (upper surface and right edge). Smoothing also affects the area with the flake scar (x5 magnification). b: view of transverse macro-striations (x10 magnification) on the left edge.* ***Artifact nº 4.*** *a: view of the lower surface of end 1, which exhibits both smoothing and macro-striations (x5 magnification). b: view of the lower face of end 2 with smoothing and macro-striations (x5 magnification). No microscopic wear was preserved on this artifact.* ***Artifact nº 8.*** *a: view of the upper surface of the working end with clear traces of smoothing (x5 magnification). b: view of the rounded end and macro-striations along the axis of the artifact (x5 magnification). c. detail of smoothing and macro-striations on the lower surface (x5 magnification). No microscopic wear was preserved on this artifact.* ***Artifact nº 9.*** *a: macroscopic view of the upper surface of the active part (x10 magnification). b: macroscopic view of the lower surface of the tool's active part (x10 magnification). c: macroscopic view of right edge. Smoothing affects the lower surface and slightly extends onto the upper surface and is associated with transverse macro-striations (x10 magnification). d: microscopic wear on the left side, 5mm from the end. Fine, organized and parallel longitudinal micro-striations are also evident (x100 magnification).*

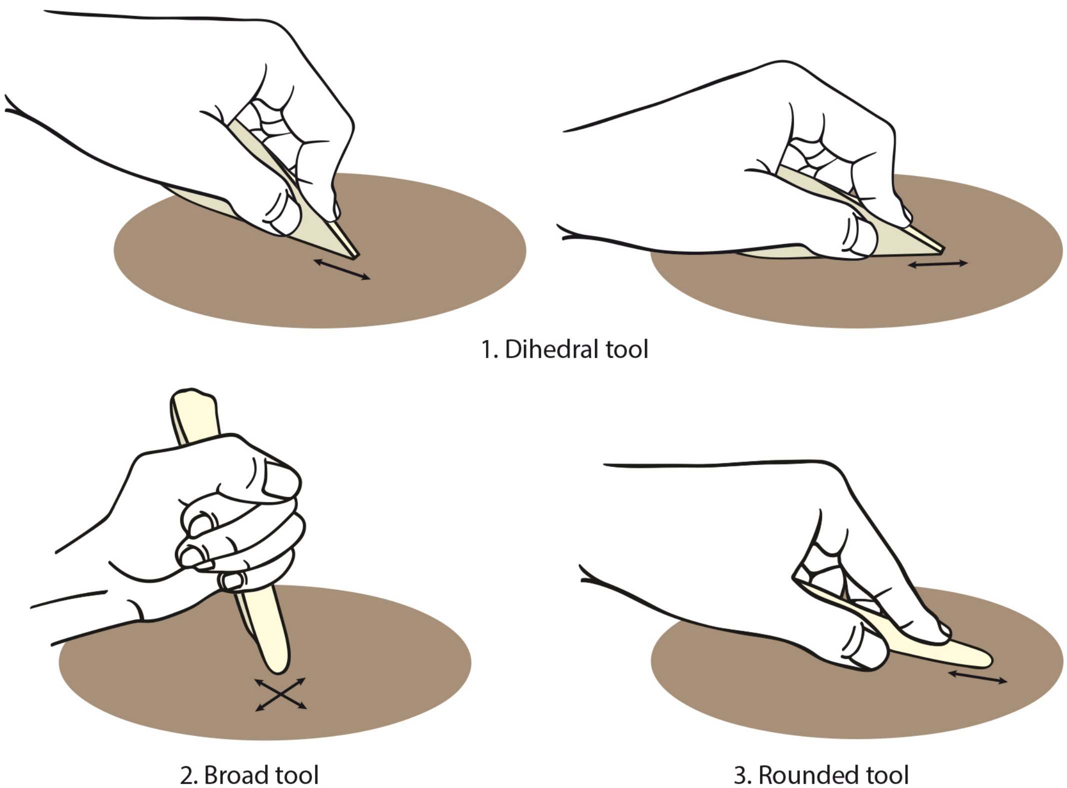


*Figure 6. Hypotheses for tool prehension and use (DAO F. Teissier).*

(producing a fan-shaped arrangement of the striations) or perpendicular to the artifact's long axis. Where it could be determined with certainty, macro-striations always pre-date smoothing. In all likelihood, they result from abrasion with a stone, which was designed to level the surfaces and soften the sharp edges of the tool's active parts before use. This would explain both why they pre-date the other traces and their "fresh" appearance on the periphery of certain active areas that did not come in contact with the worked material.

## Use of Ends

Of the three artifact types, dihedral tools preserve the clearest traces of use (see Figure 3). The initial volume of the tool blank is only moderately modified. Wear is preferentially located on one of the two lateral fracture planes (left or right) over a length of between 20mm to 30mm, including the dihedral-end, and slightly overlaps onto the opposite surface. Smoothing is very well preserved and is covered with fine, long, longitudinal and parallel striations (see Figure 3: 3c,d, 5d, and 10c,d). On one artifact, this wear co-occurs with a slight compression of the bone fibers, probably as a result of heavy pressure (see Figure 3: 5a). The microtopography is moderately worn, with the convex raised areas exhibiting either a smooth (see Figure 3: 3c,d and 10c,d) or slightly grainy texture (see Figure 3: 5d), and a few micro-pits (see Figure 3: 3c,d and 10c,d). These different macro and microscopic traces result from the repeated rubbing of a supple, enveloping material. The tools were probably held between the thumb and fingers and used in short, longitudinal movements in relation to the axis of the tool while varying the contact angle with the worked material (Figure 6: 1)—from a wide angle (close to 45°) with a limited contact surface area at the dihedral-end to a more acute angle (around 10°) with a 2cm to 3cm long contact surface. Based on comparisons with wear observed on experimental points and cutting edges (Christidou and Legrand 2005; Legrand 2007, 2017), the tools were used to work dry skins. If the tools were used as awls, as envisaged by F. Bordes (see above), wear would not be limited to a single fracture plane but would be present on both fracture planes and adjacent surfaces.

Broad tools (see Figure 4) display the most wear. Artifact nº 1 features an oblique 10mm by 5mm smoothed wear facet on the left side (see Figure 4: 1b) that extends onto the right side and slightly onto the upper surface, where it cuts the upper part of a triangular flake scar (possibly reflecting debitage?), as evidenced by significant wear on the ridges (see Figure 4: 1a). The surface exhibits numerous short, intersecting, multi-directional micro-striations combined with moderate wear of the microtopography (see Figure 4: 1e). The terminal fracture plane and spongy lower surface of artifact nº 7 display heavily developed smoothing over a 25mm by 10mm area (see Figure 4: 7ab). Wear on the surfaces is only partially preserved, and takes the form of clearly visible oblique, long, and parallel micro-striations on the raised areas of the microtopography (see Figure 4: 7d). Artifact nº 6 exhibits less-developed wear; smoothing extends over the entire width of the end but is especially well-developed in the convex area on the right side, overlapping slightly onto the adjacent surfaces (see Figure 4: 6ab) that bear long, oblique, parallel micro-striations. These traces are referable to the rubbing of a supple enveloping material. The tools were likely held with the whole hand during long, uni- or multi-directional movements involving a wide contact angle (between 70° and 80°) with the worked material (see Figure 6: 2).

Rounded tools (see Figure 5) exhibit varying degrees of wear and all display smoothing on the lower surface of the rounded active part of the tool that extends onto the cutting edge, overlapping slightly onto the upper surface. The initial blank morphology of artifact nº 2 is heavily modified, with particularly marked smoothing on the left edge (see Figure 5: 2a,b) associated with several fine, parallel, longitudinal micro-striations near the end. The entire active area of artifact nº 9 is smoothed, with more developed traces on the right edge where the ridges are clearly smoothed. Although micro-wear is generally poorly preserved, a few residual longitudinal micro-striations are nevertheless visible on the right edge (see Figure 5: 9d). A flake removal has shaved off part of the wear traces in the center of the rounded upper surface (see Figure 5: 9a). Artifact nº 4 differs from the above examples in that both ends display significant use-induced smoothing principally on the lower surface and cutting edge (see Figure 5: 4a,b). Due to insufficient preservation, no additional microscopic use-wear could be identified. Artifact nº 8 also stands out given its distinctly beveled end forming a 40° angle. The form of the tool's original blank is heavily modified; the cutting edge and the entire width of the bevel on the lower surface and a good portion of the upper surface are heavily smoothed (see Figure 5: 8a,b,c). While no microscopic wear is observable, even under high magnification, the macro- and microscopic traces again suggest the tool was used to rub a supple, enveloping material. These tools were probably held between the fingers and thumb, maintaining a narrow angle with the worked material (from 20° to 45°) while exerting pressure in short longitudinal movements (see Figure 6: 3).

After leveling by abrasion, the tools were used to rub a supple, enveloping material according to different motions depending on the morphology of the active end. The excellent preservation of the wear on the dihedral tools identifies this material as dry hide. The microscopic wear on both the broad and rounded tools is not sufficiently well preserved to identify the specific material worked. However, it is likely that they also served to work hides given clear similarities with the wear on the dihedral tools. In addition, the active parts of both tools were created using identical methods. Finally, given the mode of use and the range of soft or supple materials likely to be worked (e.g., meat, hide, plant fibers, and loose soil: Claud et al. 2019b), their use on hides is the most parsimonious hypothesis. This would be consistent with a previous use-wear analysis of Quina scrapers (n=12) from the same levels demonstrating them to have been used to work soft materials (Beyries and Walter 1996), a pattern also documented for other Quina assemblages (Beyries 1988; Claud et al. 2012). Similar data is still unavailable for the Combe-Grenal Levallois level (35) from which two of the studied artifacts derive.

### SURFACE WEAR

Half of the artifacts (n=5) also bear characteristic evidence of their use as retouchers (Figure 7) in the form of clustered linear or punctiform depressions on cortical surfaces near the ends of the tool. These depressions have V-shaped cross-sections with asymmetric edges and result from percussion on the edge of a stone tool (Mallye et al. 2012; Patou-Mathis 2002; see Hutson et al. 2018 for a review). These traces often co-occur with fine perpendicular striations, which result from the retoucher sliding over the edge of the stone tool after impact (Tartar 2012). Although doubts remain for certain assemblages[1], it is generally accepted that these objects served as small retouchers for shaping and/or re-sharpening stone tools.

The Combe-Grenal retouchers come uniquely from the Quina levels and include all three morpho-functional types (one broad, two rounded, and two dihedral tools). Apart from one of the dihedral tools (nº 5), all retouchers exhibit two areas (n=9) with traces of use at both ends, in the form of scoring on the cortical surface oriented obliquely to the long axis.

As the use of these artifacts on hides and stone tools did not involve the same active areas, no chronological relationship can be established for the two uses. Among the retouchers, one broad (artifact nº 6) and one rounded tool (artifact nº 4) exhibit large areas of use (length exceeding 45mm) composed of long, deep, concentrated, and superimposed scoring combined with scaled areas created by the detachment of small slivers of bone (see Figure 7). These pieces are very similar to the group 1 tools of Costamagno et al.'s (2018) typology for the Les Pradelles retouchers (facies 4a), which they attributed to the shaping and maintenance of Quina scrapers. This process involves a particular type of retouch that reduces the initial angle of the cutting edge using a blow that rips across the tool's surface, leaving relatively deep scar negatives (Bourguignon 1997; Mozota 2009). The weight of the dense bone retoucher is roughly proportional to that of the stone tools. The other three retouchers are lighter bone fragments and comprise one rounded (artifact nº 2) and two dihedral tools (artifact nº 3 and nº 5), all of which exhibit much smaller areas of use (20mm to 30mm in length). The depressions are shorter, shallow, and superficial, relatively dispersed and without any visible loss of material (see Figure 7), traits consistent with the retouching of lighter stone tools in a short operational sequence.

## DISCUSSION

### THE COMBE-GRENAL BONE TOOLS IN THE HIDE PROCESSING SEQUENCE

Hide processing involves multiple stages and requires different types of tools, whether in stone, bone, or other materials. Our use-wear analysis of the three types of bone tools from Combe-Grenal demonstrates them to have been used


*Figure 7. Combe-Grenal retouchers.*

in specific ways, making it necessary to explore how they complemented stone tools and in what stage of hide processing they were used.

### Primary Hide Processing Stages

Ethnographic studies and archaeological research focusing on hide processing have documented significant variability in the successive stages of the treatment and processing of animal hides (Beyries 2002; Hayden 2002; Hincker 2002; Ibanez et al. 2002; Robbe 1975). The first step, *defleshing*, involves the removal of remnant flesh and fat from the hide. This is absolutely fundamental in order to avoid the hide decomposing, and is therefore associated with even the most basic hide processing techniques (Hayden 2002). Defleshing can involve both fresh and dry hides, stretched or not, with or without the introduction of additives, and usually requires tools with convex edges (essential for processing fresh skins). While several ethnographic studies report the use of sharp bone tools (Steinbring 1966; Teite 1900; Vanstone 1994), the use of stone tools is far more common (Beyries 1988; Chahine 2002; Claud et al. 2019d).

After defleshing, the hide remains sensitive to the effects of humidity and can become very stiff if dried, limiting its potential uses and durability. The second stage, *tanning*, avoids the hide rotting, while at the same time rendering it water-resistant using an irreversible chemical combination of collagen and a tanning agent. Tanning with fat-rich animal elements, such as brain or liver, or smoke tanning, sometimes referred to as "*pseudo-tanning*," are the most basic tanning forms and the most compatible with the nomadic lifestyle of prehistoric groups (Chahine 2002; Robbe 1975). In the first step, fat is applied to the softened hide, stretched or not, and replaces the hide's natural water content. While tools can be used to spread the fat and work it into the hide, they are not essential, particularly for smoke tanning.

If hides are only tanned, they risk gradually drying out, with skin fibers clumping together to form a stiff mass. To avoid this, a third step, *currying*, softens the hide by crushing and stretching dried fibers, possibly involving the introduction of abrasive agents. A hide tensioning device, either placed directly on the ground or involving a wooden frame, is generally employed to facilitate tool use and to prevent the hide from shrinking too much as it dries (Hatt 1969; Steinbring 1966; Teite 1900). This stage does not necessarily require sharp tools and often involves unmodified pebbles or blunt implements made of wood or bone, which are less likely to pierce or damage hides (Adams 1988; Teite 1900). Hides can also be softened without tools; for example, by hand or by rubbing against a tree trunk, although the latter requires significant physical investment. Finally, a second currying phase, distinct from softening, is designed to standardize, soften, dye, or thin hides (Chahine 2002). This *finishing stage* can involve different tools as well as the addition of dyes, abrasives, or fats to improve the final appearance of the skin.

### Lithic Use-Wear Data

The first use-wear studies focusing on Mousterian stone tools in France produced evidence of hide processing (Anderson-Gerfaud 1981; Beyries 1987, 1988). However, it was not until the 2000s that researchers mobilized experimental data in order to reconstruct tool movements and accurately place them in various stages of hide processing. The pioneering work of C. Lemorini (2000) with material from La Combette and La Grotta Breuil paved the way for a new generation of use-wear studies (e.g., Claud 2008; Coudenneau 2004). More recently, a collective research program, "*Des Traces et des Hommes*" (coordinated by C. Thiébaut, E. Claud, and S. Costamagno) produced, in addition to new use-wear data from previously unpublished assemblages, a comprehensive review of available data for hide processing during the Middle Paleolithic of Western Europe (Thiébaut et al. 2019). To date, hide processing has been identified in some fifty stone tool assemblages associated with different flake production systems (Levallois, Discoid, Quina). This evidence varies from a handful of tools, as at Fumane in Italy (units BR4 and BR5, Lemorini et al. 1999), to considerably larger numbers of pieces, as at Chez-Pinaud in southwestern France (SU 22, Claud et al. 2012). It is important to note that this work also highlighted difficulties in reliably attributing use-wear on stone tools to a precise stage in the hide-working process. While hide condition is crucial, there is a continuum between fresh and dry hide and numerous factors influence the nature of the traces, such as addition of additives (ash, dye) or the use of other materials (earth, stone, wooden frame; Claud et al. 2019c). The freshness of the hide and the action of the tool may also be common to multiple stages of hide processing. Finally, the same tool can be used in several tasks, complicating placing its use to a particular stage of the hide-working process.

By far the best documented activity is the defleshing of fresh hides, which involves the cutting or scraping of hides in a tangential motion using tools with convex edges, mainly scrapers and unmodified flakes (Claud et 2012; Lemorini 2000; see Costamagno et al. 2019 for a review). The scraping of dry hides has also been documented at a number of Middle Paleolithic sites; however, its interpretation systematically raises questions. For example, is the defleshing of dry hides linked to a softening phase or does it reflect the repair of leather objects? The presence of ochre on stone tools used to scrape hides at La Cantalouette II (Bourguigon et al. 2008) could be related to the defleshing of dry hides, while a small number of artifacts from the Abri du Musée, Champ-Grand, and Latrote potentially suggests the maintenance of leather objects (Costamagno et al. 2019). At several sites, such as Fonseigner, La Combette, and Axlor, the relative diversity of hide processing tools, the identification of distinct use modes and different degrees of hide freshness suggest a hide-working process that included defleshing and pseudo-tanning. The latter may have involved an animal-derived additive, such as brain or liver, similar to what was documented at La Combette (Lemorini 2000). On the other hand, the later stages of hide-processing, in particular currying, include both hide softening and finishing and have never been reliably identified in the archaeological record. This is likely due to difficulties in interpreting activities linked to the processing of dry hides and, more importantly, the fact that these stages do not always require tools or involve tools made from materials other than flint (wood, bone, pebbles). Lithic use-wear analysis therefore allows only part of the multiple potential hideworking methods to be reliable reconstructed. Complementary hide processing tools are therefore potentially to be found among the other types of materials in archaeological assemblages, namely bone.

## The Combe-Grenal Bone Tools for Sophisticated Hide Processing

As defleshing requires sharp tools, the smooth-ended bone tools from Combe-Grenal were in all likelihood used in a later stage of the hide-working process, namely currying. Their morpho-functional characteristics, associated tool movement, and type of prehension (see above) suggest three distinct functions. The broad tools display heavily-developed wear, suggesting they were used with two hands while applying significant pressure in long movements during the **first softening stage** when the hide was still hard. The hide was likely stretched either on the ground or on a frame. The multidirectional striations on the wear facet of artifact nº 1 could reflect the presence of a fine abrasive material on the hide. The extent of wear and the movement involved (unidirectional longitudinal movement of moderate magnitude) in the use of rounded tools suggest less pressure was applied to the hide during use. These tools seem to have been used during a **later softening stage** involving a hide that had already been given a certain degree of suppleness. Finally, the dihedral tools with narrow active ends suggest more delicate work involving shorter movements on small surface areas. Hypothetically, these tools may have been reserved for working the more delicate areas of hides, such as the difficult to soften edges of hides or for the hides of small game, in the **final softening stage** or during **finishing.**

These three functional hypotheses bear interesting parallels with the differences in traces observed on the five tools used as retouchers (see above). As a hypothesis, hide processing tools may have intermittently been used as retouchers to maintain stone tools used during hide working—Quina scrapers during the first stages of softening and lighter stone tools in the later stages of the process.

The Combe-Grenal bone tools are not the first Middle Paleolithic examples to have been linked to hide softening. Several tools identified as smoothers have been reported from sites in Spain and France. A red deer rib with a distal, tongue-shaped fracture displaying significant traces of wear has been described from level F of Axlor (Biscay, Spain; Mozota Holgueras 2012). Observations with a binocular and metallographic microscope revealed the presence of an overlying polish with a fatty aspect and thin, sometimes parallel striations accompanied by more randomly oriented ones. While this evidence has been described as "*characteristic of working hides*" (Mozota Holgueras 2012: 206), the author does not specify the freshness of the hide, tool movement, or the likely processing phase during which it was used. Four additional specimens have been reported from the "Mousterian of Acheulean Tradition" levels of Pech de l'Azé I (level 4; n=1) and Abri Peyrony (levels 3A and 3B; n=3; Soressi et al. 2013), although only the artifact from Pech de l'Azé I preserved interpretable traces of wear. These pieces were initially assigned to medium-sized ungulates (reindeer or red deer) based on traditional morphological criteria (Soressi et al. 2013). However, a recent reassessment of their taxonomy using a non-destructive ZooMS methodology demonstrates that the Abri Peyrony smoothers were made on large bovids ribs (Martisius et al. 2020b). These pieces all have a smoothed, ogival end. One specimen from Abri Peyrony exhibits a series of parallel striations near the end and along one edge, with the ends modified by abrasion on a hard, granular material. The Pech de l'Azé I example bears a smoothed, slightly compressed surface associated with a polish covered in organized striations, some long and shiny, others shorter and finer. Given the morphology of the artifact and wear, the authors conclude that it was used to rub a supple material, most likely a dry hide, in repetitive longitudinal movements, suggestive of its use during the hide softening stage. Finally, Baumann et al. (2020) recently published a detailed description of more than 700 bone tools (mainly retouchers, but also retouched artifacts, several intermediate artifacts, and pieces with smoothed ends) from the Mousterian levels of Chagyrskaya Cave in the Altai region of Russia. Dated to around 50,000 years BP, this rich collection of material included 14 diaphyseal or rib fragments with smooth ends that were either abraded or used unmodified. Among the Chagyrskaya tools, three have been associated with hide processing given that *"their size, the morphology of their active end and their use wear, fit well with the evoked leather dressmaking technique"* (Baumann et al. 2020: 16).

The Combe-Grenal tools differ from these artifacts in terms of the blanks selected. Unlike the majority of currently known Mousterian bone tools, the Combe-Grenal examples are made on shaft fragments rather than on ribs. In this sense, they are more similar to the bone smoothers reported from the Lower Paleolithic sites of Schöningen and Castel di Guido (Julien et al. 2015; Villa et al. 2021). With that said, the Combe-Grenal tools are particularly distinctive in that they can be divided into three types, each likely associated with a distinct role in the hide working process. Taken together, they potentially represent a complete tool kit for softening and finishing hides, complementing data from lithic use-wear analyses and demonstrating Mousterian hide-working to have been a particularly complex process, at least for Quina groups in that these levels yielded all three bone tool types. The Combe-Grenal hide-working evidence is compatible with the final stage (stage 3) of hide preparation according to Hayden's classification, involving more time, care, and energy (Hayden 2002: 205). Hides treated in this way become more supple and flexible, readying them for transformation into a wide range of items (bedding, screens, bags, etc.) and, most importantly, the production of sophisticated garments to protect against cold and inclement weather. The production of clothes undoubtedly required more technical investment compared to other items. While opinions differ, the majority of researchers agree that such a level of sophistication was not possible in Europe before the beginning of the Upper Paleolithic. Several attempts have, however, been made to identify the type of clothing likely to have been made and worn by Neanderthals and modern humans based on various indirect data (e.g., climatic conditions, physiological adaptations to the cold, the presence or absence of fur-bearing animal remains on sites) and ethnographic evidence. While some consider both human groups to have had complex garments of comparable quality (White 2006; Sørensen 2009), the consensus remains that Neanderthals wore simpler, cloak-like garments (Collard et al. 2016; Hayden 2002; Gilligan 2007; Wales 2012) that were ill-suited to the sometimes severe climatic conditions of MIS 3, potentially contributing to their extinction (Wales 2012). One of the arguments often put forward in support of this theory is that, unlike the Upper Paleolithic, there were no specialized hide processing tools or tools advanced enough for sophisticated hide processing during the Middle Paleolithic (Gilligan 2007). While the Combe-Grenal bone tools demonstrate otherwise, the absence of additional evidence for sophisticated hide-working techniques is potentially linked to the perishable nature of the materials used to produce tools, for example wood, which are unlikely to leave any tangible trace in the archaeological record.

## TECHNO-FUNCTIONAL CHARACTERIZATION OF THE COMBE-GRENAL BONE TOOLS AND THE INFORMATIVE POTENTIAL OF INFORMAL MOUSTERIAN BONE TOOLS

The Combe-Grenal tools also show that the specialized (or not) function of a tool has little to nothing to do with the degree of technical investment involved in its manufacture, and that complex activities do not necessarily require complex tools. In this respect, the informal Mousterian bone tools from Combe-Grenal have significant informative potential. However, to understand this clearly, their techno-functional characteristics need to be assessed, as does their articulation with the broader technical and socio-economic context of Paleolithic osseous technologies.

In terms of technology, the Combe-Grenal bone tools are not elaborate and were not ‘debited’ but were instead made on diaphyseal fragments broken during carcass processing. Their active parts were created by abrasion, which is limited in extent and reflects cursory modifications rather than the genuine shaping of the active end. As such, these pieces represent neither formal nor standardized tools (d’Errico et al. 2012a; Johnson et al. 2000; Klein 1989, 2000). Functionally, however, they are undoubtedly specialized tools. Each of the three Combe-Grenal types was probably dedicated to a specific task in the hide processing procedure, half of which were also used as retouchers, potentially to shape and re-sharpen stone tools used in the same activities. While some exhibit heavy wear consistent with intense use, a single episode involving the processing of several hides prior to the tools’ abandonment cannot be excluded. The absence of evidence for maintenance clearly corresponds to the definition of expedient tools (Binford 1979; Lyman 1984) and would be consistent with the Combe-Grenal examples representing a set of informal, expedient, but specialized tools.

In Europe, the emergence of specialized bone tools is often associated with the Upper Paleolithic, with “special purpose tools” considered one of the archeological signatures of behavioral modernity (McBrearty and Brooks 2000). However, the Combe-Grenal tools are not the first examples of informal specialized tools from contexts predating the Upper Paleolithic. Several examples have been reported from significantly older contexts, including implements to exploit termite mounds from Swartkrans and Sterkfontein in South Africa, dated to between 1.8 and 1 million years ago (Backwell and d’Errico 2001; d’Errico and Backwell 2003). At least some of the most common Middle Paleolithic bone tools, retouchers, especially those used to shape and resharpen Quina scrapers (Costamagno et al. 2018), can safely be described as specialized tools. Disagreements concerning the interpretation of such tools are due to the fact that they are often considered to have undergone substantial modifications to adapt them to specific functions. However, this ignores the fact that carcass processing provides a wide range of fragments, whose various morphologies are suitable for multiple uses. The advent of the Upper Paleolithic therefore is not coincident with an increase in specialized bone tools, but rather the appearance of the first formal tools, designed for working hard animal materials and possibly requiring significant technical investment. In Europe, these tools first appear during the Middle-to-Upper Paleolithic transition in techno-complexes associated with both modern humans and Neanderthals (Baffier and Julien 1990; d’Errico et al. 1998, 2003, 2012b; Soulier et al. 2014; Tartar 2015). However, the widespread production of diverse tools in bone, antler, and ivory using techniques of varying complexity emerges only with the Early Aurignacian. Specialized tools are well represented in these assemblages, whether for hunting, in the form of split-based bone points, or for domestic activities, with smoothers and certain awls for the softening and sewing of hides, respectively. These tools had considerably long use-lives and required considerable technical investment (Tartar 2009, 2015; Tartar et al. 2006). For example, smoothers were used in relatively long and complex operational sequences and are frequently decorated with incisions. This is particularly noteworthy, as decorated objects are very rare in the Aurignacian and mostly concern personal ornaments and mobiliary art. Numerous Aurignacian assemblages have also yielded a very particular category of awls made from the mesio-proximal portions of horse metapodials, with the proximal end used to grip the tool. These objects were maintained by successive resharpening episodes throughout their long use-lives, with significant care evident in both their manufacture and upkeep, suggesting they formed part of personal tool kits (Tartar 2015).

In technological terms, our reassessment of the Combe-Grenal bone tools shows them to be consistent with the range of bone tools currently known for the Middle Paleolithic but distinct from the specialized tools associated with the earliest stages of the Upper Paleolithic. Functionally, however, these tools reflect hide processing practices that were previously difficult to detect in the Middle Paleolithic archaeological record. What is particularly interesting about these tools is the juxtaposition of limited technical investment in their manufacture with a highly specialized use involving a clear degree of expertise. Any activity, and more particularly one involving the processing of perishable materials, generally becomes "visible" archeologically only once it forms an important and regular feature of the group's techno-economic system. This tangible, archaeological visibility is most often manifested in the use of specific, standardized tools. The same applies to hide processing tools (e.g., endscrapers on blades, smoothers, awls) found in Early Aurignacian base camps, whose abundance and diversity, combined with additional more or less direct evidence, including cutmarks on bones from a wide range of large-bodied species as well as the processing and intensive use of ochre, clearly demonstrate that elaborate hide processing was a major economic activity for these groups. These activities are equally evident in the techno-economic organization of Early Aurignacian groups. The existence of independent operational sequences for blade and bladelet production designed to fulfill, respectively, domestic or hunting needs, and the diverse range of retouched stone tools on blade blanks reflect clear economic choices and technical intentions (Bon 2009). Conversely, the activities carried out at Mousterian sites are more difficult to identify— the period's stone tool industries primarily concern the production of flakes that could fulfill a wide range of needs. These flakes were often used unmodified to work different materials in a variety of ways (e.g., cutting meat or hides, scraping semi-hard to hard materials, butchery, piercing; Claud et al. 2019a). This wide range of uses is also the case for retouched tools, even the most heavily processed ones, including the highly versatile Quina scrapers that were used both for defleshing hides as well as for butchery (Claud et al. 2019a; Lemorini et al. 2016). These scrapers also frequently served as cores for the production of a new generation of tools (Delagnes et al. 2007). This ramification of the reduction sequence (Bourguignon et al. 2004) has been identified in all the major Mousterian flake production systems (e.g., Quina, Levallois, Discoid), further complicating understanding the structure of Middle Paleolithic lithic technology. Compared to Upper Paleolithic economic patterns, identifying intentions behind stone tool production and use during the Middle Paleolithic and their articulation with broader socio-economic systems is less straight-forward. Faced with these difficulties, Mousterian informal bone tools represent a precious asset for shedding new light on activities with a typically weak archeological signature, thus providing a more accurate picture of the skills and techniques used by Neanderthal groups to fulfill specific needs.

## CONCLUSION

During the first half of the 20th century, E. Peyrony followed by F. Bordes reported bone fragments with heavily-smoothed ends among faunal remains recovered during their work at Combe-Grenal. More than half a century later, our revision of the Combe-Grenal material focused on a technological, morphometric, and functional analysis of 10 particularly well-preserved examples from the site's Quina and Levallois levels. These diaphyseal fragments, mainly from red deer long bones, can be divided into three morpho-functional types: broad (n=3), rounded (n=4) and dihedral tools (n=3). Their active ends were first abraded in order to smooth the surface of the bone and blunt the sharp edges. They were subsequently used to rub a supple enveloping material identified as dry hide during what was likely the softening stage of hide-working, where hides that were already defleshed using stone tools are rubbed to render them supple and more flexible. The different Combe-Grenal bone tools were probably used during successive stages in the softening process—broad tools at the beginning, rounded ones during the intermediate phase, and dihedral tools during the final phase and/or for the processing of fine, delicate hides. Examples of each type were also used as retouchers, possibly to shape and re-sharpen stone tools involved in the same hide processing phases. These informal, expedient but specialized tools therefore would represent a complete tool set for softening hides. While lithic use-wear analysis most often provides information concerning only the very first stages of hide-working, our analysis of the Combe-Grenal bone tools reveals hides to have undergone a complex and sophisticated processing for the production of a wide range of items, particularly clothing to protect against cold and bad weather. Until now, this level of sophistication was attributed solely to anatomically modern humans. In addition to new data concerning Middle Paleolithic hide processing, our results expose the significant informative potential of informal bone tools for better understanding the complexity and diversity of Neanderthal behavior. They demonstrate that tools with little technical investment can nevertheless fulfill specialized functions requiring elevated skill levels. In this respect, the continued documentation of informal bone tools from additional contexts should help better frame assessments of Mousterian industrial variability and its interpretation.

With regard to the place of osseous materials in debates on human evolution, formal tools continue to be considered an important marker of behavioral modernity. However, the appearance of osseous tools that accompanied the dispersal of anatomically modern humans into Europe did not necessarily require new skills. Nor, in all probability, did these tools meet new needs, but rather represented a technical solution to the increased need to fulfill preexisting tasks. The behavioral "leap" coincident with the beginning of the Upper Paleolithic is thus evidence for profound changes that were undoubtedly less cognitive than they were socio-economic (Bon 2009). Maintaining an emphasis uniquely on formal bone tools masks the evolutionary mechanisms that should be the focus of research. Data accumulated to date confirm that bone formed an integral part of the range of materials used by different Neanderthal groups. Despite additional discoveries of Middle Paleolithic bone tools over the last ten years or so, such cases remain isolated and are still insufficient to generate a precise understanding of the role of these materials in Neanderthal techno-economic behavior. This lack of archaeological visibility also limits discussions concerning the socio-economic mechanisms that led to the rise of complex technologies based on hard animal materials at the end of the Middle Paleolithic and into earliest stages of the Upper Paleolithic. As such, future studies of informal bone tools should take as a starting point: 1) the systematic search for these artifact types during excavations; 2) a re-examination of assemblages that were previously reported as containing bone tools but which have not been the subject of any detailed analysis; and, 3) the incorporation of use-wear analysis in bone tool research. With regard more specifically to hide processing tools, research should be extended to other Quina and non-Quina sites for which lithic use-wear analysis has already documented such activities, particularly base camps that are commonly considered to have seen the bulk of hide processing during the Middle Paleolithic. Such a multi-aspect approach is likely to produce a clearer understanding of the importance of bone tools in hide processing and the extent and variability of this activity within the different Mousterian techno-complexes.

## ACKNOWLEDGEMENTS

The authors would like to thank the staff of the Musée National de Préhistoire (Les Eyzies-de-Tayac), especially Jean-Jacques Cleyet-Merle, Catherine Cretin, Peggy Jacquement, Stéphane Madelaine and Bernard Nicolas, as well as Louis Iserentant (Legal and Industrial Affairs Officer, CNRS) for making the loan of the collection possible. We are also grateful to Jessica Lacarrière and Olivier Bignon-Lau for their assistance in anatomical part and species identification of the blanks. A big thanks to Fabien Teissier for the realization of Figure 6. We thank Brad Gravina for reviewing the English language and for constructive comments that helped to improve the manuscript. Finally, we are grateful to the two reviewers whose comments helped to better present our research. This research forms part of the NATCH (Neanderthalenses Aquitanensis: Territoires, Chronologie, Humanité) project financed by the Aquitaine Region, France (Dir. J.-P. Faivre).

## ENDNOTES

[1]Due to the presence of retouchers with atypical traces (Costamagno et al. 2018; Tartar 2019) or a very high retoucher/retouched tools ratio (Auguste 2002; Daujeard et al. 2014).

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