

# On the Quina side: A Neanderthal bone industry at Chez-Pinaud site, France

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1 On the Quina side: A Neanderthal bone industry at Chez-Pinaud site, France

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Malvina Baumann<sup>1</sup>¶, Hugues Plisson<sup>2</sup>¶, Serge Maury<sup>3</sup>¶, Sylvain Renou<sup>4</sup>&, Hélène
Coqueugniot<sup>2,5\*</sup>, Nicolas Vanderesse<sup>2</sup>&, Ksenyia Kolobova<sup>6\*</sup>, Svetlana Shnaider<sup>7</sup>\$, Veerle
Rots<sup>1\*</sup>, Guillaume Guérin<sup>8</sup>\$, William Rendu<sup>7</sup>&

- 6
- 7 1 TraceoLab, Liege University, Liege, Belgium
- 8 2 PACEA UMR 5199, CNRS, University of Bordeaux, Pessac, France
- 9 3 Les Eyzies-de-Tayac-Sireuil, France
- 10 4 Hadès, Agence Atlantique, Bordeaux, France
- 11 5 Ecole Pratique des Hautes Etudes-PSL University, Paris, France
- 12 6 Paleolithic Department, Institute of archaeology and Ethnography, Siberian Branch of the
- 13 Russian Academy of Sciences, Novosibirsk, Russian Federation
- 14 7 ZooSCAN, International Research Laboratory 2013, CNRS, Novosibirsk, Russian
- 15 Federation
- 16 8 Géosciences Rennes UMR 6118, CNRS, University of Rennes, Rennes, France
- 17
- 18 Corresponding author : <u>malvina.baumann@gmail.com</u>
- 19 ¶ These authors contributed equally to this work.
- 20 & These authors also contributed equally to this work.
- 21 \* These authors also contributed equally to this work.
- 22 \$ These authors also contributed equally to this work.

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# 25 Abstract

26

Did Neanderthal produce a bone industry? The recent discovery of a large bone tool 27 assemblage at the Neanderthal site of Chagyrskaya (Altai, Siberia, Russia) and the increasing 28 discoveries of isolated finds of bone tools in various Mousterian sites across Eurasia stimulate 29 the debate. Assuming that the isolate finds may be the tip of the iceberg and that the Siberian 30 occurrence did not result from a local adaptation of easternmost Neanderthals, we looked for 31 evidence of a similar industry in the Western side of their spread area. We assessed the bone 32 33 tool potential of the Quina bone-bed level currently under excavation at chez Pinaud site 34 (Jonzac, Charente-Maritime, France) and found as many bone tools as flint ones: not only the well-known retouchers but also beveled tools, retouched artifacts and a smooth-ended rib. Their 35 36 diversity opens a window on a range of activities not expected in a butchering site and not documented by the flint tools, all involved in the carcass processing. The re-use of 20% of the 37 bone blanks, which are mainly from large ungulates among faunal remains largely dominated 38 by reindeer, raises the question of blank procurement and management. From the Altai to the 39 Atlantic shore, through a multitude of sites where only a few objects have been reported so far, 40 41 evidence of a Neanderthal bone industry is emerging which provides new insights on Middle 42 Paleolithic subsistence strategies.

43

# 44 Introduction

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Around 48-45 000 BP, the anatomically modern humans (AMH) arrived in Western
Europe, while the last Neanderthals disappeared. This arrival resulted in significant changes in
archaeological material cultures that define the transition from the Middle to the Upper

Paleolithic. AMH brought with them a diversity of artifacts attesting of new practices. Bone materials became a privileged medium for the manufacture of objects, such as hunting weapons, ornaments or figurines, whose functional and social specialization appears clearly through advanced shaping, achieved by scraping or abrasion. In contrast, their absence in the Middle Paleolithic has led to the assessment that Neanderthal did not produce a bone industry [1–6].

54

The discovery of more than 1,200 bone tools at the Neanderthal site of Chagyrskaya 55 (Altai, Siberia, Russia) challenges this claim [7]. The cave deposits, accumulated in late Marine 56 Isotope Stage (MIS) 4 or early MIS 3, contained 74 human remains and a lithic industry 57 58 attesting to an occupation of the site by Neanderthals with cultural and genetic affinities to Micoquian groups from Central and Eastern Europe. Around 60,000 - 50,000 years BP, 59 Neanderthals repeatedly came to the site during the early cold season to process the carcasses 60 61 of hunted Bisons [8,9]. A technological and functional analysis of the faunal remains identified more than 1,000 retouchers and approximately 100 bone tools belonging to other functional 62 categories. Although their manufacture involved percussion, with marginal use of scraping and 63 abrasion, their number, diversity and recurrence lead to their consideration as an industry 64 (systematic and organized production of a set of tools) [7]. 65

66

To date, the Chagyrskaya bone tools provide the only example of a Neanderthal bone industry, at least, for which the authorship of AMH cannot be considered [10–12]. Bone tools have already been reported in Neanderthal sites but most of the time as isolated finds. A hundred kilometers away, such objects have been identified in contemporaneous levels of Denisova cave [13–15]. They may have been made, in part, by Neanderthals [9,16,17]. In addition to retouchers, some bone tools have also been reported in Crimean Micoquian assemblages from the sites of Prolom II [18], Kiik Koba [19], Karabi Tamchin [20], Zaskalnaya VI [21], and

possibly Buran-Kaya III [22], as well as at Kůlna [23], in the Czech Republic, or at Salzgitter-74 75 Lebenstedt [24] in Germany. Outside the Micoquian zone, examples of Mousterian bone tools are even more numerous. Some have been found in Ukraine at the Molodova I site [25], in 76 France, at the Bison Cave [26], at the sites of Combe-Grenal, La Ferrassie, La Quina [27–29], 77 Pech-de-l'Azé I, Abri Peyrony [30], Montgaudier [31], Vaufrey [32], Noisetier [33], Canalettes 78 [34], and Gatzarria [35], in Spain at the sites of Axlor [36], Bolomor [37], Arlange [38], Abric 79 Romaní [39], and in Italy, at Fumane Cave [40]. These discoveries, most of them recently 80 investigated, allow us to reconsider earlier ones which were potentially too readily dismissed 81 such as those of La Quina [41], Ourbières [42], Tourtoirac [43], Néron [44], Pié-Lombart [45], 82 83 Cuva Morín [46], Rigabe [47], Hauteroche or Bois-Roche [32].

84

The use of bone tools by Neanderthals is beginning to be discussed, if not accepted, 85 because of this increasing number of reported cases. Most of these examples, only marginally 86 shaped, mostly by percussion, have been identified without a precise methodological 87 framework [32]. When identifications are not based on comparison with Upper Paleolithic bone 88 tools, they are established from analytical criteria borrowed from lithic technology, or simply 89 proposed by default when no other explanation can be provided. Doubts often remain because 90 91 of a risk of confusion with forms resulting from natural alterations or butchery activities that may mimic, modify or erase traces of manufacture and use-wear traces [48-58]. As a 92 consequence, a small number of items have been reported in each site, and Neanderthal bone 93 94 tools, except retouchers, are still considered anecdotal. Because of their manufacturing techniques, bone is sometimes regarded as a substitute material [40,47,59,60]. This is likely due 95 to a lack of understanding of the physical properties of bone and insufficient recognition of its 96 mechanical qualities [32,61]. In any case, the diversity of published identification criteria and 97

98 vocabulary make comparisons between sites difficult and prevents a more comprehensive99 consideration of a Neanderthal specific bone technology.

100

Based on the bibliographic data and the results obtained at the Chagyrskaya Cave, we 101 hypothesize that the Neanderthals produced an original bone industry, different from the Upper 102 Paleolithic standards, especially due to the predominant use of percussion. In other words, the 103 104 scattered finds mentioned above could be indicative of a more general phenomenon in Neanderthal technology, which has so far been underestimated due to a lack of appropriate 105 methodological and conceptual frameworks of study. This could imply, on the one hand, that 106 107 the previously found bone tools in various Middle Paleolithic contexts are only the most visible part of a production whose main components are yet to be identified and, on the other hand, 108 that the Chagyrskaya bone industry is not a localized phenomenon resulting from a regional 109 110 adaptation of eastern Neanderthals. To test this hypothesis, we applied to the bone assemblage of a Neanderthal settlement in western Eurasia the same techno-functional analysis as in 111 Chagyrskaya, complemented with µCT imaging. 112

113

In 2019, the new excavation of Mousterian deposits at the Chez-Pinaud site (Jonzac, 114 115 Charente-Maritime, France) provided the opportunity to reconsider the faunal assemblage of a western Neanderthal settlement. At this multilayered site, the Quina facies, corresponding to 116 MIS 4, is characterized by a large bone-bed resulting from repeated seasonal occupations by 117 118 groups that came during the cold season to process the carcasses of hunted animals on their migration routes [62]. In previous excavations, this bone-bed yielded numerous bone retouchers 119 120 [63] indicating that bone was used as raw material for tool making. It is in this archaeological context, similar to that of Chagyrskaya in terms of activities and chronology, but geographically 121 and culturally distinct [8,9], that we sought new evidence of a Neanderthal bone industry. 122

123

The Chez-Pinaud site was discovered in the late 1990s by E. Marchais. It is located on 124 the right bank of the Seugne, a tributary of the Charente River (Fig 1a), at the foot of a cliff 125 where a limestone quarrying area partially destroyed the deposit, during the 19<sup>th</sup> century, but 126 also allowed its discovery [64]. It was excavated several times, in 1998-1999 and 2002-2003 127 by J. Airvaux, then between 2004 and 2007 by J. Jaubert and J.-J. Hublin. This fieldwork 128 campaigns revealed the presence of Early Upper Paleolithic occupations and significant Middle 129 Paleolithic levels attributed to three Mousterian facies: a Quina-type Mousterian, a denticulated 130 Mousterian and a Mousterian of Acheulean Tradition [63]. 131

132

Fig 1. The Chez-Pinaud site, Jonzac, France. (a) location of the site and the main surrounding
Quina site (geographical data republished from Géoportail.gouv.fr under a CC BY license, with
permission from IGN, original copyright 2022). (b) 3D photogrammetric model of the
excavated layer (photos and 3D processing: S. Shnaider). (c) layout of the excavation units
(CAD: M. Baumann).

138

In 2019, new excavations were initiated in the stratigraphic unit (US) 22 (Fig 1b), in 139 close proximity to the 2004-2007 excavation area. US22 is composed of a yellow-brown 140 sediment of clayey sands deposited by water and solifluction [63] (S1 Fig, a-b). Preliminary 141 studies of the lithic industry from the 2019-2020 campaigns are in line with the results of 142 previous excavations. Characteristic of the Quina facies, the lithic industry includes a high 143 proportion of tools, mainly side scrapers, and their shaping and resharpening waste, while nuclei 144 145 are rare. The contribution of exogenous raw materials and finished tools, in a context where high quality local flint is available, as well as the versatility of tools and the evidence of 146

recycling, suggest a sparing use of lithic raw material [65]. This could stem from the highseasonal mobility of Quina groups [66].

149

The faunal spectrum of the US22 is largely dominated by reindeer remains (Rangifer 150 tarandus), a marker of a cold, dry and open environment [67,68]. Individuals were killed in late 151 fall and during the cold season and whole or sub-whole carcasses brought to the site for 152 processing [62]. The large accumulation of bone (S1 Fig, c), which required a long period of 153 time, and the consistency in activities, led to the consideration of the Chez-Pinaud site as a task-154 specific location (sensu Binford [69]) related to hunting arctic deer predation. Horse (Equus 155 156 caballus) and bison (Bison priscus) complete the ungulate spectrum. Small mammals include fox, (Vulpes vulpes or Alopex lagopus), arctic hare (Lepus timidus) and marmot (Marmota 157 158 marmota).

159

The spatial organization and state of preservation of artifacts indicate small-scale post-160 depositional movements of archaeological remains. Concentrations of lithic knapping waste, 161 with refitting evidence, have been found in the US22 (see A. Delagnes [63]), as well as in situ 162 163 bones anatomical connection from previous (see J.-B. Mallye, L. Niven, W. Rendu, T. E. Steel 164 [63]) and on-going [70] excavation. There is almost no taphonomic abrasion (sensu Fernández-Jalvo and Andrews [71]) on the bones and the cortical surfaces are fully preserved on more than 165 half of the faunal remains. Although visible on most pieces, weathering is limited to its first 166 167 stages [72], indicating rapid sedimentation. The near absence of evidence of carnivore activity (absence of large carnivore remains and coprolites, extreme rarity of consumption traces < 1% 168 NISP) shows that carnivores were only marginally involved in the accumulation and destruction 169 of the bone assemblage [62]. 170

US 22 was dated by Richter et al. [73], using thermoluminescence (TL) of heated flints, to  $73 \pm 8$  ka (average of three individual ages). A new dating by single-grain Optically Stimulated Luminescence (OSL) on sedimentary quartz indicate an age around 60-65 ka (Guérin et al., in prep.).

176

- **Materials and methods**
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The bone tools studied are those from the first two excavation campaigns (2019-2020) 179 conducted by W. Rendu, K. Kolobova and S. Shnaider. They come exclusively from US22, 180 181 attributed to the Quina Mousterian. They were identified following the sorting of all the faunal 182 remains, i.e., little more than 3220 remains, stored in the Service départemental d'Archéologie of Charente-Maritime (France). The sorting was done with the naked eye, then pieces with 183 possible evidence of manufacture or use were examined with a Nikon SMZ-1 stereoscopic 184 microscope. The best-preserved tools have been documented with a Makroskop Wild M420 185 (apochromatic zoom 5.8x-35x), completed by a Canon EOS 1100D camera, and with an 186 Olympus BH2 microscope equipped with semi-apochromatic objectives and interference 187 contrast. Sequences of Makroskop shots with progressive focus shift were compiled with 188 189 Helicon Focus software (HeliconSoft, Kharkiv) in order to extend the field depth over the entire framed area. 190

191

# 192 **Traceology**

193

194 The methodological framework is that of traceology, as defined by S.A. Semenov, that 195 is to say, taking into account both the traces of manufacture and use, at various scales [74,75].

In Western archaeology, these two complementary sides evolved separately through technology 196 197 studies, which reconstruct the manufacturing *chaîne opératoire* of the artifacts from the shaping macro-traces, and through functional analyses, which infer their function from macro and micro 198 use-wear. They are now at the heart of any lithic study, which is not yet the case for bone tools, 199 whose remains are less numerous and more altered. Transfer from lithic to bone has been the 200 201 most common methodological approach, both for the technological studies, with regard to 202 sequencing of manufacturing operations [76–82], and for the use-wear analyses, with regard to the microscopic scale of examination [83–91]. However, it only concerned assemblages where 203 204 the recognition of the artefacts, typologically established, did not constitute the issue of the 205 study, and from particularly favorable preserving context, mostly of the Holocene period. It is 206 now necessary to complete the referential frameworks by taking more account of the specificity 207 of the bone material and by considering markers that are scarcely or not affected by surface 208 alterations, i.e., macroscopic and/or internal.

209

# 210 **Taphonomic frame of reference**

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Our identification of organic (microorganism, animal, plant etc.) and inorganic 212 (weathering, water circulation, sediment compaction etc.) taphonomic alterations is based on 213 214 data outlined in publications [71,72,92–95]. We paid particular attention to the origin of bone fractures. The fractures considered as anthropogenic are those occurring on "fresh" bone, i.e., 215 occurring shortly after the animal's death. They are characterized by a helicoidal shape and a 216 217 slick surface and form acute or obtuse angles with the cortical side. Post-depositional 218 fragmentation generally occurs on "dry" bone, i.e., that has lost all or main part of its organic component. The fracture surfaces are straight, rough and form with the cortical side an angle 219 220 close to 90° [61,96–100]. However, the transition from fresh to dry bone is a gradual and nonhomogeneous phenomenon. Therefore, the proposed criteria do not allow for the recognition of an anthropogenic fracture on drying bone or a post-depositional fracture on fresh bone. In the archaeological material, the fracture surfaces often have mixed features, which implies reasoning in terms of trends according to the corpus studied and taking into account all available discriminating criteria (hammers impacts, general morphology, location, variability within the corpus, etc.) [101–105].

- 227
- 228 Archaeological frame of reference
- 229

230 Our identification of the manufacture and use-wear traces is based on a comparison with published archaeological and experimental data as well as on our own experiments. The nature 231 and organization of the traces observed on the archaeological material led to focus more 232 233 specifically on morpho-functional categories already identified in Upper Paleolithic contexts and some Middle Paleolithic sites, those of: (1) bone retouchers, (2) beveled tools, (3) tools 234 with retouched edges, and (4) tools with smoothed end. These categories are not defined with 235 236 the same precision. For the bone retouchers, we know both their mode of utilization and the activity in which they were involved. They are light soft hammers for retouching lithic edges 237 (S1 Text) [36,75,106,107]. For the beveled tools, the nature and localization of the traces refer 238 only to a mode of use involving percussion, but the worked material and the task performed 239 may vary (S2 Text) [35,108–110]. Bone fragments with intentional removals on one edge (S3 240 241 Text) [40,59,96,111] or with a technical blunt on one end (S4 Text) [7,30,55,88], are characterized only by a type of damage and its location relative to the main axis. For these 242 categories, many hypotheses about their function can be put forward. It is therefore necessary, 243 244 in order to complete the available data, to enlarge the experimental frame of reference.

## 246

247

Experiments specifically dedicated to Mousterian bone tools were performed by a 248 working group including French (PACEA, UMR 5199, University of Bordeaux), Russian 249 (Institute of Archaeology and Ethnography, Siberian Branch of the Russian Academy of 250 251 Sciences; ZooSCAn IRL 2013) and Belgian (Traceolab, University of Liege) researchers, among them experts in flintknapping and specialists trained to work with bones. These 252 253 experiments refer to the entire *chaîne opératoire*: from the first fracturing step of the bones (S2 Fig, a-d) to the blanks shaping (S2 Fig, e-f) and until the tools-use on different worked materials 254 255 and in task diversity in accordance with the archaeological contexts under study (S2 Fig, g-l). 256

**Experimental frame of reference** 

For the purpose of this study, forty-five long bones of medium and large mammals were 257 258 fractured: 16 femurs, 12 tibias, 11 humeri, 6 radio-ulna of cow (N=41), red deer (N=3) and 259 Equidae (N=1), adults (6 to 12 years old, N=30), young adults (6 to 12 months old, N=12) and juveniles (< 6 months old, N=3). The long bones were split with a hard hammer (quartzite 260 261 pebble of 1 to 2.5 kg) on an anvil (in situ limestone bloc or large quartzite pebble). Only the location of the impact points varied from one bone to another. Other types of bone, such as ribs 262 and vestigial metapodial (red deer and *Equidae*), were also used without fracturing step, or after 263 a first step reduction limited to a transverse fracturing. Twenty fractured bones have been set 264 aside for analyzing the variability of the percussion marks and the bone fragments 265 266 morphometry. They correspond to 156 flakes (excluding chips of less than 3 cm length and epiphyses), i.e., about 7-8 blanks per bone, with an average length of 10.28 cm (L. max. = 19.98 267 cm, L. min = 4.08 cm) and an average width of 4.3 cm (W. max = 9.88 cm, W. min = 1.46 cm). 268

The blanks shaping consisted mainly of a second fracturing step by direct percussion 270 271 for sizing, gripping and/or the active edge setting, i.e., modification of the edge angulation and/or delineation. We tested the efficiency of different hammers: soft organic (antler, 272 Juniperus communis), soft mineral (fine sandstone, limestone, schist), hard mineral (quartzite) 273 depending on the configuration of the striking platform, the size, morphology and axis of the 274 275 removals to be made. Tests were carried out to evaluate the bone response according to its state 276 of freshness, i.e., fresh (a few days after the death of the animal) and dry (loss of fatty and wet components) and our results were compared with those of previous experiments 277 [7,32,40,59,96,111–114]. 278

279

Experiments in bone knapping converge on similar observations: (1) bone responds 280 favorably to percussion, free or on anvil, (2) fresh bone responds to knapping better than dry 281 282 bone, i.e., better control of the removals morphology, (3) all hammer types (vegetal, animal and mineral) allow retouching, (4) the more acute the striking angle, the more efficient the 283 knapping; it is generally between  $40^{\circ}$  and  $60^{\circ}$  and should not exceed  $80^{\circ}$ , (5) removals are 284 easier to be performed when the percussion is applied parallel to the direction of the bone fibers 285 286 than perpendicularly, (6) the bone flakes have a butt, but the associated traces such as the bulb, 287 bulb scars, hackles, or ripples, are not systematic and not as clearly observable as on the lithic. The results diverge about the removals morphology according to the type of hammer. In our 288 experiments, a distinction can be made between the hard mineral hammers (quartzite) and the 289 290 soft hammers (wood, antler, soft sandstone). The latter allow to perform, under similar conditions, more invasive and scaled low angle removals than the hard hammers. We also 291 292 nuance previous results on the response of dry bone to knapping. The more homogeneous the material is, the easier it is for the shock wave to propagate. After the death of the animal, the 293 bone gradually loses its organic mass, starting from the outer layers, through internal 294

mechanisms of cell death and external mechanisms of exchange with the environment. This loss of homogeneity leads to irregularities in the morphology of the removals. However, once completely dry, as long as it has little or no weathering damage, the bone recovers its homogeneity. More rigid, it is particularly suitable to knapping.

299

Our bone tools were used for flint knapping (e.g., scrapers shaping), woodworking (e.g., handles manufacture), plant working (e.g., herbaceous harvesting), skin working (e.g., prototanning), ice working (e.g., fishing hole), butchery (e.g., meat cutting), and soil working (e.g., digging up roots).

304

305 Mechanical bone properties

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Bone is a complex matter composed mainly of an organic matrix of collagen fibers and 307 an inorganic matrix of hydroxyapatite crystals, organized in lamellae along the anatomical axis. 308 309 Changes in fiber orientation from one lamella to another form a solid and relatively homogeneous frame, reinforced by the prevalence of the mineral component. At the 310 311 macrostructural scale, bone has viscoelastic properties and transverse isotropic reaction. It can absorb energy by reversible deformation, fix a permanent deformation, and break if the stress 312 exceeds its resistance [61,96,115–118]. Its deformation capacity also depends on the rate of the 313 314 applied stress. The higher the latter, the higher the stiffness response of the bone. In addition, the progressive dehydration of the matter, after the animal death, increases its hardness [119]. 315 316 Bone can therefore, depending on the stress application conditions and the matter freshness, behave as a rather ductile or rather brittle material. It shares characteristics with conchoidal 317

fracture materials (development of a percussion cone below the impact area) [95,120], and asthe latter, responds to stresses in a predictable manner.

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# 321 Internal traceology

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323 The plastic deformation capacity of bone, that lithic does not have, opens an additional research field on deformations and cracks localized in the stress area, which may affect not only 324 325 the bone surface but also the underlying internal structure and are likely to supply diagnostic criteria for tool recognition. Among the imaging techniques providing access to the internal 326 327 structure of solid matters, microtomography [121] is particularly suitable for the observation of damage and micro-damage into the cortical tissue [122–128]. It is a non-destructive imaging 328 technique based on X-ray slices recombined for getting a 3D model of the scanned object, 329 330 according to the principle of Computerized Tomography [129,130]. Used mainly in the medical field, this technique is still little involved in the studies of archaeological bone artifacts [131– 331 137]. µCT could enable the implementation of a method of "internal traceology" for 332 supplementing surface information or for compensating for it when it is altered. 333

334

We performed  $\mu$ CT capture, without prior treatment of the samples, on 9 bone tools from the Chez-Pinaud site (S1-S9 Files) and 5 bone tools from our experiments, getting a total of 25 scans (S1 Table). The archaeological bone tools were chosen for their particularly good state of preservation, and to cover the morpho-functional diversity. The scanner chamber dimensions (260 mm in diameter and 420 mm in length) allowed a complete capture of each specimen at voxel sizes between 98  $\mu$ m and 26  $\mu$ m while scans of ROI (region of interest) were performed at resolutions between 33  $\mu$ m and 5  $\mu$ m (minimum values fixed by the volume to be

342	covered). The $\mu$ CT operated at a voltage of 110 to 120 kV and an intensity of 110 to 200 $\mu$ A	
343	The X-ray beam was filtered by a 0.1 mm thick copper plate.	
344		
345	We used a General Electric V Tome xs dual source microscanner (PACEA laboratory,	
346	University of Bordeaux, France). Volume reconstruction and visualization were performed with	
347	AVIZO 7.1 software (Thermo Fisher Scientific, Waltham).	
348		
349	Results	
350		
351	General features	
352		
352 353	Within the faunal remains from 2019-2020 campaigns, we identified a total of 103 bone	

the bone due to exfoliation phenomena (delamination of the outermost cortical layers). Longitudinal cracks from the weathering, combined with the weight and nature of the sediment and with the passage of the quarry machinery, probably caused much of the fragmentation of the bone remains. Only 15% of the tools are complete or sub-complete, i.e., free of postdepositional or recent breakage.

360

Of the 103 bone tools, a majority are marked by scores areas (*sensu* Mallye et al. [138]) localized on the cortical face (N=91), some have removals at one or both ends of the main axis (anatomical axis; N=10), and/or removals on the cortical and/or medullary surface of a lateral edge (N=7) and/or a smoothed area, more or less extensive, at one end (N=2). The main modifications, which changed the volume of the blanks, are always associated with one or more marginal modifications such as chipping, striations, compactions, rounding etc. The main modifications correspond respectively to the following morpho-functional categories: (1) bone
retouchers, (2) beveled tools, (3) retouched tools, (4) smooth-ended tools (Table 1; Fig 2). More
than 88% of the blanks were used as retouchers, and 81% exclusively in this way. Multiple-use
tools accounted for 9% of the total. The most common association is a bone retoucher with a
beveled end, followed by a bone retoucher with a lateral retouched edge. To date, there are no
tools that combine the four major modifications.

373

Number of tools	Туре	Number of blanks
	Bone retouchers	91
	Beveled tools	10
103	Retouched tools	7
	Smooth-ended	2
	tools	

Table 1. Bone tools, Chez-Pinaud site, 2019-2020 excavations.

Bone blanks number and count of active area per tools category.

376

Fig 2. Bone tools from the Chez-Pinaud site, 2019–2020 excavations. (a–d), (i–k) beveled
tools. (a, g–h, e–f, n) retouched tools. (a, f, j, m–o) bone retouchers. (l) smoothed-end tool
(photo: M. Baumann).

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All tools are made from bone, except for a horse incisor used as retoucher [139]. The taxa used in their manufacture are the same as those hunted and brought to the site: reindeer (34%), horse (26%) and *Bos*/bison (5%), but with different proportions (Fig 3d). Bones of large ungulates are almost twice as numerous among the tools as among the faunal remains (Fig 3a– b). While bone retouchers are made equally from large (53.8%) and medium (46.2%) ungulate
bones, multiple tools are always made from large ungulate bones. The blanks are mainly flakes
of long bones (87%): tibia (42.6%), humerus (17%), femurs (17%), metapods (12.8%) and
radio-ulna (10.6%), for anatomically determined pieces. Ribs (8.7%), phalanges (N=2), coxal
(N=1) and scapula (N=1) fragments complete the corpus.

390

Fig 3. Species spectrums, Chez-Pinaud site, 2019–2020 excavations. (a-c) faunal remains.
(b-d) bone tools (CAD: M. Baumann).

393

394 The blanks were split by direct percussion. Percussion marks and notches, sometimes associated with microcracks and/or secondary splinters, are visible on, at least, 30% of the tools. 395 Fracture morphologies show that the bones were fractured in a fresh state. The lengths of the 396 397 complete and sub-complete tools range from 5.6 cm to 15.4 cm (L. avg. = 9.1 cm) for widths between 1.8 cm and 5.1 cm (W. avg. = 3 cm). Thicknesses, rarely altered, were recorded on all 398 tools. They vary from 0.1 cm to 1.41 cm (Th. avg. = 0.7 cm). The general characteristics of the 399 blanks used to manufacture the tools are comparable to those of the faunal remains of the same 400 401 assemblage. These faunal remains show that all long bones types were fractured, with 402 approximately 17% percussion marks, while the fresh fracture rate reaches 76% of long bones. Eighty percent of the bone fragments correspond to a quarter or less of the shaft (reindeer < 5-403 6 cm; horse/bison < 7-8 cm), and 7% to between a quarter and half of the shaft (5-6 cm <404 405 reindeer < 13-14 cm; 7-8 cm < horse/bison < 16-17 cm). The lengths of the complete bone tools from medium size ungulates of the 2019-2020 excavation fall within this latter range (8 cm <406 407 medium size ungulates < 12 cm), while the lengths of the complete bone tools from large size ungulates cover the two sets (5 cm < large size ungulates < 16 cm). 408

### 410 **Bone retouchers**

411

## 412 Morphometry

413

Retouchers are the most frequently found bone tools in Middle Paleolithic contexts (S1 414 415 Text) [36,37,60,138,140–145]. US22 already had yielded nearly 510 during previous excavations; these retouchers were described and analyzed (Airvaux excavations: 202 416 417 specimens [146], Jaubert-Hublin excavations: 307 specimens [147]). The 91 bone retouchers from the new excavations show the same characteristics, indicating a continuity in the activities 418 and choices made by the Quina in the handling of these tools. The blanks are 54% from large 419 420 size ungulates (55% in Airvaux excavations and 47% in Jaubert-Hublin excavations). The tibia (22%) is the most used bone, but it is also the easiest to identify so our estimation might be 421 biased. Flat bones represent 8% of the corpus and the use of short bones is anecdotal (2 422 423 phalanges). The thickness of the retouchers is directly correlated with the bone used, with an average value of 0.86 cm for large size ungulates and 0.45 cm for medium size ungulates. The 424 length of the most complete specimens ranges from 5 cm to 9 cm, with a width of 2 to 3 cm. 425 However, the range of values is much smaller in the retouchers made from medium size 426 ungulate bones than in those made from large ungulates, which may reflect stricter selection to 427 428 achieve the dimensions required by the tools. Selection was also observed in Quina-type Mousterian layers at Les Pradelles, a secondary butchery site, where reindeer accounted for 429 98% of the faunal remains and provided 95% of the blank retouchers [144]. At the Chez-Pinaud 430 431 site, the average length of medium size ungulate retouchers (8.5 cm) is greater than those from Les Pradelles (7.3 cm). The higher proportion of large size ungulate remains at Chez-Pinaud 432 likely provided enough suitable blanks to make a stronger selection. 433

#### 435 **External modifications**

436

On our 91 bone retouchers, scores areas are mainly single (73%), sometimes double 437 (24%; Fig 4d), more rarely triple (3%), with prior scraping of the striking zone in 23% (Fig 4c). 438 Their density varies from a few scores (3-4) to the superposition of several dozen (Fig 4i), the 439 latter being less frequent. The scores are oriented perpendicular to the main axis with slight 440 variations of obliquity (Fig 4a). They are linear, more or less rough, and sometimes associated 441 with small chip removals (Fig 4b), that, according to Mallye et al. [138] indicates the use of dry 442 bone fragments, or at least, fragments which have lost some of their moist, fatty surface 443 444 component (Fig 4b).

445

Fig 4. Bone retouchers from the Chez-Pinaud site, 2019–2020 excavations. (a) scores
orientation. (b) scores associated with small chip removals. (c) scraping of the striking area. (d)
on horse tibia, n°2020. (e–g) on reindeer diaphysis, n°3727, 3396 and 3320. (h) on horse
metapodial, n°3587. (i) dense scores area. (j) on horse incisor, n° 4061 (photo: M. Baumann
except j, S. Renou).

451

At the Les Pradelles site, three groups of retouchers were distinguished based on tools 452 size and score intensity: those, (1) dedicated to shaping and resharpening Quina scrapers, (2) 453 corresponding to shaping and resharpening other tools and, (3) used occasionally for 454 resharpening various active edges [144]. This proposal highlights that the variability of 455 456 retouchers, often understood as the result of opportunistic use of non-specialized tools, may be more a matter of a "case by case" selection, adapted to the retouch to be performed. At Chez-457 Pinaud, groups of retouchers stand out, such as the small elongated specimens on the diaphysis 458 of reindeer (Fig 4e-g) with two short, well-marked scores areas (Fig 4i). The types of lithic 459

edges retouch depend on multiple factors, including the weight of the bone retoucher, its
handling capabilities, its trajectory or the energy transmitted [148,149]. The use of small
elongated flakes sets a range of possibilities that is not that of semi-complete metapod
specimens (Fig 4h), itself quite different from that of ribs or horse incisor (Fig 4j).

464

#### 465 Internal damage

466

467 The mode of use of a bone retoucher can also be revealed by its internal damage. The retouching of a lithic edge with a bone retoucher is the result of a reciprocal effect of one 468 another, combining percussion and cutting. The lithic edge penetrates the bone by cutting and 469 470 separating the fibers, while the energy transfer takes place at the bottom of the cut when maximum penetration is reached. The percussion does not only initiate a crack on the impact 471 lithic edge but also in the bone material. The propagation of the latter should depend on many 472 parameters related to the applied stress (dynamics of the blow, position and handling of the 473 retoucher, kinematics, etc.) and the state and structure of the bone (anatomical characteristics, 474 location of the active zone, humidity, temperature, etc.) [61,93,96,98,99]. The development of 475 use cracks and micro-cracks into bone tools has already been demonstrated with a reindeer 476 antler hammer [134] and some projectile points [132,136]. We therefore sought to investigate 477 this type of damage through µCT imaging of three experimental (S2 Table) and three 478 archaeological bone retouchers (S5-7 Files). 479

480

481 Cracks and micro-cracks were detected on our three experimental specimens. They are 482 frequent but not systematic and extend in the direct extension of the bottom of the scores. They 483 are mainly simple (Fig 5e), but can also be complex, with one or more secondary cracks from 484 a main crack (Fig 5c). They always follow a curved path with a tendency to reach the bone surface. Cracks can lead to partial chip detachment (Fig 5b), while the formation of a first crack promotes shrinkage if a second crack develops nearby (Fig 5d). All cracks and micro-cracks have the same orientation, in accordance with the regularity of the flintknapper's gesture. They can therefore provide information about the direction of the movement and possible changes in the position of the bone retoucher or lithic edge during the knapping process. At our scale of analysis, simple visual examination does not detect significant differences in crack length, depth, or delineation, based on the freshness states of the experimental bone retouchers.

492

Fig 5. μCT imaging of bone retouchers. (a) 3D reconstruction of an experimental sample from
a cow tibia. (b–c) cracks from use under the scores area, on sagittal cross-sections. (d–e) cracks
from use under the scores area, on transverse cross-section. (f) 3D reconstruction of an
archaeological sample from horse tibia, n°2020. (g–h) cracks from use under the scores area,
on sagittal cross-section. (i–j) cracks from use under the scores area, on transverse cross-section
(µCT image processing [IP] and CAD: M. Baumann).

499

Internal visualization of our archaeological bone retouchers is a delicate task. First, 500 501 because we are dealing with fossilized material, i.e., with a large mineral component. The 502 density of the material is greater and the grey levels recorded by the  $\mu$ CT no longer reflect, or only partially reflect, the original structure of the bone. Secondly, because the bones from Chez-503 Pinaud are altered by cracks from weathering that could mimic the technical cracks. Weathering 504 505 cracks develop along the natural lines of weakness of the bones, i.e., appearing perpendicular to the surface, when the bone is observed along its main axis (Fig 5j) and parallel to the surface, 506 507 when observed in cross-section. Cracks with similar characteristics as the damage caused by the use of experimental retouchers are visible under the scores area at 30-20 µm resolution (Fig 508 5g-j). These initial observations validate our hypothesis of the formation of use cracks below 509

510 the surface of the retouchers scores areas and the possibility of their detection in the 511 archaeological material.

512

## 513 Beveled tools

514

#### 515 Morphometry

516

517 The morpho-functional category of beveled tools is well documented in Upper 518 Paleolithic and Neolithic contexts (S2 Text) [35,85,88,108–110,150–152]. At Chez-Pinaud, the seven beveled tools range in length from 4.46 cm to 11.84 cm (L. avg. = 6.89 cm), for widths 519 from 2.51 cm to 5.11 cm (W. avg. = 3.51 cm) and cortical tissue thicknesses from 0.56 cm to 520 1.36 cm (Th. avg. = 0.99 cm). Six of them have lost their original length. Two have a post-521 522 depositional and a recent breakage, respectively, while the other four are shortened by a 523 transverse fracture at the proximal extremity. The latter have the attributes of a rapid fracture on fresh bone, posterior to the blank fracture. Their hinge morphology (fracture initiation from 524 525 the upper side; Fig 6g) or sawtooth morphology (fracture initiation from one of the lateral sides; Fig 7g) [79,82,153,154] and limited extent are characteristic of bending stress near the fracture 526 line. They may be the result of tools use. In one case, the transverse fracture is covered by a 527 striking zone (Fig 6f), indicating that the tool was reused after its deterioration. This striking 528 zone demonstrates that the beveled tool was still efficient despite its relatively short length (L. 529 530 = 6.5 cm), which is less than the average length of all specimens.

531

Fig 6. Beveled tools from the Chez-Pinaud site, 2019–2020 excavations. (a) chipping on the
cortical surface at the distal end. (b) chipping on the medullary surface at the distal end. (c) on
medium sized ungulate diaphysis, n°1026. (d) on large size ungulate diaphysis, n°3609. (e)

blunt on the medullary surface at the distal end. (f) striking surface at the proximal end. (g)hinge fracture at the proximal end (photo: M. Baumann).

537

Fig 7. Beveled tools from the Chez-Pinaud site, 2019–2020 excavations. (a) on horse humerus, n°1014. (b) edge retouch on the cortical surface. (c) chipping partially covered by a blunt on the cortical surface at the distal end. (d) on bison metatarsal, n°1527. (e) chipping on the cortical surface at the distal end. (f) chipping on the medullary surface at the distal end. (g) sawtooth fracture at the proximal end (photo: M. Baumann).

543

544 The beveled ends of our archeological specimens are formed by the cortical surface and one of the fracture surfaces caused by the blank production at an angle of about  $30^{\circ}$  to  $70^{\circ}$ . This 545 particular morphology must therefore have been obtained during the first stage of fracturing; a 546 547 result that is far from systematic given the morphological diversity of bone fragment extremities within the faunal remains of US22. Our experimental fracturing on fresh bone also produced 548 limited fragments with a morphology suitable for direct use as a bevel. Several non-exclusive 549 hypotheses can be put forward: (1) a control, during the first stage of fracturing, of the 550 551 parameters required to obtain blanks with convex beveled ends of acute angle, (2) an 552 anticipation by the selection and setting aside of suitable blanks following the processing of the carcasses, (3) a shaping by percussion of the active end posterior to the first fracturing stage. It 553 is also necessary that the edge to be shaped presents a favorable knapping angle. Two pieces 554 could illustrate this last case. 555

556

557 External modifications

The distal extremity of the shortest piece (Fig 8a) shows two generations of 3 or 4 559 560 longitudinal lamellar removals, at the junction between the cortical surface and a lateral fracture. Their location, regularity and organization, seem to refer to the burin blow technique, 561 i.e., to intentional removals. As with a lithic burin, the objective could be the shaping of the 562 active part and/or a production of bladelets. Experimentally, the removal of small elongated 563 flakes along its main axis does not raise any particular difficulty, provided that the flaking angle 564 565 is favorable. In this axis, the propagation of the shock is facilitated by the absence of curvature and the longitudinal macrostructural organization of the bone fibers. In all cases, the piece was 566 used. Its distal extremity is blunt and chipped (Fig 8b). On the larger specimen (Fig 8e), the 567 568 medullary surface of the bevel has a large and low-angled removal initiated from a lateral edge (Fig 8h). The latter is posterior to the first stage of fracturing of the blank and partially covered 569 by use-wear traces (chipping). Given the initial thickness of the blank edge, it could correspond 570 571 to a thinning form the bevel.

572

Fig 8. Beveled tools from the Chez-Pinaud site, 2019–2020 excavations. (a) set of burin-like
removals. (b) blunt over removals at the distal end. (c) chipping on the medullary surface at the
distal end. (d) on medium size ungulate diaphysis, n°888. (e) on large size ungulate diaphysis,
n°3648. (f) hinge fracture at the proximal end. (g) chipping on the medullary surface at the
distal end. (h) large and low-angle removal initiated from the lateral edge (photo: M. Baumann
except a, H. Plisson).

579

The bevels are bifacial (N = 5) or unifacial (N = 2), on the cortical and medullary surfaces (N = 6; Fig 7a) or on a lateral side (N = 1; Fig 7d). The lateral beveled tool shows a proximal fracture that is also lateral, in agreement with the axis of the stress exerted on the tool. All specimens show blunting of the cutting edge (Fig 7c), sometimes associated with visible compaction by flattening and wrinkling of the protruding areas. In 6 cases out of 7, the blunting is also associated with bifacial chipping (Fig 6a–b), more advanced on one face of the bevel (Fig 8g). We count one to four generations of small removals in the main axis, with a slight variation in their orientation. The bevel without a chipped end is marked by a bending fracture topped with a pronounced bluntness on the front and medullary surface (Fig 6e).

589

### 590 Internal damage

591

The operating process of the beveled tools involves percussion, which motivates the search for internal cracks and micro-cracks. The cutting edge of a bevel is only effective on a raw material of lesser hardness. Nevertheless, depending on this hardness, the contact between the two can alter the bone. Here, the stress is applied longitudinally to the bone fibers. To test for use-related internal damage in beveled tools, we scanned two experimental (S2 Table) and four archaeological specimens (S3-5 and S9 Files).

598

We did not identify any evidence of bone fiber deformation in the experimental 599 600 specimens. However, macroscopic cracks developed in both tools. These were cracks extending 601 a few millimeters under the surface, visible on sagittal and frontal µCT cross-sections at the distal ends. These cracks are direct extensions of removals produced during use (Fig 9b, A). 602 The short cracks located around the striking platform (which may subsequently cause chipping 603 604 of the periphery) are different from those that develop in the medial part. The latter penetrate only one or two millimeters along the main axis, but extend further in width (Fig 9e, E). We 605 606 noted one multiple crack (Fig 9d, E). In one specimen, three cracks also formed starting from the medullary surface of the distal part, below the area in contact with the worked material. 607 They follow the same direction for a few millimeters (Fig 9b, B-D). If the cracks located 608

directly under the active extremity can be related to shocks received along the main axis, i.e.,
characterized by a dominant compressive stress, those located further on the periphery could
result from repeated bending stresses, i.e., correspond to fatigue cracks.

612

Fig 9. μCT imaging of beveled tools. (a) 3D reconstruction of an experimental sample from a
Cow tibia. (b) cracks from use under the bevel, on a sagittal cross-section. (c) cracks from use
under the bevel, on a transverse cross-section. (d) cracks from use under the striking surface,
on a sagittal cross-section. (e) cracks from use under the striking surface, on a transverse crosssection. (f) 3D reconstruction of an archaeological sample from horse humerus, n°1014. (g–h)
concentration of cracks under the bevel, on a frontal cross-section. (i–m) sagittal cross-sections
of the bevel showing the non-uniform damage distribution (µCT IP and CAD: M. Baumann).

620

621 For the archaeological beveled tools, the selected anatomical fragments are close to the epiphyses. The organization of bone fibers is more complex than in the diaphysis. Unlike 622 experimental beveled tools, where the main axis of the tool is the same as the anatomical axis, 623 archaeological beveled tools have their active extremity positioned obliquely to the anatomical 624 625 axis. The cracks on the medullary surface, located on the periphery below the distal extremities, 626 cannot be directly compared to those of the experimental specimens, as they follow the natural lines of weakness in the bone structure. We can only point out that the cracks concentrate at the 627 active extremity (Fig 9h, A) and that there may be a connection between the technical micro-628 629 cracks and the development of taphonomic macro-cracks. Here, if the modifications were solely taphonomic, their distribution would be uniform, but parts of the beveled edges still show sharp 630 and acute zones (Fig 9i), while others are chipped (Fig 9l), compressed (Fig 9k) or blunted (Fig 631 9m). 632

# 634 **Retouched tools**

635

## 636 Morphometry

637

This category includes all tools in which one edge has been, according to the pattern of 638 639 removals on the bone blank, intentionally retouched (S3 Text) [7,27,28,32,36,40,155–157]. The sizes of the retouched tools from Chez-Pinaud are quite heterogeneous, but the average cortical 640 thickness, at 0.9 cm ( $\sigma = 0.2$ ), is among the highest for all tools. This could be related to the 641 need for sufficient thickness to knap the blank. The retouched tool lengths are probably not the 642 original ones. Specimens without recent or post-depositional breakage (N=4) have an average 643 644 length of 8.7 cm. They were fractured, at least at one extremity, subsequent to primary stage 645 fracturing to obtain the blank (Fig 10c).

646

Fig 10. Retouched tools from the Chez-Pinaud site, 2019–2020 excavations. (a) possible beveled tool on large size ungulate diaphysis, n°2132. (b) blunt localized at the distal end. (c) secondary fracturing step of the proximal end. (d) removals on the cortical surface at the distal end. (e) removals at the proximal end on the medullary surface. (f) possible beveled tool on reindeer metacarpal, n°143 (photo: M. Baumann).

652

#### 653 External modifications

654

Two pieces of our archeological specimens show, at one extremity, the beginning of edge convergence and a convex front like those of the beveled tools. Recent and postdepositional breaks prevent from asserting the presence of a bevel and/or damage typical of this class of tool. However, on both specimens, the preserved part is covered with a blunt that is too

localized to be taphonomic (Fig 10b). In addition to this localized blunting, they are both also 659 660 retouched. On one of them (Fig 10a), the removals are located at a lateral edge of the distal extremity and were performed in two stages. The first removals performed, two on the cortical 661 surface (Fig 10d) and one on the medullary surface, are large and scaled. The second series of 662 663 4 to 6 removals consist on an alternating and abrupt retouch, which formed a serrated profile edge. The latter, partially blunted, could correspond to an active edge. It should be noted that 664 665 the use of the tool as a retoucher is posterior to its shaping. On the second specimen (Fig 10f), the retouch is located on the medullary surface of the proximal part (Fig 10e). It is a continuous 666 retouch of at least three series of removals that form a straight edge. The opposite edge, also 667 668 interrupted by a post-depositional break, has two low-angle removals, suggesting similar processing for both edges. We have not identified any use-wear traces. Thus, one of the 669 hypotheses to put forward could be that of an adjustment for handling. 670

671

There are two small fragments of retouched bone artifacts (Fig 11). On the first one, the 672 cortical surface and a fracture (occurring on fresh bone) form an acute angle where the retouch 673 was performed. The latter is prior to the separation of this small fragment from a larger one. 674 675 The retouch is scaly, low-angle, bifacial on a first portion and then unifacial (Fig 11b). The 676 bifacial retouch is separated from the unifacial retouch by an unretouched but regularly blunted edge portion. The rectilinear leveling of the edge, its asymmetrical blunting, and the extension 677 of the latter in the retouched areas suggest that it resulted from a transverse motion of the tool 678 679 (i.e., perpendicular to the edge) in a positive rak angle, probably on soft material. This motion was still applied after the tool was retouched (Fig 11c). The second small fragment is a flake 680 coming from a larger retouched tool. Its obverse side is the medullary face, its reverse is the 681 flaked surface associated with part of a fracture from the first stage of fracturing of the blank. 682 The retouch was done on the medullary surface (Fig 11d). It consists of several low-angle 683

removals that form a sharp active edge. This active edge is slightly blunted with adjacent "stretched" and parallel reliefs, longitudinal striations and crescent-shaped chips (Fig 11f). It was probably used to cut middle soft material. The two small fragments thus belonged to larger tools whose active edges were shaped and/or resharpened by retouch.

688

Fig 11. Retouched tools from the Chez-Pinaud site, 2019–2020 excavations. (a) retouched edge fragment on large size ungulate diaphysis, n°5. (b) scalariform and low-angle removals. (c) retouch intercalated between 2 blunting episodes. (d) low-angle removals on the medullary surface. (e) retouched edge fragment on medium size ungulate diaphysis, n°529. (f) detail of the blunt with longitudinal striations (photos: M. Baumann except d and f, H. Plisson).

694

Two nearly complete artefacts show removals on a lateral edge, part of which predates 695 696 the adjacent fracture. This pattern involves the following sequence: (1) an initial fracturing aimed at obtaining the blank, (2) followed by the retouch of an edge, (3) a fracturing step that 697 removed part of the retouched edge, (4) and then an extension of the retouch to the remaining 698 part of the edge. This could correspond to a knapping accident. On the fragment also used as a 699 700 retoucher and beveled tool (Fig 7a), 7 partially overlapping removals on the cortical face are 701 present. The removals are initially invasive and semi-abrupt. Where the striking platform is preserved, they are scaled at low-angles (Fig 7b). The organization of the removals of a second 702 fragment (Fig 2n) is comparable. On the portions of the edges where the striking platform is 703 704 preserved, there is no evidence of use. The obtuse angles of the retouched edges and, in one case, the proximity to cancellous bone, do not make them suitable for use. The retouch would 705 706 be better suited to shaping for sizing and/or handling.

707

#### 708 Internal damage

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The retouch, achieved by percussion, can cause cracks and micro-cracks in the bone. However, the pattern of cracks should be expected to be significantly different from other artifacts. The stress is not applied on a surface and in the direction of the mass (likely to absorb a significant portion of the energy), as with the retouchers, but tangentially along an edge.  $\mu$ CT recordings were made on five archaeological tools (S1-2, S4-5 and S7 Files) and two experimental tools (S2 Table).

716

In the experimental tools, cracks and micro-cracks developed from the percussion point. They are not systematic and vary in size from one to several millimeters (Fig 12b–c). They are always wider in the longitudinal axis than in the transverse axis and have a curved trajectory. The areas with the most numerous and extensive cracks correspond to those parts at the edge where most of the removals were knapped. Single cracks sometimes appear at the end of the removal in direct continuation of the flaked surface (Fig 12d).

723

724 Fig 12. µCT imaging of retouched tools. (a) 3D reconstruction of an experimental sample 725 from a Cow tibia. (b) multi-cracks from shaping at the percussion point on a sagittal cross-726 section. (c) simple cracks from shaping at the percussion point on a sagittal cross-section. (d) cracks from shaping at the beginning and the end of a removal. (e) simple cracks from shaping 727 728 at the percussion point on a transverse cross-section. (f) 3D reconstruction of an archaeological sample from large size ungulate diaphysis, n°5. (g-h) frontal cross-sections of the 729 730 archaeological sample n°5, A and C, cracks from shaping at the beginning of retouches, B, set 731 of micro-cracks from use, D, multiple "star-shaped" cracks. (i-m) variation of the active edge 732 morphology on transverse cross-sections (µCT IP and CAD: M. Baumann).

On archaeological specimens, cracks also developed at percussion points (Fig 12g, A), 734 735 rarely at the end of removals. The micro-damage is more numerous and diverse than on the experimental specimens, probably due to a more complex history, including the use of the 736 737 retouched edge, its resharpening, possible accidental breaks, taphonomic alterations, etc. One tool (Fig 12f) shows micro-cracks that are not related to the retouch but to the use of the edge. 738 On the unretouched part of its active edge, a series of micro-cracks has developed directly below 739 740 the surface, over a thickness of less than one millimeter with the same pattern. Here, the density of material, visualized on the µCT cross-section by a clear increase in grey levels, is higher than 741 in the rest of the tool (Fig 12g, B). If this pattern correlates with surface damage, it could 742 743 correspond to transverse motion of the bone tool on soft material in a positive rak angle. Transverse µCT cross-sections of the edge (Fig 12i-m) confirm the pronounced and 744 asymmetric nature of the blunt with the formation of a flat on the cortical face (Fig 12k). The 745 746 retouch was probably done to restore some sharpness to the edge (Fig 12m). Internal cracks are also visible on the opposite edge, adjacent to the fracture that probably caused the fragment to 747 detach from its original tool. The multiple "star-shaped" crack could be related to a percussion 748 point (Fig 12h, D). 749

750

751 Smooth-ended tool

752

## 753 Morphometry

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One of the faunal remains under study shows at its distal end a blunt that is characteristic of use (S4 Text, S8 File). It is a portion of the mesial part of a large ungulate rib (L. = 9.44 cm; W. = 1.68 cm; cortical Th. = 0,3 cm). The tool, rather brittle, was collected in several fragments that were glued back together. Three quarters of the lower face is missing, while the proximalextremity is a recent break (Fig 13).

760

Fig 13. Smoothed-end tool, n°2020, from the Chez-Pinaud site, 2019–2020 excavations. (a)
blunted bending fracture at the distal extremity. (b) striations from use on the ventral face at the
distal extremity. (c) scraping striations on the cranial face (photos: M. Baumann).

764

## 765 External modifications

766

767 Intense scraping is visible on the dorsal, ventral, and cranial faces of the rib fragment (Fig 13c). At one extremity, a blunt covers a bending fracture that reveals the cancellous tissue 768 (Fig 13a). At this location, the junction between the ventral surface and cancellous tissue is a 769 770 flat surface (Fig 14c), whereas the junction between the dorsal surface and cancellous tissue is smoother and shows micro-flakes and tears (Fig 14d). At the top, the rounded compact surface 771 is marked by indentations and micro-flaks (Fig 14a-b). Over the entire surface, the micro-flacks 772 and indentations are partially covered by the blunt area. The latter is associated, on the dorsal 773 774 and ventral faces, with striations, shorter than the scraping striations but always more or less 775 parallel to the main axis (Fig 13b).

776

Fig 14.  $\mu$ CT imaging of a smoothed-end tool, n°2020, from the Chez-Pinaud site, 2019– 2020 excavations. (a–b) rounded and compacted surface marked by indentations and microflakes at the distal end. (c) flat surface at the junction between the ventral surface and the cancellous tissue. (d) micro-flakes and pull-outs on a smoothed surface at the junction between the dorsal surface and the cancellous tissue. (e–g) frontal, sagittal and transvers cross-sections showing a possible crack of use. 784 Experimentally, the sharpness of a bone edge decreases quite rapidly during its use, but its loss of matter is minimal unless the material being worked is abrasive. Macroscopic blunting 785 of a sharp irregular bone edge cannot result from scraping soft organic material (e.g., skin, 786 leather, bark). The latter would be ripped or pierced before a blunt had developed. The bluntness 787 of the bending fracture and the nearly spherical shape of the extremity of the rib examined (Fig 788 789 14f), which is not in the progressive extension of the rib sides, indicate shaping by abrasion. The chronological relationship between this shaping, the scraping of the sides and the use-wear 790 791 traces is unclear. The indentations and micro-flakes leveling may precede the final shaping 792 stage, due to the semi-secant character of the various surfaces of the distal extremity. Perhaps 793 are we dealing with the rejuvenation of a tip previously deformed by use? This combination of features is close to those of pressure flakers [158–162]. 794

795

### 796 Internal damage

797

The active part of this rib segment results from a combination of shaping and use-wear. 798 799 Abrasion shaping induces compressive stress, first applied randomly to the surface roughness. 800 Once the roughness is reduced, the stress is distributed more evenly over a larger contact area which reduces the pressure. This shaping does not a priori induce internal cracks and micro-801 cracks. Conversely, indentations and micro-flakes are the consequence of a point stress that has 802 803 exceeded the elastic deformation capacity of the bone and is likely to produced internal damage. On the µCT cross-sections, the rib shows several transverse and longitudinal cracks. In its 804 805 mesial and proximal parts, the through-cracks follow the same orientation as those that caused the post-depositional fragmentation. They always develop perpendicular to the cortical surface 806 toward the cancellous tissue. At the active part, the only crack detected originates at one edge 807

and traverses the cortical tissue toward the opposite edge and not toward the cancellous tissue
(Fig 14g). This could be due to a different formation dynamic. In addition, this crack starts from
an indentation (Fig 14e) and follows the same orientation as the micro-flake on the opposite
side (Fig 14f). It could therefore result from the same type of stress as the latter.

812

# 813 **Discussion**

814

# **Towards an outline of the Neanderthal bone industry**

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Our main study objective was to identify, in the western side of the Neanderthal 817 expansion zone, evidence of a common use of bone as a raw material for tool making, as we 818 819 did in the easternmost part in the Chagyrskaya Cave (Siberia, Russia). The identification of 103 bone tools among the 3220 faunal remains from the first two new campaigns at the Chez-Pinaud 820 821 site provides such evidence. This number of tools is quite large given the small area currently 822 excavated  $(7m^2)$ , but more significantly, it is equivalent to the number of lithic tools (N=109). Of the 103 bone tools, 83 are bone retouchers, similar to those previously identified at this site 823 and comparable to those found in many Mousterian assemblages across Eurasia. The originality 824 lies within the 20 additional tools used for other purposes: as wedge/chisel, lateral cutting edges 825 and, perhaps, pressure flaker. The Quina groups that occupied the Chez-Pinaud site thus 826 produced a variety of tools for different tasks. Although bone tools are much more numerous 827 at Chagyrskaya Cave [7], coming from a larger excavated area, the distribution of different 828 829 categories is more or less the same, with a large majority of retouchers (88% at Chez-Pinaud; 94% at Chagyrskaya) followed by tools with lateral retouch (6.3% and 9.7%), beveled tools 830 (4.7% and 6.8%), and smooth-ended tools (1.8% and 2%), with respectively 8.7% and 6.8% 831

multi-use tools. These four types, although disparately, have been already reported, from other
Mousterian sites, such as Axlor ("retocadores," "cincel," "hueso retocado," "alisador" [36]) and
Combe-Grenal ("retouchoirs", "outils façonnés par percussion," "pièces esquillées," "pièces à
extrémités émoussées" [28]).

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It is not yet possible at this early stage of the study to determine whether the tool blanks 837 are the result of integrated debitage within the food fracturing, a distinct operative sequence, or 838 an opportunistic later collection. A study of the variability of bone processing (by species and 839 anatomical elements) and an assessment of the degree of control over the morphometry of the 840 841 blanks remains to be carried out. However, obtaining proper edge angles without controlled fracturing seems unlikely, leaving the question open. A trend is apparent in the characteristics 842 of the blanks used. Long bones from large size ungulates (horse, bison) were mainly selected 843 844 and a strong selection was made on the remains of medium size ungulates (reindeer), showing a clear preference for the largest size and/or the densest fragments. This preference is also very 845 clear at the Chagyrskaya Cave, where more than 80% of the bone blanks are from large size 846 ungulates, whereas they account for only 52% of the ungulate remains (NISP) from the 847 848 Micoquian deposits [163]. More broadly, this pattern is consistent with the selection observed 849 in Mousterian assemblages for the retouchers [138,144,164–168].

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The shaping of the tools is clearly attested. It is mainly concentrated on the active parts. Scraping marks are visible on the active area of about 23% of the bone retouchers, a proportion close to those of the bone retouchers from the Quina deposits of De Nadale (17%) [168] and Les Pradelles (18%) [144]. Scraping was used to shape and/or clean the smooth-ended rib, while abrasion was used to shape and/or rejuvenate the tip. Only one specimen from the Chez-Pinaud site is currently available, but other smooth-ended ribs shaped by scraping and/or abrasion have
already been reported in Middle Paleolithic assemblages dated between 75 and 45 ka ago, 857 858 including those from Abri Peyrony and Pech de l'Azé [30], La Quina [41], Axlor [36], Zaskalnaya VI [21] (S3 Table, S3 Fig) or Lartet [169]. Within the Quina levels of Chez-Pinaud, 859 direct percussion is widely applied, for shaping or resharpening the lateral edges and bevels 860 and, possibly, for shaping out the prehensile parts. Among ancient bone artifacts, the most 861 frequently reported are those that were retouched, although only the least questionable 862 specimens, deeply transformed, are illustrated, such as the elephant bones bifaces [170] (S4 863 Table, S4 Fig). Following Anne Vincent's conclusions on the Charente Mousterian deposits 864 [32], we note, at Chez-Pinaud and Chagyrskya, the tendency to limit the retouch to only a few 865 866 removals, necessary and sufficient to make the active edge effective. A beveled artefact raises 867 the question of the production of bone bladelets from core-like blanks. The evidence is tenuous but consistent with some of the bone artefacts from Chagyrskaya: burin-like tools (Fig 15d), 868 869 possible bone core (Fig 15e) and bone bladelets (Fig 15c).

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Fig 15. Micoquian bone industry from the Chagyrskaya cave, Russian federation, 2008–
2018 excavations. (a) bone tool with negatives of lamellar removals. (b) detail of a burin-like
removal negative. (c) bone bladelet. (d) burin-like tool. (e) possible bone nuclei. (f) negatives
of lamellar removals (photos: M. Baumann).

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#### 876 A functional diversity to be explored

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878 Bone retouchers form a homogeneous functional category, i.e., light hammers for 879 retouching lithic edges. In US22, bone retouchers appear to be primarily dedicated to 880 resharpening side scrapers during carcass processing. Waste from shaping and resharpening 881 scrapers was primarily done with a soft hammer [65], and, among the removals, those related to maintenance dominate, while traceological analyses shows that the side scrapers were used to cut meat and hide [171], but a more precise correlation could be drawn between bone retouchers groups and specific knapping tasks [138,144,148]. For this purpose, the information provided by external damage and tools morphometry, on which Costamagno et al.'s bone retouchers groups are based [144], could be supplemented by internal damage detected by  $\mu$ CT. In particular, the cracks that developed under the scores areas can provide gesture information that would identify, for example, the bone retouchers used for the Quina retouch [149].

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Among the beveled tools, the diversity in active edges (dimensions, position, front 890 891 delineation etc.) and the distribution of use-wear traces, suggest that these tools were used in a significant diversity of tasks, involving different worked materials: soft, when blunted and 892 without chippings, harder, when chipped with limited bluntness. The short length of complete 893 894 specimens, the frequency of short and transverse shaft fractures, and the modification of the handling part of one of the tools could argue for the use of handles [110], as already 895 demonstrated for Middle Paleolithic lithic tools [172] Handles, which improve the efficiency 896 (accuracy and force) [173], are generally regarded as a significant investment of time and 897 898 energy [174], as well as an essential step in the technological evolution [175,176]. However, a 899 wooden clamp and leather strap as we have done experimentally is not a great investment.

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Based on its mechanical properties, the bone responds favorably to experimental knapping. Edge shaping by percussion does not necessarily mean the placement of an active part. This may explain the heterogeneity in retouched tools, both in terms of morphometry and retouch quality. In all cases, the retouch was performed on thick blanks and the removals, preferentially on the medullary face, seem to be limited to what is strictly necessary. Two active edge fragments provide functional clues. Both were used on soft material, one for cutting and 907 the other for scraping. In the latter, we observe that the pattern of internal damage can indeed
908 change as a function of the stress experienced. Technical advantages of bone cutting edges, at
909 a site where flint is abundant, remains to be understood.

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911 Smooth-ended tools, particularly rib tool, are often considered as hide working [29,30,36,154,177], due to the regular rounded shape of the active extremities that can be 912 913 interpreted as resulting from significant contact with a soft worked material. In our study, the Chez-Pinaud rib shows external and internal damage from a point contact area with a material 914 harder than bone, with the regular rounded active edge being the result of shaping. The 915 916 Chagyrskaya deposits have yielded, at least, two tools with similar characteristics [7]. 917 Experimentally, many tasks can lead to the blunting [178]. It should be kept in mind that such task diversity could exist in the Middle Paleolithic. 918

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#### 920 Understanding the role of bone tools in technical systems

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The recurrence of bone tool types with distinct potential functionalities in the US22 922 from Chez-Pinaud, together with that of the Micoquian assemblage from Chagyrskaya and the 923 occasional report of similar tools from numerous Middle Paleolithic sites, suggests that these 924 925 elements had a specific role to play in the pre-Upper Paleolithic technical systems and that their apparent simplicity is not synonymous with opportunism. The equivalent proportions of bone 926 and lithic tools in a task specific location, such as Chez-Pinaud, allows us to consider that the 927 two productions had a technical synchrony. While the complementarity between the bone 928 929 retouchers and the sharp lithic edges is fairly obvious in a site dedicated to carcass processing, the other functional categories of bone tools reflect a broader range of related activities that 930 931 may have taken place at the site. The functional spectrum of the Quina flint industry is limited, as it relies on a low diversity of tool types, mostly short, often thick, lacking the pointed shapes
of the biface or Levallois industries. Bone provides elongated shapes, sometimes with minimal
preparation (ribs), while its resistance to impact and relative elasticity make it better suited to
certain tasks than flint. Such complementarity is not specific to Middle Paleolithic, but it
appears all the more necessary in a technical context such as that of the Quina Mousterian.

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Whatever the system considered, its functioning necessarily requires a certain stability 938 despite its internal constraints (or contradictions) [179], which are predictable, and external 939 940 which are fluctuating. Having a low-cost solution for the execution of an essential task meets 941 this stability requirement. Possibly this is what using an easily renewable by-product of a central 942 recurring resource provides. Nevertheless, at Chez-Pinaud the selection of diaphysis and ribs from the large size ungulates, as well as the larger modules from medium size ungulates, 943 944 suggests that the raw material for tools making was not so abundant to cover all needs that the production of blanks could depend on random fracturing. For skilled flint knappers accustomed 945 also to breaking bone, obtaining bone fragments of predefined shape and edge angulation was 946 certainly not a concern. A diversity in Mousterian bone breakage pattern has been recently 947 948 evidenced [180] which may not be linked with marrow recovering only. This is a technological 949 topic to be investigated in itself, as M. Mozota Holgueras advised for retouchers [181].

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Nearly 20% of the pieces show evidence of re-use, with use as a retoucher being the most recent. This opens up the notion of blank management. Although robust, the thickness of the horse and bison bone blanks, not to mention reindeer, did not allow for successive and alternative forms as observed for lithic tools circulating from site to site [65]. This intrinsic limitation, coupled with the recurrent availability of bones, means that the bone tools discussed

here were likely produced, used and discarded in situ, as has been described elsewhere forcertain categories of lithic tools [182].

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## 959 **Conclusion**

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From the Altai to the Atlantic shore, through a multitude of sites where only a few 961 objects have been reported so far, evidence of a Neanderthal bone industry is emerging, 962 963 probably with ancient roots [183,184]. Its invisibility, even in the most recent synthesis published on Neanderthal [185], is probably due in part to ill-defined categorizations in which 964 aesthetic and ideological anthropocentric criteria inherited from the last century are still 965 966 combined. It is also related to a compartmentalization between the fields of expertise necessary for its identification: at Chez-Pinaud site, bone tools other than the retouchers are only 967 highlighted in the part of US22 currently studied. Nevertheless, regardless of the cognitive 968 value attributed to the use of bone material and its transformation techniques [169], bone tools 969 shed light on related technical registers that are little or not documented through lithic tools and 970 971 provides complementary information on Middle Paleolithic subsistence strategies. There is thus a promising avenue of research to be further explored. 972

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# **Declarations**

982 No permits were required for the described study, which complied with all relevant regulations983

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## 1516 Supporting information

- 1517 S1 Text. Bone retouchers
- 1518 S2 Text. Beveled tools
- 1519 S3 Text. Retouched tools
- 1520 S4 Text. Smooth-ended tools
- 1521

1522 S1 Fig 1. Archaeological deposits of the Chez-Pinaud site (Jonzac, France). a) location of the
1523 excavation area in 2019-2021; b) left stratigraphic cut (after Airvaux and Soressi 2005); c) view of the
1524 "bone-bed", 2021 excavation (photos: W. Rendu).

1525 S2 Fig. Experiments with replicas of Mousterian type bone tools. a) fracturation by direct percussion

- 1526 on anvil; b) fractured fresh long bones of Bovinae; c) regular flakes from bone fracturing; d) impact of
- 1527 direct percussion; e) retouched bone blank; f) flake from retouch; g) Mousterian side scrapers shaping;

h) meat cutting; i) hair removing from skin; j) wooden peeling; k) plant harvesting; l) soil digging(photos: H. Plisson).

- 1530 S3 Fig 3. Examples of ribs with smoothed end discovered in other Middle Paleolithic contexts. a,
- 1531 c–d) Abri Peyrony; b) Pech de l'Azé (after Soressi et al. 2013); e) Zaskalnaya VI (after Stepanchuk et
- al. 2017); f) Chagyrskaya Cave (after Baumann et al. 2020); g) Abri des Canalettes (after Patou-Mathis
- 1533 1993); h) Axlor (after Mozota Holgueras 2012); i–k) La Quina (after Henri-Martin 1907–1910); l–m)
- 1534 Grotte du Noisetier (after Oulad El kaïd 2016).
- 1535 S4 Fig. Examples of retouched bone artifacts discovered in pre-AMH contexts. a) Castel di Guido
- 1536 (after Villa et al. 2021); b) Nova de Columbeira (after Zilhão et al. 2011); c) Vauffrey (after Vincent
- 1537 1993); d) Poggeti Vecchi (after Aranguren et al. 2019); e) Bois-Roche (after Vincent 1993); f) Combe-
- 1538 Grenal (after Tartar and Costamagno 2016); g-h) Chagyrskaya (after Baumann et al. 2020); i) Gran
- 1539 Dolina (after Rossel et al. 2011); j) Abric Romaní (after Carbonel et al. 1994).
- 1540
- 1541 S1 Table. Microtomographic recording parameters of the experimental and archaeological tools
  1542 from Chez-Pinaud site.
- 1543 S2 Table. Experimental samples analyzed in µCT.
- 1544 S3 Table Reports (non-exhaustive) of smoothed-end ribs from Neanderthal contexts in Eurasia.
- 1545 S4 Table Reports (non-exhaustive) of knapped bone tools from pre-AMH contexts in Eurasia.
- 1546
- 1547 S1 File. 3D model, retouched bone tool #CPN19-5, Chez-Pinaud site
- 1548 S2 File. 3D model, retouched bone tool #CPN19-529, Chez-Pinaud site
- 1549 S3 File. 3D model, beveled bone tool #CPN19-534, Chez-Pinaud site
- 1550 S4 File. 3D model, beveled bone tool #CPN19-888, Chez-Pinaud site
- 1551 S5 File. 3D model, beveled bone tool #CPN19-1014, Chez-Pinaud site
- 1552 S6 File. 3D model, bone retoucher #CPN19-2020, Chez-Pinaud site
- 1553 S7 File. 3D model, retouched bone tool #CPN19-2132, Chez-Pinaud site
- 1554 S8 File. 3D model, smoothed-ended bone tool #CPN20-3581, Chez-Pinaud site
- 1555 S9 File. 3D model, beveled bone tool #CPN20-3609, Chez-Pinaud site

**Fig 1. The Chez-Pinaud site, Jonzac, France**. (a) location of the site and the main surrounding Quina site (geographical data republished from Géoportail.gouv.fr under a CC BY license, with permission from IGN, original copyright 2022). (b) 3D photogrammetric model of the excavated layer (photos and 3D processing: S. Shnaider). (c) layout of the excavation units (CAD: M. Baumann).



**Fig 2. Bone tools from the Chez-Pinaud site, 2019–2020 excavations**. (a–d), (i–k) beveled tools. (a, g–h, e–f, n) retouched tools. (a, f, j, m–o) bone retouchers. (l) smoothed-end tool (photo: M. Baumann).







**Fig 4. Bone retouchers from the Chez-Pinaud site, 2019–2020 excavations.** (a) scores orientation. (b) scores associated with small chip removals. (c) scraping of the striking area. (d) on horse tibia, n°2020. (e–g) on reindeer diaphysis, n°3727, 3396 and 3320. (h) on horse metapodial, n°3587. (i) dense scores area. (j) on horse incisor, n° 4061 (photo: M. Baumann except j, S. Renou).



**Fig 5. μCT imaging of bone retouchers.** (a) 3D reconstruction of an experimental sample from a cow tibia. (b–c) cracks from use under the scores area, on sagittal cross-sections. (d–e) cracks from use under the scores area, on transverse cross-section. (f) 3D reconstruction of an archaeological sample from horse tibia, n°2020. (g–h) cracks from use under the scores area, on sagittal cross-section. (i–j) cracks from use under the scores area, on transverse area, on transverse cross-section. (i–j) cracks from use under the scores area, on transverse cross-section. (i–j) cracks from use under the scores area, on transverse cross-section (μCT image processing [IP] and CAD: M. Baumann).


**Fig 6. Beveled tools from the Chez-Pinaud site, 2019–2020 excavations.** (a) chipping on the cortical surface at the distal end. (b) chipping on the medullary surface at the distal end. (c) on medium sized ungulate diaphysis, n°1026. (d) on large size ungulate diaphysis, n°3609. (e) blunt on the medullary surface at the distal end. (f) striking surface at the proximal end. (g) hinge fracture at the proximal end (photo: M. Baumann).



**Fig 7. Beveled tools from the Chez-Pinaud site, 2019–2020 excavations.** (a) on horse humerus, n°1014. (b) edge retouch on the cortical surface. (c) chipping partially covered by a blunt on the cortical surface at the distal end. (d) on bison metatarsal, n°1527. (e) chipping on the cortical surface at the distal end. (f) chipping on the medullary surface at the distal end. (g) sawtooth fracture at the proximal end (photo: M. Baumann).



**Fig 8. Beveled tools from the Chez-Pinaud site, 2019–2020 excavations.** (a) set of burin-like removals. (b) blunt over removals at the distal end. (c) chipping on the medullary surface at the distal end. (d) on medium size ungulate diaphysis, n°888. (e) on large size ungulate diaphysis, n°3648. (f) hinge fracture at the proximal end. (g) chipping on the medullary surface at the distal end. (h) large and low-angle removal initiated from the lateral edge (photo: M. Baumann except a, H. Plisson).



**Fig 9.**  $\mu$ **CT imaging of beveled tools.** (a) 3D reconstruction of an experimental sample from a Cow tibia. (b) cracks from use under the bevel, on a sagittal cross-section. (c) cracks from use under the bevel, on a transverse cross-section. (d) cracks from use under the striking surface, on a sagittal cross-section. (e) cracks from use under the striking surface, on a transverse cross-section. (f) 3D reconstruction of an archaeological sample from horse humerus, n°1014. (g–h) concentration of cracks under the bevel, on a frontal cross-section. (i–m) sagittal cross-sections of the bevel showing the non-uniform damage distribution ( $\mu$ CT IP and CAD: M. Baumann).



**Fig 10. Retouched tools from the Chez-Pinaud site, 2019–2020 excavations.** (a) possible beveled tool on large size ungulate diaphysis, n°2132. (b) blunt localized at the distal end. (c) secondary fracturing step of the proximal end. (d) removals on the cortical surface at the distal end. (e) removals at the proximal end on the medullary surface. (f) possible beveled tool on reindeer metacarpal, n°143 (photo: M. Baumann).



**Fig 11. Retouched tools from the Chez-Pinaud site, 2019–2020 excavations.** (a) retouched edge fragment on large size ungulate diaphysis, n°5. (b) scalariform and low-angle removals. (c) retouch intercalated between 2 blunting episodes. (d) low-angle removals on the medullary surface. (e) retouched edge fragment on medium size ungulate diaphysis, n°529. (f) detail of the blunt with longitudinal striations (photos: M. Baumann except d and f, H. Plisson).



**Fig 12. μCT imaging of retouched tools.** (a) 3D reconstruction of an experimental sample from a Cow tibia. (b) multi-cracks from shaping at the percussion point on a sagittal cross-section. (c) simple cracks from shaping at the percussion point on a sagittal cross-section. (d) cracks from shaping at the beginning and the end of a removal. (e) simple cracks from shaping at the percussion point on a transverse cross-section. (f) 3D reconstruction of an archaeological sample from large size ungulate diaphysis, n°5. (g-h) frontal cross-sections of the archaeological sample n°5, A and C, cracks from shaping at the beginning of retouches, B, set of micro-cracks from use, D, multiple "star-shaped" cracks. (i–m) variation of the active edge morphology on transverse cross-sections (μCT IP and CAD: M. Baumann).



**Fig 13. Smoothed-end tool, n°2020, from the Chez-Pinaud site, 2019–2020 excavations**. (a) blunted bending fracture at the distal extremity. (b) striations from use on the ventral face at the distal extremity. (c) scraping striations on the cranial face (photos: M. Baumann).



**Fig 14. μCT imaging of a smoothed-end tool, n°2020, from the Chez-Pinaud site, 2019–2020 excavations**. (a–b) rounded and compacted surface marked by indentations and micro-flakes at the distal end. (c) flat surface at the junction between the ventral surface and the cancellous tissue. (d) micro-flakes and pull-outs on a smoothed surface at the junction between the dorsal surface and the cancellous tissue. (e–g) frontal, sagittal and transvers cross-sections showing a possible crack of use (µCT IP and CAD: M. Baumann).



**Fig 15. Micoquian bone industry from the Chagyrskaya cave, Russian federation, 2008–2018 excavations.** (a) bone tool with negatives of lamellar removals. (b) detail of a burin-like removal negative. (c) bone bladelet. (d) burin-like tool. (e) possible bone nuclei. (f) negatives of lamellar removals (photos: M. Baumann).



**S1 Fig. Archaeological deposits of the Chez-Pinaud site (Jonzac, France)**. (a) location of the excavation area in 2019-2021. (b) left stratigraphic cut (after Airvaux and Soressi 2005). (c) view of the "bone-bed", 2021 excavation (photos: W. Rendu).





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**S2 Fig. Experiments with replicas of Mousterian type bone tools.** (a) fracturation by direct percussion on anvil; (b) fractured fresh long bones of Bovinae. (c) regular flakes from bone fracturing (d) impact of direct percussion. (e) retouched bone blank. (f) flake from retouch. (g) Mousterian side scrapers shaping. (h) meat cutting (i) hair removing from skin. (j) wooden peeling. (k) plant harvesting. (l) soil digging (photos: H. Plisson).



**S3 Fig. Examples of ribs with smoothed end discovered in other Middle Paleolithic contexts.** (a), (c–d) Abri Peyrony. (b) Pech de l'Azé (after Soressi et al. 2013). (e) Zaskalnaya VI (after Stepanchuk et al. 2017). (f) Chagyrskaya Cave (after Baumann et al. 2020). (g) Abri des Canalettes (after Patou-Mathis 1993). (h) Axlor (after Mozota Holgueras 2012). (i–k) La Quina (after Henri-Martin 1907–1910). (l–m) Grotte du Noisetier (after Oulad El kaïd 2016).



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**S4 Fig. Examples of retouched bone artifacts discovered in pre-AMH contexts.** (a) Castel di Guido (after Villa et al. 2021). (b) Nova de Columbeira (after Zilhão et al. 2011). (c) Vauffrey (after Vincent 1993). (d) Poggeti Vecchi (after Aranguren et al. 2019). (e) Bois-Roche (after Vincent 1993). (f) Combe-Grenal (after Tartar and Costamagno 2016). (g–h) Chagyrskaya (photo: M. Baumann). (i) Gran Dolina (after Rossel et al. 2011). (j) Abric Romaní (after Carbonel et al. 1994).



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S1 Table. Microtomographic recording parameters of the experimental and archaeological tools from Chez-Pinaud site.

	Identification number	Raw material	Tool type	Scanned area	Resolution (µm)	Slice nb.	Correction value	kV	μΑ
Archaeological tools	CPN19-5	Diaphysis large size ungulate	Retouched	Complete	26	1625	10.40	120	120
	CPN19-529	Diaphysis medium size ungulate	Retouched	Complete	26	1625	10.40	120	120
	CPN19-534	Humerus large size ungulate	Beveled	Complete	35	2125	8.32	120	120
	CPN19-888	Diaphysis large size ungulate	Beveled Retouched	Complete	35	1500	9.13	120	120
	CPN19-1014	Horse humerus	Beveled Retouched	Complete	67	1200	2.46	120	250
			Retoucher	ROI <sup>*</sup> 1	21	2550	3.52	120	250
	CPN19-2020	Horse tibie	Patouchar	Complete	62	1200	2.48	120	250
		Horse ubla	Retoucher	ROI 1	22	22 2250 4	4.49	120	250
	CPN19-2132	Diaphysis large size ungulate	Beveled ? Retouched Retoucher	Complete	43	1375	7.12	120	120
	CPN20-3581	Dib		Complete	54	1275	8.31	120	120         120           120         100           120         100           120         120
		large size ungulate	Smoothed	ROI 1	14	1625	27.10	120	100
				ROI 2	5	2550	74.83	120	120
	CPN20-3609	Bison metatarsal	Beveled Smoothed	Complete	43	1375	8.41	120	120
	Exp-10	Cow tibia	Beveled	Complete	89	1200	2.82	120	250
				ROI 1	13	2250	8.24	120	250
Ŧ				Zone 2	13	2250	1.69	120	250
dX,			Develo	Complete	89	1200	2.82	120	250
eri	Exp-13	Red deer femur	Develed	ROI 1	24	2250	5.22	120	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$
Ē			Retoucheu	ROI 2	24	2250	2.12	120	250
int	Exp-46	Com tibio	Retoucher	Compete	98	1500	2.78	120	250
al t		Cow tibla	Retouched	ROI 1	21	2250	6.18	120	250
00	Exp-57	Cow tibio	Retoucher	Complete	98	1200	3.18	120	250
ls			Ketoucher	ROI 1	21	2550	3.22	120	250
	Exp-58	Cow tibio	Retoucher	Complete	98	1200	3.18	120	250
		Cow libia		ROI 1	33	2250	4.02	120	250

S2 Table. Microtomographic recording parameters of the experimental and archaeological tools from Chez-Pinaud site.

	Identification number	Raw material	Tool type	Scanned area	Resolution (µm)	Slice nb.	Correction value	kV	μΑ
Archaeo	CPN19-5	Diaphysis large size ungulate	Retouched	Complete	26	1625	10.40	120	120
	CPN19-529	Diaphysis medium size ungulate	Retouched	Complete	26	1625	10.40	120	120
	CPN19-534	Humerus large size ungulate	Beveled	Complete	35	2125	8.32	120	120
	CPN19-888	Diaphysis large size ungulate	Beveled Retouched	Complete	35	1500	9.13	120	120
	CPN19-1014	Horse humerus	Beveled Retouched	Complete	67	1200	2.46	120	250
log			Retoucher	ROI <sup>*</sup> 1	21	2550	3.52	120	250
ical tools	CDN10 2020	Horse tibia	Retoucher	Complete	62	1200	2.48	120	250
	CPIN19-2020			ROI 1	22	2250	4.49	120	250
	CPN19-2132	Diaphysis large size ungulate	Beveled ? Retouched Retoucher	Complete	43	1375	7.12	120	120
	CPN20-3581	Dib		Complete	54	1275	8.31	120	120 100
		kið large size ungulate	Smoothed	ROI 1	14	1625	27.10	120	100
				ROI 2	5	2550	74.83	120	120
	CPN20-3609	Bison metatarsal	Beveled Smoothed	Complete	43	1375	8.41	120	120
	Exp-10	Cow tibia	Beveled	Complete	89	1200	2.82	120	250
				ROI 1	13	2250	8.24	120	250
E				Zone 2	13	2250	1.69	120	250
dx			Povolod	Complete	89	1200	2.82	120	250
eri	Exp-13	Red deer femur	Betouched	ROI 1	24	2250	5.22	$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	
Ë.			Retouched	ROI 2	24	2250	2.12	120	250
int	Exp-46	Cow tibia	Retoucher	Compete	98	1500	2.78	120	250
alt		Cow tibla	Retouched	ROI 1	21	2250	6.18	120	250
00	Exp_57	Cow tibia	Retoucher -	Complete	98	1200	3.18	120	250
S	Бур-57			ROI 1	21	2550	3.22	120	250
	Exp-58	Cow tibia	Retoucher	Complete	98	1200	3.18	120	250
			iteroucher	ROI 1	33	2250	4.02	120	250

S3 Table. Reports (non-exhaustive) of smoothed-end ribs from Neanderthal contexts in Eurasia.

Loc	Site	Nb.	Industry	Dates	Ref.	
	Abri Peyrony	3	MTA	MIS 3 (43 – 37 ky BP)	Soressi et al. 2013	
	Noisetier	2	Discoid	MIS 3 (42 ky BP)	Oulad El Kaïd 2016	
	La Quina	3	MAT/Denticulate	MIS 3 (48 - 40 ky BP)	Henri-Martin 1907-1910 Debénath et al. 1998	
	Lartet	4	Levallois	MIS 3 (48 - 35 ky BP)	Debénath and Duport 1971	
France	Pech de l'Azé	1	MTA	MIS 3 (51 ky BP)	Soressi et al. 2013	
	Pradayrol	1	Discoid Levallois	MIS 3	Villeneuve et al. 2019	
	Canalettes	1	Levallois	MIS 5-4 (73 ky BP)	Patou-Mathis 1993 Valladas et al. 1987	
	Vaufrey	1	Mousterian	MIS 7-6 (270-142 ky BP)	Vincent 1993	
Spain	Cueva Mórin	1	MTA (Vasconian)	MIS 3 (>43 ky BP)	Freeman 1971 Maíllo-Fernández et al. 2014	
Spann	Axlor	1	Quina	MIS 3 (>47 ky BP)	Mozota Holgueras 2012 Gómez-Olivencia et al. 2018	
Germany	Salzgitter-Lebenstedt	8	Levallois	MIS 3 (55 – 48 ky BP)	Gaudzinski 1999 Pastoors 2009	
Crimea	Zaskalnaya VI	1	Levallois (Ak-Kaya)	MIS 3 (39 – 30 ky BP)	Stepanchuk et al. 2017	
Siberia	Chagyrskaya	2	Micoquian (Sibiryachika)	MIS 4-3 (60 – 50 ky BP)	Baumann et al. 2020	

S4 Table. Reports (non-exhaustive) of knapped bone tools from pre-AMH contexts in Eurasia.

Loc Site		Nb.	Industry	Industry Dates Ref.		
	Combe- Grenal	1	Mousterian Levallois		Bordes 1961	
		1	Dentioulate	MIS 3 (39-38 ky BP)	Vincent 1993	
					Tartar and Cotamagno 2016	
	Ionzac	7	Quina	MIS $A$ (72 ky BP)	Rendu et al. 2020	
	J0112ac		Quina	WIIS + (72 Ky DI )	Richter et al. 2013	
	Vaufrey	1	Mousterian Levallois	MIS 4 (74 ky BP)	Vincent 1993	
	·			······································	Tartar and Costamagno 2016	
France	Pié-Lombard	4	Levallois	MIS 5 (70 ky BP)	Texier 1974	
					Texier et al. 2011	
	Rigabe	6	Levallois	MIS 3-5	Defleur 1988	
	8				Brugal et al. 2020	
	La Ferrassie	1	Mousterian	NR	Bordes, 1961	
	Bois-Roche	+/-15	Mousterian	NR	Vincent 1993	
	Baume de Gigny	1	Mousterian	NR	Vuillemev 1989	
		-				
	Rhede Sirgenstein	1	Micoquian (Keilmesser)	MIS 5 (70 ky BP)	Tromnau 1983	
Germany			· · · · · · · · · · · · · · · · · · ·	· · · ·	Baales and Stapel 2015	
5			Mousterian	NR	Hahn 1976	
					Ono 2006	
Belgium	Trou Magrite	1	Mousterian	MIS 3	Personal inventory	
8					Jimenez et al. 2016	
	Fumane	1	Levallois	MIS 3 (42 ky BP)	Romandini et al. 2014	
		-			Peresani et al. 2013	
	Poggeti Vecchi Casal de'Pazzi La Polledrara	Poggeti	10	Mousterian	MIS 6-7 (171 ky BP)	Aranguren et al. 2019
		10	Wousterhan	······································		
		1 +/-3	Protopontinian Acheulean (without bifaces)	MIS 7 (270-250 ky BP)	Anzidei and Gioia 1992	
<b>T</b> . 1					Marra et al. 2018	
Italy					Villa et al. 2021	
				MIS 9 (324 ky BP)	Santucci et al. 2016	
	Lademagne	+/-2			Villa et al. 2021	
			Acheulean	MIS 10-11 (405-389 ky BP)	Pereira et al. 2018	
	Contral d'	81		··	villa et al. 2021	
	Castel di		Acheulean	MIS 11 (395 ky BP)	Boschian and Sacca 2015	
	Guido				v 111a et al. 2021	

# S1 Text. Bone retouchers

The bone retoucher is a common Middle Paleolithic bone tool (Armand and Delagnes 1998; Mallye et al. 2012; Jequier et al. 2012; Mozota Holgueras 2012; Blasco et al. 2013; Abrams et al. 2014; Deaujard et al. 2014; Rosell et al. 2015; Rougier et al. 2016; Doyon et al. 2018; Costamagno et al. 2018; Mateo-Lomba et al. 2019), which already exist in previous periods (Roberts and Parfitt 1999; Langlois 2004; Smith 2013; Julien et al 2015; Kolfschoten et al. 2015; Moigne et al. 2016) and last throughout the Upper Paleolithic (Patou-Mathis 2002; Castel et al 2003; Castel and Madelaine 2003; Rigaud 2007; Tartar 2009, 2012). Identified from its use-wear traces, it has benefited from functional analyses since the first specimens were discovered (Henri-Martin 1906). Most scholars agree that it is a light hammer for shaping lithic edges (Bonch-Osmolovskyi 1940; Semenov 1964; Feustel 1973; Rigaud 1977, 2007; Schelinskii 1983; Vincent 1988; Bourginon 2001; Schwab 2009; Mozota 2012; Mallye et al. 2012). But bone retouchers are seen as an undifferentiated unit, despite their morphometrical diversity, because of the scores apparent uniformity that does not allow to see significant differences between sites or chronocultures, apart from of the longitudinal orientation of the scores, specific to Upper Paleolithic material (Schwab 2002).

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## S2 Text. Beveled tools

Beveled tools, mainly made from antler, are frequently identified in Upper Paleolithic contexts (Deffarges et al. 1974; Provenzano 1984). In later periods, Mesolithic and Neolithic, bone specimens are more common (Camps-Fabrer et al. 1998; Maigrot 2003). In techno-traceological studies, chisels (for cutting) and wedges (for splitting) are often grouped together (Provenzano 1998) because they share the same characteristics: a cutting edge at one end marked by crushing sometimes associated with a blunt area, chips or small removals, and striations oriented along the main axis of the tool. The force imparted to set them in motion can be transmitted directly by the arm, or indirectly with a hammer. In the latter case, the tools are characterized by a striking surface located on the end opposite to the bevel and materialized by a crushing area surrounded by macro to micro removals. However, the absence of a striking surface does not necessarily indicate that a hammer has not been used. This occurs when the tools are hafted, such as the bone bevels from the Swiss Final Neolithic (Voruz 1984). If the handle is not preserved, it can be revealed by: (1) the proximal end shaping (Sidéra 1989), (2) a glossing/blunting of the proximal tool edges (Maigrot 1997), a clear limit of the distal use-wear traces, or a clear change of the bone material coloration (Maigrot 2003). Repeated hammering of the proximal end can also lead to fatigue fractures. These use-fractures are reportedly quite common on bone beveled tools (Tartar 2012; Maigrot et al. 2013).

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# S3 Text. Retouched tools

The identification of an intentional retouch on bone is often put forward when all other causes that could lead to removals have been ruled out (Vincent 1993). The archaeological context allows the diagnosis to be based with greater confidence (Inizan et al. 1995). At Chez-Pinaud, the absence of carnivore consumption traces (chewing, grooves, pits, punctures, and digestion blunts; Stucliffe 1973; Haynes 1983; Campas and Beauval 2008; Fourvel 2012), dispels the first source of possible confusion regarding notches origin. The likelihood that the bone blanks were transformed by humans for technical purposes is here increased by their tool status: most were used as retouchers. Among the technical causes, bone fracturing by percussion during butchery processes also lead to the formation of removals (medullary or cortical side). In this case, the latter are related to the adjacent fracture, and sometimes to traces of the anvil's counter-strike on the opposite face, all resulting from a single event, generally a violent blow given perpendicular to the bone (Capaldo and Blumenschine 1994; Pickering and Egeland 2006).

Although there are few references about the intentional retouch of bone, positive clues of identification can nevertheless be used. Lithic knapping provides keys to understanding that can partially be transferred to bone insofar as the latter behaves like a conchoidal fracture material. However, bone is also a fibrous material whose mechanical properties vary according to the stress direction. Therefore, it responds to knapping in a more complex way than flint, due to its anisotropic structure. Nevertheless, common regularities and characteristics can be observed, implying the same reasoning in their analysis. The organization of the removals is the main criterion to consider for identifying an intentional knapping (Lyman 1984; Vincent 1993; Inizan et al. 1995).

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## S4 Text. Smooth-ended tools

Blunts are among the most common bone alterations induced by a variety of post-depositional processes (Sutcliffe 1973; Shipman and Rose 1988; Olsen 1989; Villa and d'Errico 2001; Fernández-Jalvo and Andrews 2013). The main criteria for differentiating a technical blunt from a taphonomic one is its extension, location, orientation, its transition with adjacent surfaces, and the combination of these different features. Natural erosion or dissolution tends to cover most, if not all, of the bone surface, whereas a blunt from use is restricted to the surface or edge of the active area. Hafting or gripping blunts may be more extensive, but remain related to a particular tool area. Blunt from friction into the sediments is mainly superficial and does not affect the concavities. The tool effectiveness depends on the control of its working angle. Maintaining this angle induces a regularity of the use-wear characteristics. The profile of the active edge rounding (seen in cross section) thus depends on the way the tool is used but also on the worked material physical properties, depending on whether the latter is organic or mineral, dry, fresh or wet, compact or granular, fibrous or not, etc. The maximum development of the bluntness is fixed by the minimum sharpness necessary to obtain the expected results on the worked material.

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