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

2

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17

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23

24

## 25 **Abstract**

26

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

43

## 44 **Introduction**

45

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

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

54

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

66

67         To date, the Chagyrskaya bone tools provide the only example of a Neanderthal bone  
68 industry, at least, for which the authorship of AMH cannot be considered [10–12]. Bone tools  
69 have already been reported in Neanderthal sites but most of the time as isolated finds. A hundred  
70 kilometers away, such objects have been identified in contemporaneous levels of Denisova cave  
71 [13–15]. They may have been made, in part, by Neanderthals [9,16,17]. In addition to  
72 retouchers, some bone tools have also been reported in Crimean Micoquian assemblages from  
73 the sites of Prolom II [18], Kiik Koba [19], Karabi Tamchin [20], Zaskalnaya VI [21], and

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

84

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

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

100

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

113

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

123

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

132

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

138

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

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

149

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

159

160 The spatial organization and state of preservation of artifacts indicate small-scale post-  
161 depositional movements of archaeological remains. Concentrations of lithic knapping waste,  
162 with refitting evidence, have been found in the US22 (see A. Delagnes [63]), as well as in situ  
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-  
165 Jalvo and Andrews [71]) on the bones and the cortical surfaces are fully preserved on more than  
166 half of the faunal remains. Although visible on most pieces, weathering is limited to its first  
167 stages [72], indicating rapid sedimentation. The near absence of evidence of carnivore activity  
168 (absence of large carnivore remains and coprolites, extreme rarity of consumption traces < 1%  
169 NISP) shows that carnivores were only marginally involved in the accumulation and destruction  
170 of the bone assemblage [62].

171

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

176

## 177 **Materials and methods**

178

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

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].

196 In Western archaeology, these two complementary sides evolved separately through technology  
197 studies, which reconstruct the manufacturing *chaîne opératoire* of the artifacts from the shaping  
198 macro-traces, and through functional analyses, which infer their function from macro and micro  
199 use-wear. They are now at the heart of any lithic study, which is not yet the case for bone tools,  
200 whose remains are less numerous and more altered. Transfer from lithic to bone has been the  
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  
203 the microscopic scale of examination [83–91]. However, it only concerned assemblages where  
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**

211

212 Our identification of organic (microorganism, animal, plant etc.) and inorganic  
213 (weathering, water circulation, sediment compaction etc.) taphonomic alterations is based on  
214 data outlined in publications [71,72,92–95]. We paid particular attention to the origin of bone  
215 fractures. The fractures considered as anthropogenic are those occurring on "fresh" bone, i.e.,  
216 occurring shortly after the animal's death. They are characterized by a helicoidal shape and a  
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  
219 component. The fracture surfaces are straight, rough and form with the cortical side an angle  
220 close to 90° [61,96–100]. However, the transition from fresh to dry bone is a gradual and non-

221 homogeneous phenomenon. Therefore, the proposed criteria do not allow for the recognition of  
222 an anthropogenic fracture on drying bone or a post-depositional fracture on fresh bone. In the  
223 archaeological material, the fracture surfaces often have mixed features, which implies  
224 reasoning in terms of trends according to the corpus studied and taking into account all available  
225 discriminating criteria (hammers impacts, general morphology, location, variability within the  
226 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  
231 published archaeological and experimental data as well as on our own experiments. The nature  
232 and organization of the traces observed on the archaeological material led to focus more  
233 specifically on morpho-functional categories already identified in Upper Paleolithic contexts  
234 and some Middle Paleolithic sites, those of: (1) bone retouchers, (2) beveled tools, (3) tools  
235 with retouched edges, and (4) tools with smoothed end. These categories are not defined with  
236 the same precision. For the bone retouchers, we know both their mode of utilization and the  
237 activity in which they were involved. They are light soft hammers for retouching lithic edges  
238 (S1 Text) [36,75,106,107]. For the beveled tools, the nature and localization of the traces refer  
239 only to a mode of use involving percussion, but the worked material and the task performed  
240 may vary (S2 Text) [35,108–110]. Bone fragments with intentional removals on one edge (S3  
241 Text) [40,59,96,111] or with a technical blunt on one end (S4 Text) [7,30,55,88], are  
242 characterized only by a type of damage and its location relative to the main axis. For these  
243 categories, many hypotheses about their function can be put forward. It is therefore necessary,  
244 in order to complete the available data, to enlarge the experimental frame of reference.

245

## 246 **Experimental frame of reference**

247

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

256

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

269

270           The blanks shaping consisted mainly of a second fracturing step by direct percussion  
271 for sizing, gripping and/or the active edge setting, i.e., modification of the edge angulation  
272 and/or delineation. We tested the efficiency of different hammers: soft organic (antler,  
273 *Juniperus communis*), soft mineral (fine sandstone, limestone, schist), hard mineral (quartzite)  
274 depending on the configuration of the striking platform, the size, morphology and axis of the  
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  
277 components) and our results were compared with those of previous experiments  
278 [7,32,40,59,96,111–114].

279

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

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

299

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

304

## 305 **Mechanical bone properties**

306

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

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

320

## 321 **Internal traceology**

322

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

334

335         We performed  $\mu$ CT capture, without prior treatment of the samples, on 9 bone tools  
336 from the Chez-Pinaud site (S1-S9 Files) and 5 bone tools from our experiments, getting a total  
337 of 25 scans (S1 Table). The archaeological bone tools were chosen for their particularly good  
338 state of preservation, and to cover the morpho-functional diversity. The scanner chamber  
339 dimensions (260 mm in diameter and 420 mm in length) allowed a complete capture of each  
340 specimen at voxel sizes between 98  $\mu$ m and 26  $\mu$ m while scans of ROI (region of interest) were  
341 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

353 Within the faunal remains from 2019-2020 campaigns, we identified a total of 103 bone  
354 tools. The feasibility of use-wear analysis is constrained by a loss of material on the surface of  
355 the bone due to exfoliation phenomena (delamination of the outermost cortical layers).  
356 Longitudinal cracks from the weathering, combined with the weight and nature of the sediment  
357 and with the passage of the quarry machinery, probably caused much of the fragmentation of  
358 the bone remains. Only 15% of the tools are complete or sub-complete, i.e., free of post-  
359 depositional or recent breakage.

360

361 Of the 103 bone tools, a majority are marked by scores areas (*sensu* Mallye et al. [138])  
362 localized on the cortical face (N=91), some have removals at one or both ends of the main axis  
363 (anatomical axis; N=10), and/or removals on the cortical and/or medullary surface of a lateral  
364 edge (N=7) and/or a smoothed area, more or less extensive, at one end (N=2). The main  
365 modifications, which changed the volume of the blanks, are always associated with one or more  
366 marginal modifications such as chipping, striations, compactions, rounding etc. The main

367 modifications correspond respectively to the following morpho-functional categories: (1) bone  
 368 retouchers, (2) beveled tools, (3) retouched tools, (4) smooth-ended tools (Table 1; Fig 2). More  
 369 than 88% of the blanks were used as retouchers, and 81% exclusively in this way. Multiple-use  
 370 tools accounted for 9% of the total. The most common association is a bone retoucher with a  
 371 beveled end, followed by a bone retoucher with a lateral retouched edge. To date, there are no  
 372 tools that combine the four major modifications.

373

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

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

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

376

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

380

381 All tools are made from bone, except for a horse incisor used as retoucher [139]. The  
 382 taxa used in their manufacture are the same as those hunted and brought to the site: reindeer  
 383 (34%), horse (26%) and *Bos*/bison (5%), but with different proportions (Fig 3d). Bones of large  
 384 ungulates are almost twice as numerous among the tools as among the faunal remains (Fig 3a–

385 b). While bone retouchers are made equally from large (53.8%) and medium (46.2%) ungulate  
386 bones, multiple tools are always made from large ungulate bones. The blanks are mainly flakes  
387 of long bones (87%): tibia (42.6%), humerus (17%), femurs (17%), metapods (12.8%) and  
388 radio-ulna (10.6%), for anatomically determined pieces. Ribs (8.7%), phalanges (N=2), coxal  
389 (N=1) and scapula (N=1) fragments complete the corpus.

390

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

393

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

409

## 410 **Bone retouchers**

411

## 412 **Morphometry**

413

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

434

## 435 **External modifications**

436

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

445

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

451

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

460 edges retouch depend on multiple factors, including the weight of the bone retoucher, its  
461 handling capabilities, its trajectory or the energy transmitted [148,149]. The use of small  
462 elongated flakes sets a range of possibilities that is not that of semi-complete metapod  
463 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  
468 retouching of a lithic edge with a bone retoucher is the result of a reciprocal effect of one  
469 another, combining percussion and cutting. The lithic edge penetrates the bone by cutting and  
470 separating the fibers, while the energy transfer takes place at the bottom of the cut when  
471 maximum penetration is reached. The percussion does not only initiate a crack on the impact  
472 lithic edge but also in the bone material. The propagation of the latter should depend on many  
473 parameters related to the applied stress (dynamics of the blow, position and handling of the  
474 retoucher, kinematics, etc.) and the state and structure of the bone (anatomical characteristics,  
475 location of the active zone, humidity, temperature, etc.) [61,93,96,98,99]. The development of  
476 use cracks and micro-cracks into bone tools has already been demonstrated with a reindeer  
477 antler hammer [134] and some projectile points [132,136]. We therefore sought to investigate  
478 this type of damage through  $\mu$ CT imaging of three experimental (S2 Table) and three  
479 archaeological bone retouchers (S5-7 Files).

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

485 surface. Cracks can lead to partial chip detachment (Fig 5b), while the formation of a first crack  
486 promotes shrinkage if a second crack develops nearby (Fig 5d). All cracks and micro-cracks  
487 have the same orientation, in accordance with the regularity of the flintknapper's gesture. They  
488 can therefore provide information about the direction of the movement and possible changes in  
489 the position of the bone retoucher or lithic edge during the knapping process. At our scale of  
490 analysis, simple visual examination does not detect significant differences in crack length,  
491 depth, or delineation, based on the freshness states of the experimental bone retouchers.

492

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

499

500 Internal visualization of our archaeological bone retouchers is a delicate task. First,  
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  
503 only partially reflect, the original structure of the bone. Secondly, because the bones from Chez-  
504 Pinaud are altered by cracks from weathering that could mimic the technical cracks. Weathering  
505 cracks develop along the natural lines of weakness of the bones, i.e., appearing perpendicular  
506 to the surface, when the bone is observed along its main axis (Fig 5j) and parallel to the surface,  
507 when observed in cross-section. Cracks with similar characteristics as the damage caused by  
508 the use of experimental retouchers are visible under the scores area at 30-20  $\mu$ m resolution (Fig  
509 5g–j). These initial observations validate our hypothesis of the formation of use cracks below

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  
519 seven beveled tools range in length from 4.46 cm to 11.84 cm (L. avg. = 6.89 cm), for widths  
520 from 2.51 cm to 5.11 cm (W. avg. = 3.51 cm) and cortical tissue thicknesses from 0.56 cm to  
521 1.36 cm (Th. avg. = 0.99 cm). Six of them have lost their original length. Two have a post-  
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  
524 on fresh bone, posterior to the blank fracture. Their hinge morphology (fracture initiation from  
525 the upper side; Fig 6g) or sawtooth morphology (fracture initiation from one of the lateral sides;  
526 Fig 7g) [79,82,153,154] and limited extent are characteristic of bending stress near the fracture  
527 line. They may be the result of tools use. In one case, the transverse fracture is covered by a  
528 striking zone (Fig 6f), indicating that the tool was reused after its deterioration. This striking  
529 zone demonstrates that the beveled tool was still efficient despite its relatively short length (L.  
530 = 6.5 cm), which is less than the average length of all specimens.

531

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

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

537

538 **Fig 7. Beveled tools from the Chez-Pinaud site, 2019–2020 excavations.** (a) on horse  
539 humerus, n°1014. (b) edge retouch on the cortical surface. (c) chipping partially covered by a  
540 blunt on the cortical surface at the distal end. (d) on bison metatarsal, n°1527. (e) chipping on  
541 the cortical surface at the distal end. (f) chipping on the medullary surface at the distal end. (g)  
542 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  
545 one of the fracture surfaces caused by the blank production at an angle of about 30° to 70°. This  
546 particular morphology must therefore have been obtained during the first stage of fracturing; a  
547 result that is far from systematic given the morphological diversity of bone fragment extremities  
548 within the faunal remains of US22. Our experimental fracturing on fresh bone also produced  
549 limited fragments with a morphology suitable for direct use as a bevel. Several non-exclusive  
550 hypotheses can be put forward: (1) a control, during the first stage of fracturing, of the  
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  
553 carcasses, (3) a shaping by percussion of the active end posterior to the first fracturing stage. It  
554 is also necessary that the edge to be shaped presents a favorable knapping angle. Two pieces  
555 could illustrate this last case.

556

## 557 **External modifications**

558

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

572

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

579

580           The bevels are bifacial (N = 5) or unifacial (N = 2), on the cortical and medullary  
581 surfaces (N = 6; Fig 7a) or on a lateral side (N = 1; Fig 7d). The lateral beveled tool shows a  
582 proximal fracture that is also lateral, in agreement with the axis of the stress exerted on the tool.  
583 All specimens show blunting of the cutting edge (Fig 7c), sometimes associated with visible

584 compaction by flattening and wrinkling of the protruding areas. In 6 cases out of 7, the blunting  
585 is also associated with bifacial chipping (Fig 6a–b), more advanced on one face of the bevel  
586 (Fig 8g). We count one to four generations of small removals in the main axis, with a slight  
587 variation in their orientation. The bevel without a chipped end is marked by a bending fracture  
588 topped with a pronounced bluntness on the front and medullary surface (Fig 6e).

589

## 590 **Internal damage**

591

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

598

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

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

612

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

620

621 For the archaeological beveled tools, the selected anatomical fragments are close to the  
622 epiphyses. The organization of bone fibers is more complex than in the diaphysis. Unlike  
623 experimental beveled tools, where the main axis of the tool is the same as the anatomical axis,  
624 archaeological beveled tools have their active extremity positioned obliquely to the anatomical  
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  
627 lines of weakness in the bone structure. We can only point out that the cracks concentrate at the  
628 active extremity (Fig 9h, A) and that there may be a connection between the technical micro-  
629 cracks and the development of taphonomic macro-cracks. Here, if the modifications were solely  
630 taphonomic, their distribution would be uniform, but parts of the beveled edges still show sharp  
631 and acute zones (Fig 9j), while others are chipped (Fig 9l), compressed (Fig 9k) or blunted (Fig  
632 9m).

633

## 634 **Retouched tools**

635

## 636 **Morphometry**

637

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

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

652

## 653 **External modifications**

654

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

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

671

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

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

688

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

694

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

707

708 **Internal damage**

709

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

716

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

723

724 **Fig 12.  $\mu$ CT 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)  
727 cracks from shaping at the beginning and the end of a removal. (e) simple cracks from shaping  
728 at the percussion point on a transverse cross-section. (f) 3D reconstruction of an archaeological  
729 sample from large size ungulate diaphysis, n°5. (g-h) frontal cross-sections of the  
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 ( $\mu$ CT IP and CAD: M. Baumann).

733

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

750

## 751 **Smooth-ended tool**

752

## 753 **Morphometry**

754

755 One of the faunal remains under study shows at its distal end a blunt that is characteristic  
756 of use (S4 Text, S8 File). It is a portion of the mesial part of a large ungulate rib (L. = 9.44 cm;  
757 W. = 1.68 cm; cortical Th. = 0,3 cm). The tool, rather brittle, was collected in several fragments

758 that were glued back together. Three quarters of the lower face is missing, while the proximal  
759 extremity is a recent break (Fig 13).

760

761 **Fig 13. Smoothed-end tool, n°2020, from the Chez-Pinaud site, 2019–2020 excavations.** (a)  
762 blunted bending fracture at the distal extremity. (b) striations from use on the ventral face at the  
763 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  
768 (Fig 13c). At one extremity, a blunt covers a bending fracture that reveals the cancellous tissue  
769 (Fig 13a). At this location, the junction between the ventral surface and cancellous tissue is a  
770 flat surface (Fig 14c), whereas the junction between the dorsal surface and cancellous tissue is  
771 smoother and shows micro-flakes and tears (Fig 14d). At the top, the rounded compact surface  
772 is marked by indentations and micro-flaks (Fig 14a–b). Over the entire surface, the micro-flacks  
773 and indentations are partially covered by the blunt area. The latter is associated, on the dorsal  
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

777 **Fig 14.  $\mu$ CT imaging of a smoothed-end tool, n°2020, from the Chez-Pinaud site, 2019–**  
778 **2020 excavations.** (a–b) rounded and compacted surface marked by indentations and micro-  
779 flakes at the distal end. (c) flat surface at the junction between the ventral surface and the  
780 cancellous tissue. (d) micro-flakes and pull-outs on a smoothed surface at the junction between  
781 the dorsal surface and the cancellous tissue. (e–g) frontal, sagittal and transvers cross-sections  
782 showing a possible crack of use.

783

784 Experimentally, the sharpness of a bone edge decreases quite rapidly during its use, but  
785 its loss of matter is minimal unless the material being worked is abrasive. Macroscopic blunting  
786 of a sharp irregular bone edge cannot result from scraping soft organic material (e.g., skin,  
787 leather, bark). The latter would be ripped or pierced before a blunt had developed. The bluntness  
788 of the bending fracture and the nearly spherical shape of the extremity of the rib examined (Fig  
789 14f), which is not in the progressive extension of the rib sides, indicate shaping by abrasion.  
790 The chronological relationship between this shaping, the scraping of the sides and the use-wear  
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  
794 features is close to those of pressure flakers [158–162].

795

### 796 **Internal damage**

797

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

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

812

## 813 **Discussion**

814

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

816

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

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

836

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

850

851         The shaping of the tools is clearly attested. It is mainly concentrated on the active parts.  
852 Scraping marks are visible on the active area of about 23% of the bone retouchers, a proportion  
853 close to those of the bone retouchers from the Quina deposits of De Nadale (17%) [168] and  
854 Les Pradelles (18%) [144]. Scraping was used to shape and/or clean the smooth-ended rib, while  
855 abrasion was used to shape and/or rejuvenate the tip. Only one specimen from the Chez-Pinaud  
856 site is currently available, but other smooth-ended ribs shaped by scraping and/or abrasion have

857 already been reported in Middle Paleolithic assemblages dated between 75 and 45 ka ago,  
858 including those from Abri Peyrony and Pech de l'Azé [30], La Quina [41], Axlör [36],  
859 Zaskalnaya VI [21] (S3 Table, S3 Fig) or Lartet [169]. Within the Quina levels of Chez-Pinaud,  
860 direct percussion is widely applied, for shaping or resharpening the lateral edges and bevels  
861 and, possibly, for shaping out the prehensile parts. Among ancient bone artifacts, the most  
862 frequently reported are those that were retouched, although only the least questionable  
863 specimens, deeply transformed, are illustrated, such as the elephant bones bifaces [170] (S4  
864 Table, S4 Fig). Following Anne Vincent's conclusions on the Charente Mousterian deposits  
865 [32], we note, at Chez-Pinaud and Chagyrskya, the tendency to limit the retouch to only a few  
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  
868 but consistent with some of the bone artefacts from Chagyrskaya: burin-like tools (Fig 15d),  
869 possible bone core (Fig 15e) and bone bladelets (Fig 15c).

870

871 **Fig 15. Micoquian bone industry from the Chagyrskaya cave, Russian federation, 2008–**  
872 **2018 excavations.** (a) bone tool with negatives of lamellar removals. (b) detail of a burin-like  
873 removal negative. (c) bone bladelet. (d) burin-like tool. (e) possible bone nuclei. (f) negatives  
874 of lamellar removals (photos: M. Baumann).

875

## 876 **A functional diversity to be explored**

877

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

882 to maintenance dominate, while traceological analyses shows that the side scrapers were used  
883 to cut meat and hide [171], but a more precise correlation could be drawn between bone  
884 retouchers groups and specific knapping tasks [138,144,148]. For this purpose, the information  
885 provided by external damage and tools morphometry, on which Costamagno et al.'s bone  
886 retouchers groups are based [144], could be supplemented by internal damage detected by  $\mu$ CT.  
887 In particular, the cracks that developed under the scores areas can provide gesture information  
888 that would identify, for example, the bone retouchers used for the Quina retouch [149].

889

890         Among the beveled tools, the diversity in active edges (dimensions, position, front  
891 delineation etc.) and the distribution of use-wear traces, suggest that these tools were used in a  
892 significant diversity of tasks, involving different worked materials: soft, when blunted and  
893 without chippings, harder, when chipped with limited bluntness. The short length of complete  
894 specimens, the frequency of short and transverse shaft fractures, and the modification of the  
895 handling part of one of the tools could argue for the use of handles [110], as already  
896 demonstrated for Middle Paleolithic lithic tools [172] Handles, which improve the efficiency  
897 (accuracy and force) [173], are generally regarded as a significant investment of time and  
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.

900

901         Based on its mechanical properties, the bone responds favorably to experimental  
902 knapping. Edge shaping by percussion does not necessarily mean the placement of an active  
903 part. This may explain the heterogeneity in retouched tools, both in terms of morphometry and  
904 retouch quality. In all cases, the retouch was performed on thick blanks and the removals,  
905 preferentially on the medullary face, seem to be limited to what is strictly necessary. Two active  
906 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.

910

911 Smooth-ended tools, particularly rib tool, are often considered as hide working  
912 [29,30,36,154,177], due to the regular rounded shape of the active extremities that can be  
913 interpreted as resulting from significant contact with a soft worked material. In our study, the  
914 Chez-Pinaud rib shows external and internal damage from a point contact area with a material  
915 harder than bone, with the regular rounded active edge being the result of shaping. The  
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  
918 task diversity could exist in the Middle Paleolithic.

919

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

921

922 The recurrence of bone tool types with distinct potential functionalities in the US22  
923 from Chez-Pinaud, together with that of the Micoquian assemblage from Chagyrskaya and the  
924 occasional report of similar tools from numerous Middle Paleolithic sites, suggests that these  
925 elements had a specific role to play in the pre-Upper Paleolithic technical systems and that their  
926 apparent simplicity is not synonymous with opportunism. The equivalent proportions of bone  
927 and lithic tools in a task specific location, such as Chez-Pinaud, allows us to consider that the  
928 two productions had a technical synchrony. While the complementarity between the bone  
929 retouchers and the sharp lithic edges is fairly obvious in a site dedicated to carcass processing,  
930 the other functional categories of bone tools reflect a broader range of related activities that  
931 may have taken place at the site. The functional spectrum of the Quina flint industry is limited,

932 as it relies on a low diversity of tool types, mostly short, often thick, lacking the pointed shapes  
933 of the biface or Levallois industries. Bone provides elongated shapes, sometimes with minimal  
934 preparation (ribs), while its resistance to impact and relative elasticity make it better suited to  
935 certain tasks than flint. Such complementarity is not specific to Middle Paleolithic, but it  
936 appears all the more necessary in a technical context such as that of the Quina Mousterian.

937

938         Whatever the system considered, its functioning necessarily requires a certain stability  
939 despite its internal constraints (or contradictions) [179], which are predictable, and external  
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  
943 from the large size ungulates, as well as the larger modules from medium size ungulates,  
944 suggests that the raw material for tools making was not so abundant to cover all needs that the  
945 production of blanks could depend on random fracturing. For skilled flint knappers accustomed  
946 also to breaking bone, obtaining bone fragments of predefined shape and edge angulation was  
947 certainly not a concern. A diversity in Mousterian bone breakage pattern has been recently  
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].

950

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

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

958

## 959 **Conclusion**

960

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

973

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980

## 981 **Declarations**

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

983

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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;

1528 h) meat cutting; i) hair removing from skin; j) wooden peeling; k) plant harvesting; l) soil digging  
1529 (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  
1532 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  $\mu$ CT.**

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**

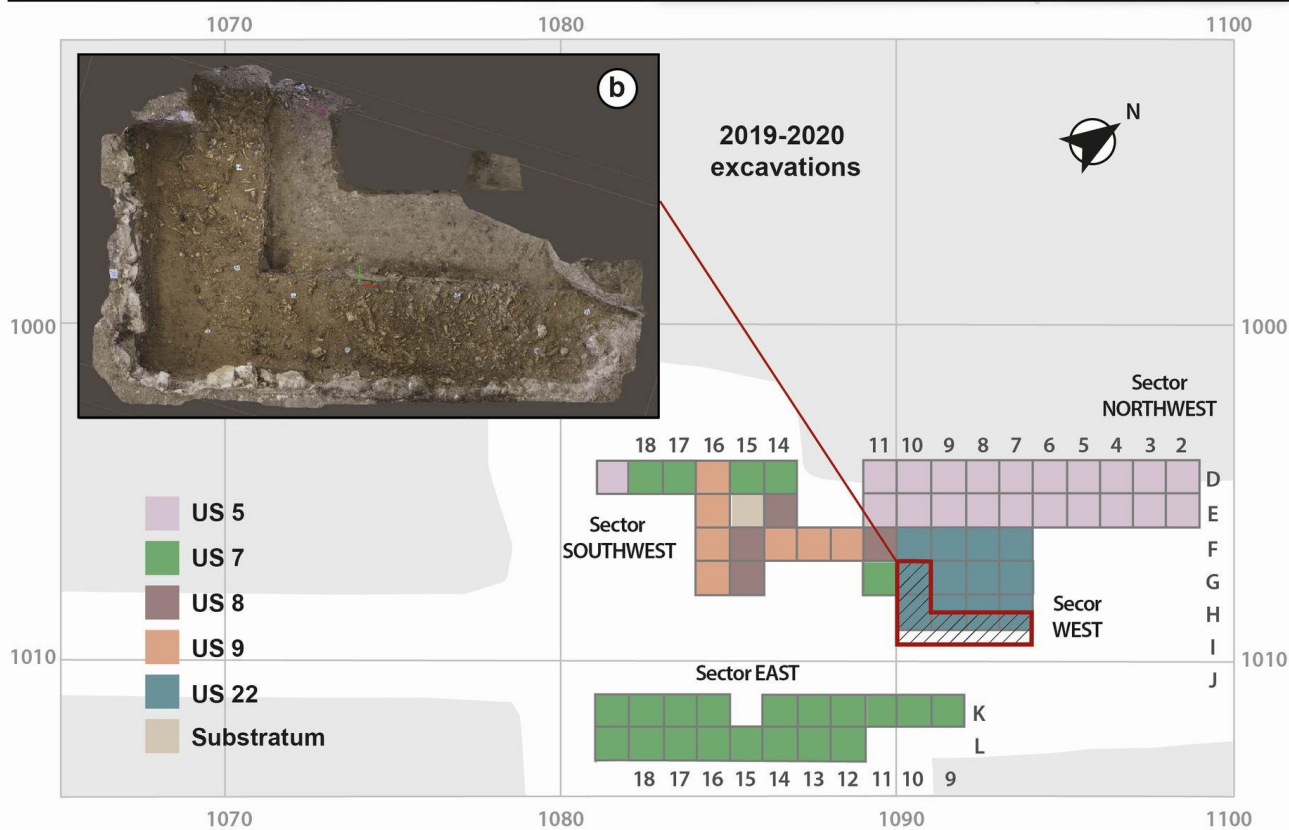
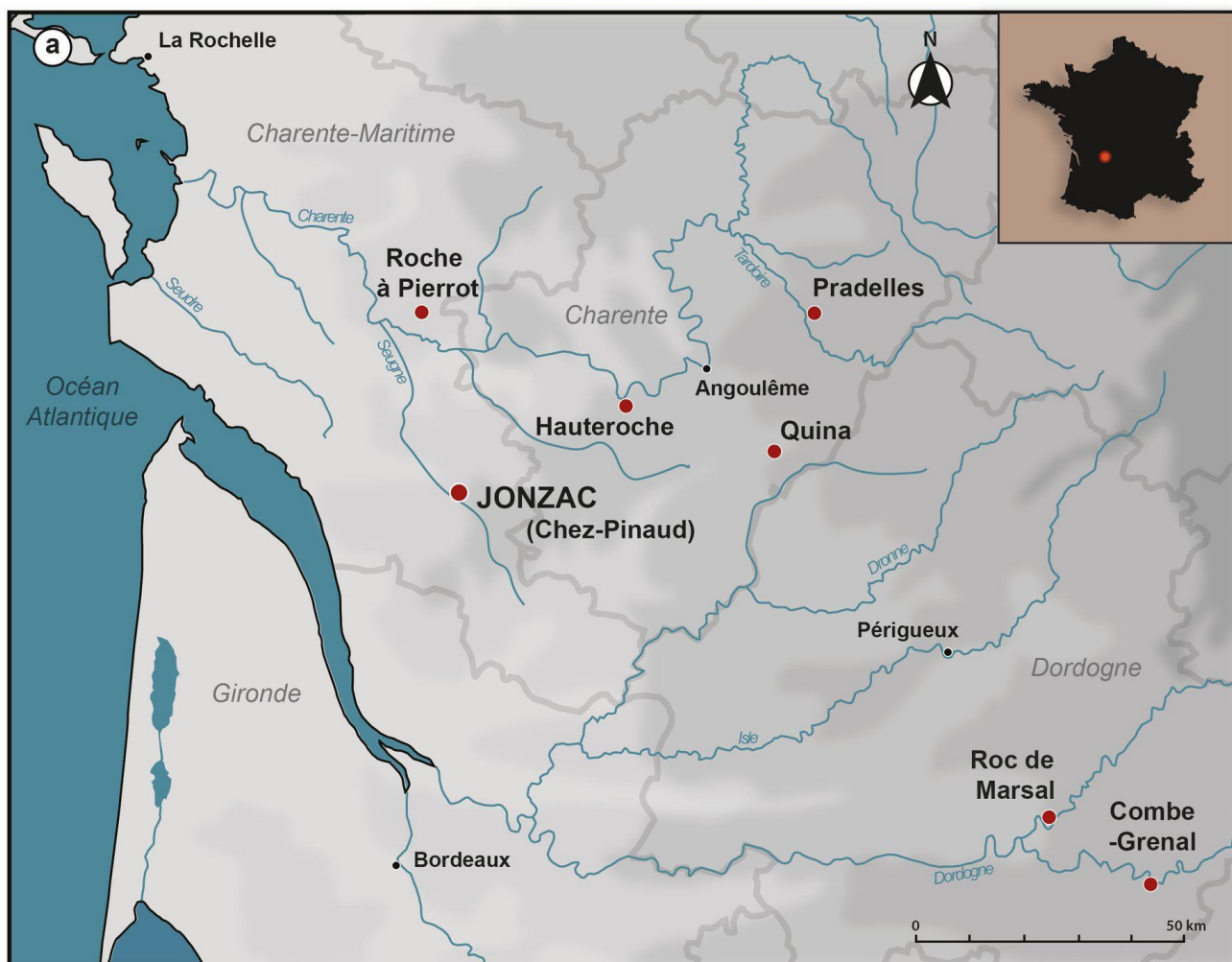
1554 **S8 File. 3D model, smoothed-ended bone tool #CPN20-3581, Chez-Pinaud site**

1555 **S9 File. 3D model, beveled bone tool #CPN20-3609, Chez-Pinaud site**

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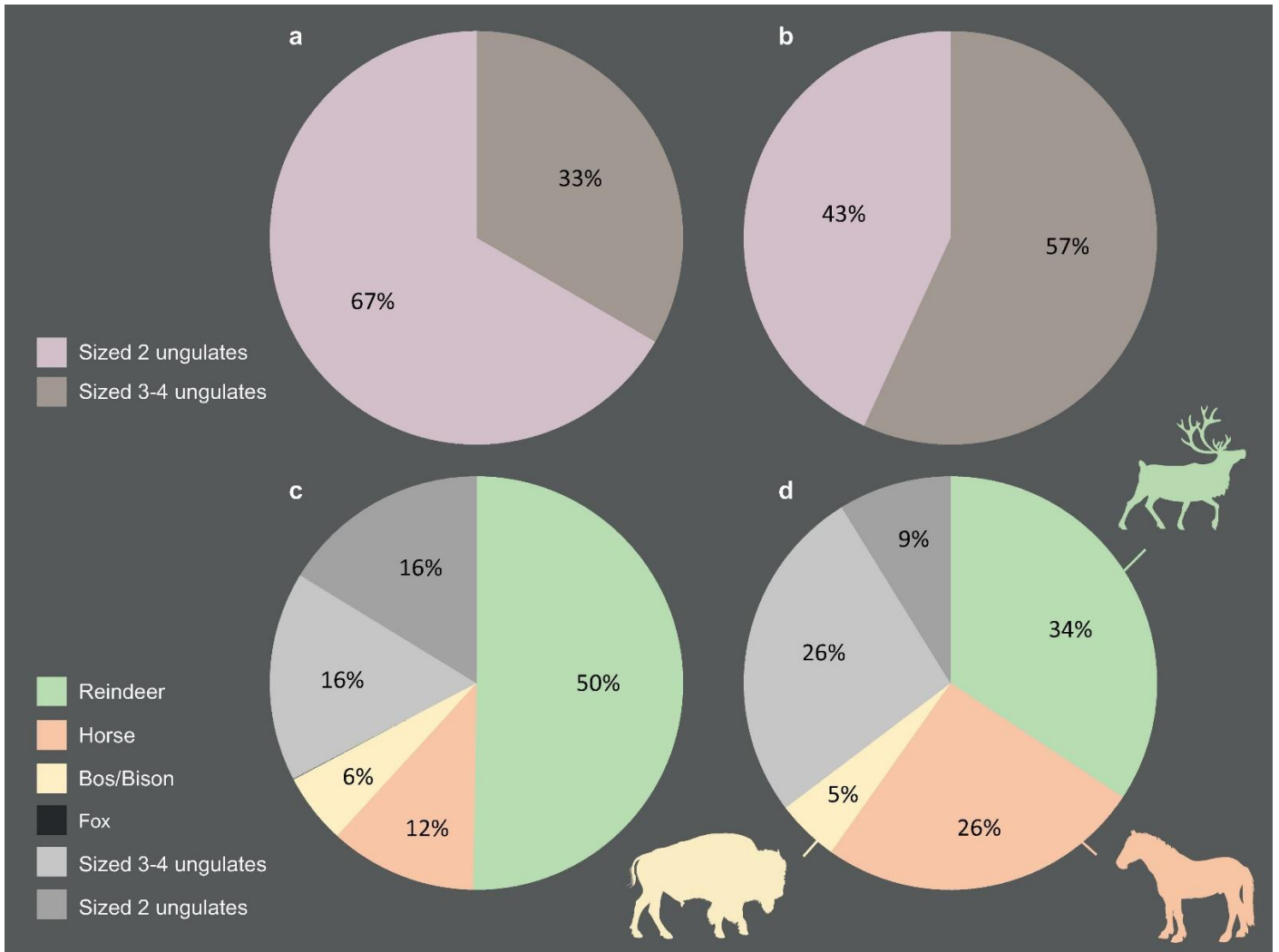
**Fig 1. The Chez-Pinaud site, Jonzac, France.** (a) location of the site and the main surrounding Quina site (geographical data republished from Géoportail.gouv.fr under a CC BY license, with permission from IGN, original copyright 2022). (b) 3D photogrammetric model of the excavated layer (photos and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



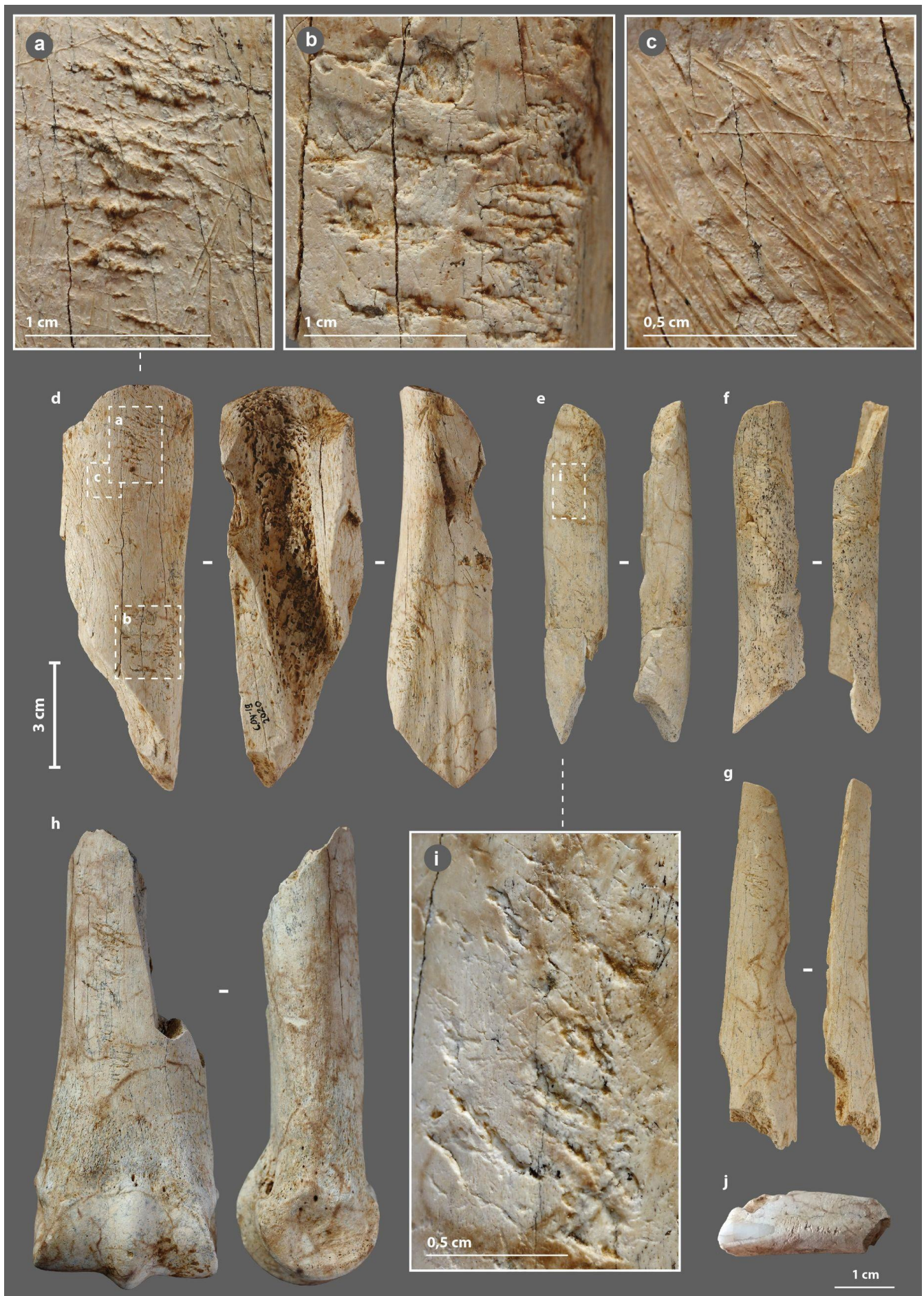
**Fig 2. Bone tools from the Chez-Pinaud site, 2019–2020 excavations. (a–d), (i–k) beveled tools. (a, g–h, e–f, n) retouched tools. (a, f, j, m–o) bone retouchers. (l) smoothed-end tool (photo: M. Baumann).**



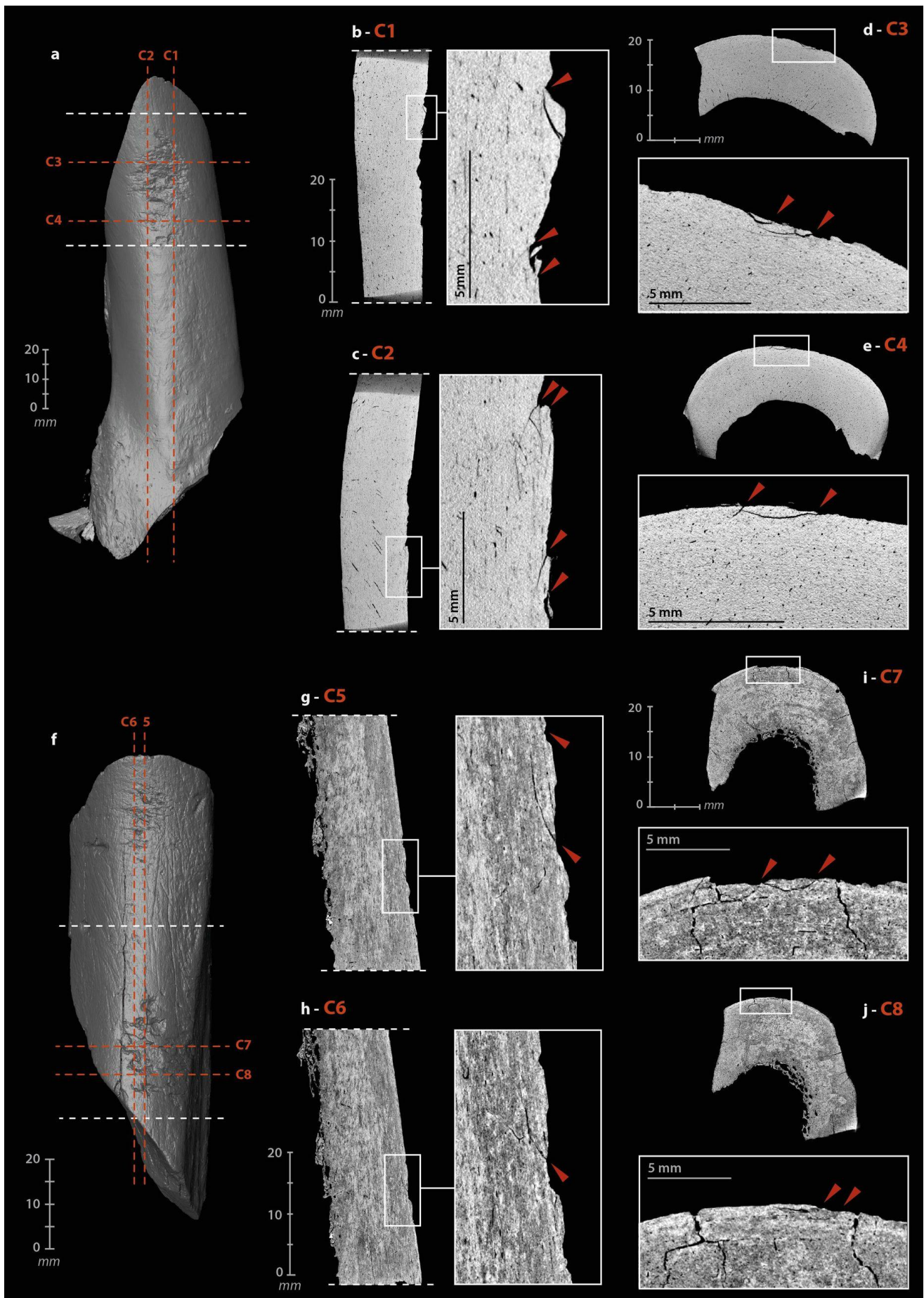
**Fig 3. Species spectrums, Chez-Pinaud site, 2019–2020 excavations. (a-c) faunal remains. (b-d) bone tools (CAD: M. Baumann).**



**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).



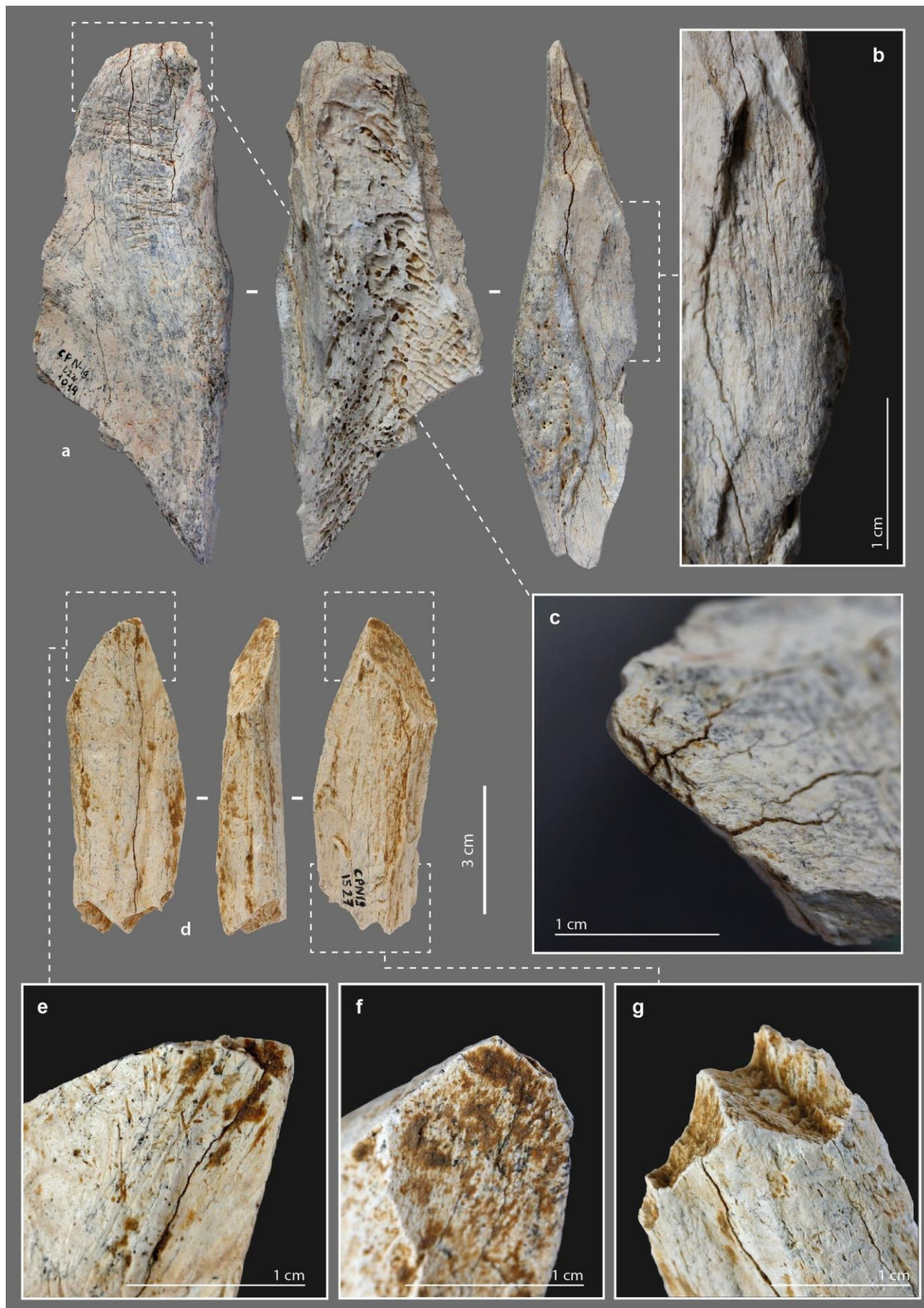
**Fig 5.  $\mu$ CT imaging of bone retouchers.** (a) 3D reconstruction of an experimental sample from a cow tibia. (b–c) cracks from use under the scores area, on sagittal cross-sections. (d–e) cracks from use under the scores area, on transverse cross-section. (f) 3D reconstruction of an archaeological 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 ( $\mu$ CT image processing [IP] and CAD: M. Baumann).



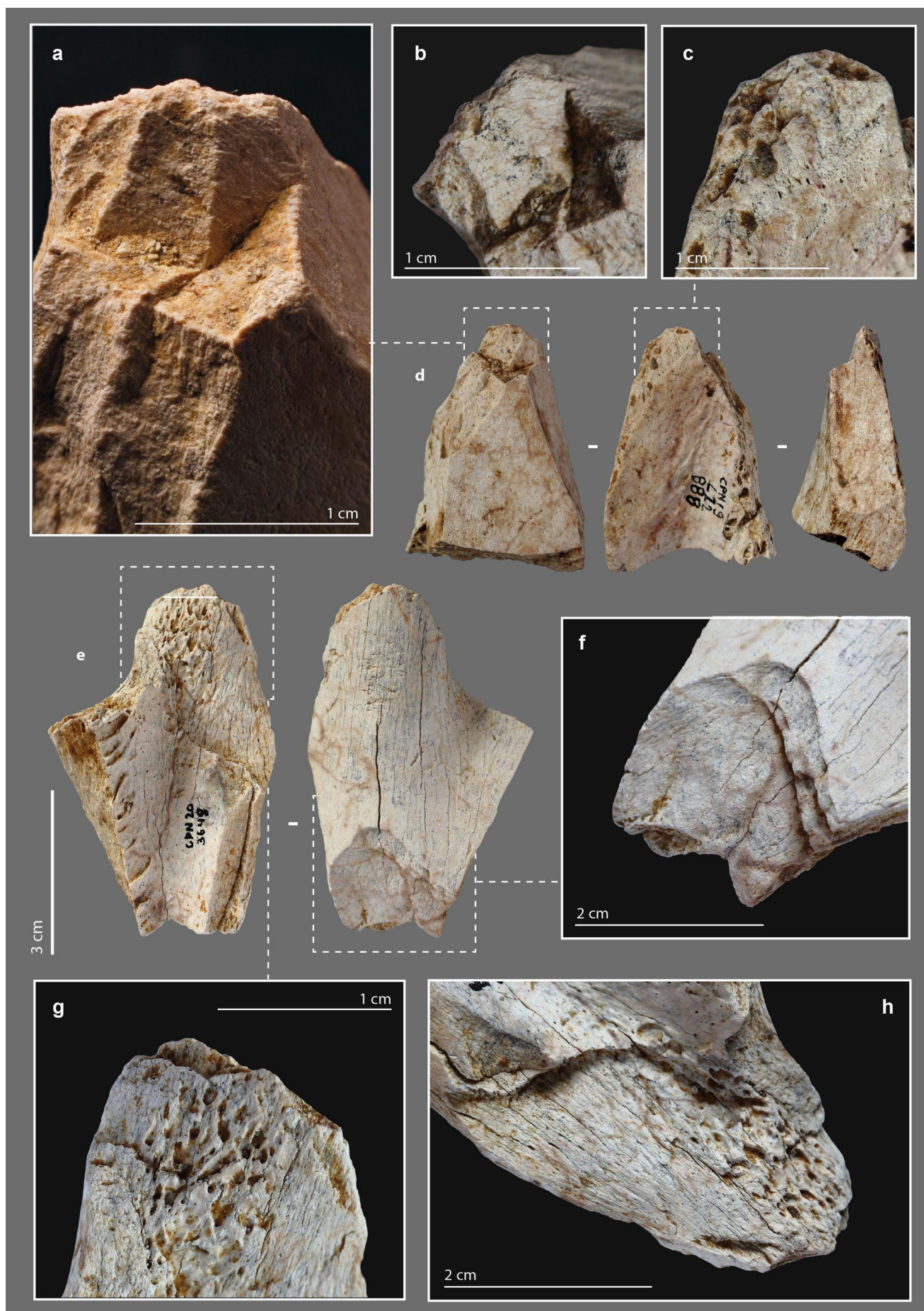
**Fig 6. Beveled tools from the Chez-Pinaud site, 2019–2020 excavations.** (a) chipping on the cortical surface at the distal end. (b) chipping on the medullary surface at the distal end. (c) on medium sized ungulate diaphysis, n°1026. (d) on large size ungulate diaphysis, n°3609. (e) blunt on the medullary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



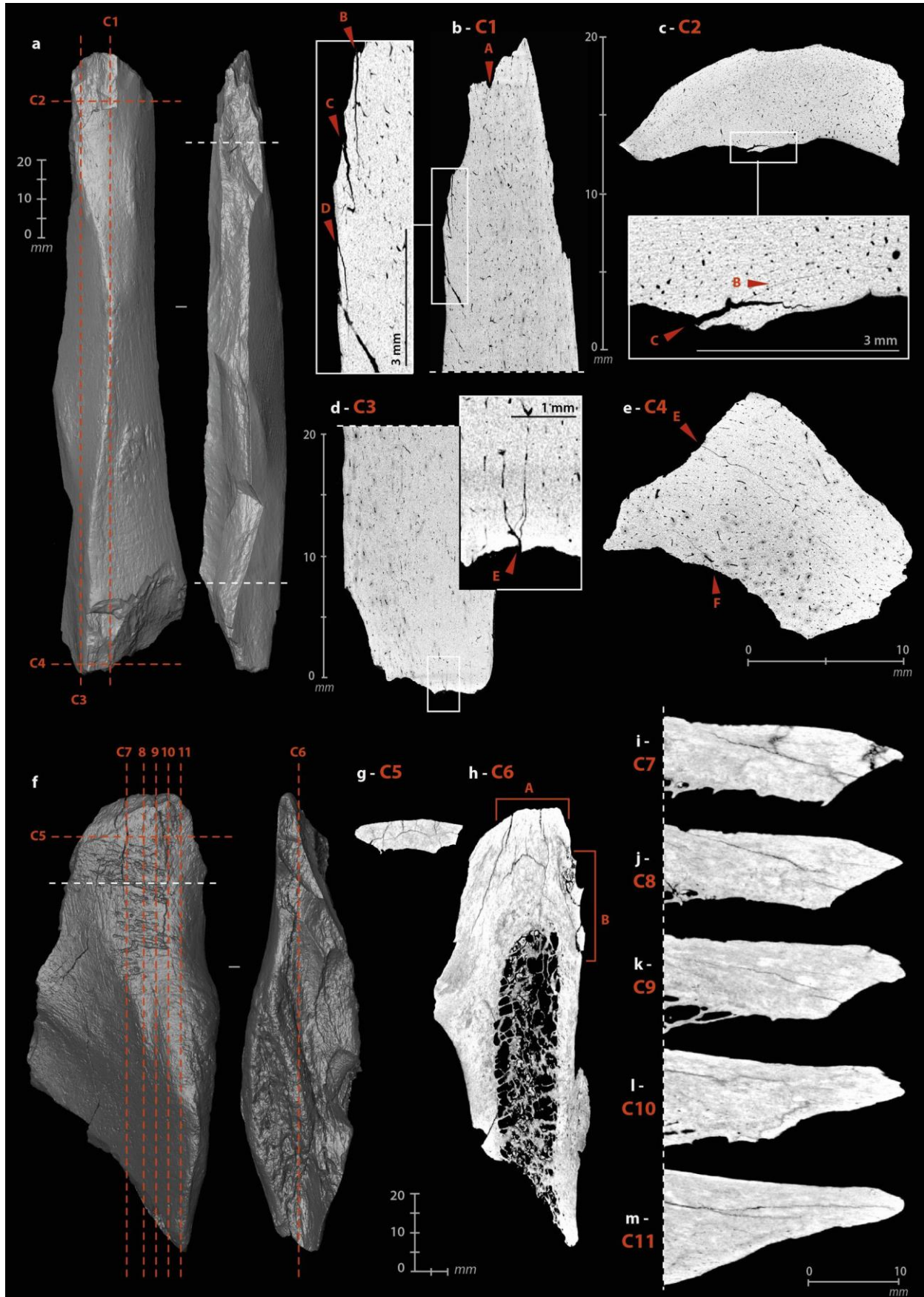
**Fig 7. Beveled tools from the Chez-Pinaud site, 2019–2020 excavations.** (a) on horse humerus, n°1014. (b) edge retouch on the cortical surface. (c) chipping partially covered by a blunt on the cortical surface at the distal end. (d) on bison metatarsal, n°1527. (e) chipping on the cortical surface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



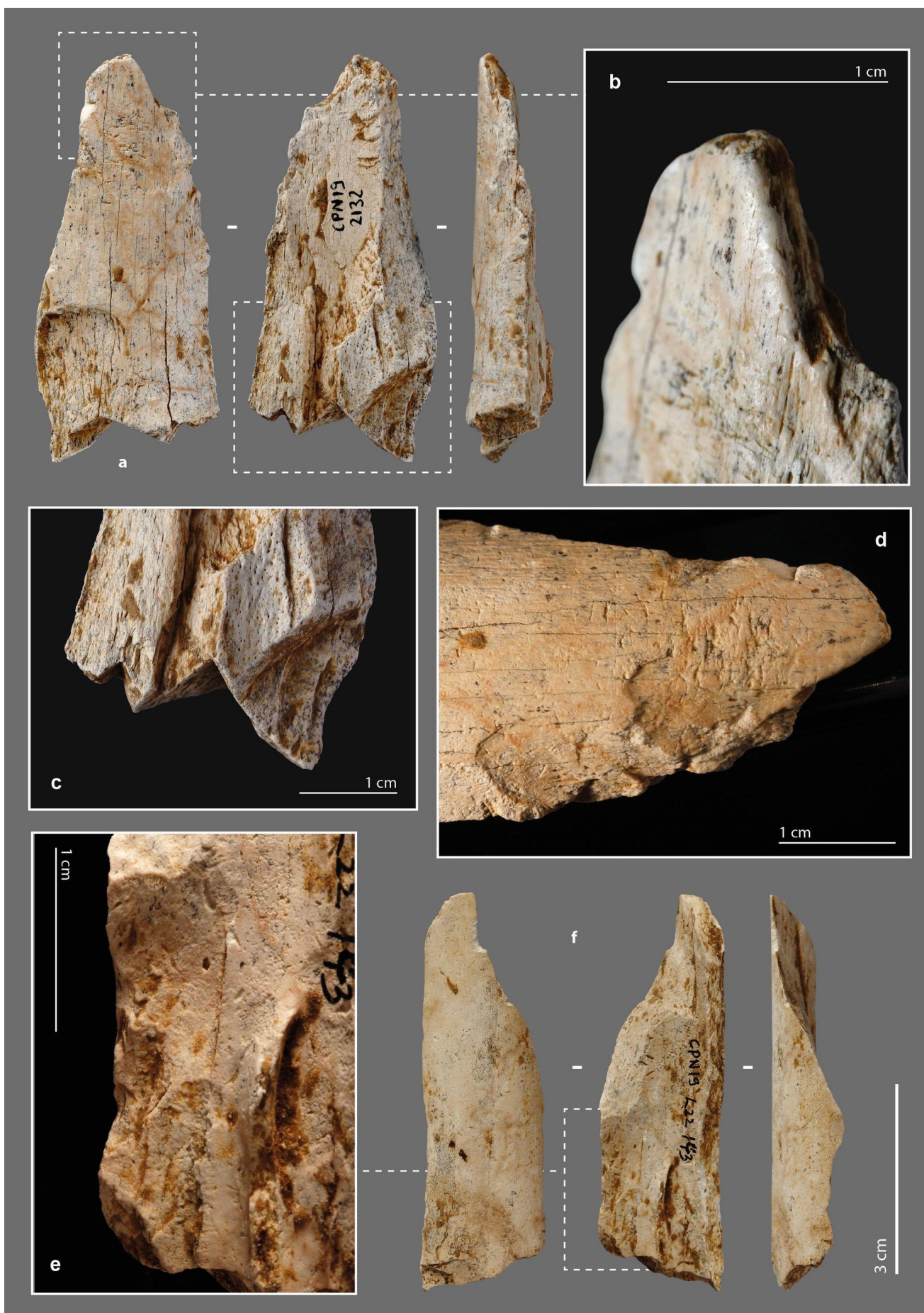
**Fig 8. Beveled tools from the Chez-Pinaud site, 2019–2020 excavations.** (a) set of burin-like removals. (b) blunt over removals at the distal end. (c) chipping on the medullary surface at the distal end. (d) on medium size ungulate diaphysis, n°888. (e) on large size ungulate diaphysis, n°3648. (f) 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).



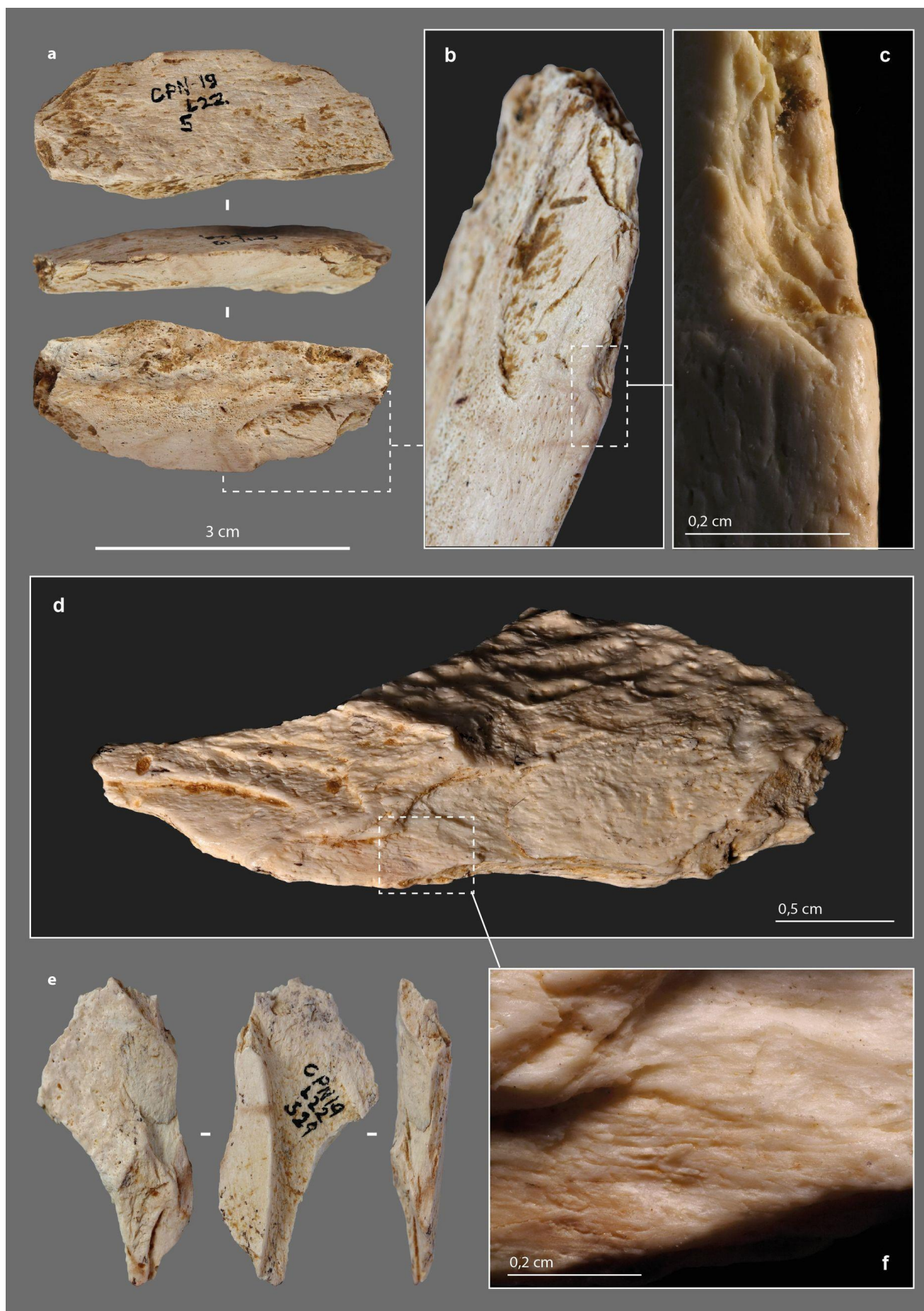
**Fig 9.  $\mu$ CT imaging of beveled tools.** (a) 3D reconstruction of an experimental sample from a Cow tibia. (b) cracks from use under the bevel, on a sagittal cross-section. (c) cracks from use under the bevel, on a transverse cross-section. (d) cracks from use under the striking surface, on a sagittal 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).



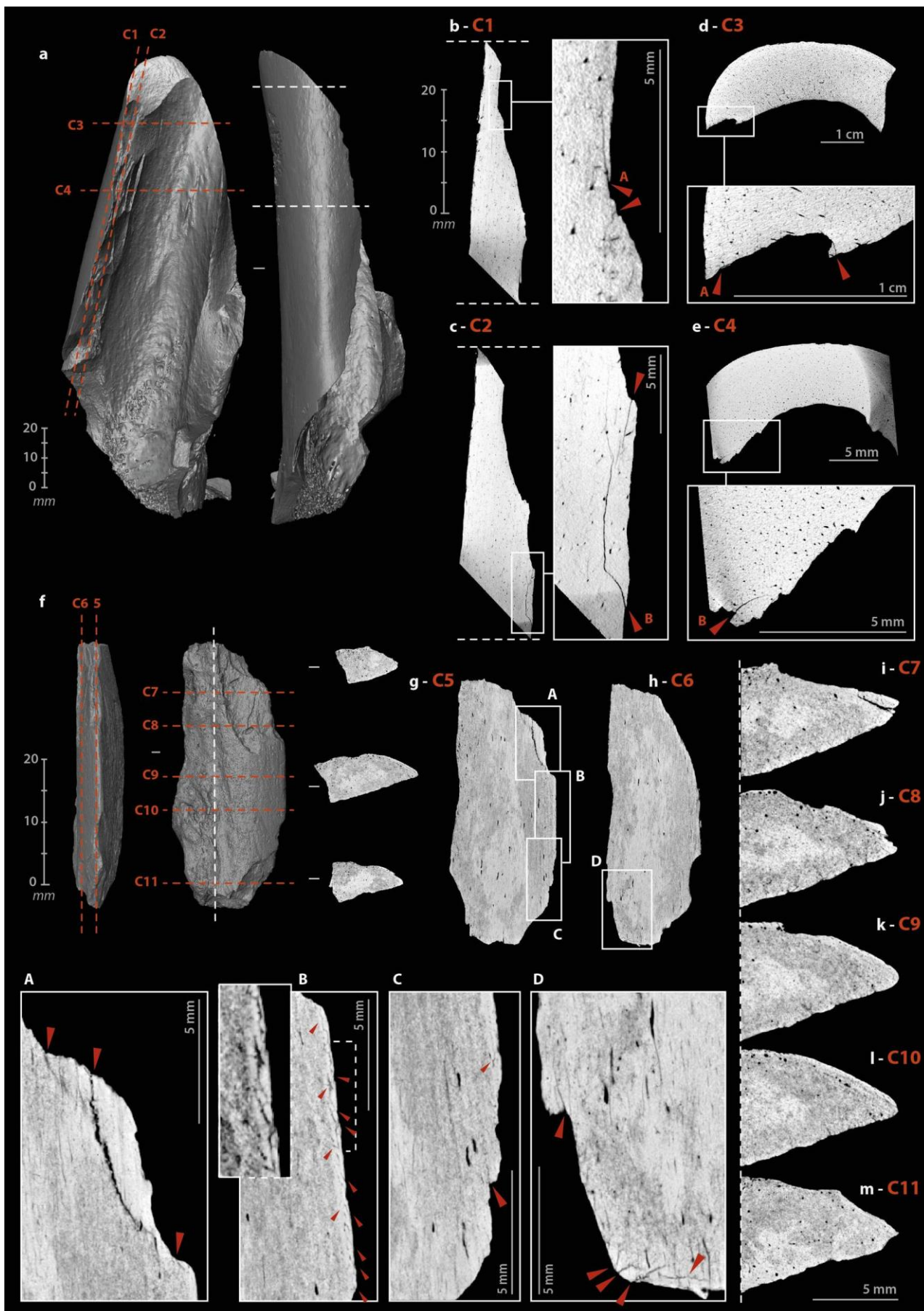
**Fig 10. Retouched tools from the Chez-Pinaud site, 2019–2020 excavations.** (a) possible beveled tool on large size ungulate diaphysis, n°2132. (b) blunt localized at the distal end. (c) secondary fracturing step of the proximal end. (d) removals on the cortical surface at the distal end. (e) removals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



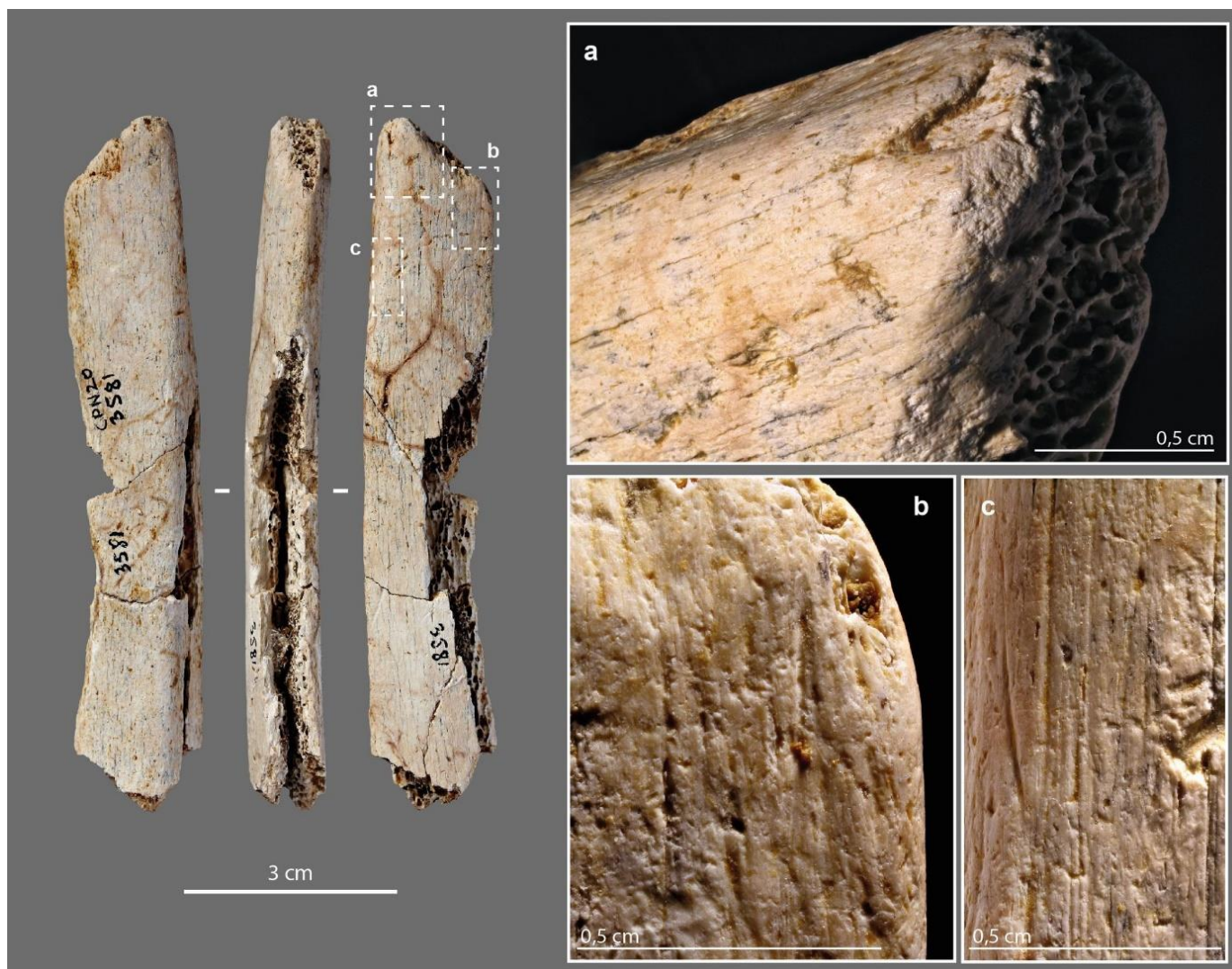
**Fig 11. Retouched tools from the Chez-Pinaud site, 2019–2020 excavations.** (a) retouched edge fragment on large size ungulate diaphysis, n°5. (b) scalariform and low-angle removals. (c) retouch intercalated between 2 blunting episodes. (d) low-angle removals on the medullary surface. (e) retouched 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).



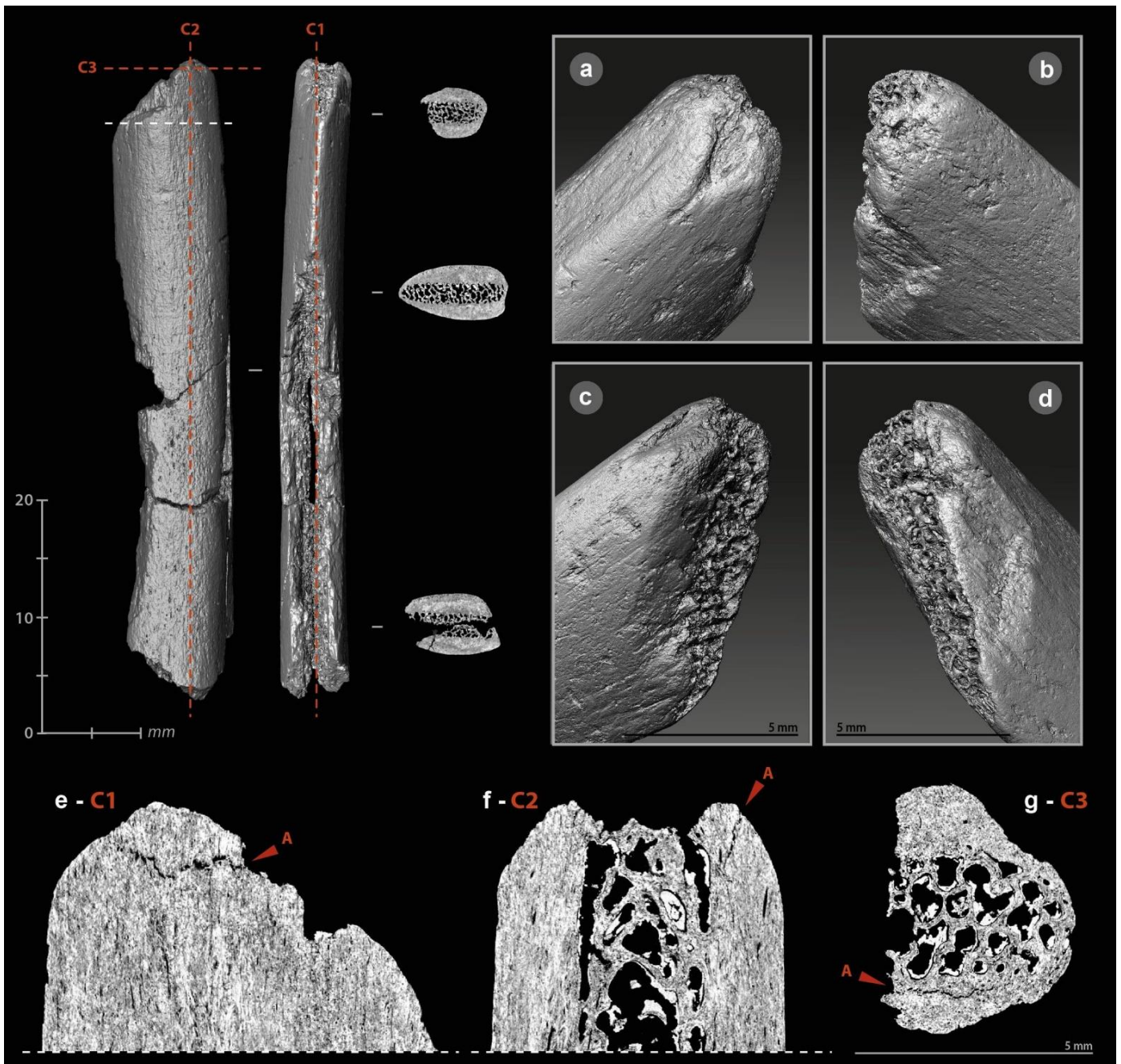
**Fig 12.  $\mu$ CT imaging of retouched tools.** (a) 3D reconstruction of an experimental sample from a Cow tibia. (b) multi-cracks from shaping at the percussion point on a sagittal cross-section. (c) simple cracks from shaping at the percussion point on a sagittal cross-section. (d) cracks from shaping 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 ( $\mu$ CT IP and CAD: M. Baumann).



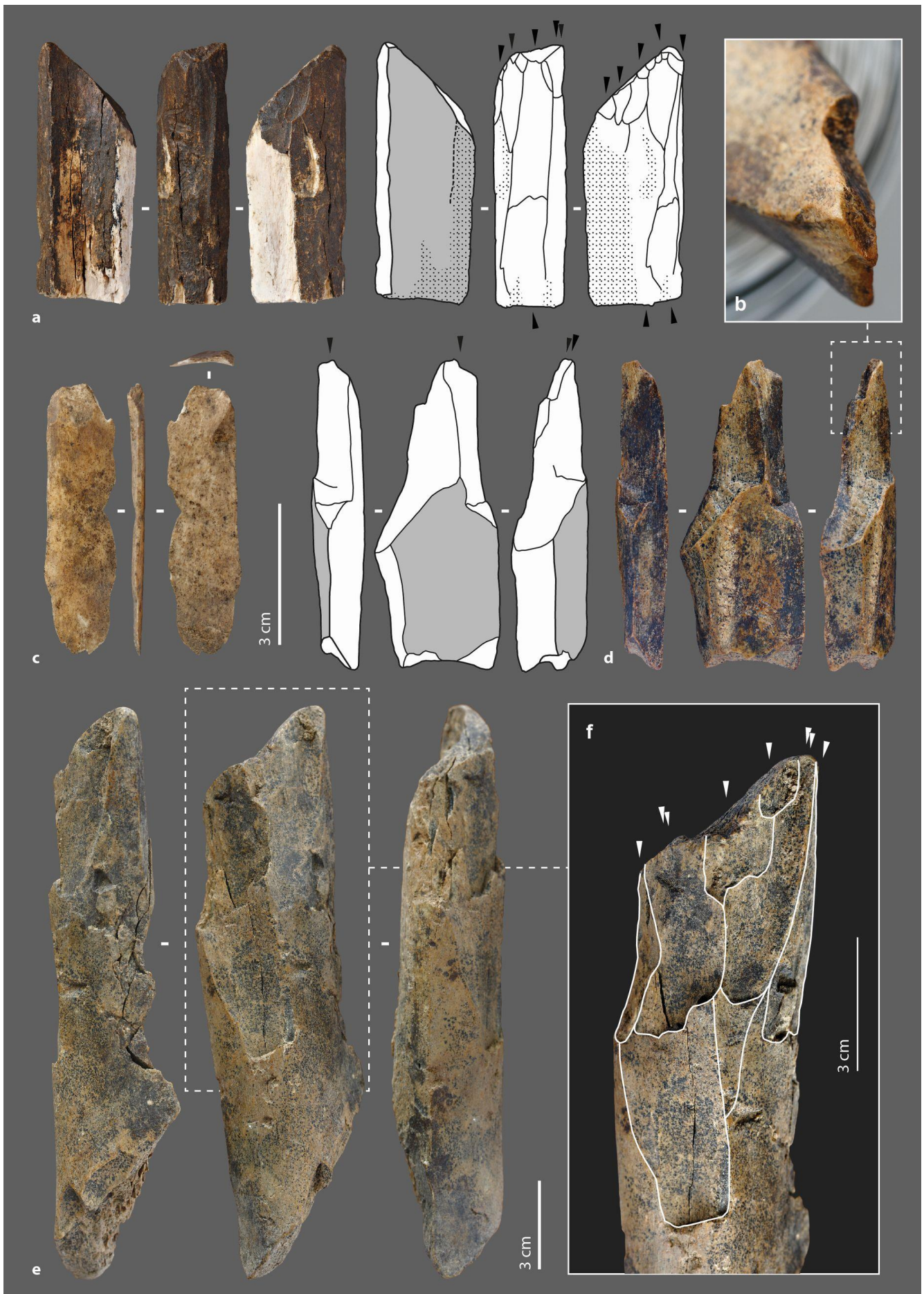
**Fig 13. Smoothed-end tool, n°2020, from the Chez-Pinaud site, 2019–2020 excavations.** (a) blunted bending fracture at the distal extremity. (b) striations from use on the ventral face at the distal extremity. (c) scraping striations on the cranial face (photos: M. Baumann).



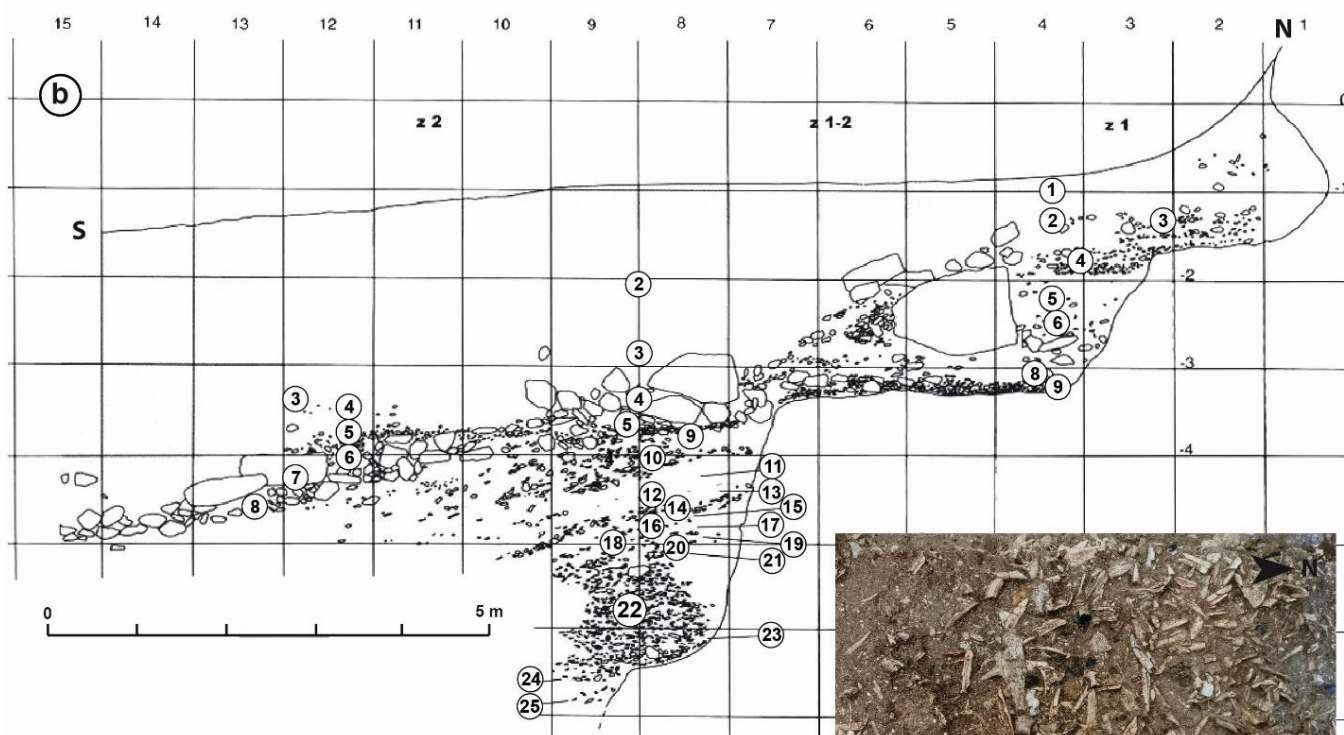
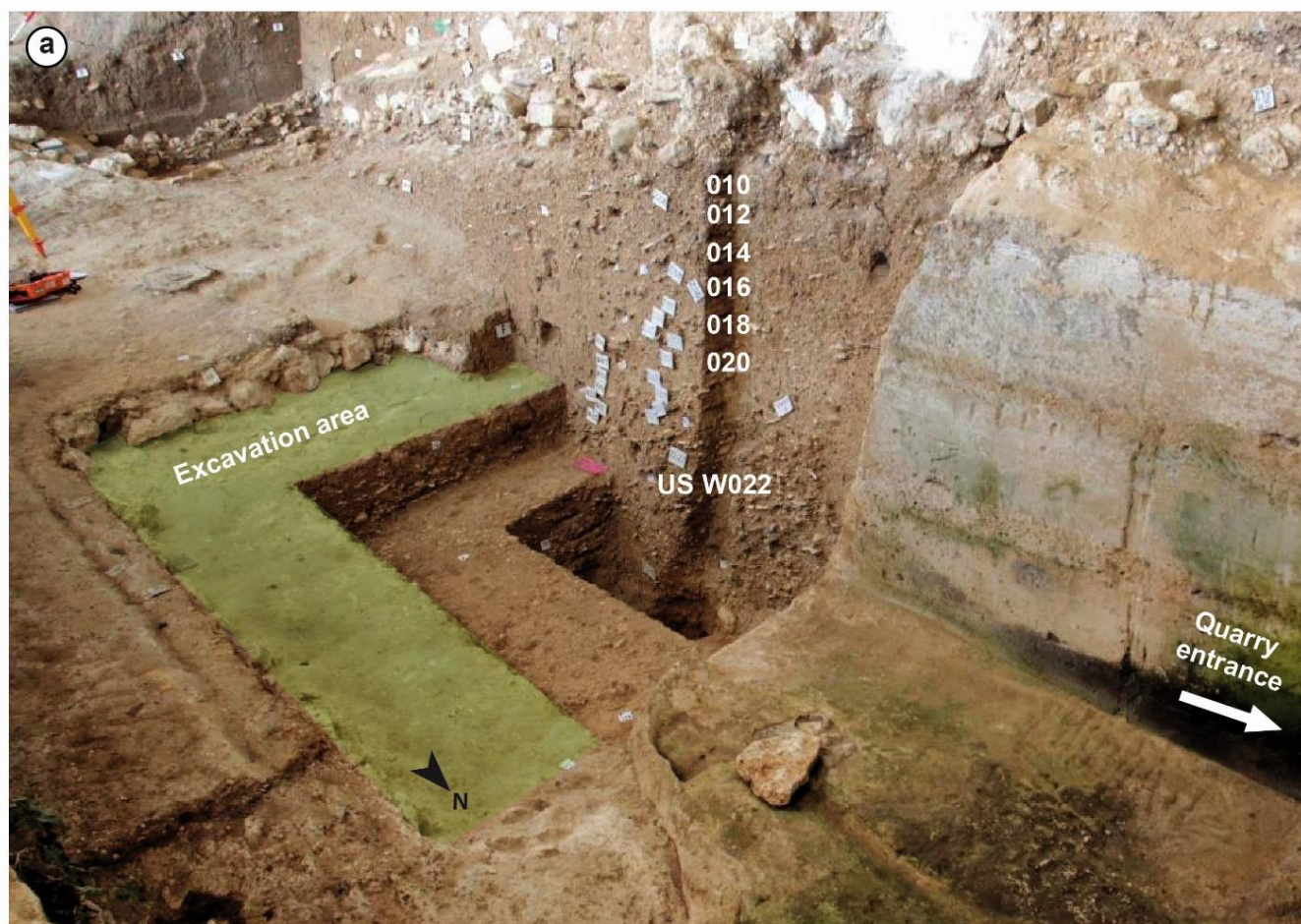
**Fig 14.**  $\mu$ CT imaging of a smoothed-end tool, n°2020, from the Chez-Pinaud site, 2019–2020 excavations. (a–b) rounded and compacted surface marked by indentations and micro-flakes at the distal end. (c) flat surface at the junction between the ventral surface and the cancellous tissue. (d) micro-flakes 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 ( $\mu$ CT 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).



**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).



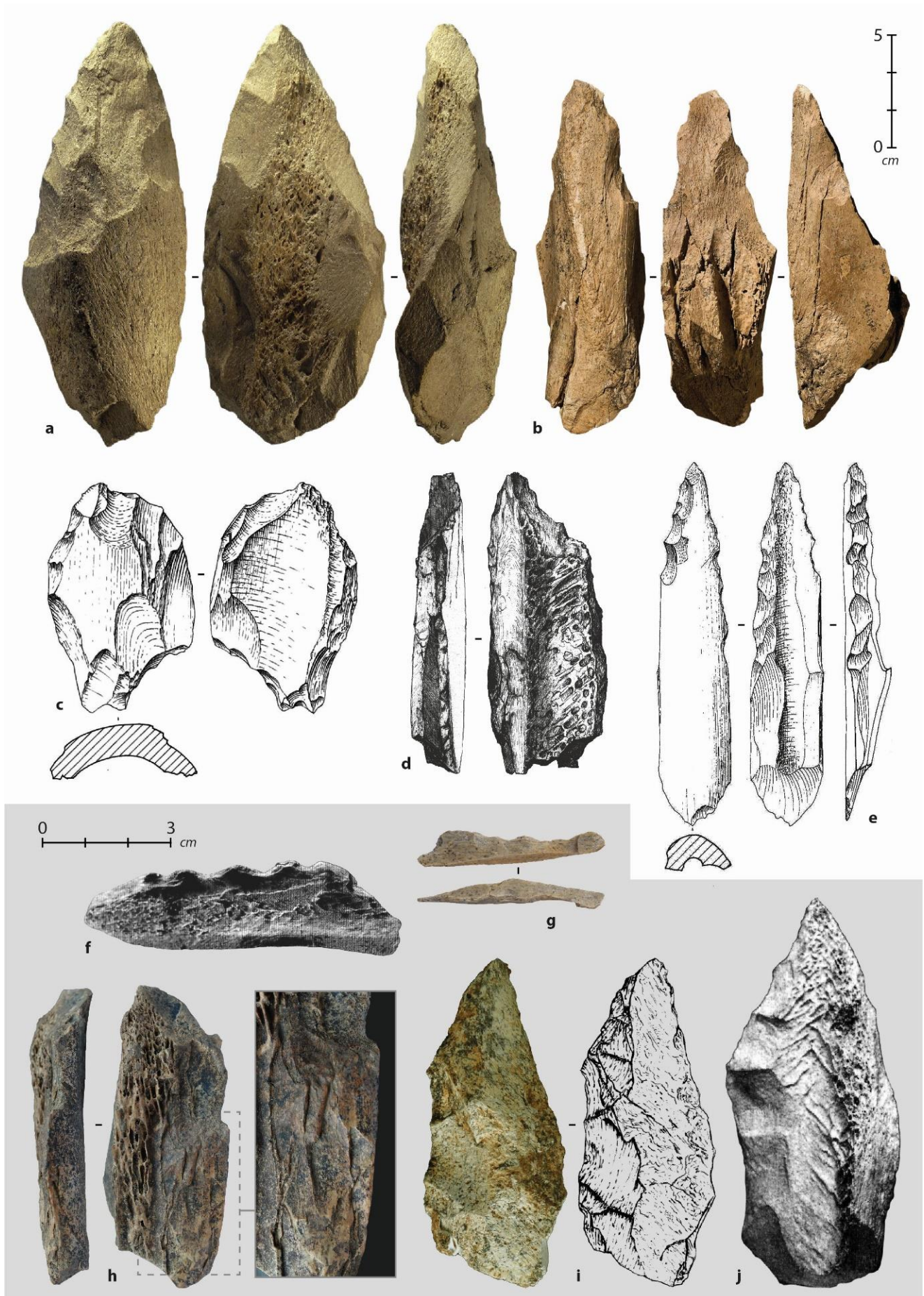
**S3 Fig. Examples of ribs with smoothed end discovered in other Middle Paleolithic contexts.** (a), (c–d) Abri Peyrony. (b) Pech de l'Azé (after Soressi et al. 2013). (e) Zaskalnaya VI (after Stepanchuk et al. 2017). (f) Chagyrskaya Cave (after Baumann et al. 2020). (g) Abri des Canalettes (after Patou-Mathis 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	µA
<b>Archaeological tools</b>	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 Retoucher	Complete	67	1200	2.46	120	250
				ROI* 1	21	2550	3.52	120	250
	CPN19-2020	Horse tibia	Retoucher	Complete	62	1200	2.48	120	250
				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	Rib large size ungulate	Smoothed	Complete	54	1275	8.31	120	100
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	
<b>Experimental tools</b>	Exp-10	Cow tibia	Beveled	Complete	89	1200	2.82	120	250
				ROI 1	13	2250	8.24	120	250
				Zone 2	13	2250	1.69	120	250
	Exp-13	Red deer femur	Beveled Retouched	Complete	89	1200	2.82	120	250
				ROI 1	24	2250	5.22	120	250
				ROI 2	24	2250	2.12	120	250
	Exp-46	Cow tibia	Retoucher Retouched	Complete	98	1500	2.78	120	250
				ROI 1	21	2250	6.18	120	250
	Exp-57	Cow tibia	Retoucher	Complete	98	1200	3.18	120	250
				ROI 1	21	2550	3.22	120	250
Exp-58	Cow tibia	Retoucher	Complete	98	1200	3.18	120	250	
			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	µA
<b>Archaeological tools</b>	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 Retoucher	Complete	67	1200	2.46	120	250
				ROI* 1	21	2550	3.52	120	250
	CPN19-2020	Horse tibia	Retoucher	Complete	62	1200	2.48	120	250
				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	Rib large size ungulate	Smoothed	Complete	54	1275	8.31	120	100
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	
<b>Experimental tools</b>	Exp-10	Cow tibia	Beveled	Complete	89	1200	2.82	120	250
				ROI 1	13	2250	8.24	120	250
				Zone 2	13	2250	1.69	120	250
	Exp-13	Red deer femur	Beveled Retouched	Complete	89	1200	2.82	120	250
				ROI 1	24	2250	5.22	120	250
				ROI 2	24	2250	2.12	120	250
	Exp-46	Cow tibia	Retoucher Retouched	Complete	98	1500	2.78	120	250
				ROI 1	21	2250	6.18	120	250
	Exp-57	Cow tibia	Retoucher	Complete	98	1200	3.18	120	250
				ROI 1	21	2550	3.22	120	250
Exp-58	Cow tibia	Retoucher	Complete	98	1200	3.18	120	250	
			ROI 1	33	2250	4.02	120	250	

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

<b>Loc</b>	<b>Site</b>	<b>Nb.</b>	<b>Industry</b>	<b>Dates</b>	<b>Ref.</b>
France	Abri Peyrony	3	MTA	MIS 3 (43 – 37 ky BP)	Soressi et al. 2013
	Noisetier	2	Discoïd	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
	Pech de l'Azé	1	MTA	MIS 3 (51 ky BP)	Soressi et al. 2013
	Pradayrol	1	Discoïd 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
	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.**

<b>Loc</b>	<b>Site</b>	<b>Nb.</b>	<b>Industry</b>	<b>Dates</b>	<b>Ref.</b>
France	Combe-Grenal	1	Mousterian Levallois	MIS 3 (39-38 ky BP)	Bordes 1961
		1	Denticulate		Vincent 1993 Tartar and Cotamagno 2016
	Jonzac	7	Quina	MIS 4 (72 ky BP)	Rendu et al. 2020 Richter et al. 2013
	Vaufrey	1	Mousterian Levallois	MIS 4 (74 ky BP)	Vincent 1993 Tartar and Costamagno 2016
	Pié-Lombard	4	Levallois	MIS 5 (70 ky BP)	Texier 1974 Texier et al. 2011
	Rigabe	6	Levallois	MIS 3-5	Defleur 1988 Brugal et al. 2020
	La Ferrassie	1	Mousterian	NR	Bordes, 1961
	Bois-Roche	+/-15	Mousterian	NR	Vincent 1993
	Baume de Gigny	1	Mousterian	NR	Vuillemeys 1989
Germany	Rhede	1	Micoquian (Keilmesser)	MIS 5 (70 ky BP)	Tromnau 1983 Baales and Stapel 2015
	Sirgenstein	1	Mousterian	NR	Hahn 1976 Ono 2006
Belgium	Trou Magrite	1	Mousterian	MIS 3	Personal inventory Jimenez et al. 2016
Italy	Fumane	1	Levallois	MIS 3 (42 ky BP)	Romandini et al. 2014 Peresani et al. 2013
	Poggeti Vecchi	10	Mousterian	MIS 6-7 (171 ky BP)	Aranguren et al. 2019
	Casal de'Pazzi	1	Protopontinian	MIS 7 (270-250 ky BP)	Anzidei and Gioia 1992 Marra et al. 2018 Villa et al. 2021
	La Polledrara	+/-3	Acheulean (without bifaces)	MIS 9 (324 ky BP)	Santucci et al. 2016 Villa et al. 2021
	Lademagne	+/-2	Acheulean	MIS 10-11 (405-389 ky BP)	Pereira et al. 2018 Villa et al. 2021
	Castel di Guido	81	Acheulean	MIS 11 (395 ky BP)	Boschian and Saccà 2015 Villa 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-Osmolovskiy 1940; Semenov 1964; Feustel 1973; Rigaud 1977, 2007; Schelinskii 1983; Vincent 1988; Bourguignon 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; Stuccliffe 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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