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## Tracing the Past: Butchering a Bison with Middle Palaeolithic Stone Tools

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1 **Tracing the past: butchering a bison with Middle Palaeolithic stone tools**

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18 **Abstract**

19 In order to better document food practices of past societies, we butchered a female adult American  
20 bison (*Bison bison*) using replicas of Middle Palaeolithic stone tools. This experiment, carried out  
21 as part of the collective research project “Des Traces et des Hommes”, was designed to test  
22 whether specific stone tools or raw materials were more efficient for certain activities, build a new  
23 dataset for activity specific use-wear patterns, and identify cut-marks characteristic (i.e. location  
24 and orientation) of each stage of the butchery process. The carcass was skinned, defleshed, and  
25 disarticulated, with the tendons also removed. Each butchery stage left cut-marks on the bison  
26 bones. Comparisons with available data for medium-sized ungulates shows comparable patterns in  
27 the interpretation of cut-marks, although some differences were observed, suggesting caution  
28 when interpreting cut-mark data on larger species such as bison. Moreover, our experiment  
29 revealed certain tools to be more efficient than others for butchery, and that the choice of tool type  
30 and/or raw material can influence the generation of cut-marks.

31

32

33 **Keywords** experimentation; butchery; Middle Palaeolithic stone tools; bison; cut-marks

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35

## 36 **1. Introduction**

37 Cut-marks on bones and use-wear on stone tools are amongst the most reliable means  
38 for identifying carcass processing by past societies. Combined with our current understanding of  
39 taphonomic processes, several different forms of experimental and ethnographic evidence are  
40 available to reconstruct past butchery practices. There is now sufficient comparative data linking  
41 patterns in cut-mark distribution and frequency with butchery activities to allow these processes to  
42 be identified on various species, including reindeer, deer, African bovids, birds or rabbits (e.g.  
43 Binford 1981; Bez 1995; Nilssen 2000; Laroulandie 2001; Lloveras *et al.* 2009; Val and Mallye  
44 2011; Soulier and Costamagno 2017; Costamagno *et al.* 2019; Soulier 2021). In order to add  
45 another reference collection to this growing body of evidence, we butchered an adult female  
46 American bison (*Bison bison*) using replicas of Middle Palaeolithic stone tools. This experiment  
47 was carried out as part of the collective research project “Des Traces et des Hommes” (coord. C.  
48 Thiébaud: Thiébaud *et al.* 2019). Our goal was to test potential correlations between stone tool  
49 types or particular raw materials and specific activities, characterize use-wear generated on stone  
50 tools for each activity, and build an interpretative framework for cut-marks that allow traces on large  
51 ungulate bones to be linked to a specific stage of the butchery process. This is of particular  
52 importance for bison, as this species is frequently encountered on archaeological sites (e.g. Speth  
53 1983; Todd and Frison 1992; Farizy *et al.* 1994; Gaudzinski 1996; Frison 2004; Johnson and  
54 Bement 2009; Rodríguez-Hidalgo *et al.* 2017) and no reference collection is currently available for  
55 this large ungulate. Here we present the results of our butchery experiment, paying particular  
56 attention to the cut-mark data, and explore whether the coding system for medium-sized ungulates  
57 is equally applicable to bison. To this end, we mobilized data from butchery experiments involving  
58 red deer carried out within the framework of the same collective research project (Soulier and  
59 Costamagno 2017; Costamagno *et al.* 2019).

60

## 61 **2. Material and methods**

62 The bison (*Bison bison*) carcass was butchered in April 2011, 48h after its death. This 300  
63 kg, twenty-year old adult female was raised at the ‘Randals Bison’ park (Lanuéjols, France) and  
64 transported in a refrigerated truck. In order to reliably recognize and interpret traces left on both  
65 stone tools and bones, the experiment was designed to avoid as much as possible carrying out  
66 more than one activity on the same area of a bone, and only one tool was used in a given activity.  
67 For example, the circular incision in the skin was made at mid-diaphysis on the metacarpals such  
68 that the tendons could be cut at the proximal and the distal end of the bone. This ensured that cut-  
69 marks potentially generated by these activities, could be reliably recorded. As control, the entire  
70 experiment was videotaped<sup>1</sup>, photos were taken, and all contacts between the tool and bone as

<sup>1</sup>A short film (in French) for also been made available under a free Creative Commons-BY-SA-3.0 license and can be viewed at <http://traces-et-hommes.revolublog.com/decoupe-de-bison-c17394045>. This video footage can be freely

71 well as tool motions were recorded for each activity on a dedicated data sheet. The butchery  
72 experiment involved several types of stone tools, including hafted examples, made of various raw  
73 materials (Table 1). All butchery activities were carried out by several archaeologists familiar with  
74 bison anatomy and experimental carcass processing, with two professional butchers present to  
75 provide advice on how to best process the carcass.

76

77 A total of 35 stone tools were used during the butchery experiments. Surgical plasticine  
78 molds were made of the edges of the stone tools before and after butchery in order to identify  
79 macro- and micro-traces. Related lithic use-wear data have already been partially published (Claud  
80 and Thiébaud 2011; Claud *et al.* 2015, 2019). The leg bones were soaked in water with enzymes  
81 and the axial skeleton buried for a year in order to be cleaned and prepared for the cut-mark  
82 analysis. Bones were observed by two zooarchaeologists (M.-C. S and S. C) under low-angled  
83 light using a 30x magnifying hand-lens. All cut-marks were recorded on Adobe Illustrator© bone  
84 templates and, for ease of presentation, cut-mark distributions on left and right bone elements and  
85 each group of vertebrae and ribs were combined on the same anatomical drawing. The action that  
86 created them was then deduced from the contact sheets filled out during the butchery experiment.  
87 Cut-mark orientations on the meat-bearing long bones were assessed and quantified using QGIS  
88 (version 3.4.11 Madeira). In order to better visualize the data, a 6-part division is shown on figures  
89 depicting cut-marks on meat-bearing long bones (1 proximal and 6 distal portions).

90

91

### 92 **3. Carcass Processing Protocol**

93

94 The carcass was entirely processed on the ground. For health reasons, the bison was  
95 already eviscerated via an opening cut in the abdomen. The first stage of the butchery process,  
96 skinning (blue and gray areas in Fig. 1), was begun from this incision, with a cut made along the  
97 throat and a circular incision around the neck. Circular incisions were then made mid-diaphysis on  
98 both metacarpals of the front legs. For the right front leg, a longitudinal incision was made on the  
99 inner side, along the limb to the ventral incision for evisceration. For the left leg, this longitudinal  
100 incision started on the inner side from the metacarpal to the radio-ulna, and continued on the  
101 anterior face on the humerus. As the proximal diaphyses of the metatarsals had been broken at the  
102 slaughterhouse, a circular incision was unnecessary on the hind legs. On both sides on the hind  
103 legs, this longitudinal incision was made on the inner face of the legs from the metatarsals up to  
104 the ventral cut made for evisceration. For the axial skeleton, the skin was removed longitudinally,  
105 pulled from the ventral incision to the spine. The skin was subsequently removed from the lower  
106 legs, starting from the circular incision on the metacarpals and the broken area of the metatarsals.

107 A longitudinal incision was then made on the inner face of both rear legs, on the anterior face of the  
108 right hind-leg and on the lateral face on the left one. The remnant skin was removed via a circular  
109 incision made as close as possible to the hooves, which on a bison is at the level of the second  
110 phalanx. For the head, the skin was first removed from the mandible, beginning with an incision  
111 along the lower teeth, and then removing the skin from the body of the mandible with a motion from  
112 the teeth to the ventral face of the mandible. The skull was skinned by first making an incision  
113 along the teeth, and then moving upward.

114 As much meat as possible (cf *infra*) was recovered from all anatomical elements,  
115 including the head. The carcass was disarticulated (red area in Fig. 1) after defleshing in a manner  
116 consistent with the storage of bones for later use. The head was removed with three direct blows  
117 with a hafted quartzite cleaver at the junction with the atlas vertebra. Once defleshed, the mandible  
118 was detached by cutting and twisting. The sternum was separated from the ribs using hafted  
119 quartzite cleavers, with the surface scraped beforehand to facilitate breakage. The right side ribs  
120 were separated from the vertebrae, with ribs 2, 3 and 4 forcibly detached once the sternum was  
121 opened, while ribs 5 to 13 were broken using a cleaver at the proximal end of the rib. The pelvis  
122 was separated from the trunk by percussion at the 4-5<sup>th</sup> lumbar vertebrae junction. The limb bones  
123 were disarticulated using cutting motions involving different tools and raw material according to the  
124 leg (see Table 1). Extensor and flexor tendons were removed from the lower legs, and we  
125 attempted to extract the horny outer covering of the hooves.

126

127

## 128 **4. Results**

129

130 A total of 2203 cut-marks were recorded on the butchered bones (Table 2). Despite paying  
131 particular attention to avoid performing multiple activities at a same location, this was not always  
132 possible. For example, tool/bone contacts on the pelvis were signaled by the experimenter during  
133 both disarticulation and defleshing; however, due to the mass of flesh, it was difficult to precisely  
134 identify the location of these contacts. Consequently, reliably interpreting cut-marks in certain areas  
135 of the carcass is complicated. Moreover, cut-marks were identified in certain areas despite no  
136 contact being reported during butchery, making it difficult to assign them to a particular activity. Cut-  
137 marks impossible to reliably assign to a specific butchery activity are shown in gray in the figures.

138

### 139 **4.1 Skinning**

140 Removing the skin from the bison's head produced cut-marks on the maxilla, just above  
141 the cheek teeth, as well as on the vestibular surface of the teeth, around the orbital zone, and on  
142 the nasal and frontal bones (Fig 2a). The circular incision around the nose left multiple transverse  
143 cut-marks both on the nasal bones and premaxilla. Cut-marks on the tympanic bulla are connected  
144 to the removal of the ears during the skinning process. Skinning the jaw (Fig. 2b) generated cut-

145 marks on teeth, both on cheek teeth and the third incisor, at the periphery of the mental foramen  
146 and the corpus of the mandible up to the mandibular angle. Transverse cut-marks were recorded  
147 on the palmar edge of the mandible, slightly extending to the lingual side.

148 On the legs, the circular incisions made at mid-diaphysis on the metacarpals are clearly  
149 visible, with transverse and clustered cut-marks evident on the medial face of both metacarpals  
150 (Fig. 3a). No circular incision was made on the metatarsals (see above). The second circular  
151 incision made as close as possible to the hooves generated transverse and clustered cut-marks on  
152 the mesial phalanges of the rear legs (Fig 3e). Scattered, oblique or sub-transverse cut-marks  
153 were left on the metacarpals and the metatarsals as well as the phalanges when stone tools were  
154 used in an oblique motion to detach the skin. Whether on the metacarpals, the metatarsals or the  
155 associated short bones, no longitudinal cut-marks were produced by the longitudinal incision in the  
156 skin, even when made on the lateral or medial faces where the skin is in direct contact with the  
157 bone.

158

#### 159 **4.2 Defleshing**

160 The carcass was nearly completely defleshed, with very little meat remaining on the  
161 bones after the experiment (Fig. 4). Just over 140kg of meat was recovered, with the axial skeleton  
162 producing 53kg and the two femurs an identical amount. Considering the mass of meat recovered,  
163 the front legs appear to be substantially less interesting. The proportions of meat recovered from  
164 the legs are very similar to what was observed by Emerson (1990:432) for a 16-year-old female  
165 *Bison bison*, where the femur accounted for 58% of the meat retrieved from the appendicular  
166 skeleton.

167

168 All the meaty long bones bear cut-marks produced during defleshing, comprising 87 %  
169 (N=741) of all cut-marks observed on the long bones. Cut-marks are evident across the entire  
170 diaphysis (Fig. 5). Cut-marks linked to defleshing are also present on or around several articular  
171 extremities, such as the tibia plateau. Defleshing cut-marks are mostly transverse or oblique, and  
172 longitudinal cut-marks produced by defleshing represent less than 3% of all marks on long bones  
173 (Table 3).

174

175

176 Significant numbers of cut-marks connected to defleshing were also recorded on the  
177 scapular and pelvic girdles (cf Fig. 2c&d), most of which are longitudinal and elongated. On the  
178 axial skeleton, most cut-marks are also longitudinal (i.e. aligned with the cranio-caudal axis).  
179 Defleshing related cut-marks on vertebrae (Fig. 6) primarily occur on the spinous process (axis;  
180 thoracic 1 to 5 and 7 to 10; lumbar 3 to 5) and on the transverse processes (cervical 5 and 6;  
181 thoracic 1, 4 to 11, 13, 14; lumbar 1, 3 to 5). Cut-marks are less frequently positioned close to the  
182 cranial or caudal articular process (axis, cervical 4 and lumbar 2), near the *fovea costalis* inferior

183 (thoracic 3) or near the inferior articular process (cervical 4 and thoracic 4). On the axis, defleshing  
184 cut-marks are also evident on the vertebral body as well as on the lamina and on both the ventral  
185 and dorsal faces of the atlas.

186 Cutmarks are mostly located at the neck and on the head of the ribs and occur both on the ventral  
187 and the dorsal faces (Fig. 7). They occur less frequently on the shaft and the sternal extremity, and  
188 only one is evident on the articular facets.

189

190           Flesh was also removed from the head, especially the cheeks, leaving cut-marks on the  
191 maxilla and the ascending ramus when the masseter muscle was removed (Fig. 2a). The removal  
192 of the tongue (Fig. 2b) produced oblique cut-marks on the lingual side of the mandible, with more  
193 transverse examples occurring just below the jugal teeth on the lingual face. Long longitudinal cut-  
194 marks are also present near the symphysis (lingual side).

195

196

### 197 **4.3 Disarticulation**

198 After being defleshed, the entire carcass was disarticulated. The head was removed by percussion  
199 with a hafted cleaver, splitting one of the occipital condyles (Fig. 8a). Some tearing is observable  
200 on the atlas vertebrae (Fig. 8b), probably resulting from the twisting of the head, and is associated  
201 with cut-marks on the cranial articulation (Fig. 2). The separation of the skull from the jaw left cut-  
202 marks on the zygomatic, the ascending ramus and on the distal face of the upper third molar. The  
203 rib cage was dislocated by percussion with a hafted flake cleaver, producing several fractures. The  
204 right transverse process is entirely or partially broken on 6 of the final thoracic vertebrae (thoracic 9  
205 to 11 and thoracic 13 to 15), as well as the caudal articular facet of the 14<sup>th</sup> thoracic vertebrae.  
206 Tearing is evident on the *fovea costalis* of the second thoracic, linked to the removal of the 3<sup>rd</sup> rib  
207 by flexion. All but the first and last right ribs were broken when removed from the spinal column  
208 (Fig. 8e). Although the left ribs were left attached to the vertebrae, three (rib 3, 8, 13) were  
209 nevertheless fractured by a blow brought to the other side of the rib cage. The opening of the  
210 sternum by percussion did not leave any marks on the ribs. The anterior and posterior portions of  
211 the carcass were separated by percussion at the 4-5<sup>th</sup> lumbar junction, which broke the 4<sup>th</sup> lumbar  
212 in 3 pieces. The mamillary process of the 5<sup>th</sup> lumbar was broken and chopmarks are evident on the  
213 body of this vertebra and on the spinous process of the sacrum (Fig. 8c).

214

215

216 Of the 850 cut-marks identified on the long bones, only 11 % (n=94) were produced during  
217 disarticulation (Table 4). Interestingly, 30% of these marks are orientated longitudinally. The  
218 detachment of the entire leg from the body and the disarticulation of the humerus produced no cut-  
219 marks on the scapula. No cut-marks were produced on the humerus when it was separated from  
220 the scapula. The disarticulation of the humerus and radio-ulna (Fig. 5), on the other hand,

221 generated several cut-marks on the distal part of the humerus of both legs as well as on the  
222 olecranon, close to the trochlear incision of the radius. A small crushed area can be observed on  
223 the anconeal process (Fig. 8d), probably resulting from twisting during disarticulation. The  
224 disarticulation of the forelimb was followed by separating the radius from the first row of carpals.  
225 Cut-marks are observable on the right pyramidal and on both legs on and around the ulnar styloid  
226 process as well as on the semi-lunars and the scaphoids.

227

228 Due to the very large muscle mass around the pelvic girdle, which requires both defleshing and  
229 disarticulation at the exact same place, only cut-marks located on the femoral head (Fig. 5c) can  
230 be confidently attributed to disarticulation, as their location and orientation match those reported by  
231 the butcher. Separating the femur from the tibia generated cut-marks on both of the femoral medial  
232 condyles as well as on the tibial plateau (Fig. 5). Numerous cut-marks were produced when  
233 disarticulating the tibia and tarsal bones, especially on the medial face of the talus, but also on the  
234 calcaneum and the cuboid (Fig. 3). Several cut-marks are also observable on the distal part of the  
235 tibia and on the malleolus. The dislocation of the metacarpophalangeal joint left cut-marks on the  
236 distal condyles of the metacarpal, close to the proximal articulation of the first phalanges and on  
237 the sesamoids. Cut-marks on the hind legs are uniquely observable near the proximal articulation  
238 of the second phalanx. Finally, cut-marks are evident on the abaxial side of a second phalanx,  
239 produced when the axial and abaxial phalanges were separated from each other.

240

#### 241 **4.4 Tendon removal**

242 Cutting the flexor and extensor tendons (Fig. 3) on the front leg with an upward motion left cut-  
243 marks on the distal half of the pyramidal, the upper part of the hamate bone and on the capitate-  
244 trapezoid, and on the upper portion of the posterior face of the first phalanges. On the hind leg, this  
245 cutting motion created cut-marks on the proximal portion of the anterior face, the condyles of the  
246 metatarsal, and on the first phalanx. Oblique and longitudinal cut-marks were also produced on the  
247 diaphyses of the metapodials, on the sesamoids and phalanges when tools were used in a  
248 longitudinal motion between the bone and the tendon.

249

250

#### 251 **5. Discussion**

252 Butchery experiments are a necessary first step towards a better understanding of cut-marks on  
253 bison as well as large ungulates in general. Although the cut-mark dataset produced during our  
254 experiment is relatively limited due to the processing of a unique carcass, several interesting  
255 patterns can nevertheless be observed

256

257 Correspondence with cut-mark patterns on medium-sized ungulates



258 The cut-mark data presented here are almost entirely in agreement with previously published data  
259 for medium-sized artiodactyles (Soulier and Costamagno 2017; Costamagno *et al.* 2019). Of the  
260 135 cut-mark codes documented here<sup>2</sup>, 127 perfectly match the medium-sized artiodactyls dataset  
261 (detailed table available here: <https://figshare.com/s/336e50835696f3d0aff8>). Some discrepancies  
262 are however evident with cut-marks produced by activities differing from those previously docu-  
263 mented for medium-sized ungulates. The least consistent codes come mostly from the vertebrae (4  
264 of the 8 non-concordant codes), where several cut-marks that would normally be interpreted as  
265 linked to disarticulation based on medium-sized ungulates data (Nilssen 2000; Costamagno *et al.*  
266 2019) were produced by defleshing.

267

268 Our data further highlights the need for caution when interpreting cut-marks near articular  
269 extremities, as 63% of the cut-marks located in these areas (portions 1 & 6) in our experiment  
270 result from defleshing instead of dismemberment.

271

272 No codes existed for several locations and/or orientations, meaning that new ones were created for  
273 the butchery of the bison (N=83; Fig. 9). As was done for red deer (Soulier and Costamagno 2017),  
274 these codes incorporate data collected by Nilssen (2000) for the butchery of large ungulates in  
275 South Africa<sup>3</sup>.

276

277

#### 278 *Cut-mark incidence: the influence of stone tools, raw material, experimenter and carcass size*

279 Cut-mark orientations are roughly similar to those documented for red deer as part of the same  
280 collective research project and hence butchered by same people. Upon closer examination,  
281 several differences are however evident (Table 5). Fewer longitudinal cut-marks were generated on  
282 the bison bones during defleshing (5.7% on the red deer vs 2.8% on the bison), while more  
283 longitudinal cut-marks were produced during disarticulation on the bison (31%) compared to the  
284 red deer (11%). However, this does not necessarily demonstrate the disarticulation of a bison to  
285 produce more longitudinal cut-marks compared to medium-sized ungulates as 1) longitudinal cut-  
286 marks produced during disarticulation mostly occur on the right femoral head and right humeral  
287 trochlea (although different butchers were involved) and no cut-marks were produced in these  
288 areas for the left limbs, and 2) longitudinal disarticulation marks were also generated in these  
289 areas during the disarticulation of the red deer (see fig 5 in Soulier and Costamagno 2017).

290

291 The participation of multiple experimenters, raw materials and tools makes it difficult to explain  
292 these differences. The two participants (Butcher V. & Butcher M.) who butchered the red deer with  
293 a quartzite cleaver produced cut-marks distributed in comparable proportions in terms of

2 Codes already identified as ubiquitous (means that can be created by several activities) excluded

3 Note that Nilssen's "Large bovid" class includes a large weight range (~from 80kgs to 600kgs) comprising 1 Blesbok, 3 Black Wildebeest and 3 Eland.

294 orientation (Table 6). In contrast, Butcher M. produced significantly different proportions of cut-mark  
295 orientations on the bison, notably transverse cut-marks. Carcass size therefore might influence the  
296 orientation of cut-marks produced during defleshing, perhaps connected to the likelihood that a  
297 heavier and therefore less manageable carcass constrains butchering movements. More focused  
298 experiments are necessary to shed additional light on the relationship between cut-mark  
299 orientation and carcass size.

300

301 Carcass size has been suggested to influence, positively or negatively, the frequency of cut-marks  
302 produced on bones (Egeland 2003; Dominguez-Rodrigo and Barba 2005; Pobiner and Braun  
303 2005). Our dataset shows that despite using the same type of tool/raw material (i.e. a quartzite  
304 cleaver), a greater number of cut-marks were produced on the bison compared to the red deer  
305 (Table 6). However, this difference is based on the total *number* of cut-marks counted on *complete*  
306 bones. In archaeological assemblages bones are *fragmented*, and it is often the *percentage* of  
307 fragments bearing at least one cut-mark that is used for analysis. How differences in the total  
308 number of cut-marks (as observed in our experiments) are related to cut-mark percentages (as  
309 reported in most zooarchaeological studies) is still poorly understood and requires further research.

310

311

#### 312 Cutmarks and cleaning treatment

313 Several of the cut-marks observed on the bison bones are superficial and may not be preserved on  
314 archaeological material as a result of post-depositional alterations. These superficial traces were  
315 primarily observed on the leg bones compared to the axial skeleton and, interestingly, these two  
316 sections were cleaned in different ways. Prolonged immersion in water with enzymes appears to  
317 slightly attack the bone surface and is therefore an unsuitable cleaning process for experiments  
318 focused on the analysis of cut-marks.

319

320

#### 321 Tool efficiency

322 In addition to exploring cut-mark distribution and frequency, our bison butchery experiment equally  
323 aimed to investigate the function and efficiency of different typical Middle Palaeolithic tools. As  
324 detailed use-wear data for these tools has been published elsewhere (Claud and Thiébaud 2011;  
325 Claud *et al.* 2015, 2019), here we focus uniquely on tool efficiency. During our experiments,  
326 quartzite tools proved more difficult to handle during butchery, as the grease quickly settled in the  
327 pores of the quartzite, making it necessary to constantly clean them. On the other hand, the  
328 quartzite cleavers proved to be extremely efficient for disarticulating the bison carcass by  
329 percussion. Moreover, hafting the cleavers both increased the force of the blow and avoided  
330 fatiguing the user by absorbing part of the shock. The hafting of two small quartzite pseudo-  
331 Levallois points equally increased their ease of use, as these pieces were very uncomfortable to

332 use when held in the bare hands. Moreover, the thin handles on to which the points were fixed did  
333 not hinder the tool penetrating the flesh and were very quick to fashion (partially split wooden stick).

334

335

## 336 **6. Conclusion**

337

338 Several reference collections resulting from controlled butchery experiments are currently available  
339 for the interpretation of cut-marks on small and medium-sized species. The analysis of cut-marks  
340 sheds light on the activity that produced them, which, in turn, permits a more accurate reconstruc-  
341 tion and understanding of the butchery *chaîne opératoire* of past human groups. In particular, ex-  
342 periments butchering red deer have linked cut-mark orientation and distribution with specific butch-  
343 ering activities (Soulier and Costamagno 2017; Costamagno *et al.* 2019). The applicability of this  
344 approach to larger mammals has, however, remained difficult to assess. Our experiment further  
345 strengthens the interpretive potential of this analytical tool, providing a new dataset for large bovids,  
346 a family that was frequently exploited throughout the Palaeolithic and into later periods. Our results  
347 confirm the applicability of the red deer butchery data for the interpretation of cut-marks on large  
348 ungulates, such as bison albeit with some adjustments to the analysis, especially elements of the  
349 spinal column. Differences observed in cut-mark orientations on the bison long bones compared to  
350 what was documented for medium-sized ungulates needs to be explored more thoroughly, includ-  
351 ing additional experiments and a better appreciation of the impact of tools and butchers.

352

353

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368

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431 **Captions**

432 Fig 1 Schematic depiction of the butchery activities carried out during the bison experiment. The  
433 locations of the circular incisions in the skin are indicated in blue (in grey: incisions made at the  
434 slaughterhouse) and the disarticulation spots are in red (lines = cutting motions; circles = disarticu-  
435 lation by percussion).

436

437 Fig 2 Cut-marks produced on the (a) skull, (b) mandible, (c) scapula, and (d) pelvis by activity:  
438 black = defleshing; green = dismemberment; blue = skinning. In grey, cut-marks impossible to link  
439 to a specific activity.

440

441 Fig 3 Cut-marks produced on the (a) metacarpal, (b) metatarsal, (c) sesamoids, (d) malleolus, (e)  
442 phalanges, (f) carpals, (g) tarsals per activity: green = dismemberment; red = tendon removal; blue  
443 = skinning. In grey, cut-marks impossible to link to a specific activity. \* abaxial side of the medial  
444 phalanx.

445

446 Fig 4 Meat remaining on a defleshed bison limb and weight of meat (kg) recovered per skeletal  
447 element. Photo © “Des Traces et des Hommes”.

448

449 Fig 5 Cut-marks on the (a) humerus, (b) radio-ulna, (c) femur, and (d) tibia per activity: black =  
450 defleshing; green = dismemberment. In grey, cut-marks impossible to link to a specific activity.

451

452 Fig 6 Cut-marks on the a) atlas, b) axis, c) cervical, d) thoracic, e) lumbar and f) sacrum vertebrae  
453 per activity: black = defleshing; green = dismemberment (atlas); purple lines = chopmarks. Grey  
454 cut-marks on the sacrum cannot be linked to a specific activity.

455

456 Fig 7 Cut-marks (in black) produced on the ribs during defleshing.

457

458 Fig 8 Splitting of a) the occipital condyles, b) the atlas, c) chopmarks on the sacrum, d) crushing on  
459 the anconeal process of the ulna and e) breakage on the ribs (in red) produced during disarticula-  
460 tion.

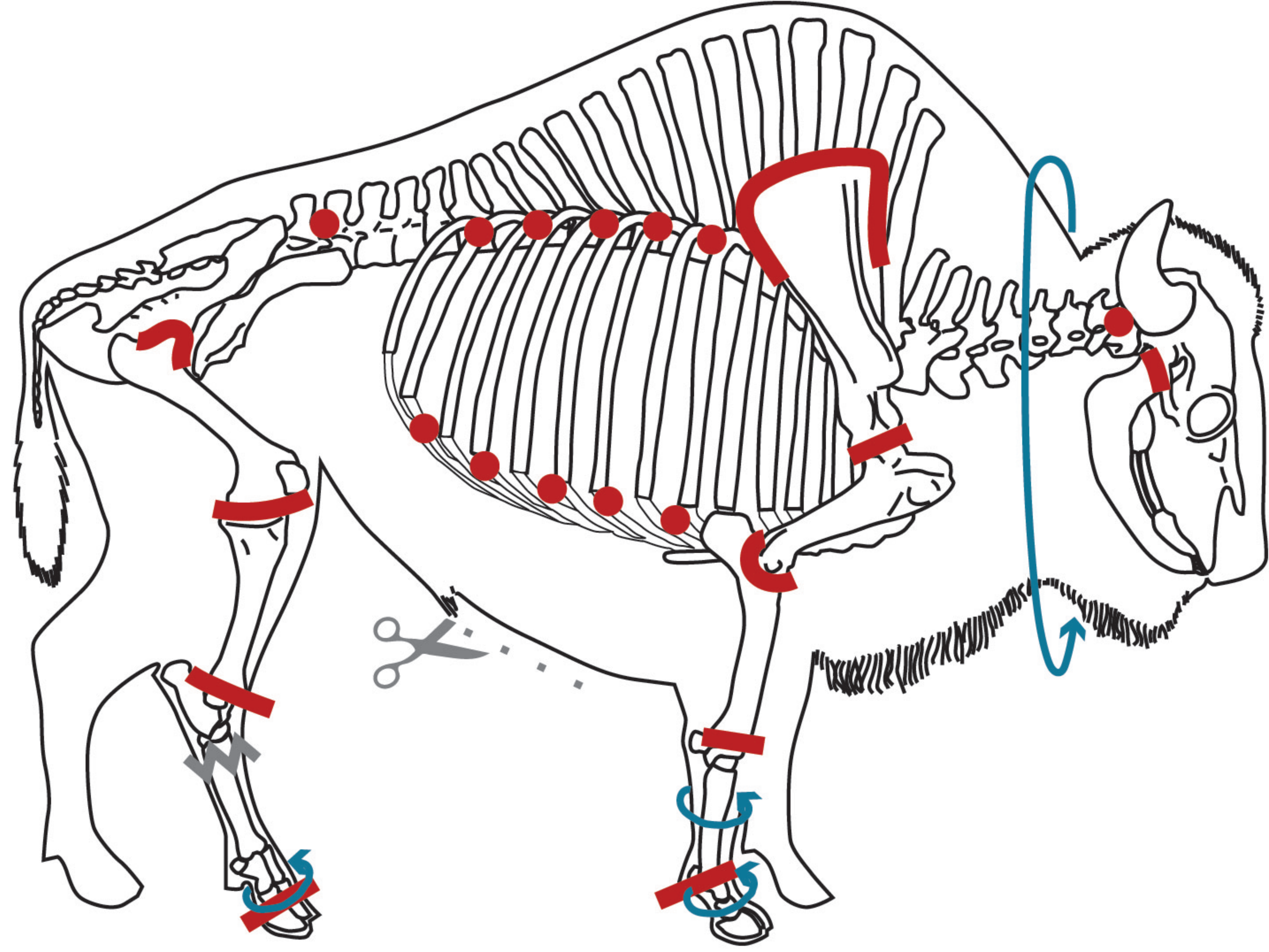
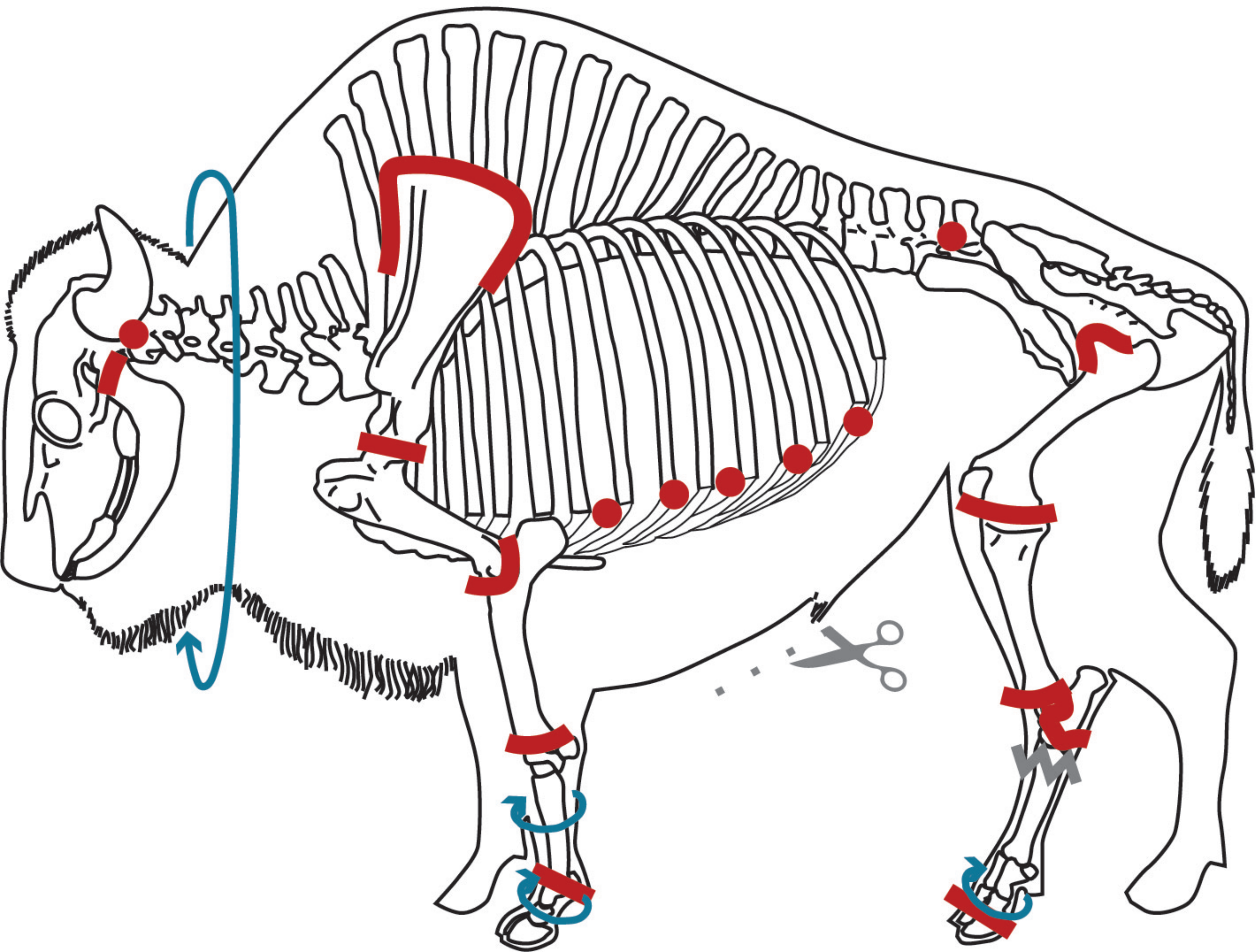
461

462 Fig. 9 New coded areas for undocumented elements (a) skull, e) ribs, j) pelvis), and new areas  
463 created on previously coded elements (b) mandible lingual side, c) sacrum, d) atlas, f) radius distal,  
464 g) metatarsal distal, h) lunate, i) calcaneum, k) first phalanx and l) second phalanx. Bluish tints are  
465 for defleshing, reddish for disarticulation, greenish for skinning and yellowish for tendon extraction.  
466 See <https://figshare.com/s/336e50835696f3d0aff8> for a descriptive table.

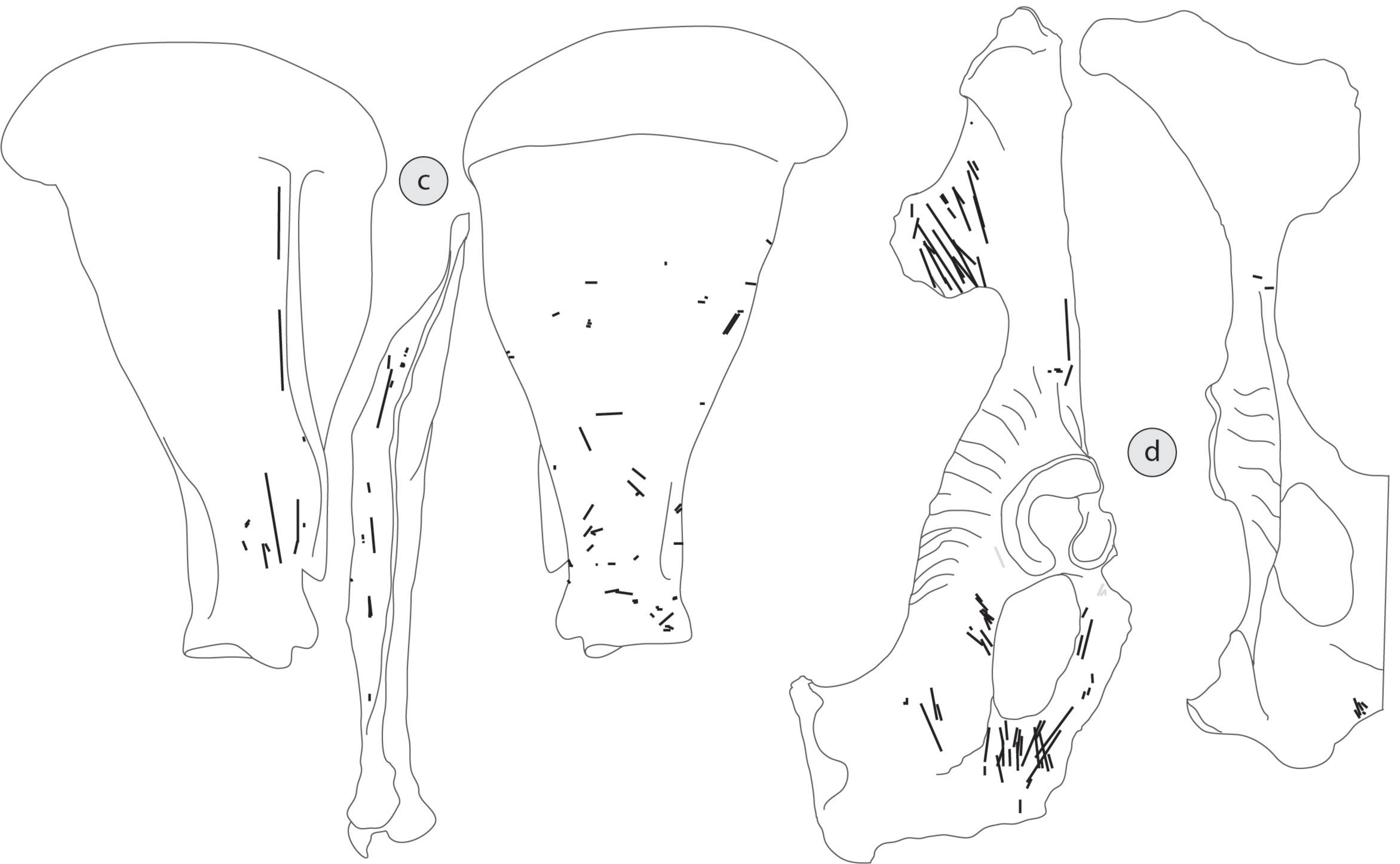
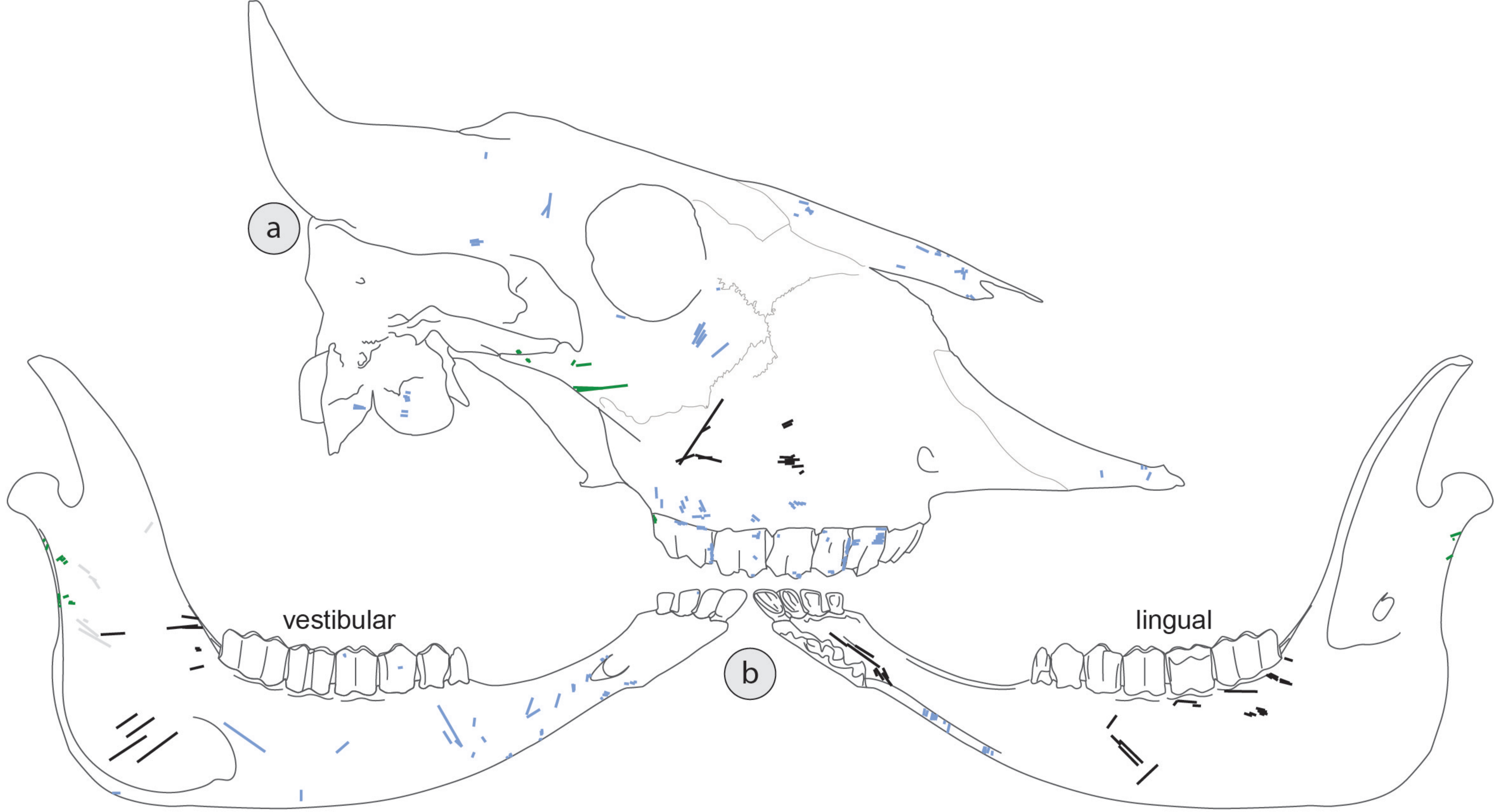
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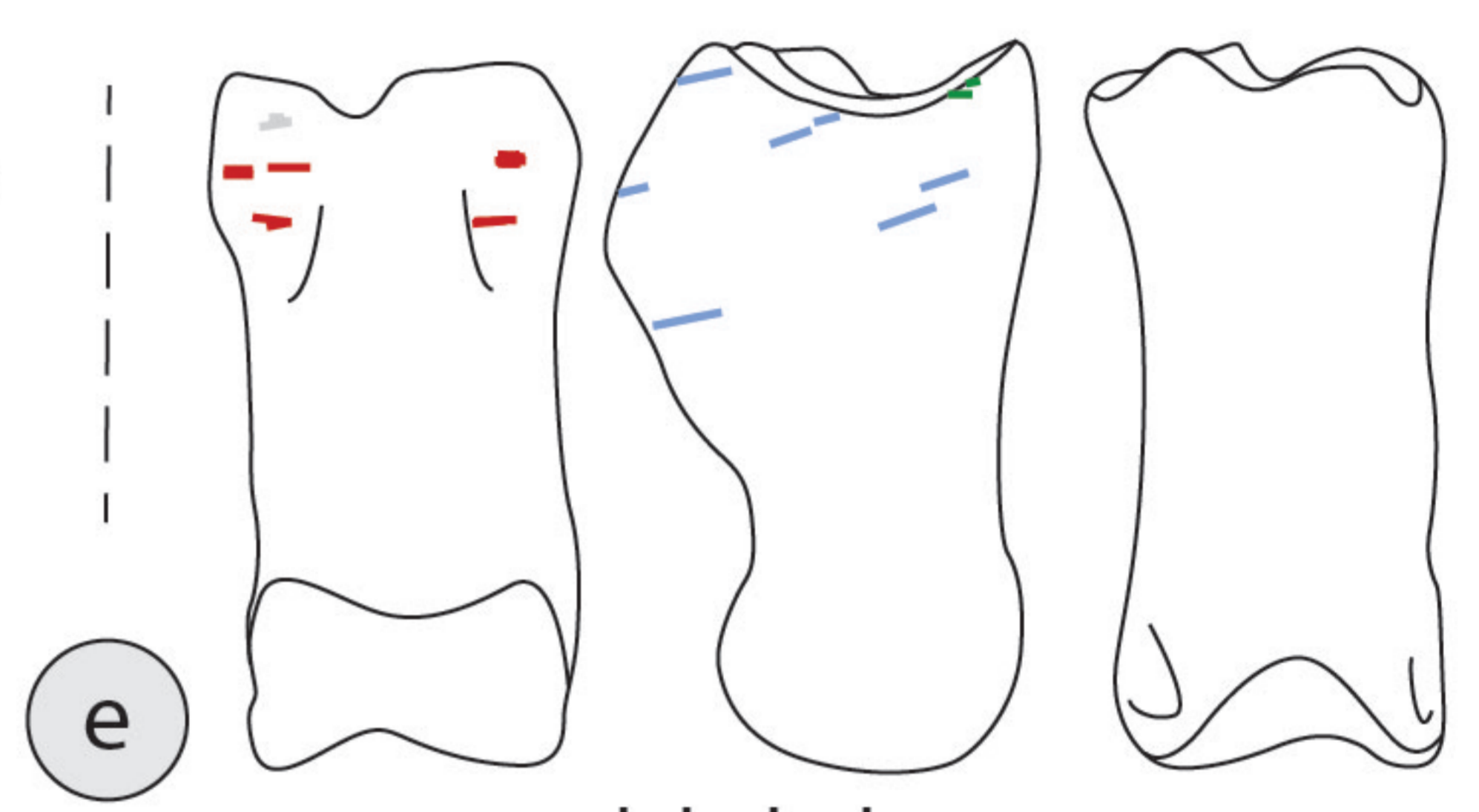
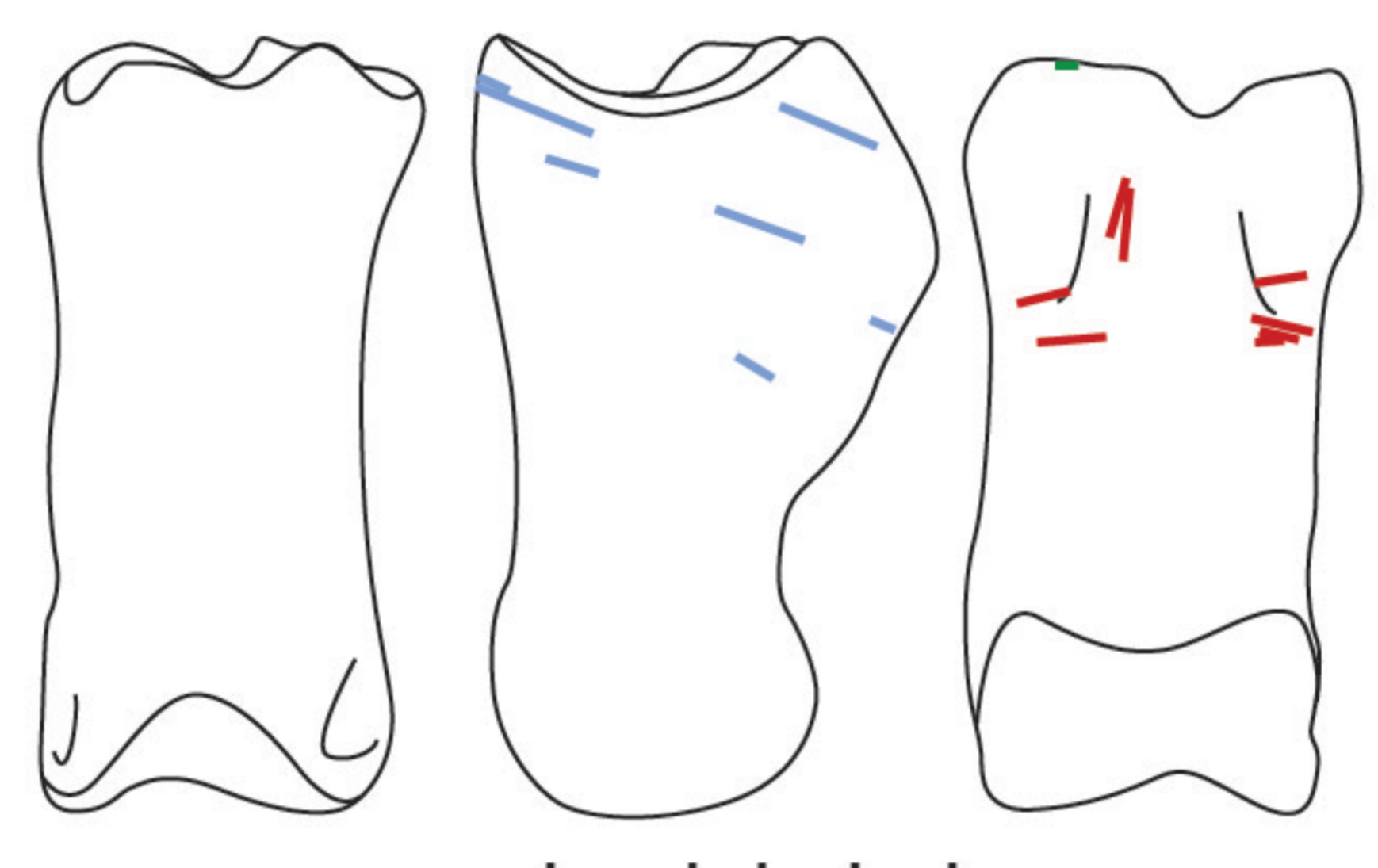
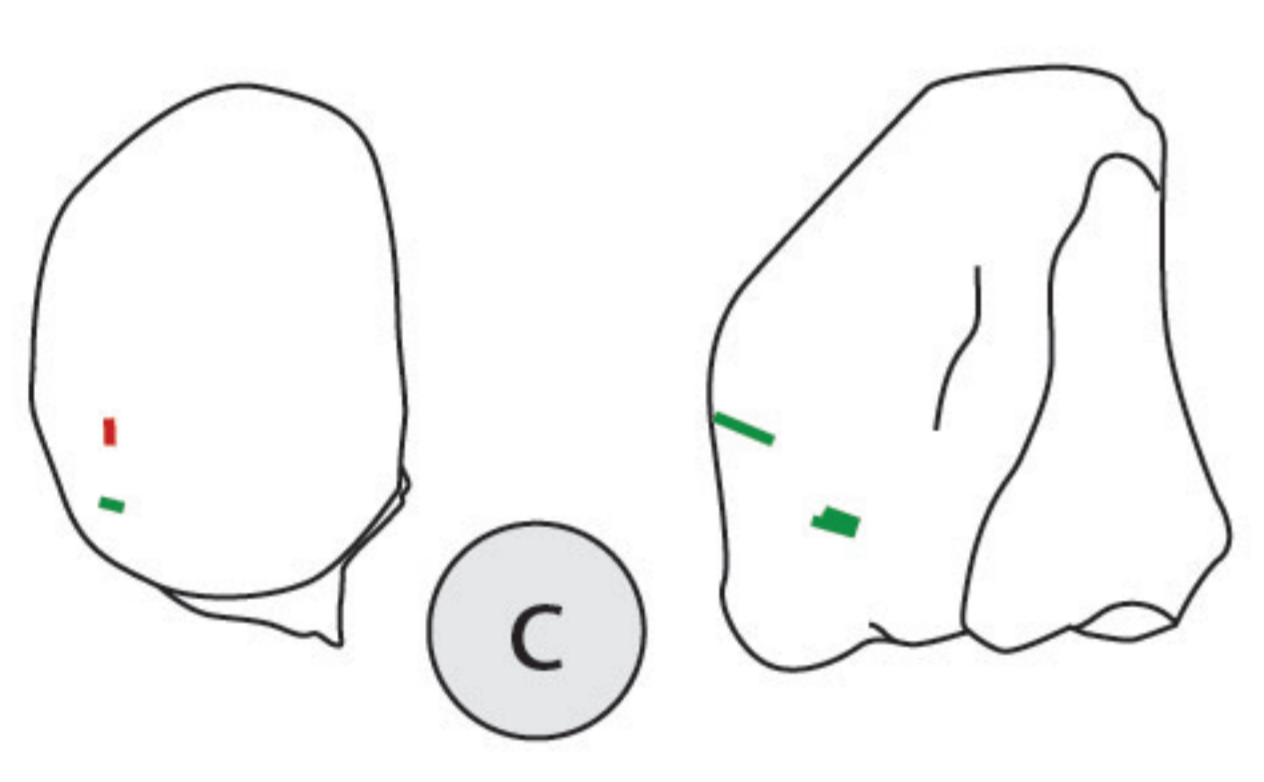
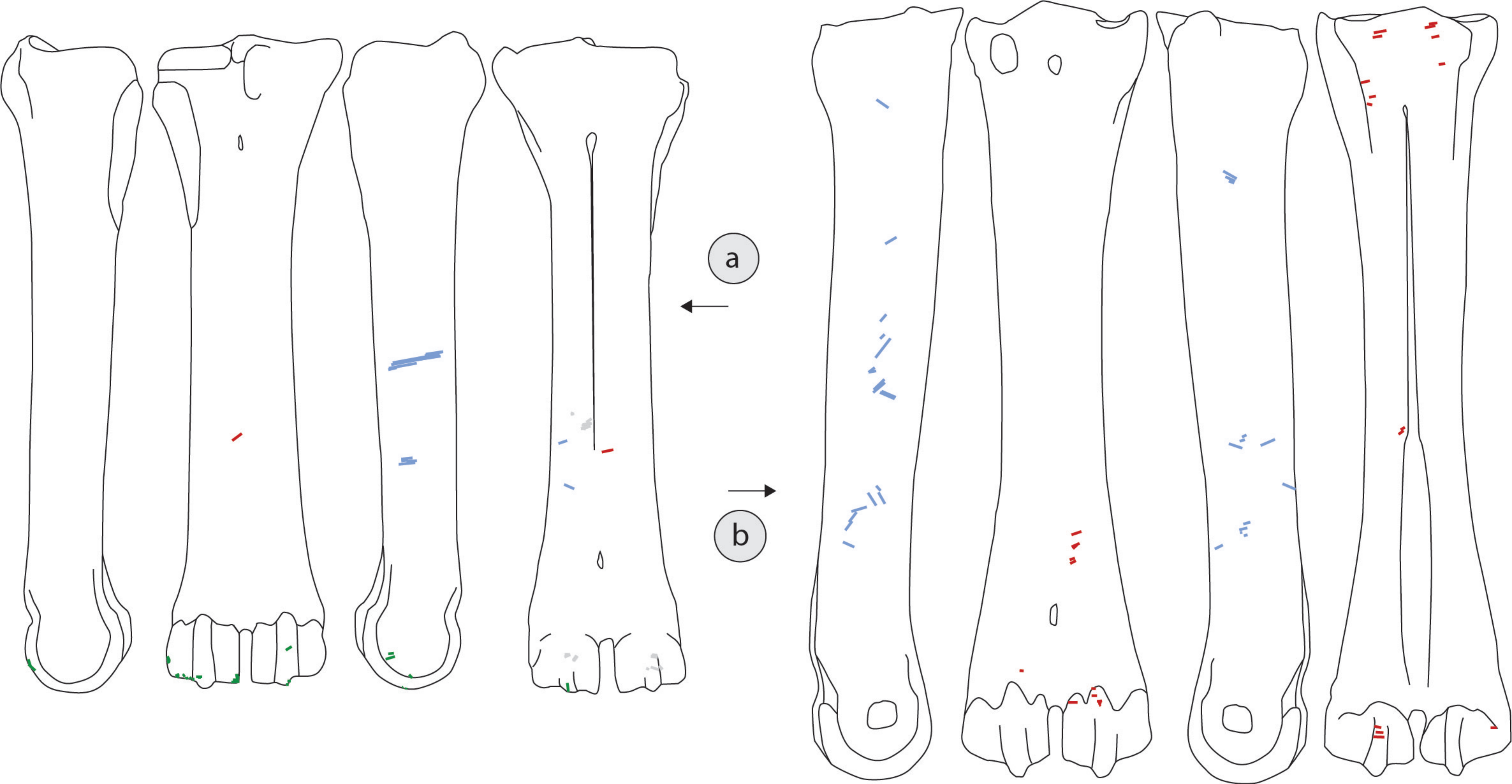
468

469 Table 1 Tools and raw materials (F=flint; Qzte=quartzite) used by activity.  
470  
471 Table 2 Total number of cut-marks produced on the bison by skeletal part.  
472  
473 Table 3 Orientation of the defleshing cut-marks on the meaty long bones. R = Right; L = Left  
474  
475 Table 4 Orientation of cut-marks produced by disarticulation. R = Right; L = Left  
476  
477 Table 5 Comparison of cut-mark orientation between bison and red deer. Red deer data derived  
478 from drawings in Soulier and Costamagno 2017.  
479  
480 Table 6 Comparison of cut-marks made with the same tool/raw material (quartzite cleaver) on a  
481 red deer and bison by two different experimenters.



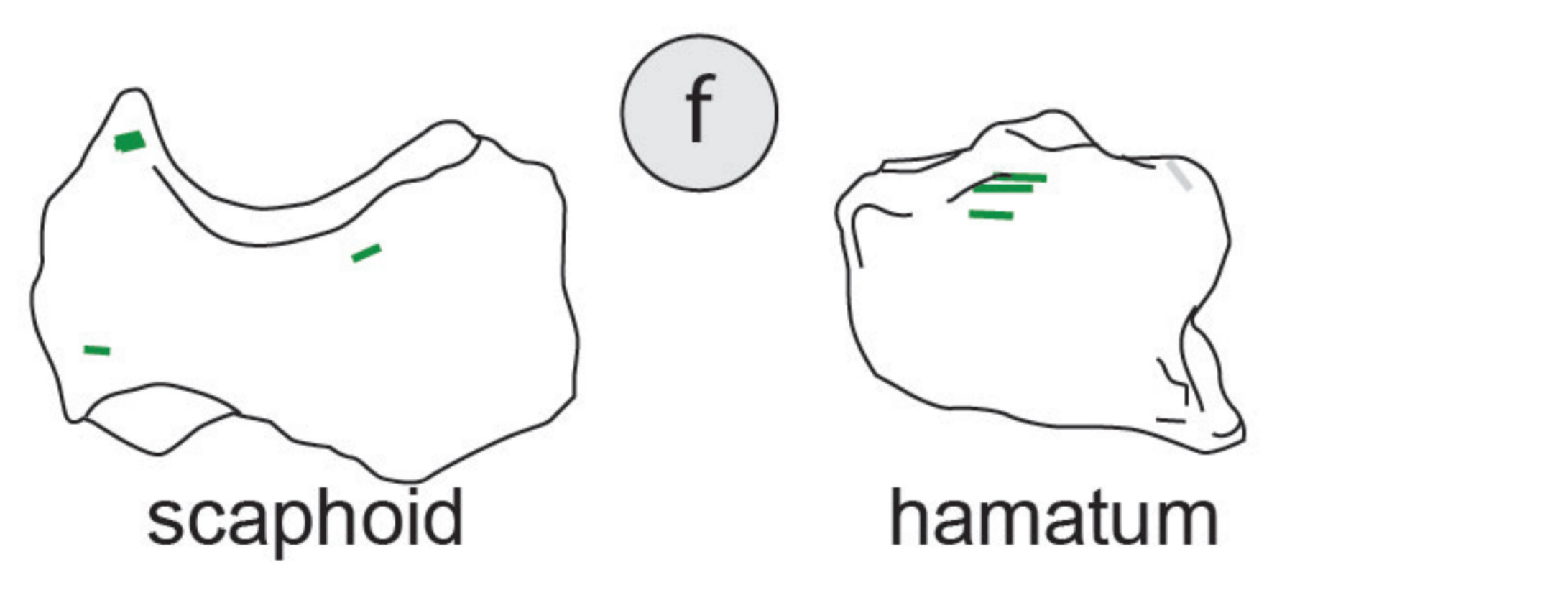
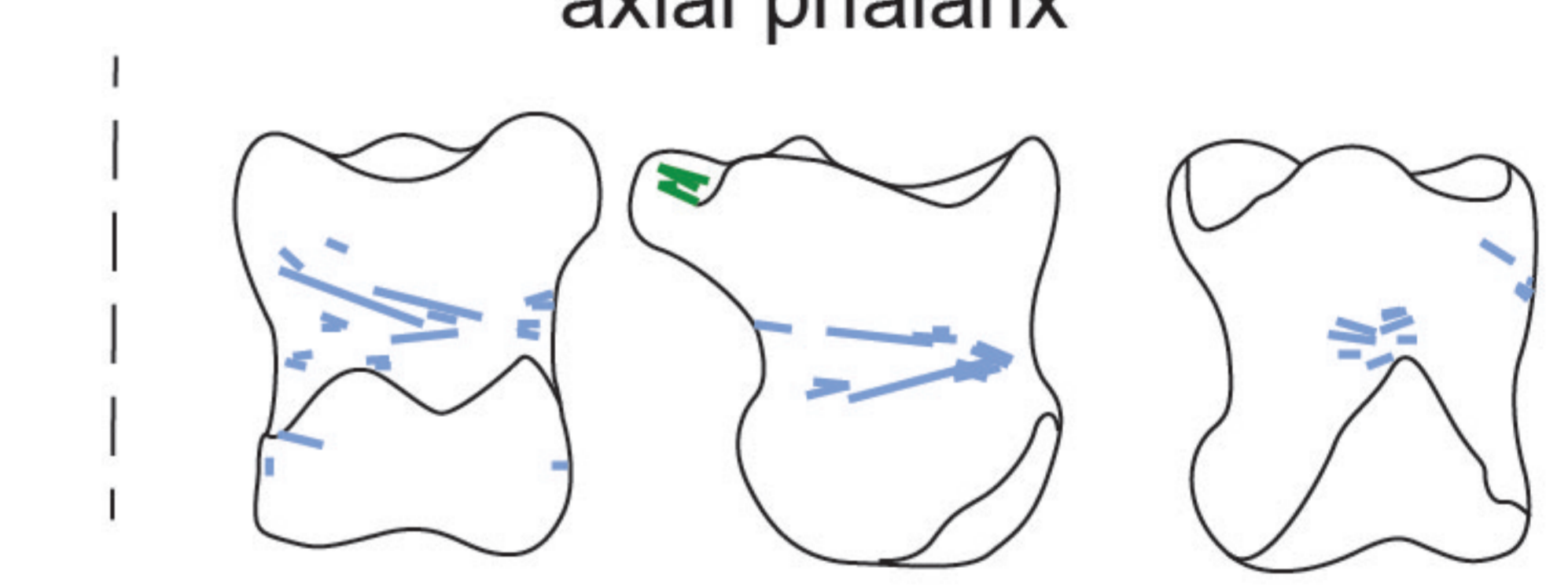
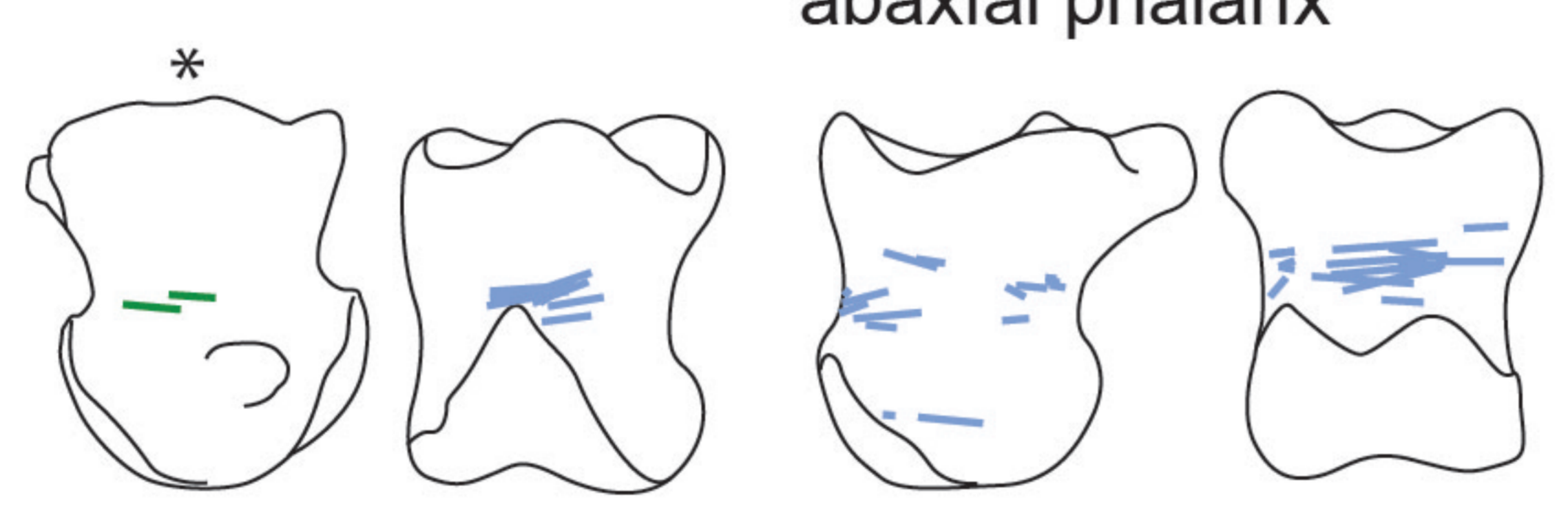
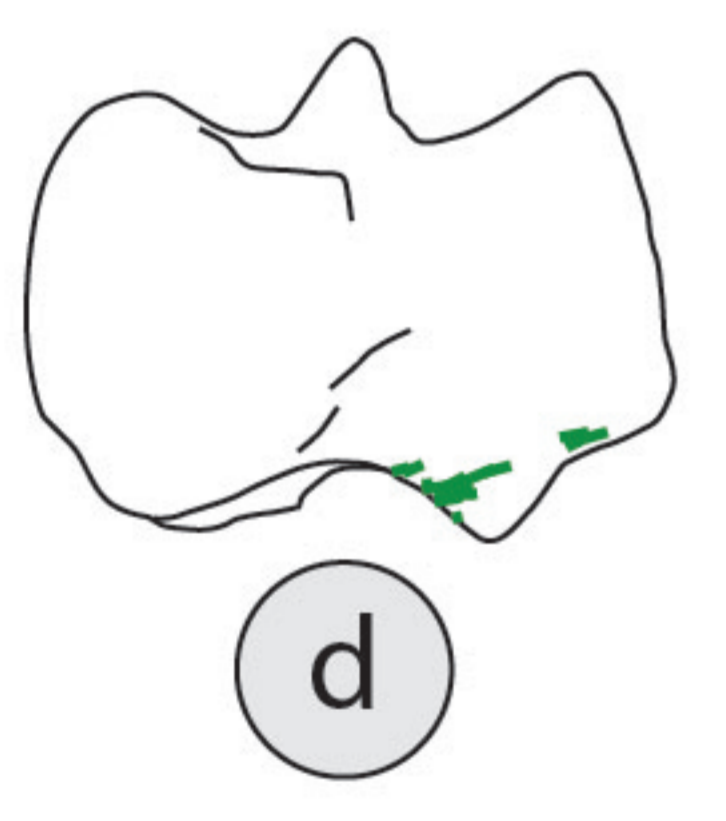






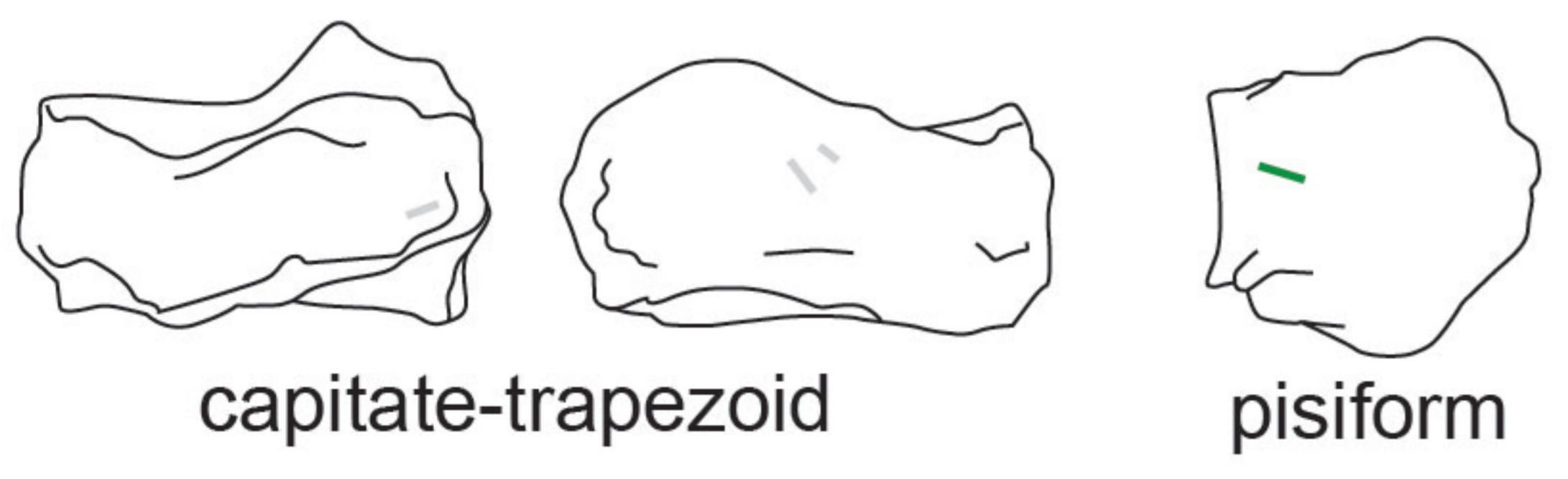
abaxial phalanx

axial phalanx



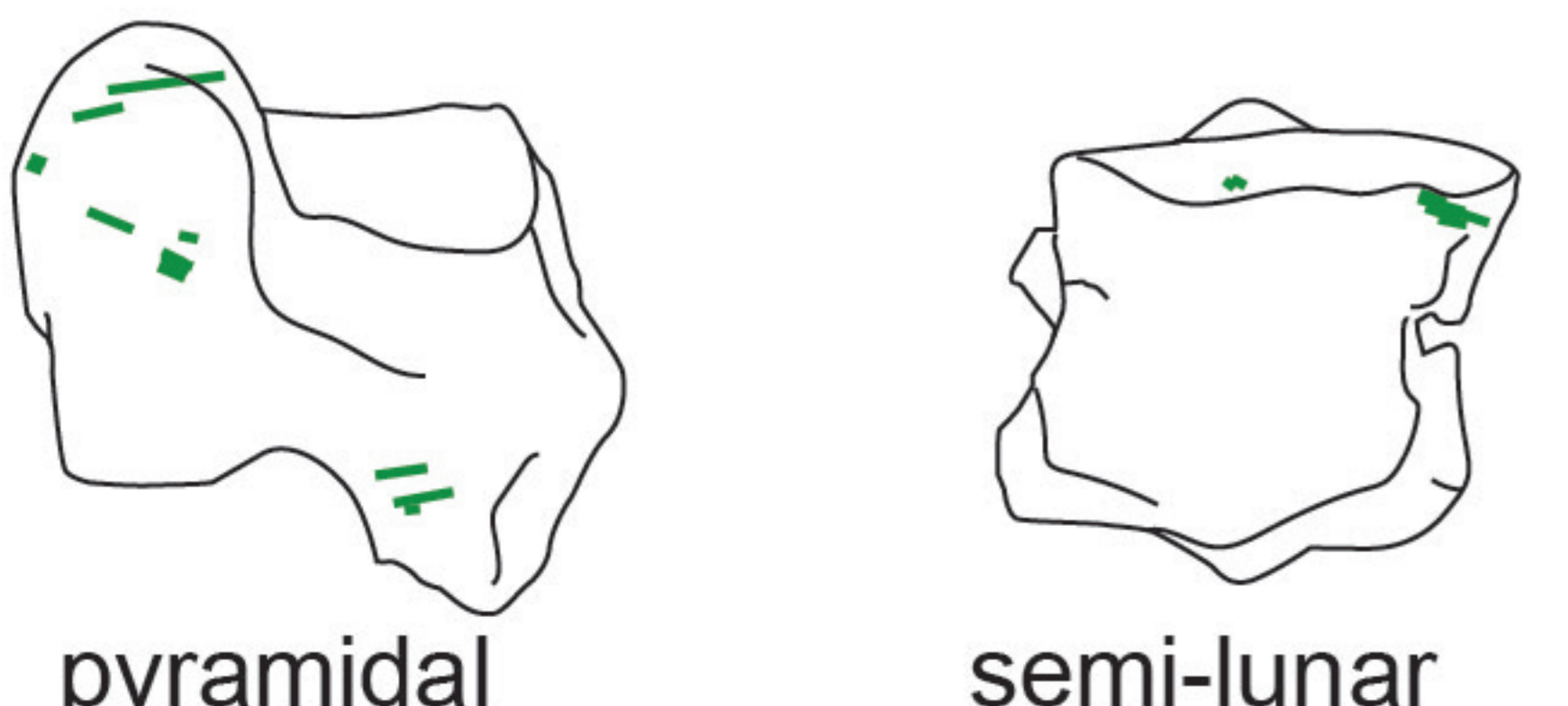
scaphoid

hamatum



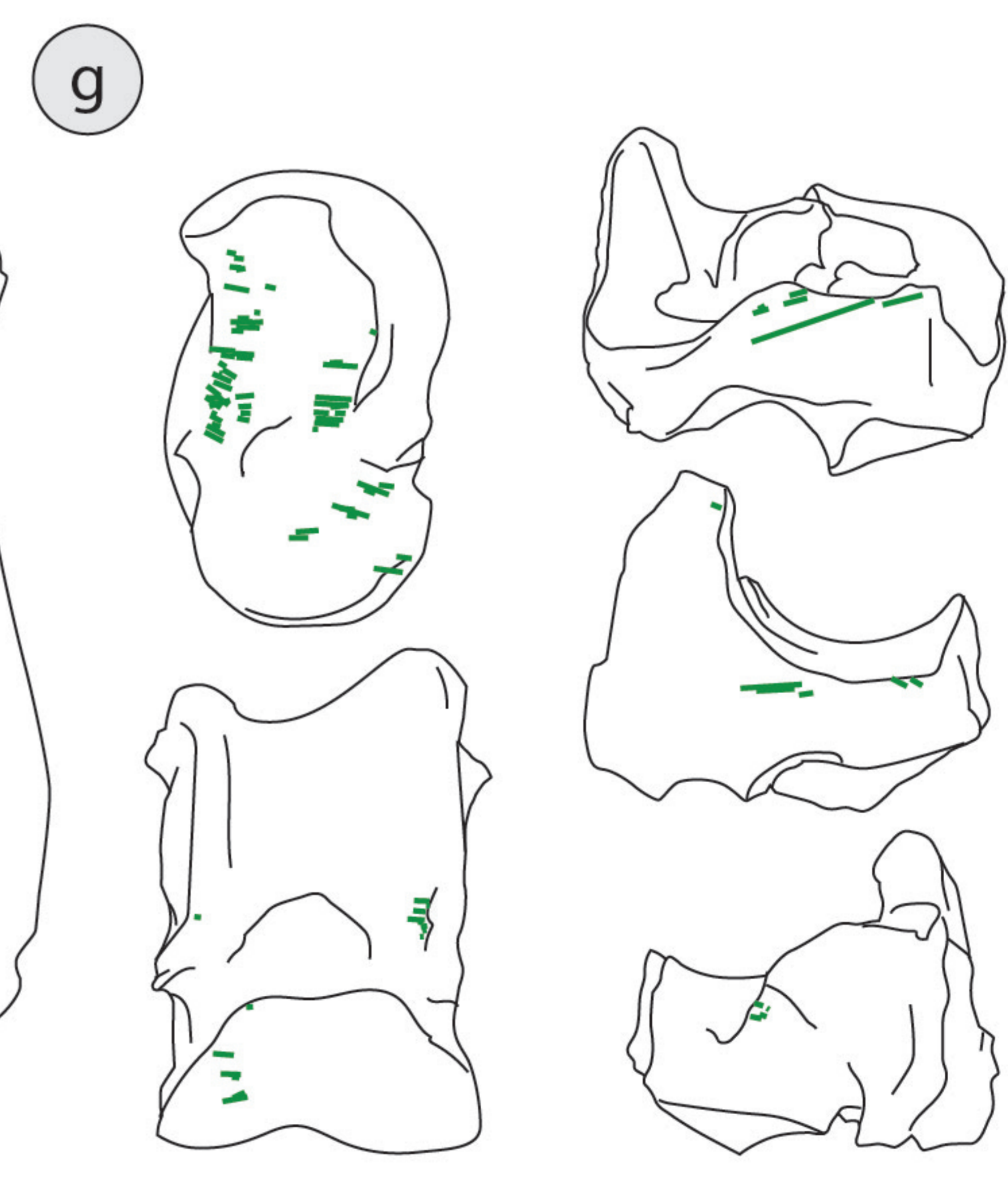
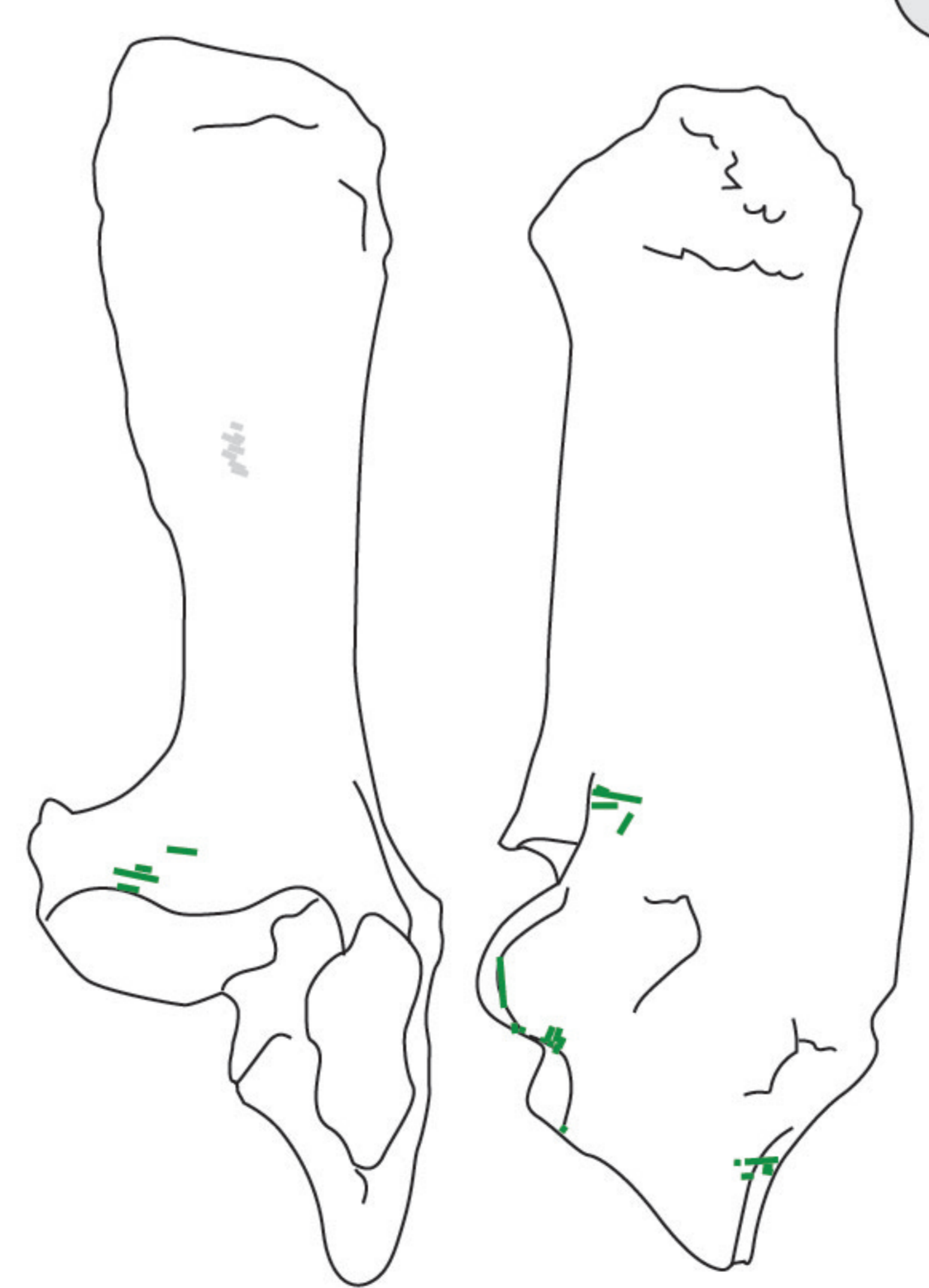
capitate-trapezoid

pisiform



pyramidal

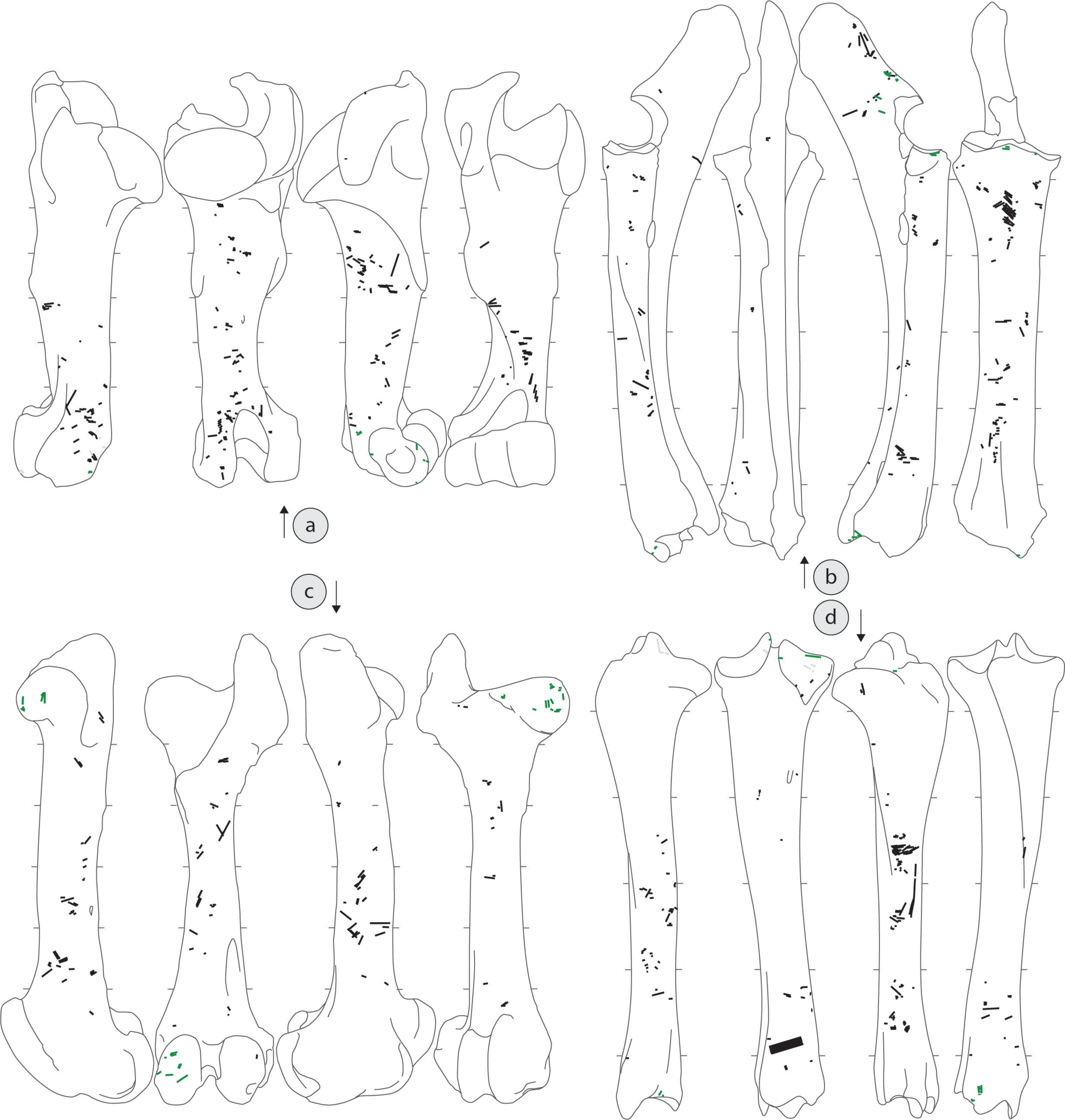
semi-lunar

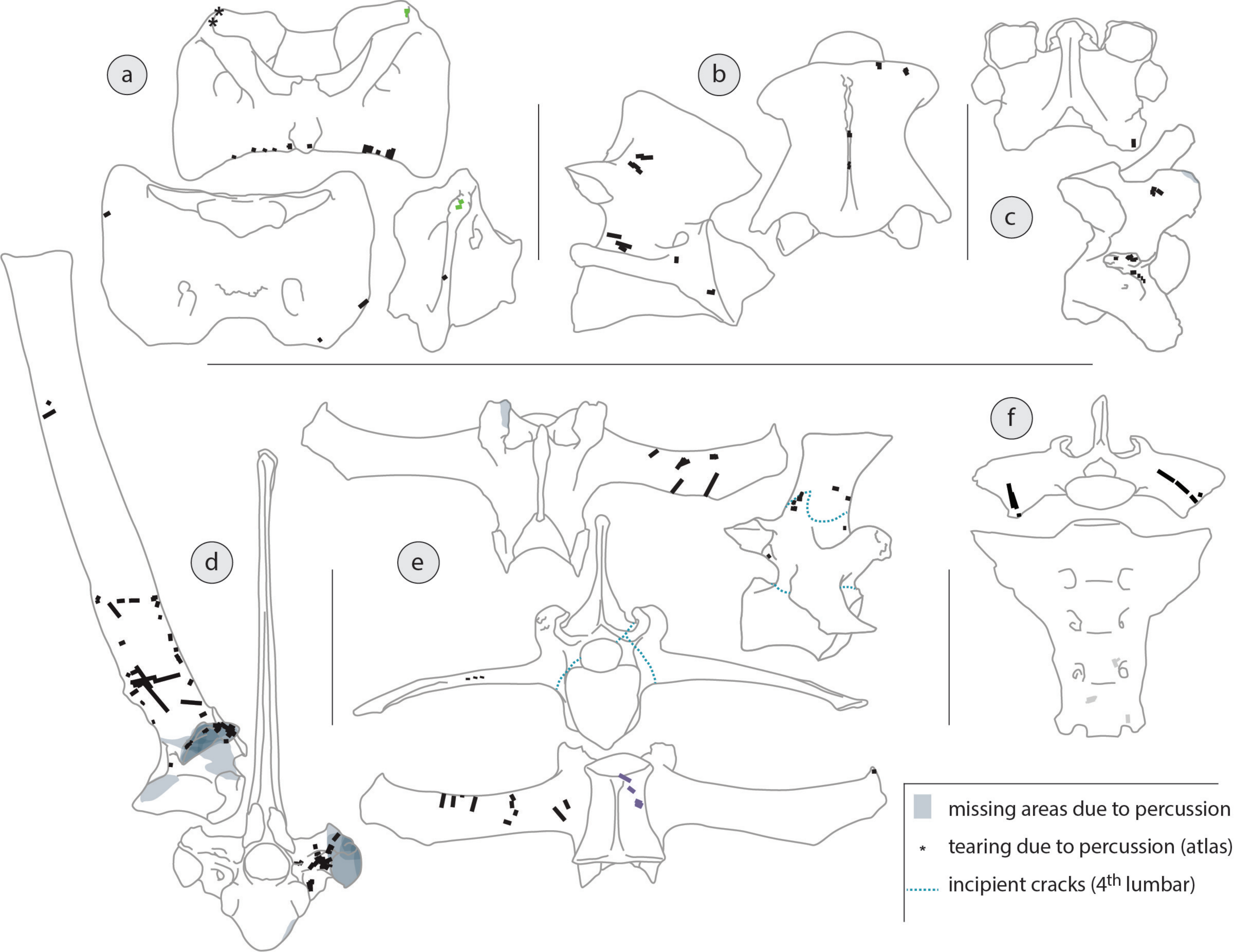


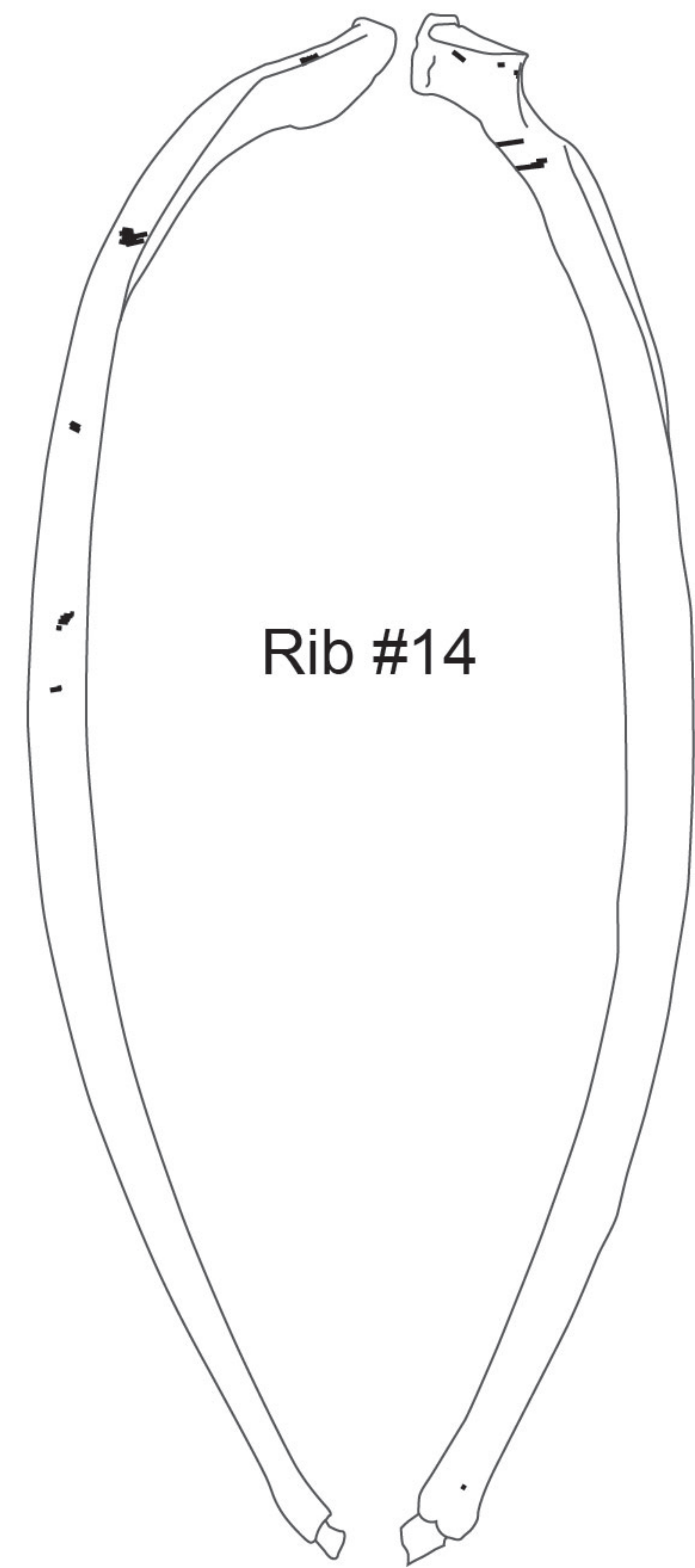
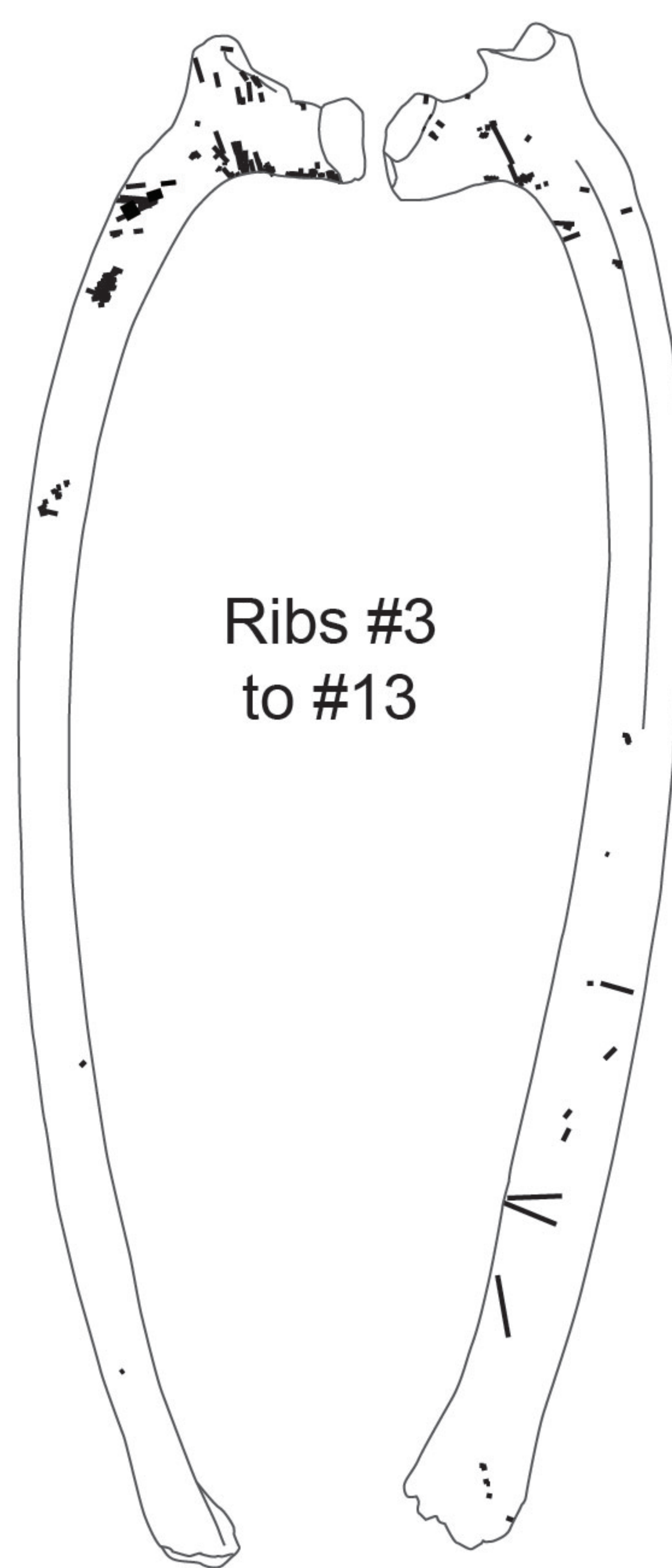
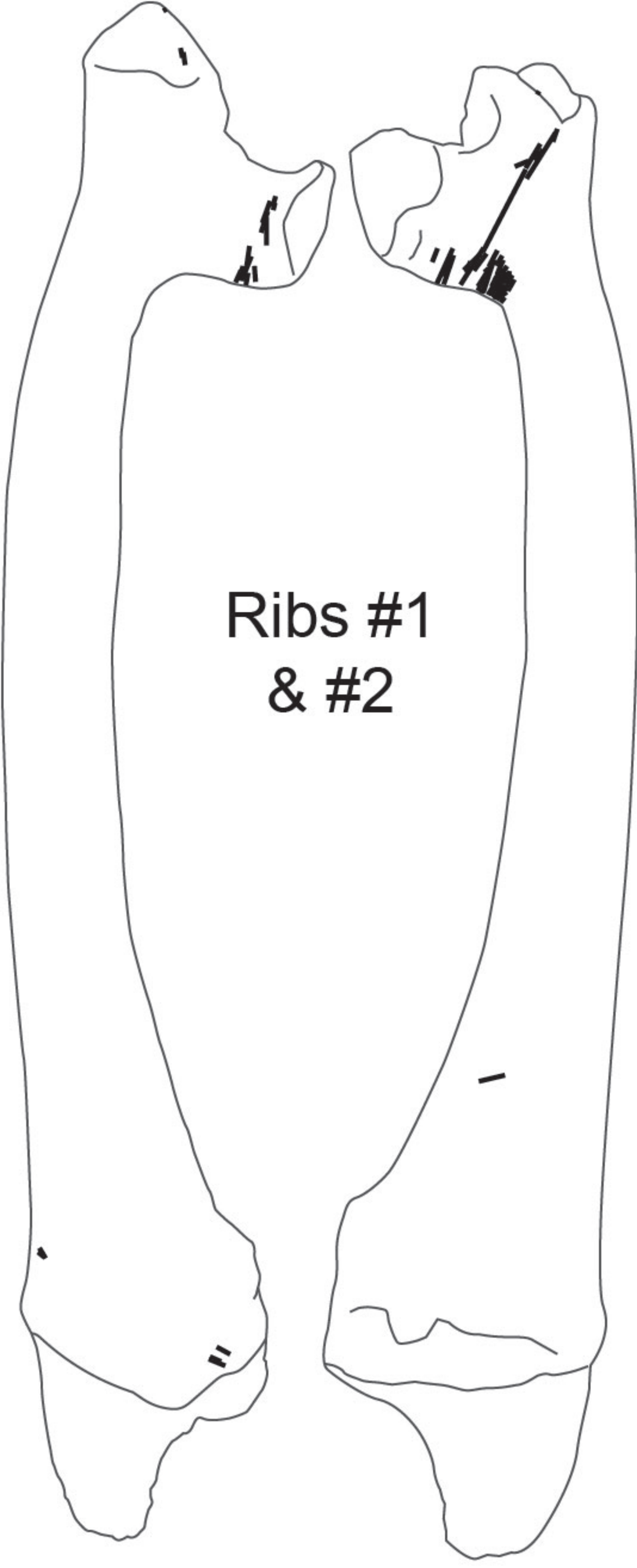
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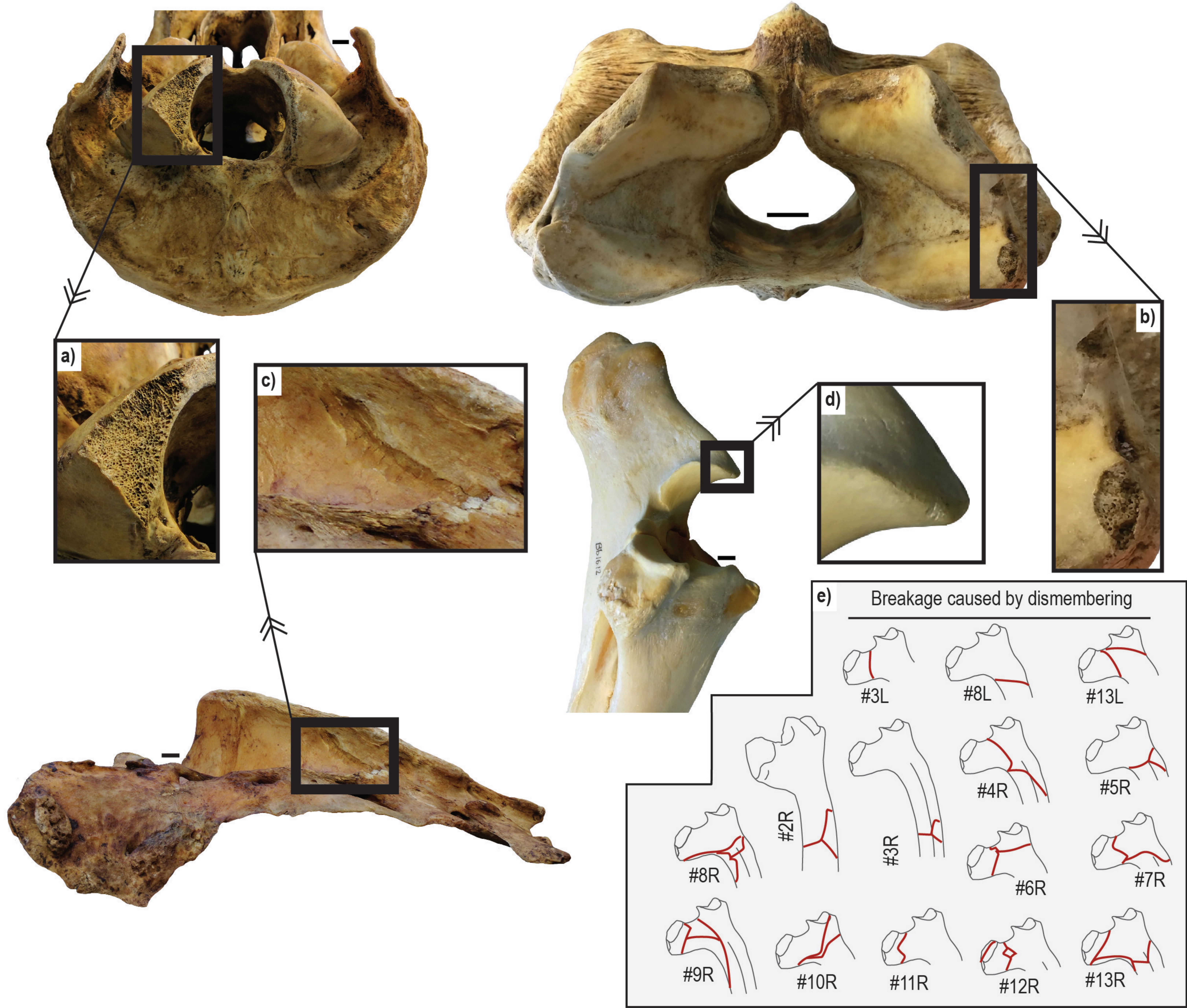


<i>weight of meat</i>	left	right
axial	53	
scapula	7	9
humerus	6	6
radioulna	0.5	1
femur	26	27
tibia	4.3	4









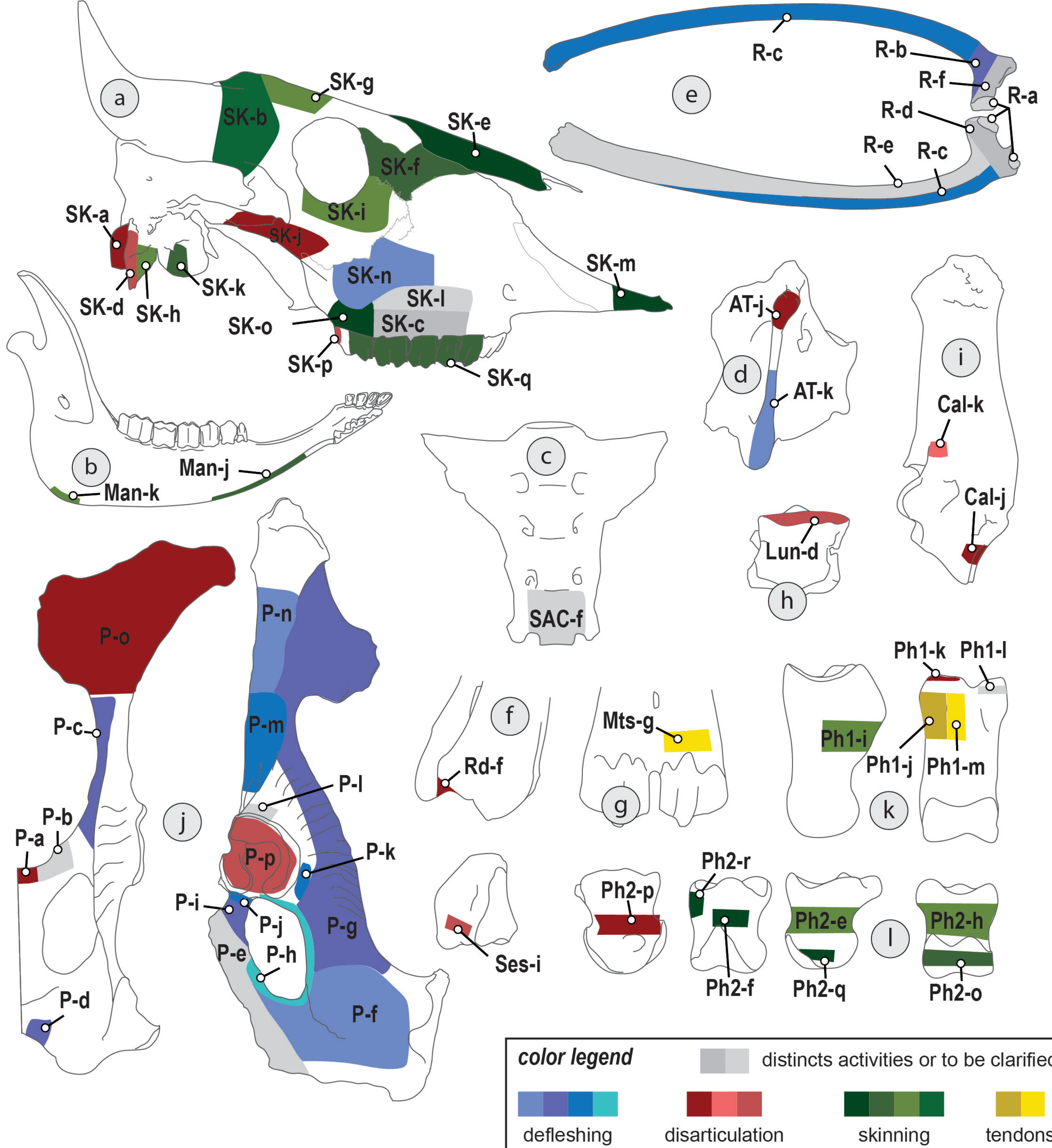




table 1

<i>activity</i>	<i>location</i>	<i>Tool &amp; raw material</i>
skinning	head	unretouched flake [F]
	forelimbs	pseudo-Levallois point [Qzte]
	hindlimbs	pseudo-levallois point [F]
	body	cortical backed flake [Qzte]
defleshing	head	pseudo-Levallois point [F] ; unretouched flake [F]
	R forelimb	bifaces [Qzte]
	L forelimb	cleavers [Qzte]
	R hindlimb	pseudo-Levallois point [Qzte]
	L hindlimb	pseudo-Levallois point [F]
	loin & ribs	mousterian point [F]
dismembering	R forelimb	biface [F]
	L forelimb	cleaver [Qzte]
	R hindlimb	denticulate [Qzte]
	L hindlimb	pseudo-Levallois point [F]
	head/atlas	hafted cleaver [Qzte]
	spine/ribs/stemum	hafted cleaver [Qzte]
	pelvis/spine	hafted cleaver [Qzte]
tendons	lower legs	flake [Qzte]

table 2

	N cuts
Skull	97
Mandible	119
Vertebrae	217
Ribs	303
Scapula	85
Humerus	225
Radioulna	228
Carpals	33
Metacarpal	69
Pelvis	86
Femur	175
Tibia	223
Malleolus	15
Tarsals	118
Metatarsal	63
Phalanges	141
Sesamoids	6
<b>Tot.</b>	<b>2203</b>

table 3

	Defleshing only : all portions								Defles			
	Humerus		Radioulna		Femur		Tibia		<i>Tot.</i>	Humerus		Radic
	R	L	R	L	R	L	R	L		R	L	R
longitudinal	9	1	2		3	1		5	<b>21</b>	5		1
oblique	67	31	68	51	37	55	43	47	<b>399</b>	37	20	49
transverse	43	57	32	49	6	31	53	50	<b>321</b>	24	42	27
<b>Tot.</b>	<b>119</b>	<b>89</b>	<b>102</b>	<b>100</b>	<b>46</b>	<b>87</b>	<b>96</b>	<b>102</b>	<b>741</b>	<b>66</b>	<b>62</b>	<b>77</b>

table 3

Fishing only : portions 2 to 5					
Ulna	Femur		Tibia		Tot.
L	R	L	R	L	
	2	1		3	<b>12</b>
39	33	51	28	40	<b>297</b>
44	5	28	51	49	<b>270</b>
<b>83</b>	<b>40</b>	<b>80</b>	<b>79</b>	<b>92</b>	<b>579</b>

table 4

Disarticulation	Humerus		Radius		Femur		Tibia		<i>Tot.</i>
	R	L	R	L	R	L	R	L	
longitudinal	2					18	9		<b>29</b>
oblique	5		1	8		14	2		<b>30</b>
transverse		4	10	7	5	5	4		<b>35</b>
<b>Tot.</b>	<b>7</b>	<b>4</b>	<b>11</b>	<b>15</b>	<b>5</b>	<b>37</b>	<b>15</b>	<b>0</b>	<b>94</b>

table 5

	Disarticulation & defleshing				Defleshing				Disarticulation			
	Bison		Red deer		Bison		Red deer		Bison		Red deer	
	N	%	N	%	N	%	N	%	N	%	N	%
longitudinal	52	6.1	200	6	21	2.8	172	5.7	29	30.9	23	11.1
oblique	441	51.8	2141	64.1	399	53.9	1956	64.7	30	31.9	113	54.3
transverse	358	42.1	999	29.9	321	43.3	893	29.6	35	37.2	72	34.6
<b>Tot.</b>	<b>850</b>		<b>3340</b>		<b>741</b>		<b>3021</b>		<b>94</b>		<b>208</b>	

table 6

	Red deer				Bison	
	Butcher V.		Butcher M.		Butcher M.	
	N	%	N	%	N	%
longitudinal	9	16.98	19	13.01	2	0.93
oblique	42	79.25	119	81.51	94	43.93
transverse	2	3.77	8	5.48	118	55.14
<b>Tot.</b>	<b>53</b>		<b>146</b>		<b>214</b>	

<sup>a</sup> Abbreviations: T = transversal; ST = sub-transversal; O = oblique; L = longitudinal ; SL = sub-longitudinal.

<sup>b</sup> Abbreviations: dist. = distal; prox. = proximal; art. = articulation; L = lateral; M = medial; P = posterior; A = Anterior; Cran. = cranial

<sup>c</sup> Location according to a division of the bone in 6 portions.

<sup>d</sup> XX + XX indicates that both activities are documented; XX(+ XX?) indicates that the first activity mentioned is attested but the activity has been modified from the initial attribution (see text). Abbreviations: DC = defleshing; DS = disarticulation; DP = skinning; TAR1 = tarsals first row; TAR2 = tarsals second row; RAD = radius; TIB = tibia; MET = metapodial.

<sup>e</sup> Abbreviation: nl. = not labeled (when the cutmarks are illustrated but not coded).

**Numbers in italics and green indicate the number of code repetitions**

bone	code	orientation <sup>a</sup>	location <sup>a</sup>	portion <sup>c</sup>
Skull	SK-a	T	occipital condyles	
	SK-b	L/O/T	base of the horns	
	SK-c	L/O	maxilla, just above tooth row	
	SK-d	O/T	caudal part of the jugular process	
	SK-e	L/O/T	nasal	
	SK-f	O/T	lacrima bone	
	SK-g		frontal	
	SK-h	L	cranial part of the jugular process	
	SK-i	L/O	zygomatic bone, around orbital cavity	
	SK-j	L/O	zygomatic arc	
	SK-k	L	tympanic bulla	
	SK-l	L/O	maxilla	
	SK-m	T/ST	premaxilla	
	SK-n	L/O	maxilla	
	SK-o	L/O/T	maxilla, above third molar	
	SK-p	L	distal face of the distal lobe of the upper third molar	
SK-q	L/O	cheek teeth		
Mandible	Man-a	T/O	incisors and alveolar arch	
	Man-b	T/O	jugal teeth	
	Man-c	T/O	horizontal branch, below jugal teeth	
	Man-d	T/O	ascending ramus, below condyle	
	Man-e	T/O	condyle and coronoid process	
	Man-f	T/O	ascending ramus	
	Man-g''	T	horizontal branch, below jugal teeth	
	Man-g'	L	horizontal branch, below jugal teeth	
	Man-j''	T	palmar edge	
	Man-k'	L	angle, horizontal branch	
	Atlas	AT-c	T/O	caudal part of the body
AT-c'		L	caudal part of the body	
AT-d		O	cranial part of the body	
AT-g		T/O	caudal part of the body	
AT-h			articular cavities for condyles of the occipital bone	
AT-j			<b>Lateral edge, cranial-most portion</b>	
AT-k			<b>lateral edge, caudal-most half</b>	
Axis	AX-b'	L	body, cranial part	
	AX-c'	L	spinous process, middle part	
	AX-g'	L	base of the spinous process	
	Ax-j	O	cranial part of the body	
	AX-j'	L	cranial part of the body	
	AX-k''	T	middle part of the body	
Cervical vertebrae	CV-b	T/O	superior articular process	
	CV-b'	L	superior articular process	
	CV-c	O	middle part of the body	
	CV-c'	L	middle part of the body	



Thoracic vertebrae	TV-a	O	spinous process
	TV-a'	L	spinous process
	TV-c	O	on the superior articular process
	TV-c'	L	on the superior articular process
	TV-d'	L	below the superior articular process, and body
	TV-i	T/O	below the transverse apophysis
	TV-j	T/O	body
	TV-l	O	transverse apophysis
	TV-l'	L	transverse apophysis
	Lumbar vertebrae	LV-a'	L
LV-f		O	base of the inferior articular process

Lumbar verte	LV-h	O	transverse process
	LV-h'	L	transverse process
	LV-m	O	transverse process
	LV-m'	L	transverse process
	<b>LV-m''</b>	<b>T</b>	<b>transverse process</b>
Sacrum	SAC-d	O	sacral ala
	SAC-d'	L	sacral ala
	SAC-e	O	body
	<b>SAC-f</b>	<b>O</b>	<b>body</b>
	<b>SAC-f'</b>	<b>L</b>	<b>body</b>
Ribs	<b>R-a</b>		<b>articulation</b>
	<b>R-b</b>		<b>neck</b>
	<b>R-c</b>		<b>shaft</b>
	<b>R-d</b>		<b>head</b>
	<b>R-e</b>		<b>shaft</b>
	<b>R-f</b>		<b>head</b>
Scapula	Sc-b	O	neck
	Sc-b'	L	neck
	Sc-c	T/O	neck
	Sc-d'	T	neck
	Sc-d	O	neck
	Sc-e	T/O	body
	Sc-e'	L	body

Humerus	Hp-b	T/ST	humeral neck	1
	Hp-m'	L	greater tubercle: below the tricripital line	1
	Hp-m''	T	greater tubercle: below the tricripital line	1
	Hs-a	T/O	shaft	2 to 5
	Hs-a'	L	shaft	2 to 5
	Hd-c	T/O	at the coronoid fossa	6
	Hd-d	T/O	edge of the trochlea to th insertion of the M. pronator teres	6
	Hd-d'	L	edge of the trochlea to th insertion of the M. pronator teres	6
	Hd-e	T/O	epitrochlea to the insertion of the M. pronator teres	6
	Hd-f'	O	dist. portion except epicondylar crest é edge of the coronoid	6
	Hd-g	T/O	edges of the olecranon fossa	6
	Hd-g'	L/SL	edges of the olecranon fossa	6
	Hd-h	T/O	capitulum	6
	Hd-h'	L	capitulum	6
	Rp-a	T/ST	close to the prox. art. (lateralmost)	1

Radius	Rp-b	T	close to the prox. art. (medialmost)	1
	Rp-c	O	prox. portion	1
	Rp-f	O	prox. portion	1
	Rp-g	T/O	prox. portion	1
	Rs-a	T/O	shaft: upper half	2 + 3
	Rs-a'	L	shaft: upper half	2 + 3
	Rs-b	O	shaft: lower half	4 + 5
	Rs-b''	T	shaft: lower half	4 + 5
	Rs-c	O	shaft: lower half	4 + 5
	Rs-c'	L	shaft: lower half	4 + 5
	Rs-c''	T	shaft: lower half	4 + 5
	Rd-b	T	close to the dist. art.	6
	Rd-c	T/O	upper half of portion 6	6
	Rd-d'	L	dist. portion	6
	Rd-d	O	dist. portion	6
	Rd-e	T/O	radial styloid process	6
	<b>Rd-f</b>	<b>O</b>	<b>dist. portion</b>	<b>6</b>
Ulna	Up-b	T/O	olecranon: dist. half of the post. part	1
	Up-c	O	olecranon: dist. half, near the semilunar notch	1
	Up-d	T/O	olecranon: anteriormost part	1
	Up-i	T	posterior aspect of the ulna	1
	Us-a	T/O	shaft	2 to 4
	Us-b	O	shaft	5
	Ud-a	T/O	ulnar styloid process [short cut]	6

Carpals	Pis-c	T	pisiform	
	Pyr-a	T/O	pyramidal: close to the prox. art.	
	Pyr-b	T/O	pyramidal: close to the dist. art.	
	Pyr-c	T/O	pyramidal: mid-bone	
	Lun-a	T/O	lunatum: close to the prox. art.	
	<b>Lun-d</b>	<b>O</b>	<b>proximal articulation</b>	
	Sca-a	T/O	scaphoid: close to the prox. art.	
	Sca-b	T/O	scaphoid: close to the dist. art.	
	Unc-a	T/O	unciform: close to the prox. art.	
	Unc-b	T/O	unciform: close to the dist. art.	
	Ctt-a	T/O	capitato-trapezoid: close to the prox. art.	
	Ctt-b	T/O	capitato-trapezoid: close to the dist. art.	
Metacarpal	Mcs-a'	T	condyles	2 to 5
	Mcs-d	T/O	shaft	4
	Mcs-e	O	shaft	5
	Mcs-f	T/O	groove: edge or inside	2 to 5
	Mcd-a	O	condyles	6
	Mcd-b	T/O	condyles	6
	Mcd-c	T/O	condyles	6
	Mcd-c'	L	condyles	6
Pelvis	<b>P-a</b>		<b>pubic symphysis</b>	
	<b>P-b</b>		<b>pecten ossis</b>	
	<b>P-c</b>		<b>ischial spine</b>	
	<b>P-d</b>		<b>ischial arch</b>	
	<b>P-e</b>		<b>inferior ramus of pubis</b>	
	<b>P-f</b>		<b>tabula of ischium</b>	
	<b>P-g</b>		<b>ischium body to iliaque spine</b>	
	<b>P-h</b>		<b>edge of the obturator foramen</b>	
	<b>P-i</b>		<b>superior ramus of pubis</b>	
	<b>P-j</b>		<b>superior ramus of pubis</b>	
	<b>P-k</b>		<b>edge outside acetabulum</b>	
	<b>P-l</b>		<b>edge outside acetabulum</b>	
	<b>P-m</b>		<b>body of ilium</b>	
	<b>P-n</b>		<b>ilium</b>	
<b>P-o</b>		<b>iliac tuberosity</b>		
<b>P-p</b>		<b>inside acetabulum</b>		
Fp-a	T/O	femoral head	1	
Fp-a'	L	femoral head	1	

Femur	Fp-b		femoral head: edge [encircling]	1
	Fp-g	T/O	greater trochanter: below	1
	Fp-h	T/O	greater trochanter: below	1
	Fs-a	T/O	shaft	2 to 5
	Fs-a'	L	shaft	2 to 5
	Fd-a	T/O	above trochlea & condyles	6
	Fd-c	T/O	condyles: on or adjacent to	6
	Fd-c'	L	condyles	6
	Fd-f	T/O	epicondyle	6
Tibia	Tp-a	T/O	intercondyloid eminence [encircling]	1
	Tp-b	T/O	tibial plateau	1
	Tp-b'	L	tibial plateau	1
	Tp-e'	O	tibial plateau: edge	1
	Ts-a	T/O	shaft	2
	Ts-b	T/O	shaft	3 + 4
	Ts-c	T/O	shaft	3 + 4
	Ts-c'	L	shaft	3 + 4
	Ts-d	O	shaft	5
	Ts-d''	T	shaft	5
	Ts-e	O	shaft	5
	Ts-e''	T	shaft	5
	Td-a	O	tibia: dist. part	6
	Td-a''	T	tibia: dist. part	6
	Td-b	O	tibia: dist. part	6
	Td-b''	T	tibia: dist. part	6
	Td-b'	L	tibia: dist. part	6
Td-c	O	tibia: dist. part	6	
Td-d	T/O	groove of the M. extensor carpi radialis	6	
Malleolus	Ml-a	O	edge of the articulation for the calcaneus	
Tarsals	Tal-a	T/O	talus: prox. articulation	
	Tal-b	T	talus: dist. articulation	
	Tal-c	O	talus: mesial part	
	Tal-c''	T	talus: mesial part	
	Tal-d	T/O	talus: dist. part	
	Cbn-a''	T	cubonavicular bone	
	Cbn-a	O	cubonavicular bone	
	Cal-a	T/O	calcaneus: middle part	
	Cal-e'	L	calcaneus: close to the malleolar articulation	
	<b>Cal-j''</b>	<b>T</b>	<b>calcaneus: close to the articulation</b>	
<b>Cal-k</b>	<b>O/T</b>	<b>calcaneus: above CAL-E</b>		
Metatarsal	Mtp-c	T	groove: edge	1
	Mtp-d	O	prox. shaft	1
	Mts-a	O	shaft [shallow]	2 to 5
	Mts-b	O	shaft [shallow]	2 to 5
	Mts-c	T/O	groove: inside	2 to 4
	Mts-f	T/O	groove: edge	2 to 4
	<b>Mts-g''</b>	<b>T</b>	<b>distal shaft</b>	<b>5</b>
	Mtd-b''	T	condyles	6
Mtd-c	T/O	condyles	6	
Sesamoid <sub>s</sub>	Ses-f	T/O	external abaxial sesamoid: contact with post. edge	
	Ses-h	T	sesamoid	
	Ses-h'	L	sesamoid	
	<b>Ses-i</b>	<b>O</b>	<b>sesamoid</b>	
Ph1	Ph1-b	T/O	contact with the proximal articulation	
	Ph1-c''	T/ST	proximal shaft	
	<b>Ph1-c</b>	<b>O</b>	<b>proximal shaft</b>	
	Ph1-d	T	contact with the proximal articulation	

Phalanges

Ph1-i	O	Mid-shaft
Ph1-j''	T/ST	tubercle axial
Ph1-k''	T	contact with articulation
Ph1-l'	L	above Ph1-d
Ph1-m	T	between the two tubercles
Ph2-b	O	contact with the proximal articulation
Ph2-h	O/T	shaft
Ph2-e	O/T	shaft
Ph2-f	O/T	shaft
Ph2-o''	T/ST	distal articulation
Ph2-p''	T	shaft
Ph2-q''	T	distal
Ph2-r	O	proximal shaft, extending Ph2-c

## Description of the coding system

anial; Palm. = palmar; Ext. = external.

at the second, in parentheses, is uncertain; XX?/XX? indicates that the protocol used does not allow discrimination between the activities; \* indicating; TN = tendon-removal; exten. = extension; flex. = flexion; SP = suspension; ANT = anterior; POST = posterior; CAR1 = carpals first row; CA

### Conditions for vertebrae and phalanges. Codes in bold are the new codes created from this bison study

face <sup>d</sup>	Nilssen <sup>b</sup>	T & H cerf <sup>b,d</sup>	Bison	
			Right	Left
	<b>DS</b>		<b>DS arrach</b>	<b>DS</b>
	<b>DP</b>		<b>DP</b>	<b>DP</b>
	<b>DS</b>		<b>DP</b>	
	<b>DS</b>			
	<b>DP</b>		<b>DP</b>	<b>DP</b>
	<b>DP</b>			
	<b>DP</b>			
			<b>DP</b>	<b>DP</b>
			<b>DS</b>	<b>DS</b>
				<b>DP</b>
	<b>DS</b>		<b>DC</b>	
			<b>DP</b>	<b>DP</b>
			<b>DC</b>	<b>DC</b>
			<b>DP</b>	
<b>Vest.</b>			<b>DS</b>	<b>DS</b>
<b>Vest.</b>			<b>DP</b>	<b>DP</b>
Vest.		DP		DP
Vest.		DP	DP	
Vest.		DP	DP	DP
Vest., Ling.		DC	DC+DS	DC
Vest.		DS	DS	
Vest.		DS+DC	DS	
Ling.		DC	DC	DC
Ling.		DC	DC	DC
Palm.			<b>DP</b>	<b>DP</b>
Palm.	<b>DP</b>		<b>DP</b>	
Vent.	DC+EV	DS (ATL/AXI)		DC
Vent.	DC+EV			DC
Dors.	DC			DC
Dors.	DC	incidental DS marks		DC
Cra.	DS	DS (CRA/ATL)		DS
<b>Lat</b>				<b>DS</b>
<b>Lat</b>				<b>DC</b>
Lat.	DC			DC
Lat.	DC			DC
Lat., Dors.	DC			DC
Vent.	DC+EV	DS (ATL/AXI)		DC
Vent.	DC+EV			DC
Vent.	DC+EV	incidental DS marks		DC
Lat.	DS+DC	DS (AXI/CER3)	DC	1
Lat.	DC		DC	1
Lat.	DC	incidental DS marks	DC	1
Lat.	DC		DC	1



Lat.	DC	DC	DC	7
Lat.	DC	DC	DC	7
Lat.		DS	DC	3
Lat.	DC		DC	4
Lat.	DS RIB	?	DC	1
Cra.		DS	DC	1
Cau.	DS RIB		DS (tearing)	1
Cra.	DC		DC	4
Cra., Dors.	DC		DC	7
Lat.	DC	DC	DC	3
Lat.		DS	DC	1

Dors.	DC	DC	DC	2
Cra., Dors.	DC	DC	DC	1
Vent.		DC	DC	2
Vent.		DC	DC	1
Vent.			<b>DC</b>	<b>1</b>
Cra., Vent.	DC	DC	DC	
Cra., Vent.	DC		DC	
Vent.	EV		?	
<b>Vent.</b>			?	
<b>Vent.</b>			?	
<b>all</b>	<b>DS</b>		<b>DC</b>	
<b>Dors.</b>	<b>DC</b>		<b>DC</b>	
<b>Dors.</b>	<b>DC</b>		<b>DC</b>	
<b>Vent.</b>	<b>DS (+EV ? DC ?)</b>		<b>DC</b>	
<b>Vent.</b>	<b>EV + DC</b>		<b>DC ? EV ?</b>	
<b>Dors.</b>	<b>DS + DC</b>		<b>DC</b>	
Lat., Post.	DC	DC	DC	
Lat., Post.	DC	DC	DC	DC
Med., Ant.	DC	DC	DC	DC
Med.	DC*			DC
Med.			DC	DC
all	DC	DC	DC	DC
all	DC	DC	DC	DC

Post.	DC	DS+DC		DC
Lat.		DC	DC	
Lat.			<b>DC</b>	
all	DC	DC	DC	DC
all	DC	DC	DC	
Med.	DC	DC	DC	DC
Med.	DS	DS (exten.)	DC	DS
Med.	DC	DS (flex.)		?
Med.	DC	DS+DC	DC	?
Lat., Ant			<b>DC</b>	
Post., Lat.	DC (+DS?)	DS+DC	DC+DS	DC
Post.	DC	DC	DC	DC
Lat.	DS	DS	DS	DS
Lat.		DS	DS	
Ant.	DS	DS	DS	

Ant.	DC (+DS?)		DS	
Ant.		DC	DC	
Med.	DC	DC	DC	DC
Lat.	DC	DC		DC
all	DC	DC	DC	DC
all	DC	DC	DC	
Med., Lat., Post.	DC	DC	DC	DC
Med., Lat., Post.	DP?/DC?	DC	DC	DC
Ant.	DC	DC	DC	DC
Ant.		DC	DC	
Ant.	DP?/DC?	DC	DC	DC
Ant.				DS
Lat.		DC	DC	
Post.	DC		DC	
Post.			DC	
Med.		DS		DS
<b>Lat</b>				<b>DS</b>
Med., Lat.	DC	DC	DC	DC
Med., Lat.		DS		DS
Med., Lat.	DC	DC	DC	DS+DC
Post.	DC	DC	DC	
Med., Lat., Post.	DC	DC		DC
Lat., Post.		DC		DC
Palm., Lat., Post.	DS	DS	DS	

Lat., Med.	DS		DS	
Ant., Lat., Post.		DS (RAD/CAR1)		DS
Ant., Lat., Palm.		DS (CAR1/CAR2)	DS	
Lat., Ant.		incidental DS marks		DS
Ant., Post.	DS	DS (RAD/CAR1)		DS
<b>Cra.</b>			<b>DS</b>	
Ant., Med., Post.	DS	DS (RAD/CAR1)	DS	DS
Ant., Med., Post.	DS	DS (CAR1/CAR2)		DS
Ant., Lat., Post.	DS	DS (CAR1/CAR2)		?
Ant., Lat., Post.	DS			?
Ant., Med., Post.	DS	DS (CAR1/CAR2)		?
Ant., Med., Post.	DS		?	
Med.		DP	DP	DP
Ant.		DP + TN ANT	TN+DP (+ ?)	DP
Ant.			DP	
Post.		TN POST		TN
Med., Lat.		DS	DS	DS
Post.			DS	DS
Ant.		DP		?
Ant.		DS		DS
	<b>DS (splitting pelvis)</b>			
<b>Dors.</b>	<b>DS + DC</b>			
	DC		<b>DC</b>	
<b>Dors.</b>	DC			<b>DC</b>
	<b>DS (splitting pelvis)</b>			
	DC		<b>DC</b>	<b>DC</b>
	DC		<b>DC</b>	<b>DC</b>
	DC		<b>DC</b>	<b>DC</b>
	DC		<b>DC</b>	?
	DC			?
	DC (+ DS ?)			
	DC		<b>DC</b>	<b>DC</b>
	UC (+US pel/sacrum?)			
<b>Dors.</b>	<b>DS pel/sacrum</b>			
	DS			
	DS	DS		DS
				DS

all	DC (+DS?)	DS		DS
Med.	DC		DC	
Ant., Lat.	DC			DC
all	DC	DC	DC	DC
all	DC	DC		DC
Ant., Post.	DC	DC	DC	DC
Post.	DC (+DS?)	DS+DC	DS	DS
Post.	DC	DS+DC	DC	
Med.		DC		DC
Cran.	DS	DC	DS	?
Cran.		DC	DS(+ ?)	DC
Cran.		DC		DC
Lat.				DC
all	DC	DC		DC
Med.	DC	DC	DC	DC
Ant., Lat., Post.	DC	DC	DC	DC
Ant., Lat., Post.	DC	DC		DC
Med.		DC		DC
Med.	DP	DC		DC
Ant., Lat., Post.	DC	DC	DC	DC
Ant., Lat., Post.	DP	DC	DC	DC
Med.			DS	
Med.	DP		DC	
Ant.		DC		DC
Ant.	DP	DC	DC	DC
Ant.			DS	
Lat., Post.			DC	
Post.		DC	DC	
Lat.		DS	DS	DS
Ant.	DS	DS TIB/TAR (flex.)	DS	DS
Ant.	DS	DS TIB/TAR	DS	DS
Med.		DS TIB/TAR (flex.)	DS	
Med.	DS	DS TIB/TAR (exten.)	DS	DS
Med.	DS	DS	DS	DS
all	DS	DS TAR1/TAR2 + TAR/MTM (depending on location)		DS
all				DS
Ant.	DC/susp.	DS (TIB/TAR flex.)	DS	?
Lat.		DS (TIB/TAR flex.)	DS	DS
<b>Lat</b>				<b>DS</b>
<b>Lat</b>			<b>DS</b>	
Ant.		TN ANT		TN
Med., Lat.		DP	DP	
Med.		DP	DP	DP
Lat.		DP	DP	
Ant.		TN ANT		TN
Post.		TN POST	TN	
<b>Post.</b>				<b>TN</b>
Post.		DP+DS		TN
Ant.	DS	DS+TN POST	TN	
Lat		DS (MET/PH1)		DS
Post.		DS (MET/PH1)		DS
Post.				TN
<b>Lat</b>				<b>DS</b>
Ant., Ext.		DS	DP	1
Ant., Ext.		DS+DP	DS	1
<b>Ext.</b>			<b>DP</b>	<b>4</b>
Post.		DS (between Ph1)	TN	4

Ext.		DP	2
Post.		TN	2
Post.		DS	1
Post.		TN	1
Post.		IND	1
Ext.	DS	DS	1
Post.		DP	4
Ext.		DP	4
Ant.		DP	4
Post.		DP	1
		US between	
Int.		phal.	1
Ext.		DP	1
Ant.		DP	1

states that the interpretation of  
AR2 = carpals second row;